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Abstracts

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Effects of additional neurologic and orthopedic factors on gait pattern in children with low- and midlumbar myelomeningocele

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Introduction

Children with lumbo-sacral myelomeningocele (MMC) show characteristic gait patterns accurately reflecting the muscle paresis involved (Duffy et al. 1996; Vankoski et al. 1997; Gutierrez et al. 2003). It is also known that tethering of the spinal cord, hydrosyringomyelia and Chiari II malformations may impair neurological function and cause motor and sensory deficits in the lower limbs, musculoskeletal deformities, spasticity, upper extremity weakness, and truncal ataxia (Yamada et al. 1995; Rauzzino and Oakes 1995). The aim of this study was to describe variations in gait pattern according to muscle paresis and additional neurological and orthopedic symptoms.

Patients and methods

Thirty-five children with MMC and functional ambulation, with a mean age of 10.4 (SD2.9) years, were included in a gait study. They were grouped according to manual muscle testing of their lower limb muscle strength on a 0–5 scale (Table). All children underwent 3-D gait analysis (VICON, Oxford) using a 6-camera system while wearing their habitual orthosis. Gait kinematic parameters in the lower and upper body were compared between subgroups. Subgroups were formed based of spasticity in the ankle, knee, or hip muscles, asymmetric paresis, and orthopedic symptoms. The characteristic gait pattern was defined by the subjects with no additional neurological or orthopedic symptoms.

Table
Groups of muscle strength

Muscle strength groups	I $N=9$	II $N=11$	III $N=9$	IV $N=6$
Knee Flexion	4	4	2–4	2–3
Hip Extension	4	3–4	2–4	0–1
Hip Abduction	4	3–4	0–3	0
Dorsiflexion	3–4	0–4	0	0
Plantarflexion	3–4	0–2	0	0
Knee extension, Hip adduction, Hip flexion 4-5				

Results

Of the 9 children in Group I the kinematic results showed significantly reduced hip extension in late stance in the group with ankle joint spasticity, and increased hip rotation and foot progression range in the group with asymmetric paresis as compared to the 4 children with characteristic gait pattern. Of the 11 children in Group II the 4 children with spasticity in ankle joint muscles showed significantly more trunk motion in the frontal and transverse planes and increased anterior pelvic tilt and hip flexion at initial contact as compared to the 4 children with a characteristic gait pattern. The 3 children with spasticity in ankle joint and knee flexion muscles showed reduced knee and hip extension during stance and increased external foot progression. Of the 9 children in Group III the children with ankle muscle spasticity showed increased posterior pelvic tilt with internal pelvic and hip rotation as compared to the characteristic group. The 2 children with spasticity in ankle, knee flexor and hip adductor muscles showed non-characteristic gait pattern in all planes, whereas one child with only orthopaedic contractures showed deviations in the sagittal plane. In Group IV, the kinematic variables seen in one child with spasticity in muscles of all lower limb joints deviated from all of those seen in the 6 children with characteristic gait pattern of the same group.

Discussion

The gait patterns deviate from the characteristic one of a patient group, despite properly aligned orthoses, when additional neuro-orthopaedic symptoms such as spasticity and joint contractures are involved. Also inadequate balance following impaired neurological function might influence the walking pattern.

Conclusion

Patients with similar muscle paresis exhibit different gait patterns. Gait analysis can contribute to increasing understanding about the variety of the patients' solution to achieve functional ambulation and be of value to find adequate measures for each individual.

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The effect of tibio-talar arthrodesis on the foot kinematics and ground reaction force course during gait

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Introduction

Degenerative arthrosis in subtalar and midtarsal joints occurring after tibio-talar arthrodesis are thought to be related to consecutive abnormal foot dynamics (Duquennoy et al., 1985, Ben Amor et al., 1999). The forward tilt of the tibia induces early talar movement in the sagittal plane as it is fused to the tibia what induces dorsiflexion stress in the mid-tarsal joints. We hypothesized that the early stress exerted by the tibio-talar block on the mid-tarsal joint during stance is associated with an early forward displacement of the ground reaction force. In addition, as the mid-tarsal joints incompletely compensate the loss of ankle dorsiflexion, we hypothesized that early heel rise occurs during gait to allow further forward tilt of the tibia. At early heel off, the GRF vector would be still posterior to the third rocker, exerting dorsiflexion stresses on the joints located between the ankle and the metatarsal heads. Wearing shoes was hypothesized to delay the heel rise compared to barefoot walk.

Materials and method

Three-dimensional gait analysis was performed in ten controls and in ten patients with pain free ankle arthrodesis fused in neutral position for more than one year as a treatment of post-traumatic ankle arthritis. Two out of several conditions of walking are reported here: walking barefoot and with the customary shoes at self-selected speed. At heel off, the following variables were obtained: anterior tilt of the tibia with reference to the horizontal axis, knee flexion, foot/tibia angle. The GRF sagittal alignment and GRF distance to the ankle were measured during the stance phase and at heel off.

Results

Walking barefoot, the walking speed was significantly lower in patients than in controls (1.09 ± 0.18 [mean $\pm$ 1SD] vs 1.28 ± 0.12 m/s, $P < 0.05$) by a stride length decrease. Walking barefoot, in patients (11 arthrodesis) compared to controls ($n = 10$), the GRF course with reference to the ankle marker was shifted forward during midstance, heel off occurred earlier (48 ± 8 vs 61 ± 5% of stance phase, $P < 0.01$) and was associated to a lower foot /tibia dorsiflexion (4 ± 3 vs $9 \pm 3°$, $P < 0.01$), a less anterior tilt of the tibia (85 ± 4 vs $78 \pm 3°$, $P < 0.01$), comparable knee flexion (0 ± 8 vs $1 \pm 3°$) and a less anterior position of the GRF with reference to the ankle marker (77 ± 9 vs 89 ± 9% of ankle—second metatarsal head distance, $P < 0.01$). The difference of height between heel and anterior sole of the customary shoes was higher in patients than in controls (17 ± 5 vs 10 ± 7 mm, $P < 0.05$).

Walking with shoes, the speed was lower in patients than in controls (1.21 ± 0.17 vs 1.37 ± 0.16 m/s, $P < 0.05$). Walking with shoes, in patients compared to controls, the GRF course, heel off (56 ± 8 vs 60 ± 3% of stance phase), tibia tilt at heel off (82 vs 4 vs $79 \pm 3°$) and knee flexion at heel off (1 ± 4 vs $1 \pm 3°$) were not significantly different whereas the foot/tibia dorsiflexion at heel off was lower (2 ± 3 vs $6 \pm 3°$, $P < 0.01$) and the GRF was still less anterior at heel off (68 ± 9 vs 84 ± 8% of ankle—second metatarsal head distance, $P < 0.01$).

Discussion and conclusion

Walking barefoot, early heel off in arthrodesis, which was associated to a less anterior tilt of the tibia than in controls, was likely related to the limitation of foot/tibia dorsiflexion and allowed the tibia to tilt forward. The position of the ground reaction force with reference to the foot during stance phase provided information which comforted the hypothesis of higher stresses applied to the mid-tarsal joints in arthrodesis during gait. Indeed during midstance the GRF distance to ankle was higher in arthrodesis than in controls. This forward shift of the ground reaction force course is likely related to the force exerted by the tibio-talar block on the distal joints and on the ground as the tibia tilted forward. In addition, at early heel off in arthrodesis the GRF distance to the ankle was lower than in controls. In other word, in arthrodesis the GRF did not reach yet the third rocker at heel off and therefore exerted additional stresses to the segment between the tibio-talar block and the metatarsal heads compared to controls.

Walking with shoes, heel off in arthrodesis was delayed by wearing shoes and approached the heel off value of controls. At heel off, the tibia anterior tilt in arthrodesis was increased by wearing shoes and approached the values of controls. The contribution of the shoes to the tibia anterior tilt is related to the importance of tilt of the shoes. This mechanism may explain that patients with arthrodesis wore more tilted shoes than controls. In patients, the ability to load the heel on the floor while tilting the tibia in midstance contributed to delay the anterior displacement of GRF compared to barefoot. However, at heel off the GRF was still more posterior in arthrodesis than in controls as the combined result of the tends to early heel off and to delay the anterior shift of the GRF.

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This study has shown that ankle arthrodesis fused in neutral position induces during barefoot walking alterations of the foot kinematics and ground reaction force course which can contribute to mechanical pathogenic effect on the joints located between the tibio-talar block and the metatarsal heads. The use of shoes improved greatly but not totally the anomalies of foot dynamics.

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Posttraumatic ankle arthrodesis: kinematic findings using a multi-segment foot model

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Introduction

The operative fusion of the ankle joint is a common orthopaedic procedure to alleviate pain, prevent and correct instability. Ankle arthrodesis is considered the primary treatment in case of non-correspondance to conservative treatment of rheumatoid arthritis and posttraumatic residual conditions (Müller et al., 1999). Reports on long-term gait results have been made indicating a decrease in sagittal plane motion concerning the hindfoot and an increase in sagittal plane motion in the forefoot (Wu et al., 2000). The aim of this study is to evaluate gait of patients who had undergone ankle arthrodesis for posttraumatic arthritis using a new, more detailed foot and ankle model.

Materials and methods

Nine subjects (5 males, 4 females) who had undergone ankle arthrodesis returned for clinical examination and gait analysis. The median age at time of examination was 62.5 years (range 45 to 73 years), age at time of operation 57 years (range 41 to 68), the post-operative follow-up time was 55 months (median) with a range from 36 to 80 months. Operative procedures were performed as internal fixations ($n = 7$) and external fixations ($n = 2$). Patients were instrumented with a set of 17 reflective markers. For data aquisition we used a Vicon 612 system with 9 cameras operating at 120 Hz. A static measurement in standing posture for reference was performed before the person was asked to walk a 7 m walk way at a self selected speed. 8 strides including stance and swing phase were monitored per leg, each of a different walking trial. For the evaluation of foot kinematics a multi-segment foot model was used (Simon et al., 2001). Kinematic data were also collected for 10 healthy individuals using the same testing protocol. Differences between means for the ankle arthrodesis and control groups were tested using independent t-tests ($P < 0.05$).

Results

Review of the radiographs showed no evidence of degenerative arthritis of the remaining foot joints.

Kinematic results are shown in the Table. The ankle angle is the generally accepted parameter to describe motion between the shank and the foot regarded as a rigid segment (a). In our model it was defined exclusively by the angular position of the hindfoot relative to the tibia (b). The loss of motion in the ankle joint is shown by the significant decrease of ROM in comparison of both groups, the results elaborated by our foot model showed a higher accuracy. A decrease in hindfoot and midfoot range of motion in frontal plane movement is seen (e) while forefoot motion does not seem to differ from controls (f). Furthermore the results show a decrease of the medial arch combined with an increase of rigidity (c,d).

Table

Kinematic measures of the ankle arthrodesis group compared to normal

	Ankle arthrodesis group ($n = 9$ patients)	Control group ($n = 10$ patients)
a) Sagittal Ankle Angle ROM° (standard)	11,54 ± 5,22*	33,69 ± 4,30
b) Sagittal Ankle Angle ROM° (foot model)	8,56 ± 3,56*	23,48 ± 4,96
c) Sagittal Med Arch ROM°	11,59 ± 4,57*	17,26 ± 10,84
d) Frontal Med Arch ROM°	5,67 ± 2,22	15,62 ± 11,23
e) Frontal Midfoot Supination ROM°	7,72 ± 3,73	10,41 ± 8,60
f) Frontal Forefoot Supination ROM°	5,54 ± 1,99	3,79 ± 3,74

Mean ± standard deviation; *statistical significance from control group $P < 0.05$.

Discussion and conclusion

As expected the operative fusion of the ankle joint limits the sagittal plane motion of the tibial to hindfoot segment due to the lack of tibiotalar motion. Despite the improved modelling approach we still see some remaining ankle joint movement which we consider subtalar movement. Our data do not confirm the thesis of a compensatory increase in forefoot motion. Quantitatively the new model shows only a slight increase in accuracy compared to the standard measuring procedure. Further improvement regarding the quality of modelling is necessary to achieve additional information which are of great benefit for the clinical evaluation.

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Gait analysis study of patients with posterior cruciate ligament and posterior-lateral corner deficiency

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Introduction

Injury to the posterior cruciate ligament (PCL) and posterior-lateral corner (PLC) of the knee causes varying degrees of disability. Surgical reconstruction of these areas is difficult and often unsatisfactory. The effects of this injury on physical function are not as well documented as those of the more common injury of the anterior cruciate ligament. This study aimed at improving our understanding of PCL/PLC injury through functional evaluation, gait analysis and electromyographic (EMG) testing.

Patients and methods

Nineteen patients with clinically and radiologically confirmed PCL/PLC deficiency and no other significant injury[b] were included in the study. The average age of the patients was 30 years (range 20–55). 90% of patients complained of instability of the knee when performing the activities of daily living and all patients complained of pain. All patients were assessed using the Lysholm and Gillquist functional knee score as well as gait analysis, including Kinematics, Kinetics and EMG of the quadriceps, hamstrings and gastrocnemius muscles. These findings were compared to our normal database. The mean Lysholm score in these patients was 51/100 (range 24–90). Those with a Lysholm score greater than 50 were designated as "copers", those with a score less than 50 were designated as " non-copers".

Results

There were 12 "non-copers" and 7 "copers". 50% of patients demonstrated a varus thrust through stance. 42% of patients demonstrated hyperextension of the knee through stance. 63% of patients demonstrated premature and prolonged hamstring activity. 37% of patients had premature activity of the gastrocnemius muscle in stance. 57% of the "copers" demonstrated premature and prolonged hamstring activity through the gait cycle compared to 45% of "non-copers" (non-significant $P = 0.25$ Fishers Exact Test). 55% of "non-copers" demonstrated premature activity of the gastrocnemius muscle in stance compared to none of the "copers" (significant $P = 0.025$ Fishers Exact Test)

Discussion and Conclusions

The observed varus thrust may be responsible for the development of medial and patellofemoral compartment osteoarthritis, a recognised problem in PCL deficient knees. Hyperextension is another recognised clinical finding in this group of patients. We have shown that this also occurs dynamically during gait, which would explain why PCL/PLC reconstruction fails over time as the grafts "stretch out". It is possible that extension block splints used in the postoperative period and gait retraining prior to reconstruction may prevent this complication.

It is known that afferent impulses generated from mechanoreceptors in the cruciate ligaments influence hamstring and quadriceps activity. This deficiency of proprioception in PCL/PLC deficient knees could explain the abnormal activity of the hamstrings in our patients. Overactivity of the hamstrings is unlikely to be a compensatory mechanism as it produces undesirable posterior translation of the tibia. Proprioception deficiency would explain the similarity of results between "copers" and "non-copers".

Premature activity of the gastrocnemius muscle in PCL/PLC patients has been previously demonstrated in isokinetic knee motion. In our study, a significant number of "non-copers" showed premature EMG activity of gastrocnemius. This is likely to represent a compensatory mechanism to stabilise the knee joint by applying a posteriorly directed force on the distal femur when the foot is fixed on the ground, thus producing a relative anterior translation of the tibia. This action would also increase the axial compression through the joint, further increasing stability

In conclusion, gait analysis revealed mechanical and EMG abnormalities that would explain some of the disabilities related to PCL/PLC deficient knees. Further, gait analysis provided adequate explanation for the development of osteoarthritis and the failure of surgical treatment in these patients. Some treatment suggestions were made, based on these findings. Dynamic overactivity of the gastrocnemius muscle may be a common compensatory mechanism is these patients and should be considered in rehabilitation programs.

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Gait patterns of ACL deficient knee before and after reconstruction

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Introduction

It has been hypothesized that injury and reconstruction of the anterior cruciate ligament (ACL) leads to alternations in lower extremity joint kinematics, kinetics and energetic patterns during gait. These gait parameters may develop as a result of muscle adaptation and neuromuscular reprogramming, possibly in response to pain or instability, to stabilize the knee and to prevent re-injury during gait The studies in literature (Bulgheroni et al., 1997; Ciccoti et al., 1995; DeVita et al., 1997) suggest the time between injury and surgery may also influence the type of gait pattern observed in ACL reconstructed patients. It is possible that individuals who have chronic ACL deficiency may develop gait patterns different then those tested in the acute stages of the ACL injury. Additional studies are necessary to either support or refute the development of a quadriceps avoidance gait pattern. The aim of this study is to determine how select gait parameters may change as a result of anterior cruciate ligament (ACL) deficiency and following ACL reconstruction.

Materials and method

The study was performed on 15 male (29.7 ± 6.52 years; the height 177.9 ± 8.7cm, the weight 81.4 ± 7.4 kg) and 6 female patients (37.5 ± 9.1 years; the height 160.1 ± 5.85 cm, the weight 62.0 ± 6.6 kilograms) who underwent ACL reconstruction by the bone — patellar tendon — bone technique.

Gait analysis was performed using zebris ultrasound based system with a 19-point biomechanical model and eight-channel-electromyography. The surface EMG electrodes attached to m. vastus medialis and lateralis, m. adductor longus and m. biceps femoris. From the spatial coordinates of the investigated antropometrical points the kinematical data (step length, step width, knee angle and relative ACL movement parameter) was calculated The muscle-activity is characterized by EMG envelope-curve in time-function.

Results

The results obtained from the operated subject were compared with those of healthy knee. The difference in the step width, the step length and the knee angle between two legs is significant prior and 6 weeks after the surgery; the difference is 3 – 10 percent in postoperative 4 month. The difference in the relative ACL-movement parameter between two legs is significant until the 8th month after the surgery. The EMG results suggests that, the m. vastus avoidance pattern developed at 72 percent of patient, the activity of m. vastus could be detect 4 months after the surgery. The m. adductor longus works just during the start of the stance phase and during the end of swing phase. The m. adductor longus shows activity at the end of the stance phase just 4 month after the surgery. The results show the importance of biceps femoris in the rehabilitation after the ACL reconstruction.

Discussion

The acute ACL deficient subjects showed an increased knee extension during the stance and reduced flexion during swing phase. The relative ACL movement parameter describes the tibial translation into the direction of ACL. The present investigation indicated that the acute injured limb exhibited a greater tibial translation as compared to controls and to contralateral non-injured limb. Analysing EMG data and comparing to kinematic data, we see that a reduction of extensor activity (quadriceps), and reduction in muscle adductor longus activity and an increase in muscle biceps femoris activity, as a more complex neuromuscular mechanism, in order to assure joint stability. It has been demonstrated that the m. biceps femoris is effective synergists to the ACL in reducting tibial translation. The chronic ACL deficient knee-position curves showed flexion-extension-flexion pattern during the stance phase. No significant differences were observed compared to control group's. In the present investigation, evidence of a quadriceps avoidance pattern was not observed, as a chronic ACL deficient subjects exhibited no significant differences in knee characteristics compared to the control group. The chronic ACL deficient individuals demonstrated reduced tibial translation into the direction of ACL compared to acute ACL deficient patients. However, the difference is significant compared to controls and to non-injured contralateral non-injured limb. It is possible that the chronic ACL deficient subjects actively try to reduce tibial translation helping muscles.

The results suggested that after approximately 4 months, ACL reconstructed patients can approach normal gait pattern, but more time is needed to re-establish pre-injury tibial translation characteristics. These data demonstrated a time-related trend toward re-establishment of pre-injury gait patterns, but suggest that several months may be needed for this patterns to develop. The measured muscle EMG activity may support the explanation that at least 8 months are needed for the biomechanical rehabilitation after ACL reconstruction. The normal activity of muscles returns 8 months after surgery. The EMG patterns of ACL reconstructed patients appear to approach the values observed in control group. The quadriceps activity is increased during the stance phase at acute ACL reconstructed patients and is decreased at chronic ACL reconstructed patients. The muscle adductor longus activity is increased during the pre-swing phase. Also, co-contraction of the biceps femoris during the pre-swing is greatly reduced during the rehabilitation. Surgical repair significantly alters lower extremity gait patterns and re-establishment of pre-injury gait patterns takes 8 months to occur, which is shorter than the 10-12 months long histological rehabilitation.

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The radiographic compararison of static and dynamic measurements of the mechanical alignment of the lower limb by the Vicon VX3-dimensional gait analysis system

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Introduction

Surgeons who perform total replacement of the knee are particularly interested in the axial alignment of the lower extremity. Several studies have concluded that the durability of the Total Knee Replacement is partially dependent on the postoperative axial alignment of the lower extremity. There is controversy concerning the best method for measuring this alignment radiologically. Moreland et al. (1987) has described a precise method of measurement of the mechanical alignment of the hip/knee/ankle joints from radiographs. This measurement should correspond to the mechanical alignment measured by Vicon VX 3-dimensinal gait analysis system using Vicon Clinical Manager (VCM) software (Oxford Metrics, Oxford, UK). The measurement of mechanical alignment of the lower limb has previously been compared using a 2-dimensional gait analysis technique that confirmed the accuracy of the system in comparison with radiographs (Gray et al., 1995). A similar study using a 3-dimensional gait analysis technique confirmed its accuracy in comparison with radiographs for a group of post-menisectomy patients (McNicholas et al., 1997).

Materials and method

The purpose of this study is to validate radiologically the static and dynamic mechanical angle of the lower limb measured by the Vicon VX system and VCM in a group of patients with significant knee pathology and a wide range of measurements in alignment. The Dundee Gait Lab uses the protocol described in CAMARC (Del. No. 17 1995) to align the marker set such that knee rotation should equal zero. This is achieved by aligning the markers on each segment so that the plane they form is perpendicular to a clinically determined sagittal plane, rather than parallel to the intercondylar axis. The correlation between the results of the Vicon VX system and long leg radiographic measurement was tested. Data was acquired from 31 legs in total. 24 legs were assessed seen prior to undergoing Total Knee Replacement, 7 legs were assessed postoperatively. They had the long leg standing films and kinematic assessment during standing (static) and level walking (dynamic).

Results and Discussion

The mean value for the Varus/Valgus alignment of the limbs, as measured in long leg radiographs, was 4.32° (range-17 to 20). The mean value for the Varus/Valgus alignment of the limbs as measured by the Vicon VX system during standing was 3.4° (range −9.6 to 22.4) and during level walking was 4.01° (range −7.2 to 20.7). These results were highly correlated with a correlation coefficient of: 0.877 for the Static Vicon Measurements and 0.835 for the Dynamic Vicon Measurements. The mean values were very close, with the arithmetic differences between the first pair (Static) being 0.90 and the second pair (Dynamic) being 0.30, which is better. Improvements in these relationships were not obtained when anatomical modelling artefacts, caused by marker-based errors in knee rotation, were considered. This contradicts the findings of the previous study of McNicholas et al which demonstrated that the modelling artefacts significantly affected the results when considering knee rotation errors of greater than 5°. These differences compare favourably with the reproducibility reported for roentgeno-graphic assessment of the Hip Knee Ankle axis which has been shown to have a variability of up to 2° (Odenbring et al., 1993).

Conclusion

This concludes that the Vicon VX 3-dimensional system measures the mechanical alignment (static and dynamic) of the lower limb comparably with standard radiographic techniques in those patients who have a wide range of alignment measurements.

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The influence of walking patterns on hip joint replacement wear — a pilot study of hip arthroplasty patients 10 years post-operatively

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Introduction

Wear of ultra-high molecular weight polyethylene (UHMWPE) is the predominant problem affecting the long-term success of total joint arthroplasties in vivo. Recent studies (Saikko and Alhroos, 1999; Bennett et al., 2002) have emphasised the importance of multidirectional motion on the wear of the UHMWPE acetabular component. Simulator wear tests in vitro have recorded over 100 times greater wear for multidirectional motion compared to linear motion (Wang et al., 1996; Smith and Unsworth, 2000). Wear of the UHMWPE acetabular cup is influenced by the sliding distance and wear trajectories of individual points on the femoral head. Differences in gait kinematics may account for substantial differences in wear rates and the ultimate success or failure of the implant. A pilot study was undertaken to determine the trajectory and distance traversed of specified points on the femoral head for individual THR (total hip replacement) patients 10 years post operatively.

Materials and method

Hip joint gait kinematics during normal walking were determined for 7 THR patients 10 years post-operatively using retro-reflective markers and a lower body marker set. Data was captured at 50Hz. Subjects were chosen at random from patients attending 10-year review clinics. Wear measurements were made radiographically using an established technique. Movement loci for 20 points on the femoral head were modelled (MATLAB) for each subject using kinematic data captured during gait analysis.

Results

Movement loci differed in both shape and size over the femoral head ranging from wide, open paths (Figure 1) to more longitudinal paths (Figure 2). The average point sliding distance ranged from 12.97 to 24.13 mm between subjects. Loci shape ranged between subjects from longitudinal paths with gentle directional changes to wide paths with sudden directional changes. Wear paths for normal subjects tend to be elliptical, oblong or figure-8 in shape. Reduced range of ab/adduction and internal/external rotation at the hip joint produced more longitudinal paths.

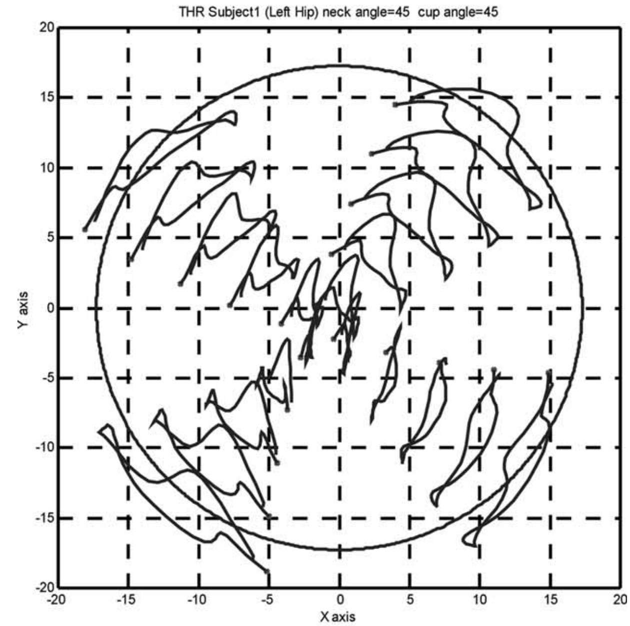

Figure 1. Movement loci Subject 1

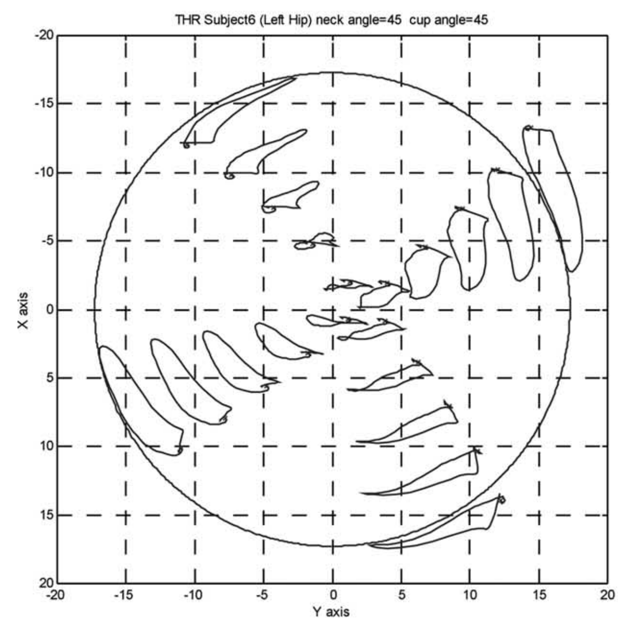

Figure 1. Movement loci Subject 1

Discussion

The relief of pain and the restoration of function is the main benefit of THR, with gait kinematics often failing to improve to normal levels (Franz et al., 2002; McCrory et al., 2001; Stauffer et al., 1974). However, THR implants are designed and tested using ‘‘normal’’ gait patterns and do not account for differences in individual patient kinematics. Normal gait kinematics produce wide, open paths which are associated with high wear rates. THR patients often display a restricted range of hip ab/adduction and internal/external rotation which produce more linear paths that are associated with greatly reduced wear rates. Longitudinal paths cause orientation hardening and increased wear resistance while wide paths cause increased shear and greater wear rates. As THR patients display hip joint gait kinematics which range from normal to restricted levels, this may account for the variance in wear rates of patients post-operatively.

Conclusion

Differences in gait kinematics produced very different movement loci in terms of sliding distance and shape. It is proposed that wide, convoluted paths cause significantly more wear than linear paths. Differing gait kinematics may have a significant influence on UHMWPE wear rate and the long-term survival of implant replacements.

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Thursday 11th September 2003 10.34–11.14
Lecture 1

Thursday 11th September 2003 11.14–12.38
Oral Session 2: Cerebral Palsy 1

The mechanical work of toe walking in children with cerebral palsy

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Introduction

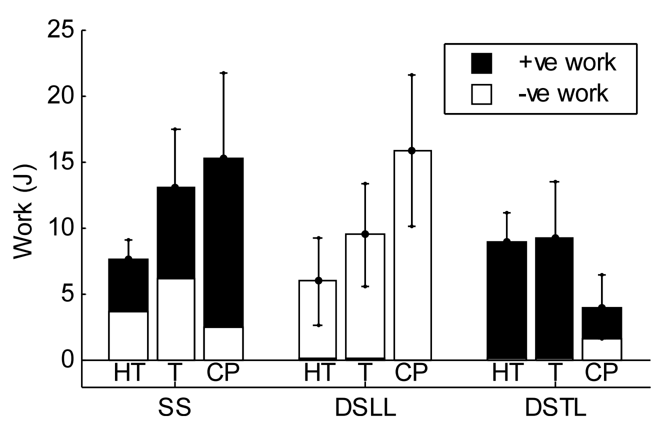
A number of workers have extrapolated findings from studies of voluntary toe-walkers to toe-walking secondary to spastic cerebral palsy (Kerrigan et al., 2000; Davids et al., 1999; Childs et al., 2002). While joint kinematics and electromyography patterns may be largely similar in the two groups, no work has yet been reported comparing the mechanical energetics of these subjects. Here, we detail the mechanical work done in toe-walking children with spastic diplegic cerebral palsy (SDCP), and in normally-developing (ND) children who were asked to walk with a natural (heel-toe) and a toe-walking gait pattern. Our hypothesis is that there will be no significant differences between the mechanical energetics of voluntary- and pathological-toe walkers.

Materials and methods

Six ND children were asked to walk through the laboratory at a self-selected walking speed under two conditions; heel-toe walking and toe walking. We also searched our laboratory database for toe walking children with a diagnosis of SDCP. These children were weight-matched to the ND group. In each group, only trials with consecutive forceplate hits were selected (AMTI OR6 sampled at 1kHz). The methods of Donelan et al. (2002) were adopted to calculate instantaneous powers, and the work done between different events in the gait cycle, from forceplate data alone. The method includes separate contributions to power from the leading and trailing limbs during the period of double support. Significance was determined using the Student's t-test ($P < 0.05$).

Results

The Figure depicts the positive and negative work done during single support (SS) and double support (DS) for ND children during heel toe walking (HT) and toe walking (T), and for SDCP children (CP). Contributions from the leading (LL) and trailing limbs (TL) during DS are separated. During SS, there are approximately equal amounts of positive and negative work done in the ND group under both walking conditions. Children with SDCP do significantly more positive than negative work ($P < 0.01$) in this phase. Also, these children do more negative work with the leading limb during double support when compared to ND children toe walking ($P < 0.05$) or heel toe walking ($P < 0.01$). There is significantly less work done by the trailing limb of children with SDCP during double support than by ND children toe walking ($P < 0.05$) or heel toe walking ($P < 0.01$).



Discussion and conclusion

Contrary to our initial hypothesis the distribution of positive and negative work in the gait cycle is significantly different between voluntary- and pathological-toe walkers. Specifically, in the SDCP group most of the positive work of walking is performed during SS, whereas, in the ND group the majority of positive work is performed by the trailing limb in DS, irrespective of walking style. Our results imply that voluntary toe walking is not similar biomechanically to toe walking in children with SDCP, and suggests that intervention in cerebral palsy that diminishes power generation in SS may reduce the velocity at which the child can progress.

Acknowledgements

This work was supported by the One Small Step Charitable Trust.

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The Incidence of an in-toeing gait pattern in cerebral palsy

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Introduction

Children with cerebral palsy often walk with an in-toeing gait pattern. In the normal population the incidence of in-toeing has been documented (Aktas et al., 2000) and the three most common causes of this pattern have been identified as internal tibial torsion, metatarsus adductus and femoral neck anteversion (Aston, 1979) The incidence of an internal hip rotation gait and the possible causes of this gait pattern have been investigated in the cerebral palsy population (O'Sullivan et al., 2002). However, the incidence of an in-toeing gait pattern due to rotation at any level in the lower limb has yet to be examined. The purpose of this study was 1) to establish the incidence of in-toeing gait in patients with cerebral palsy, and, 2) to examine where (hip-femur, knee-tibia or ankle-foot) the excessive internal rotation was occurring in this group.

Materials and Methods

Based on a previous study of normal subjects ($n = 33$, age range 5–14) excessive average dynamic in-toeing (foot rotation relative to pelvis) was defined as -4.3^{o} (mean $\pm$2SD). Three hundred and sixty nine patients with cerebral palsy (diplegia-58%, hemiplegia-42%, age range 4–51) who had undergone gait analysis using the CODA mpx30 system from 1998-2003 were reviewed. The overall incidence of in-toeing was calculated in the cerebral palsy population. This group was subdivided into patients with hemiplegia or diplegia and their gait data were studied to identify at which level (hip-femur, knee-tibia or ankle-foot) the excessive internal rotation was occurring based on data (mean$\pm$2SD) from the normal group.

Results

Of 369 patients, 149 (40.4%) patients walked with at least one lower limb demonstrating excessive dynamic in-toeing with a higher incidence among diplegics (47.2%) compared to hemiplegics (31.0%). In the hemiplegic group the incidence of in-toeing was more common among those with left sided involvement (left 40.5%, right 18.2%). In diplegics in-toeing was a unilateral feature in 80.2% of cases with the left leg being the most commonly affected (left-side 69.5%, right-side 30.5%). In-toeing was secondary to a single primary deformity (average internal rotation > 2SD normal) in 57.5% of diplegics and 37.5% of hemiplegics with the problem found to be multi-level in the remainder. The incidence of the primary deformity at each anatomical level is outlined in the Table.

Table
Level of primary deformity in hemiplegia and diplegia

Level of Primary deformity	Hemiplegia ($n = 18$)	Diplegia ($n = 69$)
Hip-femur	34.4% ($n = 8$)	46.4% ($n = 32$)
Knee-tibia	27.8% ($n = 5$)	23.2% ($n = 16$)
Ankle-foot	27.8% ($n = 5$)	30.4% ($n = 21$)

Discussion

In this study, the incidence of dynamic in-toeing was defined in children with cerebral palsy. This was found to be a significant problem affecting 40.4% of the population. It is a multi-level problem occurring at the level of the hip-femur, knee-tibia and ankle-foot. While the hip-femur is the most common primary cause both in hemiplegics and diplegics the incidence of primary deformities at the knee-tibia and ankle-foot is significant. Further studies are needed to identify factors contributing to internal rotation at these levels.

Conclusion

In-toeing gait is a significant problem in Cerebral Palsy affecting 47.2% of diplegics and 31% of hemiplegics. The most common level of primary deformity occurs at the hip-femur (34.4% in hemiplegics, 46.4% in diplegics) with significant primary deformities also occurring at the knee-tibia (27.8% in hemiplegics, 23.2% in diplegics) and ankle-foot (27.8% in hemiplegia, 30.4% in diplegia).

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Muscle–tendon length ratios in children and adults

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Introduction

Work from Hof (2002) and Griffiths (1989) has implicated tendon mechanical properties in the mechanical function of the musclotendinous unit. In his model of the triceps surae, Hof predicted that much of the musculotendinous length changes in walking and running occurs in the tendinous components (the series elastic element, SEE) while the muscle fibres may contract only slowly. Work from Griffiths showed that animals, with smaller belly-tendon length ratios such as wallabies, exhibit large amounts of elastic recovery. Musculoskeletal models, describing movement, incorporate descriptions of the mechanical properties of musculotendinous actuators. Due to the lack of experimental data, these models make assumptions about fundamental relationships between the model elements. For example, the model reported by Zajac (1989) may be limited in scope since values for normalised tendon slack length, l_{ts}, (the ratio of resting tendon length, including the aponeurotic component, to optimal fibre length) were derived from adult cadaveric data. In his model, l_{ts} is a determinant of the stiffness of the SEE.

Children with cerebral palsy often walk in equinus. This gait pattern may take mechanical advantage of elastic energy stored in the muscle complex. Our previous ultrasound work (Fry et al., 2003) has shown that muscle bellies in these children are shorter than in their normally developing peers with the implication that tendon lengths are longer. In this study, we use an ultrasound technique to measure fibre, belly and tendon lengths in normally developing adults and children and in children with spastic diplegic cerebral palsy (SDCP).

Materials and method

An ultrasonic imaging technique (Fry et al., 2003) was used to generate 3D reconstructions of the medial gastrocnemius and Achilles tendon in 4 limbs of normally developing adults (AD), 9 limbs of normally developing children (ND) and 5 limbs of children with SDCP. Data were collected with the subjects lying prone on the couch with their ankles at their resting angle. The length of a fibre in the centre of the belly was measured for each subject. The lengths of the muscle belly and the tendon were estimated by fitting third order polynomials to the centroids of transverse sections reconstructed from the 3D ultrasound data. Values for l_{ts} were derived according to the definition of Hoy et al. (1990). Ratios of belly length to tendon length were calculated for each subject.

Results

	AD ($n = 4$)	ND ($n = 9$)	SDCP ($n = 5$)	AD vs ND	ND vs SDCP
Belly – tendon length ratio	0.57 $\pm$ 0.05	0.56 $\pm$ 0.05	0.45 $\pm$ 0.04	$P = 0.83$	$P < 0.01$
Normalised tendon slack length	7.66 $\pm$ 0.71	6.42 $\pm$ 0.90	6.39 $\pm$ 0.49	$P = 0.03$	$P = 0.93$

Discussion and Conclusion

We found l_{ts} in the AD group to be consistently smaller than the values of 8.85 and 9 quoted by Hoy et al. (1990) and Zajac (1989). Further, in the ND and SDCP groups, l_{ts} was up to 33% lower than the cadaveric values. Figure 6 of Hoy et al. (1990) shows that a small alteration in l_{ts} affects muscle force – length relationships profoundly, so accurate determination of this parameter may be required to avoid misleading model results. Children in the SDCP group had smaller belly – tendon length ratios. Animals with smaller ratios use elastic storage and recovery to progress (Griffiths, 1989). Positioning of the ankle in equinus at initial contact combined with greater compliance of the Achilles tendon may allow children with SDCP to absorb large amounts of energy during the loading phases of gait, with the prospect of recovery of this energy at a later stage in the gait cycle.

Acknoledgments

Ms Nicola Fry was funded by a grant from the Wishbone Trust supported by the Hudson Foundation, The Clothworkers Foundation, the London Law Trust and the Harold Wingate Foundation. The ultrasound scanner used in this work was funded by The Charitable Foundations of Guy's & St Thomas' Hospital, and the One Small Step Charitable Trust.

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Relating knee kinematics, muscle lengthening profiles and spasticity level of the rectus femoris in children with cerebral palsy

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Introduction

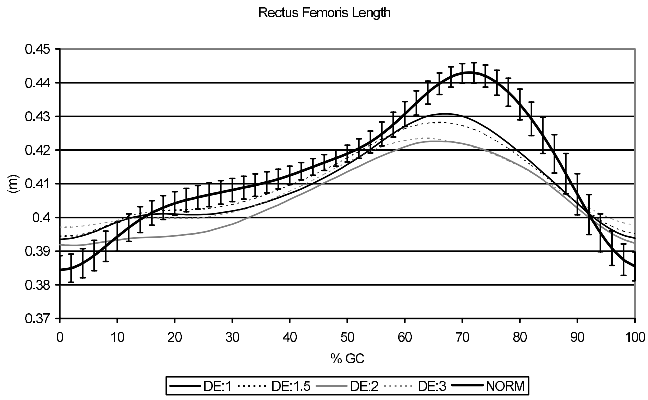
Stiff-knee gait in cerebral palsy is frequently associated with abnormal activity patterns in the M. rectus femoris (RF). Most studies reported changes in knee kinematics (delayed and decreased peak knee flexion amplitude) in combination with altered timing of the M. rectus femoris. Central hypothesis underlying the phenomena is that prolonged activation of the rectus induced by the stretch-reflex restrains the free flexion-extension pendulum movement of the limb in swing. The present study extends the work of Stewart et al. (1999) by documenting changes in muscle lengthening profiles of the M. rectus femoris during gait indicating the effect of increasing levels of spasticity as documented by the Duncan Ely test.

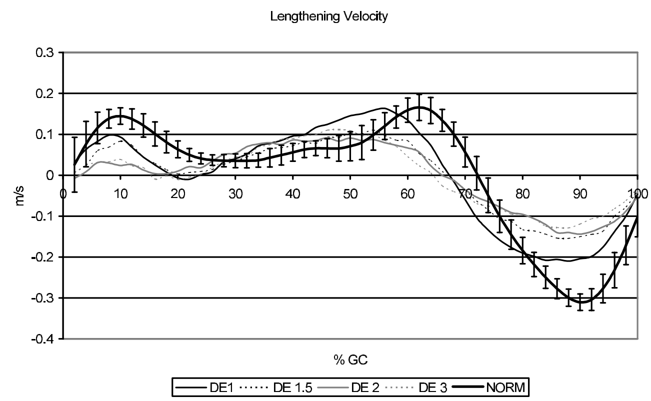
Materials and Methods

The study population consists of 35 children (age range: 6–10 years) with confirmed diagnosis of spastic diplegia presenting decreased peak knee flexion in swing as documented by a three dimensional movement analysis system (VICON). Based on the results of the Duncan Ely test, patients were grouped into 4 groups, each of them including 15 limbs (DE: 1-DE: 1.5-DE: 2 and D.E: 3). None of the children underwent previous orthopaedic surgical interventions of the lower limbs or were within 6 months after Botox treatment. Based on the joint kinematics of the hip and knee, muscle lengths of M. rectus femoris was calculated using SIMM based on a four segment musculoskeletal model taking into account 3DOF at the hip. Using the same musculoskeletal model, muscle length profile of RF was calculated based on a normative data set of 20 persons.

Results

Significant reduction and delay of peak kneeflexion amplitude in swing was observed with increasing spasticity of the RF ($P < 0.01$). Significant reduction of the maximal excursion of RF in swing, as well as a shift of the event towards early swing phase was found with increasing spasticity ($P < 0.01$). Length of the RF at the onset of swing was significantly lower for the patient group compared to normals ($P < 0.01$). With increasing spasticity level, muscle length at the onset of swing is further reduced ($P < 0.01$). The maximal excursions velocity of RF was significant lower in the patient population ($P < 0.01$) compared to normals.





Discussion and Conclusion

The presence of decreased peak knee flexion in swing as observed in CP children is often related to the restraining action of the M. rectus femoris on the pendulum movement of the lower limb in swing. Within the present study population a reduction and delay of maximal knee flexion amplitude in swing was confirmed and could be related to the level of spasticity of the M. rectus femoris, as documented clinically by the Duncan Ely test. A significant reduction of the maximal excursion of the rectus femoris during swing was found with increasing spasticity. Furthermore, a significant shift of the maximal excursion towards early swing was documented. Both these findings indicate that with increasing spasticity, lengthening of the M. rectus femoris is restricted therefore reducing the period of eccentric muscle action. It is believed that theses findings in the muscle lengthening profile reflect the restraining action of the stretch reflex on the muscle lengthening. The present study highlights the dissociation between the knee kinematics and the muscle length profiles already indicated by Stewart et al. (1999). It raises awareness that peak knee flexion is not a direct indicator of the muscle action of the rectus femoris muscle: Maximal peak knee flexion occurs during a period during which the rectus femoris muscle is no longer lengthening but has already reversed it action to shortening.

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EMG-analysis of the leg muscles in hemiplegic children with and without hinged ankle-foot orthoses

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Introduction

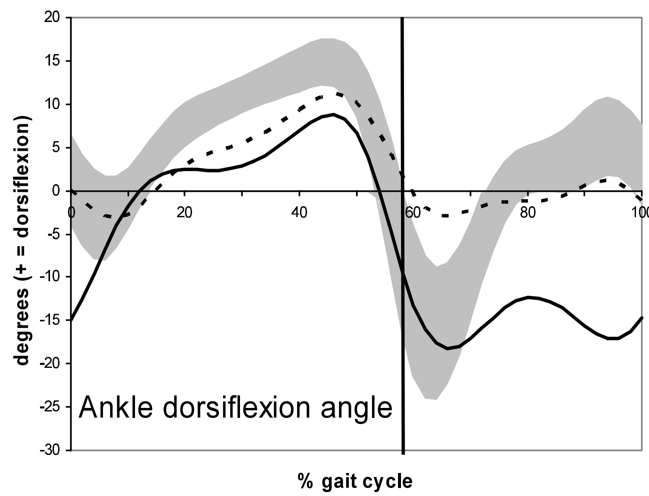
A toe walking gait pattern is typical for hemiplegic CP patients. Previous studies involving three dimensional gait analyses (Abel et al., 1998; Brunner et al., 1998; Romkes and Brunner, 2002) showed that an ankle foot orthosis (AFO) is successful in correcting the excessive plantarflexion angle and thereby improving these patient's gait pattern. Beside information on changes in joint angles, joint moments and powers or energy consumption with an AFO, information on changes in muscular function is also required to investigate the full effects of AFOs. The AFO achieves its function by modifying the forces and moments which the body is subjected to. When the body's internal force system is inadequate, most commonly an abnormal pattern of motion will occur. If, however, an orthosis has been correctly designed, constructed and applied to the patient, it may act or resist this abnormal pattern of motion and hence restore more normal function. The myoelectric signal, recorded as electromyogram (EMG), during gait provides valuable information with respect to timing of muscular activity. An AFO can correct the excessive plantarflexion in the swing phase of gait to improve pre-positioning of the foot for initial contact and allow a heel strike. EMG data on this improvement of gait function towards normal have been less investigated. The aim of this study was to evaluate changes in muscle activation in children diagnosed with hemiplegic CP during gait with and without wearing AFOs.

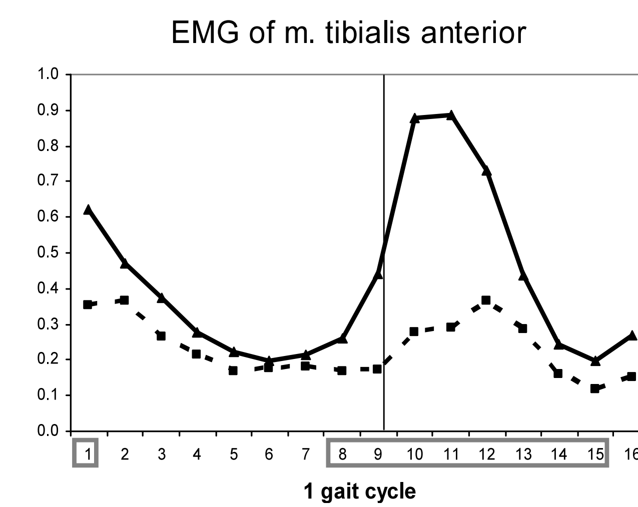
Methods

10 Children (6 boys, 4 girls; mean age 9.7 $\pm$ 1.6 years) with mild to moderate hemiplegic CP have been investigated. The children did not have any prior surgeries or fixed contractures and were experienced users of hinged AFOs. The children were tested barefoot and wearing a hinged AFO and shoes. Only children with an initial toe-strike barefoot and a physiological heel-strike with the AFO were included. All children performed a 3D gait analysis with a 6-camera, 50 Hz VICON 370 motion capture system (Oxford Metrics ltd., UK) and two forceplates (Kistler Instrumente AG, CH). Surface EMG (Zebris/Biovision, Germany) of the vastus medialis, vastus lateralis, rectus femoris, biceps femoris caput longum, semitendinosus, and tibialis anterior muscle groups was collected of the involved side. A matched control group of 10 healthy children was included in the study to provide comparative kinematic data.

Results

Mean ankle plantarflexion at initial foot contact was $15.0° \pm 9.7°$ when walking barefoot and $0.1° \pm 6.3°$ of dorsiflexion with the AFO. Kneeflexion angle at initial contact was increased compared to the control subjects and was not influenced by the AFO. A slight but significant increase in hip flexion at initial contact was seen in the patient group when wearing an AFO. However, values were not different from the control group. There were no significant differences at the level of the pelvis or in other selected kinematic parameters. EMG data showed reduced tibialis anterior muscle activity by the AFO in all patients. Other muscle groups tested did not show alterations.





Discussion and Conclusion

When toe-walking gait pattern in hemiplegic CP patients is altered by an AFO into a heel-toe gait pattern, activity of the tibialis anterior muscle is reduced. These results indicate that the pathological muscle activation pattern present in CP-patients is not only due to spastic activation but also to a compensation for the abnormal gait pattern.

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Analysis of the correlation between gait analysis, magnetic resonance imaging and gross motor function measure in subjects affected by cerebral palsy

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Introduction

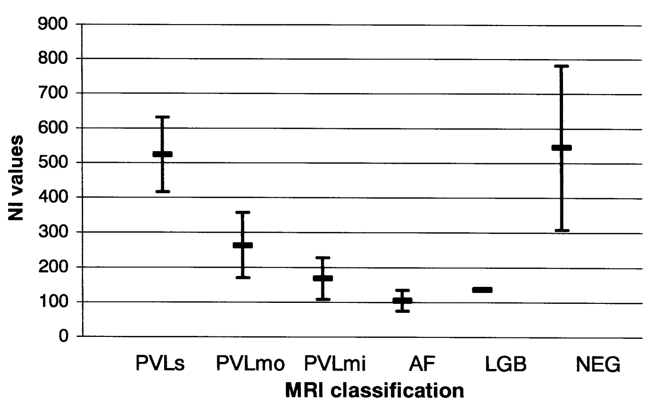
Cerebral Palsy (CP) is a pathology that affects the Central Nervous System (CNS). One of the primary effects of CP is a functional limitation in movement. There are many methods to investigate this kind of pathology and in particular each method analyses a specific aspect of that pathology. The most common diagnostic tools used for CP are: Magnetic Resonance Imaging (MRI) to analyse the size and position of the patient's cerebral lesion, Gross Motor Function Measure (GMFM) to analyse the patient's functional ability, Ashworth scale to analyse the muscle spasticity level and 3D Gait Analysis (GA) to objectively investigate and characterize the patient's gait pattern. Since there are many diagnostic methods that are applied to a single patient, it is important to understand the correlation between these different clinical evaluations. In particular, in order to compare GA data and other diagnostic evaluations, the Normalcy Index (NI) proposed by Schutte et al. was selected. Previous studies (Tervo et al., 2002; Novacheck et al., 2000) have examined the correlation between physical functioning and gait measures. The aim of this study was to assess the correlations between Normalcy Index (NI), MRI results, and GMFM scores in children with CP.

Materials and Method

25 children with CP (mean age = 5.6 years, range: 3–13) were analysed with an interdisciplinary clinical functional assessment including: MRI, GA, and GMFM. MRI results were classified as: PVLs for severe periventricular leucomalacia (PL), PVLmo for moderate PL, PVLmi for mild PL, AF for focal anoxia, LGB for basal ganglia lesion and NEG for a negative MRI. None of the subjects had undergone previous surgery, and all of the subjects underwent GA at "L. Divieti" movement analysis Lab of Bioiengineering Dept. of Politecnico di Milano (Milan, IT). An 8-camera optoelectronic system with passive markers (ELITE, BTS S.p.A., Milan, IT) working at sampling rate of 100 Hz was used to measure the movement. 10 healthy children (mean age = 9 years, range: 6–15) were also analysed with as control group (CG). The mean NI was computed from the kinematic data for both the healthy and pathological subjects. Statistical analysis was performed using T-test (P value < 0.05) and Pearson correlation (R).

Discussion and Conclusion

The MRI results showed 3 patients with PVLs, 4 PVLmo, 4 PVLmi, 9 AF, 1 LGB and 4 patients had negative MRI. In Figure 1, NI mean value for the subjects classified based on MRI results are shown. This graph represents the correlation between MRI classification and NI. It is possible to observe that lower the NI values correlate with the less severe cerebral lesions. Statistical analysis ($P < 0.05$) confirmed that the NI is able to distinguish between subjects with different cerebral lesions. Children with NEG MRI had NI values similar to NI value of subjects with PVLs ($P > 0.05$). The relation between NI and GMFM is represented by a Pearson's correlation $R = -0.74$. This means that a higher NI is strongly correlated to a lower GMFM. The correlation was stronger if only the GMFM score related to the walking ability was considered.



From these results it's possible to conclude that there is a good correlation between the gait ability represented by the NI and the position and size of the cerebral lesion obtained from MRI. However, MRI is ineffective in characterizing patients with CP who have a negative MRI. Based on gait and functional ability, GA and GMFM seem to be more effective at defining the pathological condition of patients affected by CP. A complete clinical evaluation should always include different diagnostic and clinical assessments. This study demonstrates that GA may be used in order to better define the functional limitations related to a neurological condition.

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Lower limb kinetics in assisted ambulators

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Introduction

Children with spastic diplegic cerebral palsy (SDCP) often use assistive devices when walking. Previous studies of assisted walking have looked at changes in kinematics in able-bodied subjects (Sheng et al., 2001) or children with spastic diplegia (Greiner et al., 1993), or measured force transmitted through the subjects' sticks (Tyson, 1998). Here, we examine the relative contributions of the lower-limb net extensor moments, and the relationship between selected kinetic and kinematic parameters in two groups of spastic diplegic children: assisted (group A) and independent (group B) walkers. Neptune et al. (2001) recognised the dominant role of the ankle plantarflexors in providing vertical support. We speculated that children who need to use assistive devices have weak ankle plantarflexors. We hypothesised that the plantarflexor moments of children in Kaye walkers would be reduced compared to their independent peers.

Method

Data from 14 children with a diagnosis of spastic diplegic cerebral palsy who walked barefoot with the assistance of a Kaye posterior walker (group A aged 5–13 years; mean age 8.86) were compared to data from a group of 11 independent walkers (group B aged 7–11 years; mean age 8.81 years), with the same diagnosis. Subjects in group B were selected to have similar levels of fixed deformity at the hip and knee to those in group A. All subjects were reported to be community ambulators, as defined by Hoffer et al. (1973). Kinematic and kinetic data had been collected during routine 3D gait analyses using a Vicon 370 six camera system and three AMTI force plates. For Group A, data was taken from a period of single support (SS) during an illustrative trial where the walker, identified by additional markers, was clear of the force plates. For both groups, extensor moments were calculated using the inverse dynamics model implemented in Vicon Clinical Manager. Linear regression analyses were performed between minimum knee flexion and individual mean extensor moments during SS. Between group comparisons were made using the Student's t- test (unpaired, unequal variance) with significance set at $P = 0.05$.

Results

There was no significant difference in joint excursion in the sagittal plane of the two groups at the hip, knee or ankle. No significant relationship existed between the mean hip extensor moment ($r^2 = 0.01$, $P = 0.73$) or the mean ankle plantarflexor moment ($r^2 = 0.02$, $P = 0.7$) and minimum knee flexion in either group. However there was a strong correlation between minimum knee flexion in stance and the mean knee extensor moment in both groups (independent $r^2 = 0.54$, $P = 0.01$; assisted $r^2 = 0.68$, $P = < 0.01$). No significant differences between the mean levels of the knee extensor moment ($P = 0.09$) or the mean hip extensor moment ($P = 0.52$), in the two groups, were found. Mean plantarflexor moments were significantly smaller ($P = < 0.01$) in the assisted group (group A) (Group A 0.39 Nm/kg $\pm$ 0.16; Group B 0.72 Nm/kg $\pm$ 0.19). The mean of the walking speeds in group A was significantly slower than that in the independent group ($P = < 0.01$).

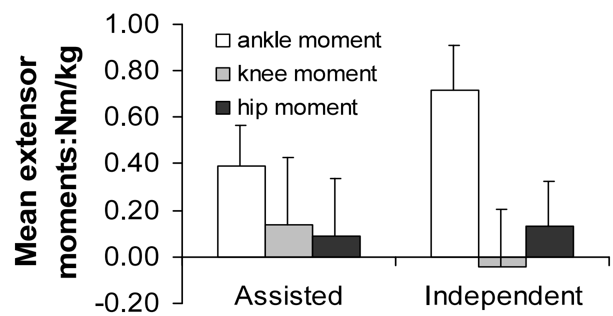

Figure: Mean extensor moments (+1SD) in single support for assisted and independent walkers

Discussion and Conclusion

Our results show a significant difference in the ankle plantarflexor moment between the two groups, with this smaller in group A. Plantarflexors generate forces for vertical support and forward progression in walking (Neptune et al., 2001). Increased forward trunk lean, accommodated by the walker, may assist the weak ankle plantarflexors in maintaining forward propulsion. This study shows that correction of ankle plantarflexor lever arm dysfunction and maintenance of ankle plantarflexor strength may have an important part to play in the maintenance of independent ambulation in children with SDCP, and the development of independent gait in the assisted walker.

Acknowledgments

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Thursday 11th September 2003 14:10–15:34
Oral Session 3

Prosthetics

Biomechanical effects of polymer gel-filled foot orthoses on healthy individuals during normal walking

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Introduction

During the last decade, there has been a trend towards use of mass-produced insoles to provide cushioning and shock absorption for the foot and proximal joints and thus improved stability and forward propulsion. Mass-produced insoles are not only fitted to subjects with pathological gait conditions but also to normal individuals during daily and/or sporting activities. Research on the biomechanical effectiveness of foot orthoses on normal individuals is limited and mainly focused on semi-rigid and rigid custom-made insoles (Stacoff et al., 2000; Nester et al., 2003). In this study, we investigated how normal subjects respond during gait when fitted with polymer gel-filled mass-produced insoles.

Materials and methods

3D-gait analysis was carried out for six male, healthy, adolescents (with a mean age of 29 years), wearing the same type and size of shoes and fitted bilaterally with a polymer gel-filled full-length soft foot orthosis. Fifteen spherical retro-reflective skin mounted markers were placed at specific anatomical points. Each subject performed eight consecutive gait cycles, at self-selected speed, under two experimental conditions; shod, and shod with insoles. Their performance was captured and processed by means of a motion analysis system manufactured by Qualysis AB, utilising seven infrared cameras at a capture rate of 100 Hz. Selected temporal and spatial parameters were then calculated and unpaired t-tests used to characterise the differences observed between the test conditions.

Results

When the gel-filled insoles were used, walking speed, cadence, stance phase period, stride length and range of motion of the pelvis, hip, knee, and ankle at the sagittal plane were increased, compared to the shoe alone, but the observed differences were not statistically significant. However, when the pelvic motion was considered, although the increment of the range of motion was small, the maximum tilting angle was increased by 18.8%. At the coronal plane, the range of motion of the pelvis, and hip, were not significantly increased too. When the range of motion of the ankle was considered, the observed increment, although not statistically significant ($p = 0.0723$), was quite high (39.3%). In addition, the range of motion of the knee was significantly decreased ($p = 0.0029$), due to decreased abduction. At the transverse plane, the range of motion of the pelvis and the ankle, were not significantly changed. However, the observed increment in the maximum rotation of the pelvis was quite high (68.7%). In addition, the range of motion of the hip, was decreased by 37.4% ($p = 0.0416$) due to decreased internal rotation, and the range of motion of the knee was increased by 59.1% ($p < 0.0001$).

Discussion and conclusion

Gel-filled orthoses provided increased values of the temporal parameters of gait, greater hip flexion, knee flexion, and ankle dorsiflexion. In addition the maximum ankle dorsiflexion occurred later in the stance phase, suggesting that the body was allowed to move forward longer before the heel was forced to raise. Hence, although the positive effect of the orthoses on the gait profile was not statistically significant, and generally minimal, these findings might be of clinical importance given the high-energy cost of human walking. Furthermore, since the sagittal motion of the pelvis, hip, knee, and ankle did not change substantially with this orthosis, and taking into account the results of previous investigation (Quesada and Sawyer, 1995) which indicated that a similar type of insoles had little effect on the peak plantar pressures, one of the reasons for the positive effect reported by the manufacturers of these orthotic devices, might be that they affect the transverse and frontal rotations of the tibia on the femur and thus influence the direction of the resultant knee joint reaction force vector.

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What are orthoses doing for children with myelomeningocele?

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Introduction

In children with myelomeningocele (MMC) neuro-muscular function is impaired to varying degrees, leading to distinguishable characteristic kinematic gait patterns reflecting the amount of paresis [1–3]. Orthoses of the Ferrari type have existed in Europe for several decades [4] but only a few studies of gait with children with MMC using these orthoses have been published to date. The AFOs have a slightly flexible ankle joint and are set to a few degrees of dorsiflexion. The KAFO have a freely-articulating knee joint and a thigh cuff. The aim of this study was to quantify the changes when the orthoses are introduced in gait kinematics (trunk, pelvis, hips, knee and ankle), kinetics (moments, powers and work) and placement of the center of mass anatomically [5].

Materials and methods

Of a total of 38 children with MMC who had functional ambulation and participated in a gait study, 15 subjects who habitually used orthoses and could walk barefoot were included in this analysis, 11 males, 4 females, 7–14 yrs of age. All subjects had muscle strength grade 4–5 in hip flexors, adductors and knee extensors, 3–4 in hip extensors, 2–4 in knee flexors, 0–4 in dorsiflexors and 0–3 in plantarflexors. The children were tested in 3D gait analysis (Vicon Motion Systems) using a six-camera system with two embedded Kistler force plates. Kinematics, kinetics, temporal parameters and location of the center of mass relative to the hip joints were recorded. All subjects wore the orthoses they habitually used, 9 AFOs and 6 KAFOs. In two children, no kinetic data was attained.

Results

With their orthoses, 11/15 subjects had a less anteriorly flexed trunk than when barefoot (Fig. 1). 14/15 subjects reduced their lateral trunk sway range with an average reduction of 11°. All subjects had more knee extension in mid-stance (average 12°). 13/15 had increased hip extension in stance (average 7°). 13/15 had less maximum dorsiflexion and 12/15 more plantarflexion in pre-swing (9° and 5°). The knee extension moment during stance was significantly reduced and less negative work was done at the knee. 4/13 subjects had a net internal varus moment in stance while barefoot but all 4 reduced the internal varus moment with orthoses. Plantarflexion moment with orthoses increased in 14/15 children. In nearly all subjects, the center of mass was positioned more medially, closer to the hips (Fig. 2). Cadence was lower and step length was longer with orthoses.

Fig. 1: An example subject's gait first barefoot, then with his AFOs.

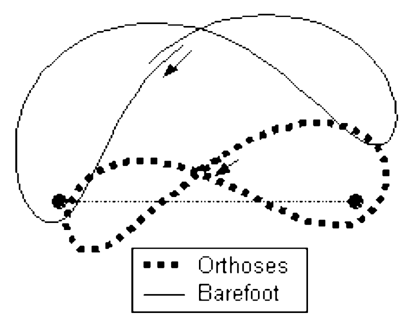

Fig. 2: The anatomical transverse plane trajectory of the center of mass relative to the hip centers (shown as black circles) of a subject. Each trajectory is the average of 5 gait trials.

Discussion

The orthoses enabled the subjects to stand more upright and use more hip sagittal range of motion, and prevented dropping into a crouch position. The slightly flexible footsole allows some 'toe-off,' but by preventing excessive dorsiflexion the knee could extend in stance, reducing valgus stresses and power absorption at the knees. The loading on the quadriceps was reduced, and the tendency in most to lean forward was eliminated. The increase in hip range of motion enabled the subjects' to take longer steps. The reduction in lateral trunk sway may be due to the increased moment attained at the ankles and the better frontal plane stabilization at the knees. The resultant pattern places the center of mass more centrally. The orthoses compensate for ankle instability and enable mechanisms to produce a more stabile, upright, appealing and efficient gait in children who can also walk barefoot. Investigating how these orthoses improve gait in children who can also walk barefoot will aid in understanding how they work on children who lack strength in even the hip abductors and hip extensors and are unable to walk barefoot, and will ease the process of trial-and-error on the patients.

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Knee brace migration: determining the relative kinematics of the leg and brace during cycling

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Introduction

Among the published subjective analyses of functional knee braces, a common complaint among participants is distal brace migration. As the primary function of the brace is to displace loading on the knee by constraining its motion and accepting some of the applied force during activity, it is crucial that the kinematics of the brace match, as closely as possible, the kinematics of the normal knee. Without this congruency between leg and brace kinematics, the protective effects of the brace on the ACL are deemed to be substandard, as the axes of rotation of brace and knee are not aligned (Regalbuto et al., 1989). As such, the purpose of this investigation was to determine the extent of relative motion that occurs between the leg and brace during cycling and establish how this motion changes over time.

Materials and methods

A group of five healthy male participants (age 22–27 years) were recruited for inclusion in the study. After informed consent was obtained, each participant's right leg was measured and fitted with the Bauerfeind Softec Genu brace (Bauerfeind USA, Inc.) according to the manufacturer's specifications. The anatomical reference system and triads used to define motion were defined according to methods described by Lamontagne et al. (2001). Further to this protocol, two additional non-collinear triads were placed on the proximal and distal aspects of the brace with respect to the hinge. Participants were asked to cycle for 15 min at 60 rpm with a frictional resistance of 20 N applied to the flywheel. During this period, 3D videographic data were collected for 10 s during the 1st min, as well as following the 5th, 10th and 15th min marks. For each subject the kinematics of the leg and brace were determined independently during one cycle revolution. Relative motion of each segment was calculated using methods previously described by Grood and Suntay (1983). The resulting 3D kinematics of the leg and brace were averaged across subjects, plotted against each other, and the root mean square (RMS) error between the leg and brace for each angular orientation was calculated.

Results

Computation of the RMS error revealed that there was essentially no increase in relative brace-leg movement over the duration of testing for any of the three kinematic parameters examined. There was, however, a consistent difference between the kinematics of the leg and brace, which persisted over the 15-min testing period. The difference between leg and brace kinematics was greatest when the angle of the leg in any single plane reached its maximum value, which corresponded to maximum flexion at the knee.

Discussion

The finding of greatest dissimilarity between leg and brace kinematics occurring at maximum flexion is congruent with the findings of Regalbuto et al. (1989) who established that increased forces and moments at the hinge, indicating mismatch between the brace and leg, were largest during flexion of more than 60 degrees. Differences found between kinematics of the leg and brace, in terms of flexion/extension, were most likely the result of slight movement of the brace along the longitudinal axis of the leg due to bunching of the fabric of the brace behind the knee. Differences in angles of abduction/adduction were perhaps caused by the rigidity of the lateral supports of the brace and, hence, their ability to resist bending along their length. The leg, however, was free to abduct and adduct about the knee within the limits afforded by the elastic material of the brace. Lastly, it is believed that disparities between the kinematics of the leg and brace in terms of internal/external rotation are caused by motion of the leg about its longitudinal axis within the brace.

Conclusion

Although it was found that there was not an increase in relative movement between the brace and leg over time, there was a disparity between the kinematics of the two, which was consistent throughout the entire testing period. This difference between the leg and brace kinematics is believed to cause an offset of the optimal placement of the brace hinge with respect to the knee axis of rotation.

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Physiotherapy

Effects of balance training and detraining on the static and dynamic balance in fallers and non-fallers, elderly subjects

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Introduction

As falls happen when the subjects have balance or walk disorders (Tinetti, 1986) and that walk requires more attention with ageing (Geurts et al, 1991), we can hypothesise that training could prevent falls. The aim of this study was to evaluate the effects of training based on balance and walking on the different parameters of walking and the effects of detraining in healthy elderly fallers and non-fallers in order to limit falls.

Material and Methods

Subjects

Sixteen subjects studied were assigned to one of 2 groups, according to their history of falling: 8 fallers (F) aged 71.1 ± 5.0 years and 8 non-fallers (NF) aged 68.4 ± 4.5 years. The fallers had suffered an average of 3.4 ± 1.7 falls during 2 years before this study. The inclusion criteria were to be at least 60, to have a stable medical treatment (a treatment which was regular and for at least 3 months), not to have fractures or surgery of inferior limbs, prosthesis, soles, auditory, ocular and/or vestibular problems. The exclusion criteria were a cranial trauma with or without loss of consciousness, sores on inferior members or on feet.

Protocol

The subjects were evaluated 3 months before the training period (first evaluation), 2 days before the training period (second evaluation), 2 days after the end of the training period (third evaluation) and 3 months after the training period (forth evaluation). Each new fall suffered by any one subject in the course of the 6 months was noted.

Physical measures

All the subjects performed firstly an unipedal test (the subjects stood on one foot with their eyes open for 30 s). The number of times they placed the other foot on the floor was recorded. They repeated this test in the same way with their shut eyes. Spontaneous walking has been studied with VICON 370 system under single-task and dual-task conditions. The single task was to walk spontaneously and the dual task was to walk spontaneously with a full glass of water in one's hand. The walking parameters measured were cadence (steps/min), walking speed (m/s), stride time (s), step time (s), single support (s), double support (s), stride length (cm) and step length (cm).

Physical training

The subjects attended two supervised 1-h exercise sessions per week for 3 months. At each session, subjects undertook exercises to develop static and dynamic balance in single or dual task conditions.

Results

Table
Comparison of unipedal test, walking speed, cadence and stride length in fallers and non-fallers 3 months before training (J0), before (J1) and after (J2) training period and 3 months after training without stimulation (J3).

		Unipedal test		Walking speed (m/s)		Cadence (step/mn)		Stride length (m)	
		Eyes open	Eyes shut	Single task	Dual task	Single task	Dual task	Dual task	Dual task
Fallers	J0	4.1 ± 3.3	9.5 ± 4.5	0.87 ± 0.35	0.79 ± 0.01	1.07 ± 0.16§	1.10 ± 0.18	1.12 ± 0.08	1.10 ± 0.19
	J1	4.2 ± 5.2*	9.9 ± 5.2*	0.88 ± 0.23*	0.80 ± 0.30*	1.17 ± 0.08*§	1.14 ± 0.14*	1.17 ± 0.05*	1.07 ± 0.09*
	J2	1.0 ± 1.7*†	3.9 ± 2.9*†	1.20 ± 0.04*†	1.03 ± 0.12*†	0.97 ± 0.06*†	1.01 ± 0.04*†	1.24 ± 0.04*†	1.21 ± 0.10*†
	J3	3.6 ± 2.6†	9.1 ± 3.7†	0.91 ± 0.35†	0.79 ± 0.04†	1.09 ± 0.15†	1.21 ± 0.07†	1.09 ± 0.10†	1.00 ± 0.10†
Non-fallers	J0	1.4 ± 1.2	6.4 ± 1.0	0.88 ± 0.27	0.88 ± 0.16	1.07 ± 0.10	1.10 ± 0.10	1.09 ± 0.04	1.14 ± 0.09
	J1	1.5 ± 0.5*	7.6 ± 2.0	1.05 ± 0.06*	0.97 ± 0.22	1.13 ± 0.05*	1.10 ± 0.12*	1.16 ± 0.04*	1.11 ± 0.13*
	J2	0.2 ± 0.3*	3.1 ± 0.9†	1.25 ± 0.05*†	1.13 ± 0.05	0.96 ± 0.04*†	1.01 ± 0.04*†	1.25 ± 0.10*†	1.23 ± 0.07*†
	J3	1.6 ± 0.9	5.7 ± 1.0†	0.92 ± 0.24†	1.07 ± 0.08	1.08 ± 0.10†	1.20 ± 0.15†	1.07 ± 0.07†	1.07 ± 0.09†

Values are expressed by mean ± the standard deviation; single task: spontaneous walk; dual task: spontaneous walk with a glass of water in the hand; § $p < 0.05$ significant difference intra-group between J0 and J1; * $p < 0.05$ significant difference intra-group between J1 and J2; † $p < 0.05$ significant difference intra-group between J2 and J3.

Discussion and conclusion

This study has demonstrated that physical training based on balance and walking under single and dual task conditions improves significantly static balance and the different parameters of walking under single and dual task conditions. Moreover, this study showed a loss of capacities during 3 months before the trained period for stride time, single support time for fallers in the two conditions. After 3 months without stimulation after the trained period, a loss of the effects of the physical training was found for fallers and non-fallers on the different parameters of walking in the two conditions and on the unipedal tests.

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Quantifying rehabilitation of locomotor skills in incomplete spinal cord injury

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Introduction

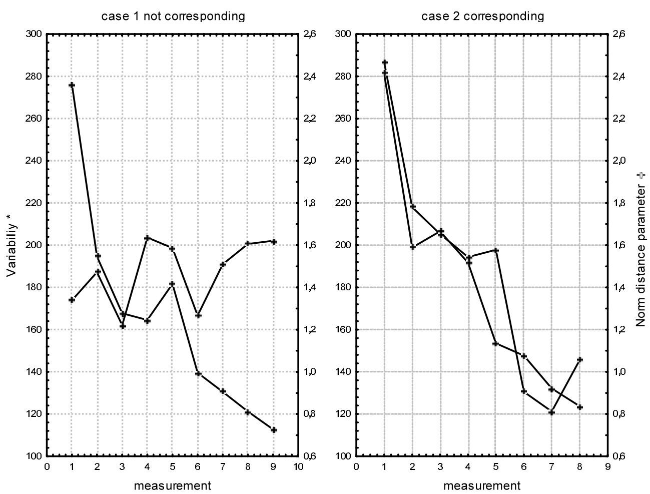
Effects of rehabilitation on locomotion concerning the "quality of gait" are difficult to quantify. One aspect is certainly how well a patient can maintain his motion within the boundaries of the normal values. The application of a "norm distance parameter" as a measurement of gait quality has been introduced by our group (1). Another key feature of normal locomotion is the ability to maintain the motion with little variation over repeated cycles. A measurement modality has been established for the gait of ataxic children (2). This computation of the variability uses the trajectory of the ankle marker during swing. The purpose of this study was to test the hypothesis that in the process of rehabilitation for incomplete spinal cord injury (SCI) there is a "normalization" of the gait compared to standard normal values as well as a reduction in the variability of the motion.

Patients and methods

Nineteen consecutive patients with incomplete SCI were included in this study 1.99–12.2002. There were 10 females and 9 males. The average age was 45 years. The neurologic level of SCI ranged from C 02 to L 05. The motor function was assessed using the ASIA motor score. All of these patients were in the primary rehabilitation after the onset of spinal cord injury and underwent treadmill training. 3-D gait analysis data have been recorded on the treadmill at different points in time during rehabilitation using a six-camera system (Motion Analysis, Santa Rosa, CA) with retro-reflective markers for an average of 67 s per trial. Furthermore time distance parameters of the treadmill training at the time of the gait analysis were recorded. The variability was calculated according to the method described (2) as well as the norm distance parameter.

Results

There was a reduction of the variability of the swing phase for all but 3 patients over the course of the rehabilitation treatment. These two patients however had good motor function and showed low variability initially. There was some congruence, especially initially, between the progression development of the norm distance parameter and the variability. However there were 7 patients where the development of the normal distance parameter did not correspond to the reduction of variability. Fig 1 gives examples of both cases.



Discussion

The norm distance parameter is a measure for deviation compared to the normal gait. It corresponds to the remaining functional deficit due to the laceration of the spinal cord. In contrast the locomotion becomes more stable during the rehabilitation process expressed by a reduction in variability. This observation finds a clinical explanation in the idea that patients learn to use the remaining function more effectively in the course of the rehabilitation. In this process walking speed and distance also improve. The combined analysis of the norm distance parameter and the measurement of the variability provide a reliable method of monitoring and evaluating the locomotion in the rehabilitation of incomplete spinal cord injury.

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Upper limb

Trunk and upper limbs movements during walking in children with cerebral palsy

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Introduction

Kinetics and kinematics of ankle, knee joints along with pelvis displacements have been studied in normal children and in children with cerebral palsy (CP) using three dimensional movement analysis. Few studies exist in the literature, that have assessed the role of the trunk and of upper limbs swing during walking in healthy and pathological subjects The normal walking is characterised by reciprocal arm swing during the gait cycle. It is generally accepted the idea that the arm swing is necessary to balance trunk rotation forces and therefore to reduce the intensity of the ground reaction forces and to minimise the energetic cost [1]. Moreover, upper limb swing during gait seems to play an important role in reducing the rotations of the trunk especially during walking at high speed particularly in single limb stance phase [2]. Gait of children with CP is characterised by an ample variety of profiles and the upper limbs play again a fundamental role to compensate the moments of rotation generated on the trunk and on the lower limbs. The purpose of this study was to investigate the behaviour of the upper limbs during gait of children with CP with the aim to identify characteristic patterns of the movement and to better specify the compensatory strategies introduced by the upper limbs and the trunk.

Materials and methods

The behaviour of the upper limbs and the trunk during gait of 25 children affected from spastic diplegia (mean age 11.4 years, range 6–17) was analysed together with 10 control subjects matched by age. All the pathologic subjects were able to walk independently without assistive devices. 3D Gait analysis was performed in the ''Movement Analysis Laboratory'' of the Stella Maris Scientific Institute, accordingly to the protocol proposed by Davis [3]. Data acquisition was carried out through an optoelectronic motion analyser (Elite BTS, Milan) equipped with six infrared cameras and one force platform (AMTI). A protocol with 8 reflective markers was used to identify the position of the upper limbs and trunk. Markers were placed in correspondence of precise anatomical landmarks: shoulder acromion, lateral epicondyle of the humerus, midpoint between the radial and ulnar styloids (bilaterally), spinal processes of C_4 and S_2 (mid point between bilateral PSIS's). Kinematic analysis was conducted on the following calculated angles: absolute angle of the trunk referred to the global laboratory coordinate system, angle of the arm on the sagittal plane (angle between the arm and the trunk), angle of the arm on the frontal plane, angle of the elbow (angle between the arm and the forearm).

Results and discussion

Children with cerebral palsy, compared to control group subjects, generally show an increase of range of motion (ROM) of trunk in cardinal planes. The reciprocal arm swing in sagittal plane are smaller and often asymmetric, while the arm movements are bigger on frontal plane. Often upper limbs during gait cycle are constantly elevated in frontal plane with hands at shoulder level. The ROM increase of arm swing on frontal plane often compensate an excessive trunk displacement on the same plane, with or without ROM increase of pelvic obliquity.

The results of this study confirm the clinical findings that in children with CP different kinematic patterns of upper limbs and trunk exist. Frequently it is possible to distinguish the different clinical forms of CP by the analysis of the movement patterns of upper limbs and trunk.

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3D kinematics analysis of the upper limb in children

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Introduction

The aim of this study is to define a reproducible protocol to analyse the 3D kinematics of the upper limb in children.

Material and method

For measurement, we used the VICON optoelectronic system with six cameras. In order to avoid displacements between markers during movements and to be able to study the movements of anatomical referential systems, we defined two kinds of referential systems: anatomical referential systems and tripod referential systems.

At a rest position, we measured simultaneously the position of these two referential systems and during movements we measured only the position of the tripod referential systems. Anatomical referentials were: for the thorax: the two sterno-clavicular joints and the xyphoid process, for the arm: the medial-lateral epicondyle and the acromion, for the forearm: the medial-lateral epicondyle and the radial-ulnar styloïds, for the hand, the radial-ulnar styloïds, the second and the fourth metacarpus.

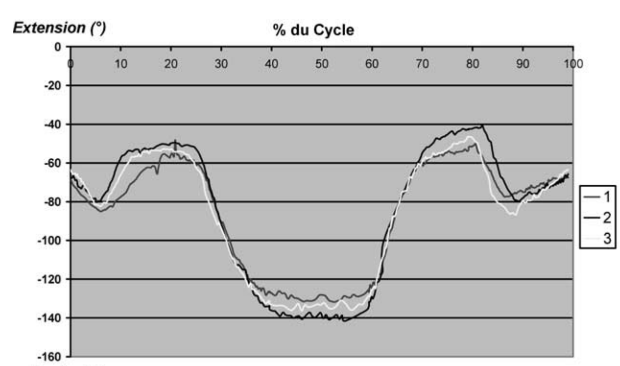
Rigid tripods on which markers were placed were used during movements. These tripods were fixed using a strap on the distal and dorsal part of the forearm, on the dorsal part of the hand and on the sternum, and using an elbow brace on the distal and lateral part of the arm. Two tasks were defined in order to study the movement in the three plans. The subject being sitting on a chair. Task 1: the subject was asked to take an object on a table placed in front of him, and then to bring the object to his mouth. Task 2: the subject was asked to take an object placed on a table in front of his right knee and displaces the object on the table in front of his left knee.

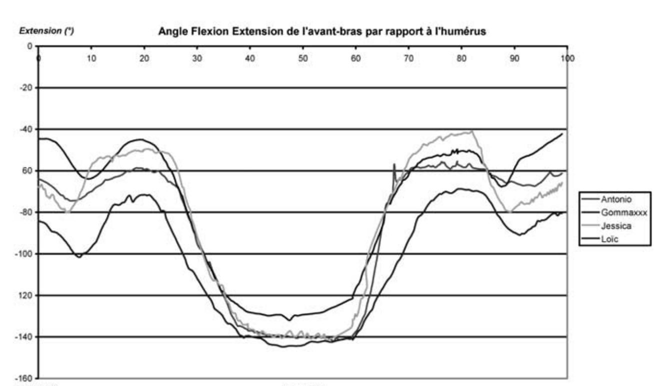
The positions of the humerus with regard to the sternum, of the forearm with regard to the humerus, of the hand with regard to the forearm and of the thumb with regard to the hand were studied during each task.

The data were collected from 12 children, age 7–16 years, performing the two tasks and for 6 of them, an electromygoraphic measurement was performed for 6 muscles.

Results

Fig. 1 shows representative graphs of flexion-extension of the forearm with respect to the humerus for one subject for the task 1 repeated 3 times. Fig. 2 shows the same movement of four different subjects. The data were normalized in order to compare the curves of the different subjects.





For the two depicted tasks, visual analysis, standard deviation and CMC (Coefficient of multi correlation, Kabada) shows reproducibility and uniformity in strategies adopted by the subject in shoulder and elbow motion. For the wrist, radial and ulnar motion were not reproducible as they have too small magnitude.

Discussion and conclusion

Evolutions of the protocol are under progress by the introduction of the measurement of thumb motions. As for gait analysis, we fell that this upper limb motion protocol can be a useful tool for evaluation of patients with neurologic disorders like cerebral palsy. We hope that such a protocol, coupled with electromyography analysis, will help the clinicians in the evaluation and treatment of these pathologies.

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Thursday 11th September 2003 16:04–17:34
Poster Session 1

Upper Limbs and Sports

Motor pattern changes in single-joint arm movements at different speeds in hemi-paretic patients

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Introduction

Human movement can be performed under different dynamic conditions. Gravity and inertial forces are crucial in movement process planning. This is obtained by adjusting the amplitude and activation time of antagonist and agonist muscles with different level of co-contraction and reciprocal contraction. After pathologies like hemi-paresis, it is possible to observe alteration of this mechanism. The study of the different strategies in pathology is the focus of rehabilitation both for clinical assessment and for exercises choosing. Consequently, we investigated the shoulder movement in hemi-paretic subjects, performing their arm in up and down movement at different speeds on the vertical plane. They were requested to point at a target in front of them and to come back. In particular we wanted to understand whether they were able to utilise the external forces, like gravity or inertia, and how in planning movements of paretic arm.

Materials and method

We examined 2 patients with hemi-paresis: the former (C1, 11 y.o.) acquired hemi-paresis at the age of 8; the latter (C2, 8 y.o.) showed hemi-paresis as a consequence of cerebral palsy. A 6-camera VICON 512 system and two AMTI force plates gathered the 3D kinematic and kinetic data. Synchronised surface EMG data was recorded using an 8-channel wireless Noraxon TeleMyo system. The investigated muscles were: trapezius, deltoid, pectoral and biceps brachial.

Patients were standing on a force plate and performed up and down movement pointing at a target in front of them at three different speeds. They were asked to move naturally, then quickly and finally as fast as possible.

Results

Both in upward and downward movements no flexion nor extension of elbow or wrist was observed, neither humeral rotation. On the health arm of the first patient (C1), we found that changes in movement speed were accompanied by changes of EMG patterns[2]. When the movement was done at slow speed, the activity of deltoid (upper arm flexor) was predominant, with little biceps brachial activity, and it seemed to be dependent upon gravity; in fact, this activity showed its own maximum when the arm weight was maximum (90 degrees of flexion). Conversely, at the beginning of fast movement, there was a high level of co-contraction, probably aimed to increase the joint stability. Afterwards, during the final phase of fast flexion, there was a reduction of EMG activity: this fact proved that the CNS would take advantage of inertial forces. On the paretic side, movements were accompanied by higher activity of trapezius and lower activity of deltoid. Moreover, there was minor evidence of the co-activation at the beginning of fast movement. The second patient (C2) showed high activity of the trapezius in all the trials, both in health arm and in paretic one. Besides, during fast movement on the paretic arm there was no burst of EMG activity, but it was continuous without pause or reduction until the end of the movement. For C1 and C2 patients, the maximum velocities were 520 and 460°/s, respectively.

Discussion and conclusion

The differences between the EMG patterns of movements at slow and high velocity show: in the former, CNS plans movement taking into account gravity; in the latter, inertial forces are determinant. In the paretic arm of acquired pathology these controls are still possible, although same difficulties and reduction in velocity. In CP we note same differences in health arm too, like a bigger activity of trapezius, but with ability in balance both gravity and inertial forces. On the contrary, in the paretic arm we noted a continuous EMG activity and power alteration that led to consider the inability in balancing inertial forces.

Basing on these considerations, we can suppose that as in C2 there has been a limitation to express movements at high speeds since the childhood, this could in turn limit strategy learning process in the control of inertial forces. In this case, we had to teach the production of EMG burst by example, through arm throwing and swinging exercises. On C1 patient, conversely, we had to improve the control on a kept pattern of co-ordination.

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Head–trunk–lower limbs positioning in jumping tasks for dance expertise

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Introduction

Most of studies using kinematic measurements on jumping tasks analyzed the coordination of lower limbs (ankle, knee and hip) in order to determine segmental chronology and spatio-temporal variations as well in expert sportmen and dancers (Ravn et al., 1999) as in adult or children (Jensen et al., 1994). Head position (with visual and vestibular inputs) could be essential to regularise balance and perform maximal vertical jump. However, none study concern the head-trunk-lower limbs coordination in these jumping tasks. One study about hopping, (Assaïante et al., 1997) showed an articulated operation of the head–trunk unit during flight phase while during landing, the operation is en bloc suggesting that trunk may constitute a stable reference frame for balance control in dynamic tasks. The aim of our study is to examine the positioning of head, trunk and lower limbs comparatively for expert dancers to untrained participants for the push-off phase in jump.

Materials and methods

The jumps were filmed in the sagittal plane. Reflective markers were placed on the right side of the participants at the following anatomical landmarks: Frankfort plane (head position), acromion process, iliac spine, trochanter, tibial plateau, lateral malleolus. A numerical camera operating at 100 frames/s recorded the jumps (JVC…). A digital timer connected to a capacitor platform recorded the flight time and the height of the gravity centre of the participant during the jump (Ergojump, GMBH). Starting from a natural standing position, participants executed bipodal counter-movement jump keeping their hand on the hips throughout the entire jump. The order was to realize a maximal vertical jump. Five trial were measured with 30 s between each jump to respect physiological characteristics for the chemical energy recovery. Population was divided into two main groups: 7 international adult dancers and 6 age-matched untrained participants. For kinematic analysis, head pitch angle, trunk tilt angle and knee flexion angle were measured on the push-off phase of each jump. For statistic, these angles were subjected to an analysis of variance (ANOVA) and correlated to jump height to verify the involvement of the segmental body positions.

Results

For jump performances, ANOVA showed that the height difference of counter-movement jump was not significant ($F(1.11) = 1.06$; $p < 0.33$) between dancers (23.9 cm, S.D. = 3.6) and untrained participants (21.7 cm, S.D. = 4.1). However, trunk tilt angle at maximal flexion of lower limbs was significant ($F(1.11) = 5.13$; $p < 0.05$) more bend forward for untrained participants (30.8°, S.D. = 7) than for dancers (22.8°, S.D. = 5). The knee angle at the maximal flexion of the lower limbs was significant ($F(1.11) = 6.23$; $p < 0.05$) higher for dancers (102°, S.D. = 5) than for untrained participants (91°, S.D. = 10). The head positioning during the push-off phase changed significantly ($F(1.11) = 6.20$; $p < 0.03$) for dancers from 11.8° (at maximal knee flexion) to 4.3° (at maximal jump height) but not for untrained participants (from 15.5 to 10.5°). The analysis of two angle parameters showed a correlation between jump performance and head pitch angle only for untrained participants ($r = 0.63$; $p < 0.05$) but not for dancers ($p > 0.05$), and a correlation between performance and knee flexion angle only for dancers ($r = 0.71$) but not for untrained participants.

Discussion

Although height performance is not significantly different between ballerinas and novices we note that experts use a different positioning strategy. For dancers a less knee flexion angle could favor a better use of elastic energy while it is not the case for untrained participants. In fact, according to Bosco et al. (1982) more knee angle flexion increases the push-off phase and decreases elastic stockage. Ballet dancers for aesthetic requirements and posturo-kinetic organisation keep the trunk more vertically during the push-off phase (as demonstrated by Mouchino et al.), maintaining the hip the shoulder and the head above the sustentation base. If head and trunk positioning recorded by ballerinas reveals a more strictly postural control, otherwise this aesthetic requirements could imply a less jump performance. Conversely, the trunk is too much bent forward and head as too much extended for novices.

Conclusion

By expert ballerinas, aesthetic requirements of postural control interact in opposition with mechanical and neuromuscular factors which improve performance.

Acknowledgments

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Posture

Analysis of postural stability: correlation with body mass index

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Introduction

Obesity is one of the commonest pathologies of industrialized countries and anorexia is spreading between young people. Many studies have been published on these pathologies and their consequences, but none used a biomechanical approach. We are interested in the biomechanical analysis of postural stability of underweight, normal – weight and obese subjects. A quantitative assessment of postural stability during quiet standing in relation to body mass index (BMI) value provides useful biomechanical information about the effect of anomalous body weight increasing or decreasing. Moreover, the stability analysis of a selected patient could give indications on the effectiveness of rehabilitative treatments. Main aim of this study is to examine postural stability in underweight and obese subjects in comparison to normal subjects using a biomechanical approach.

Materials and methods

A total number of 39 subjects divided into 4 subgroups in relation to BMI value were analyzed: group A) 3 underweight (25 years < age < 26 years; 17.59 < BMI < 18.07); group B)17 normal weight (24 years < age < 26 years; 18.35 < BMI < 24.87); group C) 13 obese (24 years < age < 38 years; 31.51 < BMI < 35.6); group D) 6 severe obese (20 years < age < 41 years; 36.23 < BMI < 51.18). Selection criterion for all subjects was no suffering from any musculoskeletal pathology. A motion measurement system (ELITE, BTS S.p.A., Italy) provided the 3D coordinates of reflective passive markers and a force platform (AMTI, Newton, MA) provided ground reaction forces and the centre of pressure (COP) trajectory. 11 markers were placed over the spinosus processes every two vertebrae from c7 to sacrum; 2 markers were placed on right and left acromion, 2 markers on right and left ASIS, 2 markers on right and left knee; 2 markers on right and left malleolus and 2 on right and left 5th metatarsal head to retrieve the position on the feet with on the force platform. Each subject was asked to stand on the force platform in orthostatic indifferent position with eyes open for 3 successive acquisition trials. Each trial was 50 s long. Significative indexes were extracted using COP trajectory both in anterior-posterior (A/P) and medial-lateral (M/L) direction. The pattern length (PL) of COP trajectory was calculated as follows:

$$PL = \sum_{i=1}^{n-1} \sqrt{x_{i+1} - x_i^2 + y_{i+1} - y_i^2}$$

where x_i (medial–lateral direction) and y_i (anterior–posterior direction) are the coordinates of COP at ith acquisition instant. COP position with respect to feet position on the force platform was evaluated by taking into account the M/L (X-distance) and A/P (Y-distance) distances between the center of the ellipse containing 90% of COP points and the midpoint of malleula markers coordinates. Excursion of COP A/P and COP M/L displacements versus time (ExcAP, ExcML) were calculated as the difference between the maximum and minimum value of the X and Y coordinate of COP in time. To allow comparisons between different subjects, a normalization factor that takes into account for different body heights was used. Statistical analysis was performed using ANOVA test for multiple comparisons and T-test for post-tests (subsequent comparison between 2 subgroups only).

Results

We found statistically significant correlations between variations of the calculated parameters and variations of BMI value. The control group of normal weight subjects shows the minimum value of PL parameter; underweight, obese and severe obese show a higher value of this parameter. The groups are clearly distinguishable using PL values. X-distance shows no differences between the analysed groups. Y-distance gives the same results as PL: the minimum value is to notice for group B. ExcAP shows no differences between the groups. ExcML gives the same results as PL and Y-distance.

Discussion and conclusion

The selected parameters explain the different postural strategies during quiet standing trials. PL and ExcML reflect the imbalance degree of each subject, because they are an oscillation measure. The fact that normal weight subjects reach the minimum of these parameters is a proof that both increasing and decreasing weight beyond certain thresholds lead to a general loss of stability during standing. Y-distance evidences that groups A, C and D moves their COP forward with respect to feet position in comparison to B group. This result can be associated with Exc parameters: to compensate for a higher imbalance (demonstrated by ExcML values) people in A, C and D group move their COP forward (Y-distance values) in comparison with B group. In general, we found strong correlation between anomalous BMI and increasing imbalance during quiet standing.In conclusion, postural analysis gives further information on the role of body mass variation in postural stability. Our simple acquisition protocol could be very helpful in the assessment of postural imbalance due to underweight or obesity and it could be used as a control tool after an appropriate rehabilitation program.

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Body somatotype and standing balance in adolescent idiopathic scoliosis

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Introduction

Adolescent idiopathic scoliosis (AIS) is the most common form of scoliosis and usually affects young girls. Posture and type of spinal curvature are associated with standing instability in this population (Nault et al., 2002; Le Blanc et al., 1997). In addition, body morphology was also recognized as a factor related to standing balance (Horak et al., 1997). It was shown in young able-bodied girls that ectomorphic (tall with respect to weight) subjects are more unstable than endomorphic (heavy and large) subjects. AIS girls have a higher ectomorphic component and a smaller mesomorphic component (bony and muscular) than a comparable group of able-bodied subjects (Le Blanc et al., 1997). It is reasonable to assume that AIS ectomorphic girls have greater standing imbalance characteristics than able-bodied individuals. The aim of this study is to determine the effect of body somatotype on standing balance in an AIS population.

Material and method

Thirty six AIS and 35 able-bodied girls participated in this study. Their average age was 12 years and their average height and weight were 151 cm and 42 kg, respectively. Their somatotype was determined from measures related to body fat, limb circumferences and joint widths. Standing balance was measured using a forceplate (64 Hz). Subject maintained a quiet standing posture for 64 s with eyes open. The measurement was repeated three times. Mean center of pressure (COP) and sway surface area were calculated from forceplate data. AIS and able-bodied girls were classified according to their dominant somatotype (endomorphic, mesomorphic and ectomorphic). The mean group size was 12 though the number of subjects per group varied from 8 to 16. ANCOVAs were performed with age, height and weight as covariables to determine statistical differences ($p < 0.05$) between the AIS and able-bodied groups and compare values between somatotypes for each group.

Results

The sway area of the AIS group was 34% larger and their COP was 11 mm behind that of the of the able-bodied girls. For the ectomorphic girls, the AIS group displayed an antero-posterior (AP) COP closer to the back of the heels than the able-body group (Fig.1) by 12 mm. For the endomorphic groups, AIS girls displayed about twice the sway area of the able-bodied girls. No differences were observed in the mesomorphic group.

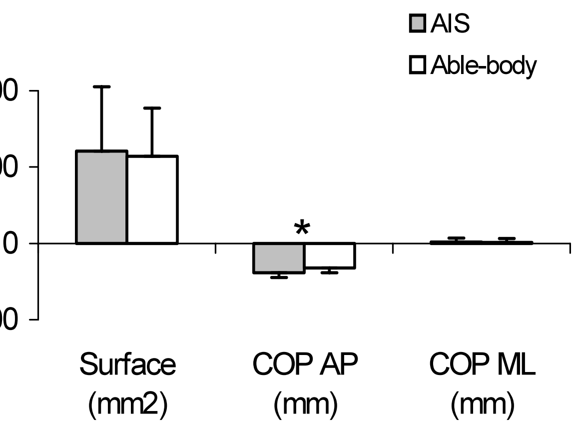

Fig 1. Balance parameters for the ectomorphic girls

Discussion and conclusion

Though sway area was only statistically larger in the AIS endomorphic group, values for the mesomorphic and ectomorphic AIS groups were larger but not significantly different. This can be explain by the fact that able-bodied endomorphic girls were shown to be much more stable than ectomorphic girls (Allard et al., 2001) thus increasing the chance of finding a difference between the endomorphic groups. AIS is associated with a hypokyphosis of the spine. This could be enhanced by a postural attitude where the COP is located closer to the heels. This was observed in the AIS group and particularly in the ectomorphic AIS group. It was also shown in a previous study (Nault et al., 2002) that AIS girls have a tendency to lean their trunk backwards. It is reasonable to assume that ectomorphic AIS girls are more at risk than either the endomorphic or mesomorphic girls who do not display differences in their COP positions and have greater bony and muscular masses.

Endomorphic AIS girls have a greater standing imbalance than their able-bodied counterparts while maintaining similar COP positions. It appeared that ectomorphic AIS girls have a tendency to lean more backwards than a comparable able-bodied group. This could emphasize a hypokyphosis attitude and increase the risk of spinal deformity progression.

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Postural control in 14–15-year-old teenagers in response to slow lateral oscillations of the support

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Introduction

Musculo-skeletal growth is not a linear function of age. During ontogenesis, periods of relatively stable increase in body size alternate with periods of accelerated growth. Puberty is characterized by important structural and functional changes during a short time. Moreover, the body scheme, slowly built during childhood by integration between vestibular, visual and somatosensory informations, is probably affected during puberty. The body scheme contributes to the development of the internal representation of action that constitutes the base of feed-forward control to compensate in advance for the destabilizing effects of the movement. Which are the consequences in postural control of these important morphological and functional alterations that occur during puberty? Which sensori-motor strategies use the teenagers to preserve their motor performance is still an open question?

Materials and methods

To address this problem, ten 14/15-year-old girls and ten 14/15-year-old boys performed this experiment. They were asked to maintain their vertical body orientation with or without vision (eyes closed), despite the very slow lateral oscillatory angular movements of the supporting surface. These imposed oscillations of the support were chosen in amplitude and frequency in order to be either above (±5° at 0.06 Hz) or below (±5° at 0.01 Hz) the semicircular canal threshold. Thus, the lower frequency of the support associated with eyes closed constitutes an interesting situation to selectively investigate the proprioceptive contribution to postural control. The efficiency of postural control was examined in terms of rotation about the frontal plane (roll). An automatic optical TV image processor was used in analyzing the kinematics of knee, pelvis, shoulder and head rotations. The time course of the orientation of these anatomical segments were analyzed during the perturbation. Moreover, for the pelvis, the shoulder and the head, the time course of anchoring indices were also defined so that comparisons could be made concerning the stabilization of these body segments with respect to the inclination of the support and the external space.

Results

The preliminary results obtained in teenagers show lower performances than young adults to maintain their trunk vertically in absence of inputs from the semicircular canals and of visual cues. These results suggest a transient deficit of proprioceptive contribution to control postural orientation. However, the control of postural orientation is significantly improves by vision. Moreover, pelvis stabilization on the support strategy adopted by teenagers to control their equilibrium contrasts with pelvis stabilization in space strategy adopted by adults.

Conclusion

Taken all together, these first results support a sort of regression in the development of postural control during puberty. Further investigations should help to test if this regression in spatial organization of balance control is also associated with a regression in temporal organization of balance control mainly based on feed-back control instead of feed-forward mechanisms.

Locomotor balance control in children with internal rotations of the lower limbs

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Introduction

During ontogenesis, internal constraints such as maturation of the central nervous system (CNS) and the musculo-skeletal growth undergo constant changes. Therefore, one of the key questions raised by the developmental approach is how the CNS of the child recalibrates motor commands in order to adapt to new internal constraints. When studying the emergence of postural strategies, it is essential to distinguish between strictly biomechanical constraints and those reflecting maturation of the CNS. To address this problem, we have exposed our subjects to situations requiring various types of adaptation. The postural adaptation protocols were based on 1. specific constraints given by the character of the task which covered situations of different equilibrium difficulty and 2. chronic skeletal abnormalities, such as torsion of the lower extremities. Up to now, the development of balance strategies in children with orthopaedic deficits has attracted little attention. The purpose of this study was to investigate long-term adaptability of the CNS in controlling balance during various locomotor tasks in 5–6 and 7–10 year-old children with internal rotations (IR) of the lower limbs. Internal rotation means abnormal horizontal torsion of tibial and/or femoral bones about the vertical axis.

Materials and methods

This study was focussed on the development of the ability to control upper body segments during walking on flat ground, along a straight line and on a beam. The efficiency of balance control was examined in terms of rotation about the vertical axis (yaw) and on a frontal plane (roll). An automatic optical TV image processor was used in analysing locomotor parameters and the kinematics of foot, pelvis, shoulder and head rotations. For the pelvis, the shoulder and the head, appropriate anchoring indices were defined so that comparisons could be made concerning the stabilization of a given body segment with respect to its adjacent supporting anatomical segment and the external space.

Results

All IR children, whatever their age, showed a lower gait velocity, particularly in difficult balance conditions, associated with a decrease of yaw and roll shoulder stabilization in space. These results suggest certain "clumsiness" in balance performance. However, the effect of the local biomechanical deficit remained limited to the lower limbs and did not affect the upper body coordination 5/6 year-old children. By contrast in 7/10 year-old children, the development of head stabilization in space was affected.

Conclusion

This was demonstrated by an "en bloc" operation of the head-trunk unit instead of the articulated mode of operation of the head-trunk unit systematically adopted by the control group. Thus, as pelvis stabilization remains the main reference frame to organize balance control, in older children, the biomechanical anomaly of the legs causes a sort of regression in the development of whole body balance strategies. Further investigations should help to test if these skeletal abnormalities of the lower extremities only delay the use of the head reference frame or if they remain a life-long obstacle to the building of the repertoire of reference frames.

Is control of walking immature in new-walkers?

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Introduction

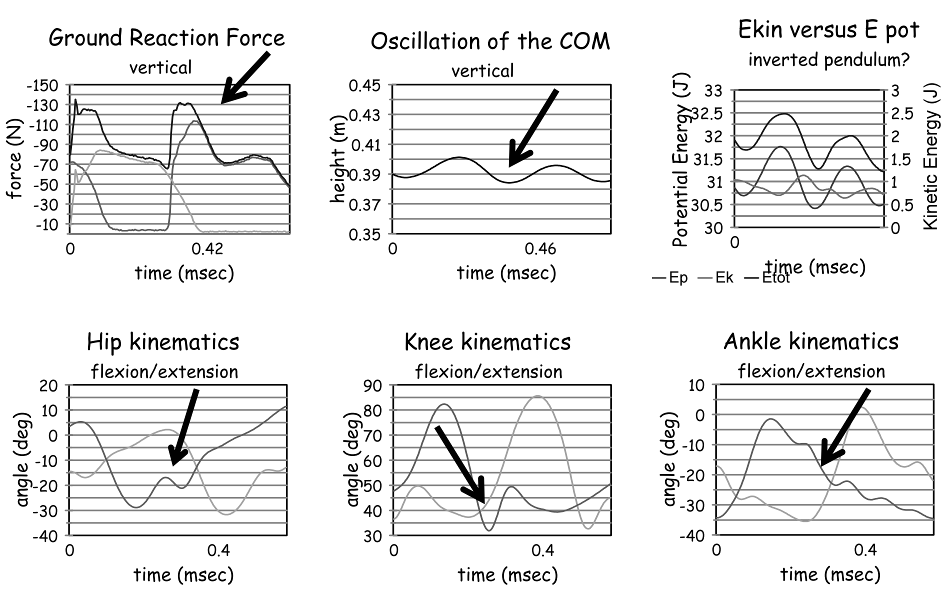
Normal walking is a tightly controlled cyclic movement. Feed forward control will properly activate different muscles in order to fulfill the combined task of maintaining an upright posture and generating a forward movement (Winter, 1996). Neuronal and mechanical feedback will continuously correct the muscle activation pattern, thus altering the movement in order to maintain balance and generate an efficient walking pattern (Dietz, 2002). New walkers are confronted with both a lack of experience and a neuro-musculo-skeletal system that is rapidly developing. These factors make it plausible that their movement control is not yet as fine tuned as in adults. This immature neuro-musculo-skeletal control could be reflected in the resulting movement pattern.

Materials and methods

Eight able-bodied subjects were included in this study. Their walking experience ranged from 2.5 weeks to 6 months. Ground reaction forces were recorded (2 AMTI force platforms, 0.5 m × 0.4 m, 250 Hz) separately for each foot. Their lower extremity kinematics was registered using an automated retro reflective camera system (Vicon Motion Systems, Mcam 460, 6 camera's, 250 Hz). A non-commercial software package (Human Body Model Toolbox, Bert Otten) was used to determine flexion-extension angles of hip, knee and ankle. To look at efficiency of the walking pattern in new-walkers, the oscillations of the center of mass and the resulting patterns of external kinetic and potential energy were calculated.

Results and discussion

After heel contact new walkers show a downward movement of the body together with a negative acceleration (deceleration) of the center of mass (peak in vertical ground reaction force). At this time hip flexion, knee flexion and ankle dorsiflexion is observed. These movements are reversed after 80-90 msec. Probably the stretch of the antigravity muscles activates a neuronal feed back loop leading to muscle contraction and thus preventing collapse of the supporting leg. Most likely energy is absorbed during the stretch of these muscles after heel contact. This could be compromising for exchange between kinetic and potential energy as observed in the inverted pendulum mechanism characteristic for mature walking.



Conclusion

Two questions arise from looking at the ground reaction force patterns and joint kinematics in new walkers: Is neuronal feed back important during weight acceptance? Does stretch of the antigravity muscles has an influence on the inverted pendulum energy exchange?

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Physiotherapy and Prosthetics

The influence of hyperpronation of the feet on pelvic alignment in standing

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Introduction

Pronation of the foot is an essential motion of the normal function of the lower extremity. Its main contribution to the gait cycle is shock absorption and adaptation of the weight bearing foot to the surface. Hyperpronation is defined when hind foot motion is excessive, prolonged, and/or occurs in inappropriate timing of the stance phase (Donatelli, 1987). Hyperpronation of the foot may cause mal alignment of the lower extremity and frequently leads to injuries of joints, tendons, knee pain and stress fractures (Tiberio, 1988). A review of the literature indicates that a correlation is found between hyperpronation of the foot and tibial rotation, patella and knee joint alignment (Klingman et al., 1997; Stergiou and Bates, 1997; Inman, 1976). To our knowledge there is no evidence documented on the relationship between hyperpronation and pelvic alignment although, several researchers do suggest a possible connection (Gross, 1995; Tiberio, 1987; Tiberio, 1988).

The purpose of this study is to examine the effect of hyperpronation of the feet on the lower limb and pelvic alignment.

Materials and method

Thirty-one healthy subjects (13 men and 18 women, age ranged from 23 to 33 years) were put into hyperpronation in standing position induced by wedges of different slopes of 10, 15 and 20°. The base line for comparison was natural standing position and the sequence of trials was random. Each setting was maintained for 20 s and a sample of 4 s was processed and measured. Changes in the alignment of the lower extremity and pelvic were measured by a computerized system of motion analysis (VICON®).

Results

The results indicate that as a consequence of induced hyperpronation, a statistically significant increase in calcaneal valgus ($p < 0.000$), internal tibial rotation ($p < 0.001$), internal femoral rotation ($p < 0.000$) and anterior pelvic tilt ($p < 0.009$) was found. A strong correlation (Pearson correlation coefficient) was found between induced hyperpronation of the feet and the rotational motion of the tibia, femur and pelvic tilt ($r = 0.511$ up to 0.950).

Discussion and conclusion

These finding suggest that a correlation exists between motion at the distal segment (the foot) and the proximal segment (the pelvic) of the body and indicate that hyperpronation and proximal postural mal alignment are linked.

The implication of this study advocates that when addressing pelvic and lower back dysfunction, the alignment of the foot should be examined as a contributing factor.

In addition, addressing foot mal alignment is essential for treating and preventing pelvic and low back dysfunction.

Acknowledgments

The authors thank Tel-Aviv Medical Center and Prof. Wientroub head of Children's orthopedic department for approving this study to be conducted at their laboratory, Meital Kfir and Reuven Batt for their help in data collection and processing.

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Immediate effect of two types of orthoses on 3D lower limbs kinematics and kinetics

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Introduction

Although plantar orthoses are regularly prescribed to correct lower limb kinematics and kinetics, only few studies evaluated in a quantitative and non-invasive way the effect of plantar orthoses on knee kinematics. Our research group developed a non-invasive harness allowing three-dimensional (3D) assessment of knee kinematics while limiting errors caused by soft tissue movements with respect to underlying bones (Sati et al., 1996a,b; Ganjikia et al., 2000). The purpose of this study was to evaluate quantitatively immediate effect on kinematics and kinetics following orthotic treatment of rear foot valgus.

Methods

For this study, 10 female and 10 male subjects aged between 16 and 54 years ($m = 28.4$; S.D. $= 8.9$) were selected. All presented a flexible rear-foot valgus greater than 5°. 24 lower limbs underwent kinematic and kinetic assessments (four subjects were evaluated for both left and right knees). The orthoses used were Bioptech and Bioform (Bi-Op, Joliette, Canada). The Bioptech is a semi-rigid orthosis with high control and the Bioform is flexible and exerts a lighter control. The subjects were asked to perform 30 s walk under 3 conditions at confortable speed: 1) without orthosis, 2) with Bioform and 3) with Bioptech. Order of testing was selected randomly before the experiment. The subjects were wearing standardized sandals and walked on an instrumented treadmill (Adal 3D, Médical Développement, France). The treadmil measures the 3D ground reaction forces during walking. Real time recording of the bone's space position was performed via infra-red emitting diodes which were attached non-invasively to the femur and the tibia by mean of the harness. A system of three cameras (Optotrak, Northern Digital, Canada) was used for recording and computed 3D kinematics of the knee.

Results and discussion

Results showed that, depending on the subject, immediate effect of foot orthotic treatment on 3D lower limb kinematics and kinetics could vary. For kinematics: in 13 of 24 cases, increased external tibial rotation of the knee was observed when subjects walked with the rigid orthoses compared to the walk without orthosis. In 12 of 24 cases, the flexible orthosis had no effect on knee tibial rotation and abduction. Most effects on kinematics were small. Fig. 1 shows typical patient for whom an increase of tibial external rotation was observed with the wear of the rigid orthosis. Kinetics: the flexible orthoses affected the anterior-posterior force in 8 of 24 cases and the rigid orthoses affected the medial-lateral force in 11 of 24 cases. Most observed effects are in accordance with the desired correction of orthoses as well as with the work presented in the literature. For example, Lafortune et al. (1994) using intracortical pins showed reduction of tibial internal rotation. Nevertheless, this is a first attempt to quantify non-invasively effect of orthoses on knee kinetimatic.

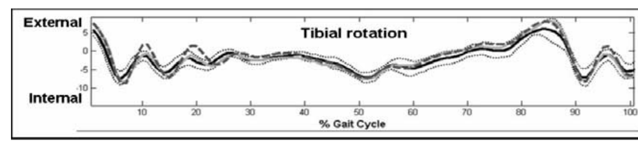

Figure1: Tibial rotation curves typical patient. Black line represent knee joints angles during gait without orthosis. Black dotted line give the aquisation error (mean standard deviatin). Grey dashed one represent gait with rigid orthosis. Grey plain one represent gait with flexible orthosis. Only stance phase of gait was analysed.

Conclusion

This study aimed at assessing the effect of plantar orthopaedic treatment on 3D lower limb kinematics and kinetics. Preliminary results showed that the method could be useful to quantify the effects of the orthosis on kinematics and kinetics and could allow a quantitative functional assessment of the patients lower limbs.

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Dynamic ankle foot orthoses in children with spastic diplegia-effects on posture during free stance and during free stance with voluntary movement

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Introduction

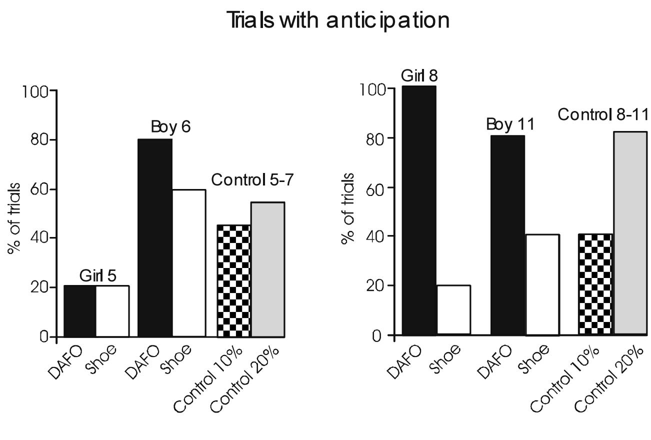
DAFOs (dynamic ankle foot orthoses) are often prescribed to children with cerebral palsy to improve posture and function. We investigated a reaching movement in children with spastic diplegia when wearing DAFOs in combination with shoes and shoes only, and in normally developing control children wearing shoes. Our hypotheses were that CoP (center of pressure) displacement (sign of anticipatory postural adjustments) precedes the arm movement in children with normal motor development but not in children with spastic diplegia, that the use of DAFOs can facilitate the emergence of such patterns and that DAFOs improve posture and provide a stable base of support in standing.

Materials and method

Eight children with spastic diplegia, ages 5–12, who were using DAFOs at the time of the study participated. The control group consisted of 8 normally developing children matched for age and gender. The children were standing on two force plates (AMTI), while reaching for a cup placed on a shelf. Vertical, medial/lateral ground forces and CoP were registered. The optoelectronic ELITE system registered the position of 5 reflecting markers attached to the right side of the body. Standing with DAFOs was compared to standing with shoes alone, and three 7 s trials of free stance and 5 reaching trials were recorded. Anticipatory adjustments were measured by CoP divergences prior to onset of the reaching movement (Four children could be included in the analysis). Postural orientation during free stance was measured by comparing the distance between the body markers and an imaginary line falling through the malleolus (Seven children could be included in the analysis).

Results

The results showed that more trials while using DAFOs showed an anticipatory divergence of the CoP than when wearing shoes only in the spastic diplegia group (See fig. I). In the control group, anticipatory CoP divergences were registered mainly when the target was placed at arm length+20% distance. At arm length+10%, it seemed that the task was mainly performed with continuous adjustments as opposed to anticipatory. The weight distribution between the feet was significantly less unequal in standing wearing DAFOs than in standing with shoes alone. However, lateral stability as reflected by the lateral force distribution beneath the feet, was not improved by DAFOs. In postural orientation there were differences indicating that five children decreased the distance between the knee marker and a vertical line falling through the malleolus when using DAFOs, i.e. having a more straight leg.



Conclusion

DAFOs seem to have some benefit by providing a more dependable frame of reference for modulation of the reaching movement and providing a more equal weight distribution between the feet in standing. DAFOs can be regarded as a suitable complement to other treatments in children with spastic diplegia.

Acknowledgements

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Kinetics of a carbon spring af-orthosis and its influence on the kinetics of gait

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Introduction

Ankle foot orthoses are commonly used for patients with functional restraints of the ankle joint. Typically such devices are rigid and allow no or only a predefined ankle motion if an additional hinge joint is used. Carbon springs allow motion which can be adjusted individually to the patients' abilities and could offer dynamic support due to the spring. In our clinic 5 patients were provided with carbon spring orthoses of type "Spring" from the company Gottinger. The clinical results were good concerning the walking ability. Goals of the study are to examine a) the kinetics of the carbon spring orthosis itself and b) if the spring mechanism supports the kinematics of the patients' gait.

Materials and method

The carbon spring of the orthosis is L-shaped (indicated in white in fig.1). The polio patient examined in this study was provided on one side with the orthosis.

A 9-camera Vicon motion capture system and Kistler force plates were used. Three markers (1. LEG, 2. HEEL, 3. TOE) were attached to the orthosis and the shoe to define the aperture angle. The spring characteristics as function of this angle was determined by loading the spring via manually pressing the orthosis onto a force plate. The moment acting between the two legs of the spring was determined and fitted with a quadratic function of the angle.

The patient was asked to walk with and without orthosis and the gait kinetics was monitored using the common clinical model [Kadaba 1990]. The contribution of the orthosis acting onto the anatomical ankle joint was calculated by use of the spring characteristics determined before.

Results

The analysis of the kinematics reveals that the orthosis contributes to a more physiological gait: In stance phase the patient showed an improved pattern in the knee and hip joint due to a stabilisation of the ankle. In swing phase the orthosis prevents a foot drop.

Furthermore, the spring functionality of the orthosis could be attested: The orthosis stores energy with increasing dorsiflexion and spring tension in mid stance. His energy is used at the end of stance phase for push-off. In this phase we determine a maximum moment of about 0.8 Nm/kg body weight (solid line) and a contribution of the orthesis spring onto the ankle of 0.3 Nm/kg (dashed line).

Discussion and conclusion

The idea to use flexible materials for orthoses is not new and their influence on gait patterns has been tested [Ounpuu 1996]. To our knowledge nevertheless, an explicit spring-like character could not be veryfied. In testing the dynamic behavior of the orthesis separately of the gait analysis, the evaluation of external moments acting onto anatomical joints becomes possible and is easy to carry out.

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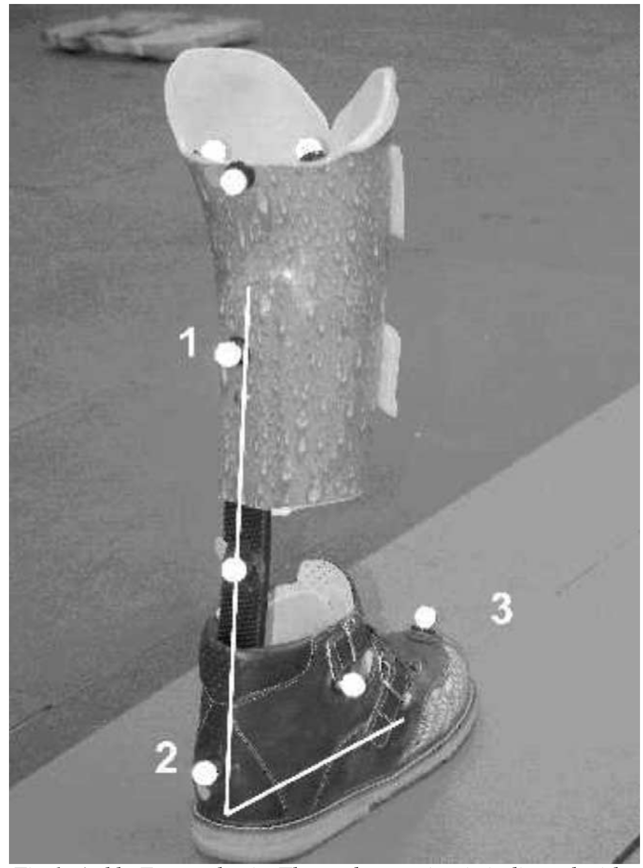

Fig 1: Ankle Foot orthosis. The carbon spring is indicated with white ilnes. Markers 1-3 define the angle between the legs of the spring

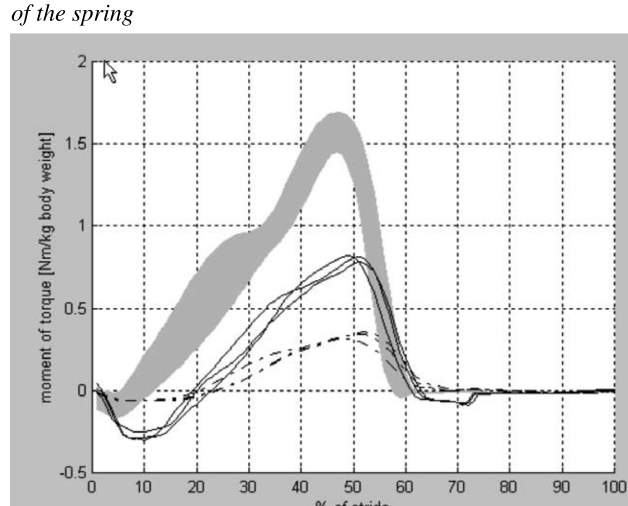

Fig 2: Moment of the orthosis acting onto the patients 'ankle (dashed line), total momemt of anatomical joint plus orthotic contribution (solid line) and normal behavior (in grey)

Some clinical studies of human movement at the rehabilitation clinic

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Introduction

The spondylolisthesis represents serious medical problem, in which one of the vertebras is slipped forward. Asymptomatic spondylolisthesis occurs with a small slipping. The higher slipping is followed by pain and neurological symptoms, and surgery is very often needed. There are six types of spondylolisthesis and they are as follows: dysplastic (congenital) spondylolisthesis, isthmic, degenerative, traumatic, pathologic and post-surgical spondylolisthesis The most frequent localisations of spondylolisthesis are two distal segments of vertebral column. The normal spinal unit represents stable structure, which is proved by the vertebral column ability to resist both the big acute and repetitive load. This stability is supplied by the spinal stability system, made of three subsystems (active and passive musculoskeletal subsystem, and CNS) worked in interaction. The active musculoskeletal subsystem protects against occurrence of instability, when the passive musculoskeletal subsystem is failed. It is very important from the rehabilitation point of view, because it safeguards the stability of lumbar vertebras by co-contraction of the antagonists. The active musculoskeletal stability subsystem disorder leads to the segmental instability, which means loss of the motion segment strength. For all the reasons mentioned above the main goal of the clinicians at the rehabilitation department is to secure the improvement of muscular dysfunction mm multifidi and m. transverses abdominis.

Materials and Methods

All examined patients, included in this project were patients of the Rehabilitation department in Košice-Šaca. There were hospitalized five patients after the operation of degenerative spondylolisthesis at this department in 1999–2000. Four of them were the patients with spondylolisthesis of L5 and one with listhesis of L4. All the patients underwent ambulance rehabilitation in the following years with average 3.5 times per year because of chronic intermittent course of troubles, especially pain emphasizing at lumbar vertebrae with irradiation into the lower limb, paresis and the weakness of lower limb and the pain at the other parts of the vertebral column. Motion capture system SMART, from Italian company e-Motion, was used for the study. The small passive markers were placed on the anatomically important points on patients' bodies. Patients were captured by the motion capture system during walking forward and backward, and during trunk bending forward. Trunk bending forward examination requires making the biggest motion in vertebra column and therefore it was the most important examination.

Results

We have analysed the lumbar vertebrae dynamics, flexion and lateral flexion by the SMART system, in an effort to make the hyper-mobility in the segments above the fusion objective. The following functional disorders were recognized: recidivous dysfunctions in the key points of the vertebra column, segmental dynamics disorder of lumbar vertebrae, middle thoracic vertebrae and ribs, absence of pelvic rotary synkinesis, as well as irritable symptoms L4, L5 and S1. The permanent muscular dysbalance was recognized in the pelvic, neck and shoulder. Achieved results have documented hypermobility of the L4-5 of the patients, who have instrumental fusion L5–S1. Even bigger hyper-mobility was detected in the segment L3–L4. This hyper-mobility was changed by the hypo-mobility in upper segment of lumbar vertebrae. The smallest mobility was detected just above the segment with the biggest hyper-mobility that is in segment L2–L3.

Discussion and conclusion

The presented method represents one of the possibilities how to diagnose the segmental mobility of the vertebral column. We have been motivated by this method for its further usage of patients' evaluation with different diseases of motion system, as there do not exist many objectives diagnostic methods in our field of the study. As for the pain, the patients confirmed that operations reduced their pain, which were evaluated as positive. But due to objective disorder of both/static and dynamic/strong dysbalance they have still remained to be the chronic patients of the Rehabilitation department.

Acknowledgements

Special thanks to the staff of e-Motion Company for their support, and to the clinicians of Rehabilitation clinic Kosice-Saca for the cooperation in our project.

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Philosophical and theoratical considerations behind the new hypothesis for stroke rehabilitation

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Introduction

Many therapies evolved in last few decades but none was flawless and results are not exhilarating. Patients who come to therapists in present times continues to have the similar abnormal postures and typical hemiplegic gait as it happened to the Stroke Patients in the last century. Can I stop this from happening, if a subject normal today, gets Stroke in coming years and comes to me for rehabilitation? The answer is yes, if we begin to look at the Stroke symptoms with highest simplicity without any bias and ask ourselves questions why on earth these symptoms appear with time? What are the root causes and the factors that triggers the consistent symptoms like spasticity and abnormal postures to surface? Can we stop them from surfacing? Can we make weak and flaccid muscle come back in normal action in a chain reaction? Yes we can have Victory on Stroke with clinical therapeutics based on following hypothesis

Hypothesis

Therapeutics with the new hypothesis are designed to...

a) Make stroke CNS recognize cortically and Sub cortically to integrate weak side with good side actively at all times during all postural activity and to recognize the dangers of favoring and depending on good side constantly for balance and movement.

b) Give freedom to the C.O.M. to shift towards the weak side thereby change Sub cortical and spinal equations to chanalise the cortical and sub cortical outflow.

c) Recognize that muscle is purely a victim of chaos happening at cortical sub cortical level. Therapeutics must not target the muscle alone (as is done with Boutoux) For revolutionary results, change must occur globally from every single living cell of the stroke subject.

d) Functionally integrate the physically united two sides of trunk and make the weak side lead the good side. This is true victory for stroke patients over his stroke.

e) Influence body segments in contact with ground; to generate and chanalise the forces in muscles in chain reaction thereby stimulate muscles in different segments through interneurons, motor units at all levels in spinal cord using interlimb knowledge within all four limbs, intralimb sensations, intraspinal, intracerebellar connection and cerebello-cerebellar connection to stimulate intrafusals and extrafusals thereby change the fate of the muscle to near normal action.

f) Influence the role of the so-called "Master" the CNS, using the so-called "follower" the PNS such that the role is reversed. Follower becoming Master during the stage when the CNS is recovering. Thereby changing inflow to the CNS before it gets adapted to the changed circumstances and thus put strong demand on the CNS to express what exactly is desired.

For the best results, patients must be chosen very carefully. He could be of any age, any sex and at any time after stroke. But determination to get best results and willingness to work few hours a day (in spite of the temporary pain from musculoskeletal system) and able to take decision himself.

Results

Results are miraculous even in patients with perceptual and sensory involvement where in although there is loss of cortical recognition of sensation the PNS is waiting for Vasa therapy which influences the right sensorimotor spinal subcortical interconnection to get what exactly is desired.

Discussion

Times have riped that clinicians must work in co-ordination and team with Bio-engineers and Neurophysologists and Muscle Biologists because the new measures have to be invented to be able to measure the efficacy of therapeutics by recording the state of the patients before and after clinical therapeutics. Neurologists work in teamwork with Neuro radiologist and Neuro pathologists and Neurorehab doctors for diagnosis.

Gait

Can movement training of hemi paretic arm and hand influence gait? — A case study

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Introduction

In Europe and North America the stroke-incidence in the population is 1 out of 1000. On average 85% of the victims suffer a loss of motor function to one side, i.e. hemi paresis (Duncan et al., 1992). In both the acute and the chronic phase active intervention is important in the rehabilitation of stroke victims (Olney and Richardson, 1996; Aquilonius and Fagius, 1994; Lundeberg, 2000). Increased understanding of the plasticity of the brain could lead to improved strategies to support and reestablish lost functional capacity after stroke (Johansson, 2000; Bakken et al., 2001; Nagel and Rice, 2001).

The objective of this case study was to obtain increased understanding of the relationship between intensive movement training (focused at the hemiparetic arm and hand) and motor function, balance and gait concerning kinematics and temporo-spatial parameters.

Material and method

Subject

A 70 year old man with stroke since 8 months ago, which led to a right motor deficit in arm/hand and leg/foot. Most of the improvements due to spontaneous recovery are considered to take place during the first 6 months after the onset (Olney and Richardson 1996).

Clinical measurements

Modified Motor Assessment Scale (including arm/hand function), Modified Ashworth Scale (concerning tone in the paretic arm and hand) and Bergs Balance Scale.

Laboratory gait measurements

A 3-dimensional gait analysis was performed using Qualisys Track Management system with 6 Pro Reflex cameras and a Kistler force plate.

The case was investigated with the clinical and laboratory measurements once before and once after a training programme.

Training programme

The treatment was given during 3 weeks, 4 days a week, 5 h a day at the geriatric day care-center, Uppsala University Hospital. The programme included a variety of functional exercises in sitting and standing executed mainly with the right arm and hand. During the study no other training was performed.

Results

The clinical measurements showed only minor improvements. On the contrary the results of the laboratory gait analysis were more significant; the speed accelerated with 125%, the stride (right leg) increased 50%, and the cadence improved with 24%. In agreement with the temporo-spatial data, the kinematic data showed an increased flexion with 20° in the right hip during the initial contact, loading response and midstance (which corresponded to the angle in the unaffected leg). The knee-flexion in the initial swing and mid-swing increased with 20° in both legs. Thus the kinematics of this patient got close to normal values (Winter, 1987).

Discussion and conclusion
Some research indicate that it could be possible to obtain improvements in other areas than the specifically trained (Bakken et al., 2001; Lundeberg, 2000). This a possible explanation to the results in this study. Even if a single subject experimental design would have been preferable, the results from this single case study, indicate that further investigations would be valuable.

Acknowledgements
We would like to thank the Dept. of Physiotherapy at Uppsala University Hospital, who made this study possible.

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Interjoint coordination for adolescent during different gait conditions: an example of coordination between hip and knee

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Introduction
Gait is characterized by temporal organisation between several articulations and corporal segments. Trunk, thighs, legs and feet present different coordinations during gait cycle. The relative phase angle between joints as function of time quantified this coordination (Burgess-Limerick et al., 1993). For adolescent gait, satchel carrying could induce a significant increase in trunk forward lean, double support and stance duration, and decreased trunk angular motion and swing duration (Hong et al., 2000). The aim of this study is to explore coordination between hip and knee during gait with three conditions of load carrying.

Material and method
Adolescent (12 years, 44.5 kg, 1 m 53) walked on gait walk at free speed. Three conditions were studied: gait without load, gait with load of 10% bodyweight (10% BW) and gait with load of 20% BW (20% BW). The homogenous load was located on satchel, carrying on back with two straps. The gait was studied with VICON 612 with camera CCD (120 Hz). Markers were positionned on: right knee, right ankle, right shoulder and right trochanter. Gait cycle were determined with Logabex plate-form (1080 Hz). Five strides were studied per condition of carriage. Only right side was studied here.
Angles were calculated according Winter (1990) in vertical plan. The angular velocities data were low-pass filtering: Butterworth 2nd-order filter with a cut-off frequency of 5 Hz (Van Emmerick et al., 1996). Phases were calculated like explained by Hamill et al. (1999) with the same analyse: the continuous relative phase (CRP) was calculated over the complete cycle with mean and standard deviation (S.D.), the variation of CRP was calculated at each point by average S.D. over the complete profile and coefficient of variability defined by Winter (1990): CV = S.D. × 100/Mean.

Results
Phases for each articulation per gait condition obtained, relative phases were calculated (Fig. 1). The Table presents mean, SD and variability for the three conditions. Although global CRP do not show differences between gait conditions, these results show a increase of CRP variability during gait when load carriage increase to. A t-test (0.05) along gait cycle show significant difference between CRP with 0%BW and CRP 20%BW between 64 and 73% gait cycle. A F-test (0.05) aren't associated with significant result.

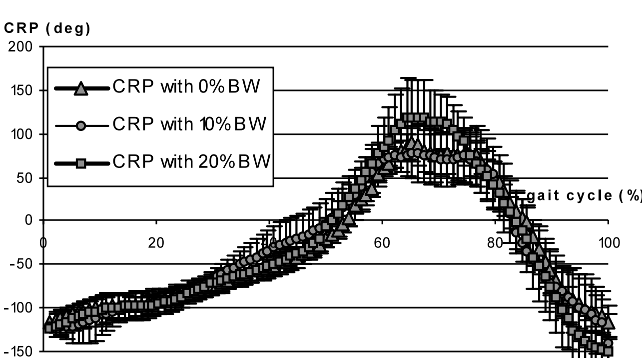

Fig 1: Continuous relative phase (CRP) pattern between trunk and thigh during gait with different loads

Table
Mean CRP (deg), standard deviation CRP (deg) and CRP variability (no unit)

	Mean	SD	Variability
CRP 0%	−32.28	17.13	53.06
CRP 10%	−31.80	20.80	65.40
CRP 20%	−30.96	21.32	68.87

Discussion and conclusion
In a biomechanical structure such complex as human body, CRP let to reduce complexity. This study show that CRP variability increase with load carrying. Hamill et al. (1999) show that this variability is greater for healthy individuals than people with pathology. However, load carriage seem influence coordination between hip and knee and increase in freedom of CRP.
Other studies could maybe precise these results. Coordinative structures can be muscles synergies and EMG of principal muscles in gait could maybe show similar conclusion.

Acknowledgements
Parents, adolescent and ethic committee (Lille) gave their approval for this study.

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Gait analysis in children with spastic hemiplegia: abnormalities in the uninvolved lower limb respect to the involved one

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Introduction
Gait analysis has become an important role in the assessment of children with cerebral palsy and an important tool in treatment outcome evaluation. Few scientific works were dedicated to the study of gait pattern in children with spastic hemiplegia and in particular kinematic and kinetic aspects of the uninvolved lower limb are not yet sufficiently analysed.
The main aims of this study are the evaluation of kinematic and kinetic behaviour of uninvolved lower limb of children with spastic hemiplegia (right and left) and the comparison of this behaviour with that one of involved lower limb during walking and that one of normal children.

Materials and methods
A total number of 31 children with diagnosis of hemiplegia (21 children with right hemiplegia—RH group, mean age: 9 ± 2.7 years; 10 children with left hemiplegia—LH Group, mean age: 10.5 ± 2.2 years) were analysed. The selection criteria of the children were: diagnosis of hemiplegia; children able to walk independently; no previous orthopaedic surgery or pharmacological treatment at the lower limbs. Twenty normal children (mean age: 10.6 ± 3 years) were also analysed as control group (CG).
Data from surface electromyography (EMG), 3D gait analysis and video analysis were collected and analysed. In particular an eight channels telemetric system (TELEMG, BTS, Italy) was used to acquire the EMG signals from surface electrodes placed over quadriceps, hamstrings, gastrocnemius/soleus and anterior tibialis muscle groups. Six infrared cameras (ELITE 2002, BTS, Italy) were used to capture the 3D coordinates of surface markers placed on the subject's body according to Davis protocol (1) and simultaneously force plate data and video information were collected using two platforms (Kistler, CH) and two video camera system (Videocontroller, BTS, Italy).
Temporal and spatial parameters, kinematics (ankle, knee, hip and pelvis movements on 3 planes) and kinetic data (ground reaction forces, moment and power of ankle joint and centre of pressure trajectory) were analysed for each leg. Each gait parameter was compared between the different group, i.e. the uninvolved limb of right/left hemiplegic patients, the involved limb of hemiplegic patients, the normal limbs of normal subjects. The data underwent statistical analysis using paired t-test ($p < 0.05$).

Discussion and conclusion
Main results are summarized here. Children with hemiplegia demonstrated for the uninvolved limb a stance phase (ST) significantly longer ($p < 0.05$) than CG (ST in uninvolved limb: LH group = $62.1 \pm 1.99\%$, RH group = $61.1 \pm 3.3\%$; CG = $59 \pm 1.9\%$). The ST of the involved limb reduced respect to the CG. As concern kinematic results: on the sagittal plane, the knee joint of the uninvolved limbs showed a significantly increased flexion in mid stance phase (uninvolved limb: LH group = $25.6 \pm 7.5°$, RH group = $27.6 \pm 7.7°$; CG = $16.9 \pm 4.4°$) and a significantly increased peak of flexion in Swing phase (uninvolved limb: LH group = $65.9 \pm 6.9°$, RH group = $63.8 \pm 6.6°$; CG = $58.8 \pm 4.8°$). The knee of involved side demonstrated a typical behaviour of "genu recurvatum" (hyperextension in stance phase), mainly observed in LH group. The hip joint of the uninvolved limb had a significant increased flexion at initial contact (uninvolved limb: LH group = $39.5 \pm 7.8°$, RH group = $41.4 \pm 7.7°$; CG = $31.9 \pm 4.9°$) and a significant increased peak of flexion in Swing phase (uninvolved limb: LH group = $42.5 \pm 6.7°$, RH group = $42.5 \pm 7.2°$; CG = $33.2 \pm 4.1°$). The hip of the involved side demonstrated a limited range of motion on the sagittal plane. Finally as concern kinetic parameters, the 91% of analysed subjects showed in the uninvolved limb the absence of ankle dorsiflexion moment peak in the stance phase (while the involved side is characterized by a double bump pattern) and an increased absorbed work in mid stance of ankle power.
The subjects analysed in this study are characterised of abnormalities in the involved limb (2) that are typical of subjects affected by Hemiplegia. Besides this, the data reported in this study demonstrated that the uninvolved limb presents abnormalities in temporal, kinematic and kinetic parameters. Our findings demonstrated that these patients walk with an abnormal

kinematic and kinetic strategy of the uninvolved limb probably to compensate the kinematic and kinetic abnormalities of the involved limb. These conclusions have important clinical implications in the management of children with spastic hemiplegia.

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The kinematics of gait in children with scoliosis and excessive arching of the foot

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Introduction

The kinematics structure of the gait of a normally developing 6-year-old does not differ in structure from that of an adult, despite the fact that the individual gait does not settle down until the age of nine [1]. The integration of the components of gait into a mature pattern and the process of settling into a gait stereotype may be disturbed in children of this age by the onset of various irregularities of body posture and build. Two of these are the asymmetrical positioning of particular elements of posture in the frontal plane linked to deformity of the spine and of the whole torso that goes on to develop in three planes — scoliosis [2,3] and also a structural disorder of the components of the supporting and load-bearing lower limbs, including the foot, characterised by increased arching [4]. The aim of this study is to examine the kinematics features of gait of 6-year-olds in whom scoliosis and an excessively arched foot had been diagnosed and a comparison of the results obtained with those for the gait of children with normal posture, the purpose being to determine how these irregularities are linked with gait.

Material and methods

A kinematics examination was carried out by means of a video-computer system of the gait of 43 children with scoliosis and excessive arching of the foot and of 33 children whose posture conformed to the norm. Video recording of gait (at 50 Hz) took place in the sagittal plane (with the subject at right angles to the video camera) and in the frontal plane (with the subject along the axis of the camera) [5]. The following kinematics parameters of gait were examined: stride length and stride period, the duration of the support and swing phases, velocity, cadence and step width. During the single support phase the values of the most important angles were determined, for both legs, for the relationship of body parts at selected joints: the angle of the tarsus to the tibia, the angle of the femur to the tibia and the angle of the longitudinal foot axis in relation to the line of progression.

Results

The children with scoliosis and excessive foot arching were characteristically similar in height, build and length of the lower limbs to the children with normal posture. However, analysis revealed statistically significant differences in the kinematics features of gait. The differences concerned all kinematics features of gait except for the stride length and the angle of the femur to the tibia in the knee joint during the single support phase. The children with scoliosis and excessive foot arching had a greater mean value for the stride period and a greater duration of the single support phase of the lower limb. In addition, the angle of the tibia in relation to the tarsus was greater, as was the angle of the longitudinal foot axis in relation to the line of progression. They also had a greater mean step width, evaluated in relation to the distance apart of the hip joints and the length of the lower limbs. They showed smaller mean values for the swing period, cadence and velocity.

Discussion and conclusion

The postural disorders under discussion, scoliosis and excessive arching of the foot, had a negative impact on the gait of 6-year-olds and was detrimental to its quality. The results for the gait examination of children with normal posture [5] were similar to those for their contemporaries in examinations conducted by other authors [1]. Children with scoliosis and excessive foot arching walked more slowly and with a lower cadence. They took longer to perform the gait cycle and the single support phase, during which the tarsus was severely distorted, while the swing phase was carried out in a shorter time. Furthermore, they walked with a greater step width (wider than the span of their hip joints) and placed their feet at a greater angle in relation to the line of progression. In the light of the differences between the results obtained, it may be anticipated that the irregularities analysed, when appearing in combination in one child, will exert an adverse influence on the child's mode of locomotion which demands further examination. The links found between the above-mentioned disorders and gait suggests the advisability of the earliest possible detection of faulty build and posture. They should also be taken into account for the purposes of preventive and remedial practice, with reference not only to posture, but also to manner of gait.

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Children performance in stair descent

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Introduction

Stair descent has been widely investigated respect to a lot of dimensions and conditions: kinematics and dynamics, stair inclination (Riener et al., 2002), influence of visual system (Christina & Cavanagh, 2002), and many others. However, these studies were devoted to analyse the performance of adults and/or elderly people: the latter are known to be more sensible to differences in the stair task respect to the level walking, and therefore more likely to fall. Moreover, it has been proved that the greater amount of fallings occurs while performing the last three steps, suggesting that the problem could be related with the switch between the stair descent and the level walking, instead of the stair descent by itself. Stair descent could be a dangerous task overall for subjects suffering of pathogenesis of lower-extremity disorders (Brechter & Powers, 2001), or with cerebellar injuries. In the meanwhile, only few studies (Sienko Thomas et al., 2002) investigated the performance of children. While it is proved that, in level walking, from 5 to 7 years old their performance is similar to the adults' one (McFadyen et al., 2001), nothing is said about how they deal with the stair task. The purpose of this study is to provide normative data on the performance of children in early puberty age, while facing with the stair descent task. Particular attention would be paid on the cycle of step involved in the switch between the stair and the ground.

Materials and method

Five children, aged within a range of 8–12 years old (heights ranged 156–165 cm), were required to descent a four-steps stair. They had to start with the right foot, and descent along three different levels of inclinations (the slopes were determined at 24, 30 and 40°). For each one of the three conditions, subjects have to: descent the stair five times in order to familiarize with the task and three times to collect measurements of their performance. A comprehensive analysis of joint moments, together with data about power generation and dissipation during the foot-ground contact, is required to understand the movement made in stair descent in the group of subjects. Kinematics was recorded using the VICON system that is a camera-based optometrical system, while forces were collected placing two force platforms in correspondence of the second and the forth step (grounding). ANOVA analysis with repeated measure was computed in the post-processing the kinetic and kinematic data.

Results

The main differences depending on slope were found in the sagittal angle of the knee and of the ankle ($p < 0.05$). The power absorption in the contact with the ground increased with the stair slope ($p < 0.05$) while, when compared with level walking data, the same power was near to zero. This data suggests that the mechanical constraints in the stairs task would force subjects to change mainly knee and ankle strategies to adapt the ones already structured in level walking.

Discussion and conclusion

The study has provided an integrated analysis of mechanics and dynamics of stair descent in a group of normal children. A comparison with the results in literature for adults samples show that children of 8–12 years old are substantially not different in stair descent with respect to adults. While confirming the differences in strategy and distribution of the effort found in level walking in others age samples, our results, referred to normative controls, have direct relevance to rehabilitation of children with locomotion impairments, and the detailed analysis could be used as a database for a orthotic device development based on artificial neural networks.

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Walking with platform shoes — normal walking pattern?

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Introduction

Nowadays young people are wearing platform shoes for fashionable reasons. But these shoes were not designed to be comfortable and healthy, they were designed to be trendy. There are some studies about platform shoes dealing with the higher injury risks caused by the increased lever arm. There are no published data's (known to us) reporting on the influence of platform shoes onto the gait pattern. Some of the platform shoes have a small high heel component. The biomechanical influence of high heeled shoes was the topic of many research papers. So it would be interesting to evaluate the effect of these shoes and compare the results to high heeled walking.

Methods

The subjects for this investigation were 16 young female students. All of them had experience in walking with platform shoes and had the same shoe size. A 3-dimensional optoelectronic system (Motion Analysis Cor.) combined with two force platforms (AMTI) were used to acquire the kinematic and kinetic parameters. Physical examination was performed including ROM, force and alignment of the lower extremity. Three conditions were analyzed: walking barefoot (BF), walking with gym shoes (GS) and walking with platform shoes (PS). The analyzing order was chosen randomized. All trials were carried out at self selected speeds. The platform shoe had 10.3 cm heel height and 6 cm toe height. Statistical analysis for the kinematic and kinetic parameters were performed by using the paired t-test.

Results and discussion

Some significant differences between the three conditions were found. The Table shows the results for the temporal-spatial parameters. The kinematic parameters showed a reduced max knee flexion during the swing phase and a increased max. knee extension in stance phase for PS conditions. No differences for the pelvic and hip motion was detected. The significant greater plantar flexion of the PS was caused by the shoe geometry. A reduced ROM of the ankle joint was found for the GS and PS. In the transverse plane a reduced foot progression angle was found for both shoe types compared to BF walking. The kinetic parameters showed a higher valgus moment for PS during second half of the stance phase compared to BF. The lowest power generation at the ankle joint was found by the PS followed by the GS and BF walking. At the frontal hip moment after loading response BF and GS walking showed a significant higher moment compared to PS. Upper body rotation increased with PS compared to BF and upper body forward leaning was higher in PS and GS compared to BF.

Table
Temporal-spatial parameters (* significant differences $p < 0.05$)

Conditions	Velocity (cm/s)	Cadence (steps/min)	Step width (cm)	Step length (cm)	Stance phase (%)
Barefoot	124.9 ± 11.5	115.2 ± 6.3	9.9 ± 1.9	64.9 ± 3.8	60.4 ± 1.0
Gym shoe	130.1 ± 11.5	112.3 ± 6.5	11.4 ± 1.7	69.5 ± 3.8	60.8 ± 1.8
Platform shoe	127.7 ± 12.7	109.6 ± 6.4	11.8 ± 1.6	69.7 ± 4.4	59.6 ± 2.0
Significant results			BF-GS*, BF-PS*	BF-GS*, BF-PS*	

Summary

The differences found were not so big as expected. Not all reported results for high heeled walking (Opila-Correia, 1990; Kerrigan et al., 1998; Snow and Williams, 1994) are corresponding with our PS results. Especially the results for the pelvic and hip are not corresponding to high heeled gait pattern. The increased valgus moment in the knee joint at the end of stance phase while wearing PS can be related to reduced foot progression angle. The risk of injury caused by supination or pronation trauma due to the thicker sole (increased lever arm) should not be neglected.

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Three-dimensional clinical gait analysis in normal brazilian adults

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Introduction

Gait serves an individual's basic need to move from place to place. As such, walking is one of the most common activities that people do on a daily basis. Ideally, walking is performed both efficiently, to minimize fatigue, and safely, to prevent falls and associated injuries.

Methodology

Twenty-nine subject, fifty-eight limbs (twenty-one women, eight men) with average age of 26.5 ± 5.6 years, with no history of musculoskeletal or neurological impairment and self-select speed were included. Informed consent was obtained. Three dimensional gait data were collected with VICON 370 system with six cameras. Time-distance (walking velocity, step length, cadence, single and double support) and kinematic (joint rotation angles of pelvis, hip, knee and ankle in sagittal, coronal and transverse planes) data were processed using Vicon Clinical Manager software.

Results

Time–distance values were: walking velocity 118.7 ± 12.1 cm/s; step length 62.8 ± 5.5 cm, cadence 92.6 ± 4.5 steps/min; single support 35.9 ± 1.9% of gait cycle and double support 28.0 ± 3.2% of gait cycle. Kinematic variables of the pelvis, hip, knee and ankle in sagittal, coronal and transverse planes gait with mean values (S.D.) are presented in Fig. 1.

Discussion and conclusion

The pattern of normal gait described by countless authors (1, 2, 3) had as base studies in a local population. In Brazil and South America the few laboratories that accomplish clinical gait analysis use data originating from other countries to serve as comparative method in exams of pathological gait patterns. Therefore, the great value importance of the use of an own and local database is to serve Brazilian clinical and scientific communities in future studies.

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Methodology and Modelling

Dimensionless approach to decrease the inter-subjects variability of walking parameters

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Introduction

The great data base variability makes it difficult the identification of locomotor parameters responsible of the senior's fall risk. The variability coefficients (CoV) of each measure results, in part, of using spontaneous speed. As a matter of fact, the natural speed depends of many intrinsic (gender, age, anthropometry, fatigability...) and extrinsic (environmental) parameters. The purpose of this study was to verify that using a dimensionless approach for similar speed (S_{sim}) determination makes it possible to reduce the inter-subject variability of locomotor pattern.

Materials and method

Fourteen male subjects (22 ± 3 years) took part in the study. Pairings were made on the basis of subjects' leg length (L), body mass (m) and size. From these parameters, 7 pairs of similar anthropometric subjects were obtained matching 7 referent subjects to 7 doubles. Three walking trials were carried out. In the first one, the spontaneous speed (S_{spon}) of the referent subjects is identify then imposed during the walking tests. In the second, the doubles had to walk at their referents' S_{spon}. In the third, the doubles had to adopt a similar speed ($S_{sim} = \text{Nfr}.(gL)^{0.5}$) computed from a fraction of the Froude number (Nfr) and the leg length (L).

The optoelectronic system (SAGA 3) connected to two force platforms (Logabex) were used to assess the kinematical and kinetic parameters.

The centre of gravity displacement was computed from the marks coordinates and an anthropometrical model.

Results

At S_{sim}, the mean CoV of the vertical oscillation (Cgz) and the horizontal displacement Cg(y) of the centre of gravity decreased by 4% and 20%, respectively compared to tests performed at S_{spon}.The mean CoV of the vertical ground reaction force (Fz) and of the antero-posterior force (Fy) were by 35% and 20% significantly lower at S_{sim} than at S_{spon}, respectively.

Discussion and conclusion

Our study of the human locomotion shows that the determination of similar walking speed from a fraction of the Froude number and the leg length makes it possible to reduce the inter-subject variability of a group of subjects. The results let foresee direct medical and paramedical

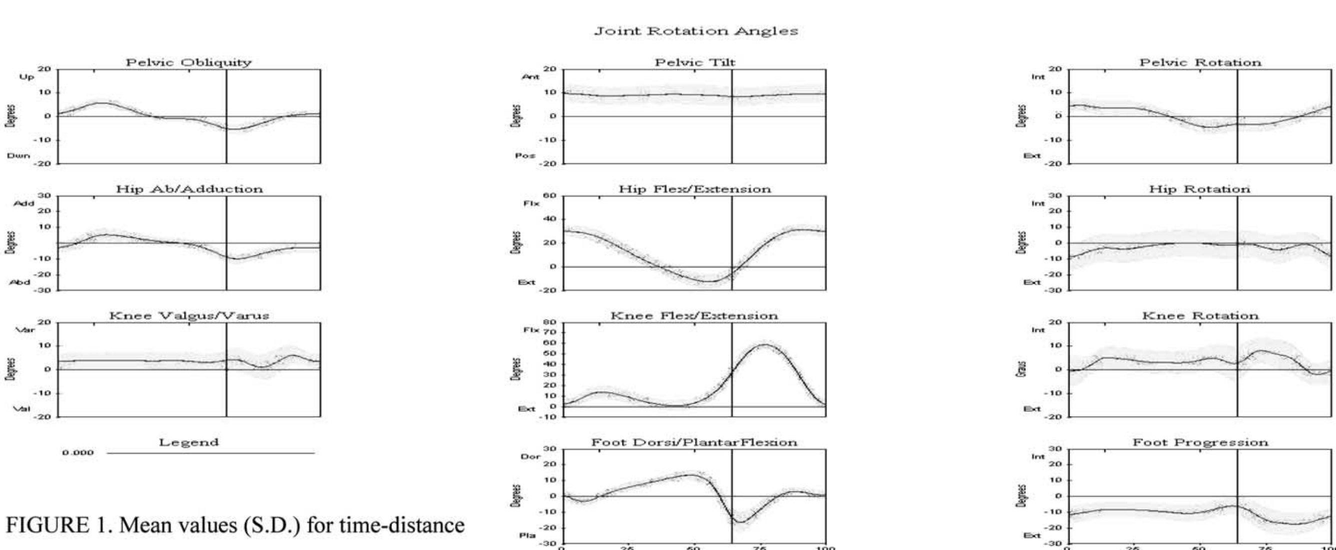

FIGURE 1. Mean values (S.D.) for time-distance

applications to detect pathological factors from normal similar values or to survey the effects of a rehabilitation period.

Acknowledgments
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Automatic recognition of sharp transients during human locomotion

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Introduction

Sharp transient phenomena associated to the impact of the foot with the ground can be observed in the Ground Reaction Forces (GRF). The recognition of such irregularity has been questionable and this phenomenon has been considered as an artefact up to 1980, when Light [1] defined it as "Heel strike Transient" (HST). Light put into evidence that the sharp impact of the foot with the ground could cause impulsive loads propagating by the limb joints, through the spine up to the head. It has been observed [2] that such impulsive loads, present also in the vertical component of GRF of normal subjects, could be dangerous for the joint and could be responsible of some pathologies (low back pain, osteoarthritis). The time-frequency representation adopted in the study [3], revealed the presence of two kinds of HST: a sharp impulsive irregularity, such as that described into the literature, short in time, localised at 15% of stance phase, and a smooth, not impulsive irregularity, rather long in time up to the first peak of vertical component of GRF. The smooth HST identification was obtained by cross comparison of the vertical component and the antero-posterior component of GRF. The classification was performed throughan high number of parameters obtained by wavelet transform of the signal.

An automatic tool for the reliable recognition and classification of the transient phenomena is the aim of the present study. In order to reduce the high number of classification parameters and to automatically classify the different HST typologies, two different techniques are adopted: the principal component analysis (PCA) and the self organising map (SOM) [4, 5]. This would simplify the clinical gait classification.

Materials and methods

The examined population is composed by 23 young subjects presumed to be normal. Each subject is asked to walk barefoot on the pathway continuously. 3D Data are collected and three trials during which the foot stroked examined has its stance on the force platform are retained. GRF are processed component by component. The wavelet transform is applied to each force component as a filtering technique [6]. The first 130 samples of the data are processed. Data are qualitatively classified in three groups: no HST, sharp HST and smooth HST [3]. The PCA and SOM according to [4, 5], are adopted for data processing. The first one provides a synthetic description of the three classes. For the PCA analysis the set of data is subdivided in two subset. The 40% of the trials are used for the identification phase. The PC model obtained is applied to the validation group constituted by the 60%. Instead the SOM can capture the temporal structure of the variable examined modelling the interconnections among the variables. The same trials fractions as in PCA was used for SOM training.

Results

The PCA technique identifies three parameters for the classification. It allows a better classification of the sharp HST with respect SOM technique.

In the first case the percentage of the success in the classification, analysing the three GRF components are following:

Vertical component of GRF	76%
Antero-posterior component of GRF	72%
Medio-lateral component of GRF	61%

These percentages increase if the trails with smooth HST are considered as no HST.

By the SOM, the best network for the purpose of the study is constituted by a grid 9×4, the linear initialisation of the code book vectors and the bacth type learning. These characteristics allow a quick convergence of the algorithm. The percentages obtained in this case are just lower than these obtained with the PCA technique. Smooth HST is poorly identified by both methods. A friendly interface is defined as a support of clinical decision making.

Discussion and conclusion

Each of the two methods allows a correct identification of the sharp HST, but the PCA seems more appropriate. It could be hopeful to adopt the PCA for extracting the features and the SOM for classifying.With respect to the results in [3], this study put into evidence the relevance of the 3rd component of GRF.

The identification of the smooth HST remains under discussion. This incertitude could be attributed to the border line characters of such transient.

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3D kinematic analysis of the traumatic cervical spine using the ZEBRIS system

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Introduction

The mechanism of minor cervical sprains has been explored in various studies. While symptoms consecutive to such traumas are widely described, their objectivation and the evaluation of the harm incurred remain tricky. Especially because conventional X-ray pictures identify the different bone lesion but not the injuries of the soft tissues. The aim of the study is to propose a simple protocol for non invasive head motion measurement of a large number of patients with various cervical spine injuries in order to search for specific motion patterns related to these cervical damages.

Material and method

The ZEBRIS CMS 70P ultrasonic measurement device is used to record 3D motion of the cervical spine.The interpretation frame for the head motion is defined on the subject's torso with several landmarks taken by a measuring pen. The subject is seated, eyes closed, and asked to perform successively: flexion-extension, lateral bending and axial rotation, each sequence is repeated three times.

A 3-transmitter head helmet and a 3-transmitter shoulder device supply the relative angular position between head and thorax at each instant of the movement. For each movement sequence, the 3D head motion with regard to torso is processed to obtain 3 curves versus time: one main rotation, two coupled rotations.For purpose of comparison, the curves are normalized with regard to time.

Preliminary collected data: 128 asymptomatic subjects are considered and 23 injured patients are followed.

Preliminary results

Asymptomatic data was used to create corridors to which the symptomatic data is compared. The main motion pattern seems to be the same for all the populations, only the amplitudes of the symptomatic subjects are decreased. Changes were observed in velocity as well as in some coupling patterns. As an example fig. 1 shows that the whiplash group presents modified coupled lateral bending during the flexion-extension.

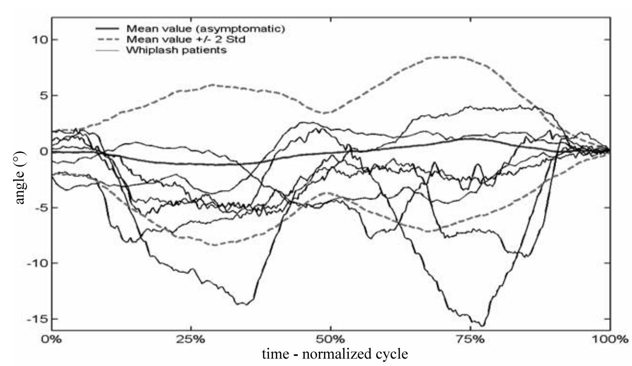

Figure 1: Six whiplash patients superposed to a corridor composed of 120 asymptomatic subjects

Discussion

This efficient protocol is adapted to clinical large scale study: it requires only 15 min for material set up and 5 min per patient measurement. The patients present different kinematic patterns, as found by OSTERBAUER. Particularly, coupling motion is modified for all the pathologies. Future studies will focus on this element of the cervical kinematic. The aim is now to increase the symptomatic database to define other characteristic patterns for a significant population of the different specific pathologies.

Conclusion

Relevant clinical tool and protocol for objective evaluation of the trauma and its evolution. Once completed, the database should provide a basic research tool for a better understanding of mechanisms of injury, particularly when combined with finite elements analysis.

Acknowledgments
To the staff at the orthopedics and emergency departments of the Hôpital de la Pitié-Salpétrière in Paris.

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The effect of electrode positioning errors on EMG envelope during gait

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Introduction

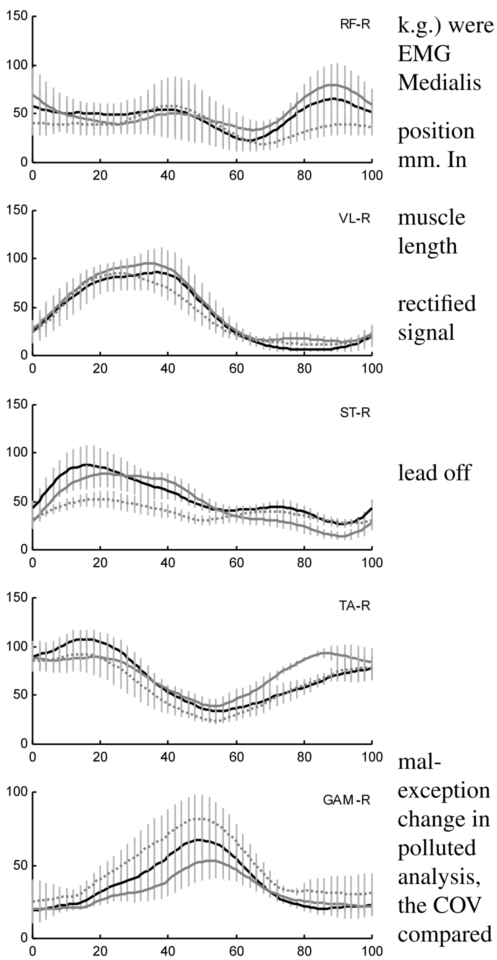
In movement analysis in general, and specifically in gait analysis, measurement of surface EMG during gait is an important tool to assess muscle function in its functional context (1). A qualitative interpretation of the so called "raw" EMG signal is used to assess active-non active patterns. Quantitative assessment of muscle coordination uses the envelope of the EMG signal as a representation the relative active state of the muscle.

Both types of interpretation, but especially the quantitative one, is dependent on how well the measured MEG signal is representing the activity of the muscle. This relation is greatly affected by electrode positioning. Although it is hard to standardize electrode positioning in the presence of anatomical variation, several attempts have been done, resulting in a review of the European SENIAM initiative (2). First aim of proper positioning is to maximize specificity, i.e. to minimize of cross talk. However in a recent study it was shown that electrodes that are properly positioned over the muscle belly, may result in a different EMG envelopes, depending on the longitudinal alignment (3). This study is aimed at an evaluation of a longitudinal shift of electrodes over the muscle belly, taking the SENIAM guidelines as a reference.

Method

Ten children with cerebral palsy (age range 9 – 15, bodyweight, range 28 – 60 kg.) were evaluated after a regular clinical gait assessment in the gait lab. Surface EMG (bipolar recording) of m. Tibialis Anterior (TA), m. Gastrocnemius Medialis (GAM), M. Vastus Medialis (VM), m. Rectus Femoris (RF) and m. Semitendinosis (ST) was measured. SENIAM guide lines (2) were used to position the electrodes. Electrode surface was 1 cm^2 and interelectrode distance 24 mm. In addition to the standard position, one pair of electrodes was placed proximally and another pair distally, along the longitudinal axis of the muscle belly. distance between (the center of) pairs was 48 mm. Range of thigh length was 29 – 38 cm, shank length 31 – 42 cm.

EMG was processed into the envelope by means of low-pass filtering the rectified EMG signal at 2 Hz. An ensemble average profile was calculated for each signal over a number of strides. For comparison two indices were calculated (4): coefficient of variation (COV) and mean profile variation (MPV) were calculated for comparison of all three muscle profiles per subject.



Results and discussion

A typical result is shown is Fig. 1. The black line represents the standard lead-off position of the electrodes. dotted lie distal and gray line proximal deviation. Quantitative assessment is shown in the Table

Muscle	Mean COV (range)	Mean MPV (range)
RF	0.17 (0.08 – 0.22)	0.11 (0.03 – 0.18)
VM	0.20 (0.11 – 0.28)	0.19 (0.09 – 0.32)
ST	0.25 (0.17 – 0.30)	0.22 (0.16 – 0.36)
TA	0.15 (0.07 – 0.30)	0.11 (0.03 – 0.31)
GAM	0.17 (0.10 – 0.22)	0.15 (0.09 – 0.20)

By qualitative inspection the EMG profiles were only mildly affected by a mal-positioning of the electrodes along the longitudinal reference. The only exception is Semitendinosis, where the distal position produces a relative large change in the profile. Also some distal EMG measurement of the distal ST were so polluted with movement or other artifacts. This is conformed by the quantitative analysis, showing that ST-EMG recordings were relatively less consistent. Overall the COV (an (inverse) index for the consistency of the profiles) are quite low when compared to another study on inter laboratory reproducibility (4). The MPV was comparable to the results of this study.

Conclusion

When care is taken to position electrodes according to the SENIAM guidelines (with special attention to ST) the envelope of the Mean rectified EMG signal) is a relatively well protected against the groung.

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A motor function measure for neuromuscular diseases. Validation of a secondary version scale

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(Waiting for modifications!!) *Objectives*: To describe the Motor Function Measure scale (MFM), a clinical measure of quantification of motor function suitable for neuromuscular diseases (NMD) and the setting up of the protocole of validation.

A new framework for biomechanical modelling

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Introduction

The state of the art in biomechanical modelling has benefited from many recent technical improvements. For example, motion capture equipment is achieving ever higher resolution and data capture rates, enabling more markers of decreasing size to be used, in turn making the tracking of small body segments possible. The progress in computing power also makes much more complex problems soluble within reasonable time frames. Complementing this is the increase in complexity of the biomechanical models being used in clinical settings. For example, multi-segment foot models are becoming popular and the complex kinematics of the shoulder girdle has been addressed. However, the many and varied approaches to biomechanical modelling are disparate, making the conjunction of many models into larger, high-resolution models difficult. Models written at different institutions are often "hard-coded" in a particular programming language, which makes them difficult to amend and extend.

This paper proposes a new modelling paradigm that addresses the lack of a standardised and flexible, yet powerful language for biomechanical models.

Materials and methods

The proposed modelling language is based on XML (eXtensible Markup Language), which is of a hierarchical nature and contains implicit rules for structure and format. XML is widely used for many other purposes, and many software components for reading and manipulating XML documents are already available. An example hierarchy is shown in Fig. 1.

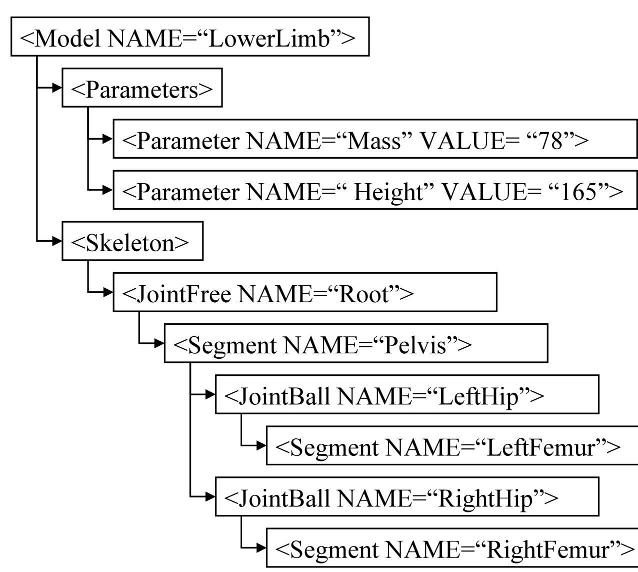

Figure 1. Example Model Hierarchy.

The proposed language will allow a full hierarchical kinematic and kinetic description of a skeleton, including general joint and segment constraints as well as body segment parameters (BSPs) and subject specific parameters. Furthermore, the language will allow the definition of parameters that can be optimised using advanced mathematical techniques (e.g. Roren and

Tate, 2002), and also the use of regular mathematical expressions in the specification these parameters. For example, BSPs can be specified using published regression equations, and sets of known formulae for population sub-sets can be used automatically, (e.g. Winter, 1984) for adult males. The use of expressions also allows models to be constrained by fixing markers and joint centres to points, lines and planes.

Solution of each specific modelling problem will use built-in advanced mathematical algorithms such as generic inverse kinematics, inverse dynamics, advanced filtering algorithms, minimisation of degrees of freedom (DOF) cross-talk and global optimisation techniques (e.g. OLGA, Charlton et al., 2002). These processes are model independent and are hence ‘‘hidden’’ from the modelling language itself, reducing the knowledge and training requirement for those using it.

Discussion

The use of a hierarchical language is very applicable to biomechanics due to its similarity to the skeletal system. Standardisation of model specific information in this language also helps to segregate the model description from the model application and will allow for easier comparison of both the models themselves and the subsequent data analysis. Also, the level of expertise required to manipulate such a model is decreased, thereby increasing the model accessibility and ease of use.

Furthermore, the proposed new language will allow advanced existing and potential modelling techniques to be incorporated as part of the language's ‘‘biomechanical modelling toolkit’’ in a flexible and extendible way. This future-proofs the language since new methods and concepts can be added without having to consider backwards compatibility issues with existing models. For example, a commonly used biomechanical model used for gait analysis of the lower limb (Davis et al., 1991, Kadaba et al., 1990) can be fully implemented.

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Global optimization of a double inverted pendulum model for the ankle and hip joint torques estimation in standing

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Introduction

In human standing, the computation of joint torques may be useful to investigate ankle or hip postural strategy. Despite the fact that inverse dynamics don't need an explicit mechanical model, it is well known that it entails estimation errors particularly in case of small movements. The aim of this study is to propose some tools that improve ankle and hip torques estimation for further postural strategies investigations.

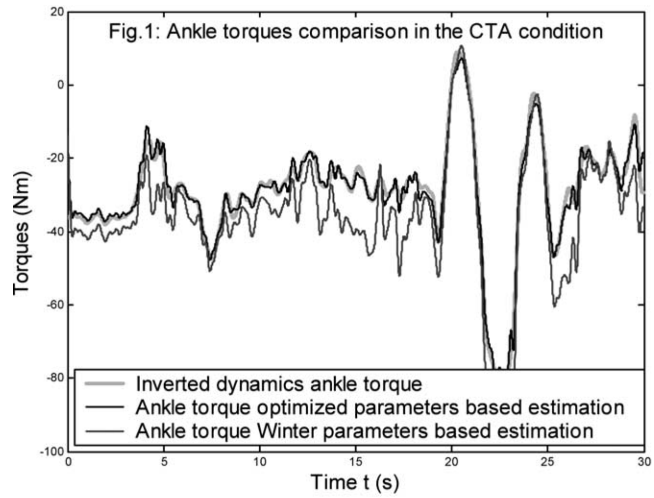
Materials and method

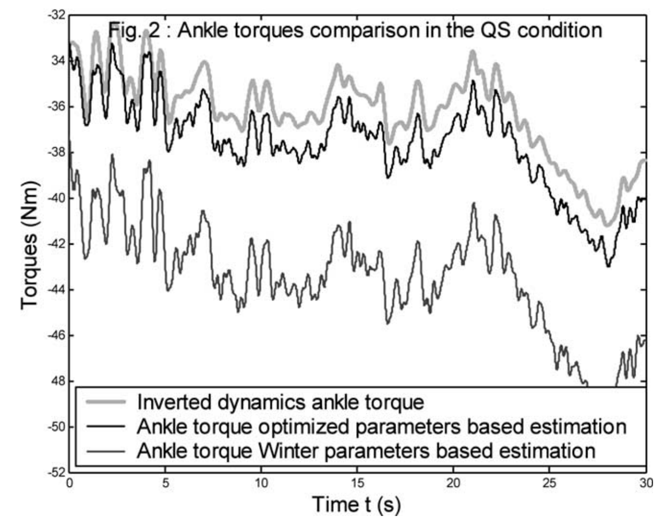
A double inverted pendulum model, articulated to the ankle and to the hip, is derived from Lagrange equations. This model can be written in his compact form as where $\Theta = (\theta_1\ \theta_2)$ is the two link angular vector with respect to the vertical, $U = (\Gamma_1\ \Gamma_1)$ is the torques vector at each joint, M, S, D, G are (2×2) matrix depending on Θ and inertial parameters m_1, m_2, I_1, I_2, L_1, L_2, f_1, f_2, the lower and the upper limb mass, inertias, lengths, friction coefficients and K a coefficient given the position of the lower limb center of mass regarding to L_1. Using this model to estimate joint torques with inertial parameters data given in anthropometric tables is subject to uncertainties (Winter 90). We propose to use a global optimization algorithm, a simulated annealing, to evaluate individual inertial parameters (Bonnemoy 91). An 8 M-cam Vicon 670 system allows the measurement of Θ during standing. It is therefore possible to compute a model-based estimation of the ankle torque Γ_1. The feet being supposed to be rigid and fixed to an AMTI force plate, we assume that applying the inverse dynamics on the feet allows estimating the ankle net torque with a fairly good accuracy (Barbier 03). We call this so computed ankle torque the inverse dynamics ankle torque $\Gamma_{1,\mathrm{ID}}$. The vector of parameters to be estimated is $\Phi = (m_1\ m_2\ I_1\ I_2\ L_1\ L_2\ f_1\ f_2)$. Let us define $\Phi_{\max}$ and $\Phi_{\min}$ the bounds for each parameters. The optimization problem is under constraint $0 < \Phi_{\min} \leq \Phi \leq \Phi_{\max}$.

One subject, 28 years old, 69.76 kg weight and 1.85 height, participate in the validation study. The subject has no previous orthopedic ailment or neurological disorders that could affect his standing posture. The subject was fitted with 14mm reflective markers to define 11 body segments. He was then asked to realize two movements. The first was quiet static standing (QS) and the second was a combined trunk flexion/extension with ankle oscillation (CTA) to disturb standing and to test the efficiency of the following global optimization algorithm.

Results and discussion

Fig. 1 shows a comparison between the different ankle torque estimation approaches in the CTA condition. Despite a good Pearson coefficient of correlation that confirms the goodness of the fit between the anthropometric table-based result and the inverse dynamics one (0.95), the mean position error value is 6.9 Nm and the standard error 7.23 Nm. The comparison between optimized parameters based ankle torque estimation and the inverse dynamics-based ankle torque shows the benefit of the global optimization process. This is confirmed by a better Pearson coefficient of correlation (0.99) as well as a mean position error of 0.1 Nm and a standard error reduced to 1.5 Nm. The accuracy of the optimized parameters is also observed in the QS condition (see Fig. 2), the optimized parameters based estimation remains closer than the anthropometric table based estimation regarding to the inverse dynamics-based ankle torque. Moreover, the optimized parameters obtained on an identification data set also improve the estimation accuracy on other data sets. This validates the obtained parameters.





Conclusion

This study shows that the use of an explicit mechanical model combined with a global optimization process allows estimating the ankle and hip joint torques in standing with a fairly good accuracy. These tools may now be used in further studies for the investigation of postural strategies in standing.

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On optimal control design in human movements

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Introduction

Motion control of humans is challenging due to the great number of joints and muscles and the complex musculo-skeletal dynamics. A very important question is how such systems are controlled in dynamic motion tasks like reaching, standing-up, or running. In our study, a conceptual framework for dynamics-based control design in constrained and unconstrained motion tasks is developed.

Methods

Voluntary, ballistic-like movements are to be controlled in an open-loop manner, (Karniel and Inbar,.1997). The performance indices are the positioning error and the movement execution time and they are minimized applying triphasic control functions (Kiriazov, 2001). A control learning scheme is proposed that has the following features: a) existence of feasible solutions can be guaranteed; b) motion synthesis done with a small number of decision parameters; c) convergence within minimum number of trials.

Feedback controllers are to be applied in case of constrained motion, e.g. for posture or trajectory tracking stabilization. We propose a method for designing decentralized sliding-mode controllers with maximum degree of robustness. It is based on explicitly defined design relations that present optimal trade-offs between bounds of model uncertainties (external disturbances) and control force limits.

Results

To illustrate the proposed control concepts, a dynamic model of standing-up three-link body motion is taken into consideration. The trunk and shank rotations are considered as constrained motions and, consecutively we have to apply to them closed-loop control. The rotation of the thigh, with the massive trunk hinged to it, is a ballistic-like movement and for its optimal synthesis we apply open-loop control. In a neighbourhood of the vertical posture, we use optimal robust stabilising controllers for all the body segments.

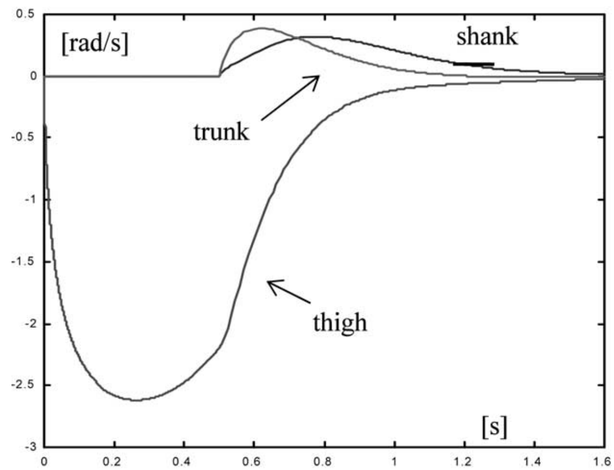

Figure 1: Velocity time histories

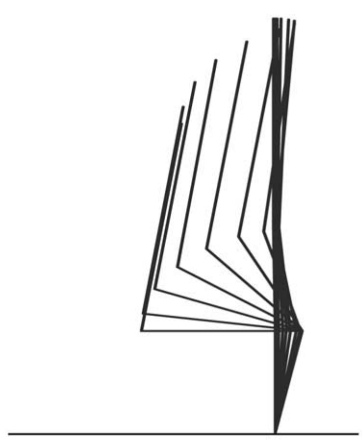

Figure 2: Stick-diagram of standin-up motion

Conclusion

Based on the proposed approach, actual problems in biomechanical engineering, human animation, virtual reality, and biorobotics can be addressed. In particular, efficient control design techniques for neuro-prosthetic systems or functional neuromuscular stimulation, in various motion tasks can be developed. Besides standing-up, special attention in our study is devoted to control of posture and walking

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Motion analysis of human lower jaw in 3D during mastication of different nutriment

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Introduction

The range and pattern of human masticatory system movements during function are of considerable interest and they are a typical example of kinematically and mechanically indeterminate system. Two segments, the mandible and the skull, are able to move with respect to each other. These movements are guided by two temporomandibular joints. In each joint a mandibular condyle articulates incongruently with the articular surface of the temporal bone. The articular capsule is slack. Due to this construction both joints allow for movements with six degrees of freedom. The jaw movements are not limited to rotations about one or more axes defined by the joint. If the joint surfaces are assumed to be undeformable and maintain contact all the time, the mandible still is able to move with four degrees of freedom. Jaw movements can be defined by the three dimensional path traveled by the lower central incisor. This can be accomplished in various ways with the system that is able to move with at least four degrees of freedom. Consequently, the masticatory system must be considered as kinematically redundant. The knowledge of lower jaw movement in population is very important for dominant anatomical direction assessment during occlusion and for bite force direction specification. The aim of this study is experimental detection of occlusal contact bank rate (number of biting) during processing of one bolus. The next measured quantity is amplitude and direction of motion of lower jaw during masticating.

Materials and method

In this study is used a method of motion analysis to record three dimensional movements of mandible. There were used three SONY DCR-TRV900E digital video camera recorders for lower jaw movement recording and software APAS for video sequences processing, three dimensional reconstruction of lower jaw movement by the method of direct linear transformation and result evaluating. Video cameras calibration was achieved by specially constructed calibrating cage. Three-dimensional space was calibrated into Cartesian coordinates. The x coordinate represents lower jaw movement in lateromedial direction (lateropulsion, mediopulsion), y coordinate represents lower jaw movement in cranial direction (abduction, adduction) and z coordinate represents lower jaw movement in ventral direction (propulsion, retropulsion). The special pointer was made of dental wire and was rigidly fixed to patient lower dentition in order to measure lower jaw movement. Black marker was attached at the opposite end of the pointer in order to read pointer coordinates with cameras. Other black markers were set at anatomically significant points of patient face in order to eliminate patient head movement during recording. Each subject of experimental research was asked to masticate different nutrition e.g. bakery, nuts etc. This procedure was recorded by three video cameras. These cameras were placed at such a three different places, so all makers should be recorded at all cameras. The clappers were used for time synchronization of cameras. Cameras recording frequency was 50 half frames/s. Totally 55 patients with physiological dentures were participated in this trial.

Results

From video record of simultaneously recorded camera views were obtained coordinates of all markers during recorded lower jaw movement. The coordinates of markers were detected from video records in software APAS for all three camera views. The direct linear transformation method was used for markers displacement computation in x, y, z axes and other geometric and kinematics parameters of mandibiular movement. This method was used for camera calibration and the marker position computation and it is involved in APAS software. The outcome of data evaluation is comparison of lower jaw motion rate in x, y and z direction, its amplitude and most frequently observed direction of lover jaw movement.

Discussion and conclusion

The statistical analysis of this experiment is being evaluated at present time within one patient and within statistical sample of 55 patients. The analysis of contact pressures and bite forces during masticating will be also made concurrently with three dimensional motion analysis in the future.

Acknowledgement

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Friday 12th September 2003 8:30–9:10
Lecture 2

Friday 12th September 2003 9:10–10:34
Oral Session 4: Cerebral Palsy 2

Comprehensive treatment of ambulatory children with diplegia: an outcome assessment

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Introduction

With the evolution of gait analysis the so-called ''single event multilevel surgery'' has become a well established treatment option for children with cerebral palsy (CP). In addition some centers perform a selective dorsal rhizotomy for spasticity treatment in qualifying patients [Gage JR and Novacheck TF, 2001]. To assess the safety and efficacy of this treatment approach, appropriate technical and functional outcome measures must be evaluated [Butler C, et al., 1999.]. This study shows that significant improvements in gait, energy consumption and overall function can be achieved through the use of gait analysis, orthopaedic surgery and spasticity reduction.

Materials and method

A retrospective study design was used to evaluate the outcome for ambulatory spastic diplegic children. The cohort of patients were selected from the existing database at the Motion Analysis Laboratory. Subjects underwent comprehensive pre-operative and post-operative 3-D gait analysis no more than 18 months before, and between 8 and 24 months after the date of the surgical intervention. The patients were categorized into three treatment groups: orthopaedic surgery only (ORTHO), orthopaedic surgery and selective dorsal rhizotomy (ORTHO+RHIZO) or selective dorsal rhizotomy only (RHIZO). The order of surgery for the combined intervention group was not used as a selection criteria or a grouping variable. Outcome assessment was based on gait pathology using 16 clinically relevant kinematic parameters (normalcy index), gait efficiency (steady-state oxygen consumption rate) and functional data from patient report surveys (functional assessment questionnaire-FAQ). Paired t-tests were performed to assess the statistical significance of pre-post changes in the outcome measures.

Results

One hundred and thirty-five patients meeting the inclusion criteria were identified from the existing clinical database from the Motion Analysis Laboratory. Improvements were seen in all outcome measures. A significant majority of subjects (77%) improved on a predominance of outcome measures. Only 8% of subjects worsened. 82% showed an improved (decreased) NI. Pre-post improvements in normalized oxygen consumption rate were found to be statistically significant for the entire sample of subjects (14% decrease). A modest improvement in the FAQ 10-level walking score was observed for the entire study population (+0.4 levels). All treatment groups demonstrated net addition of higher-level skills post-operatively (Figs. 1–3).

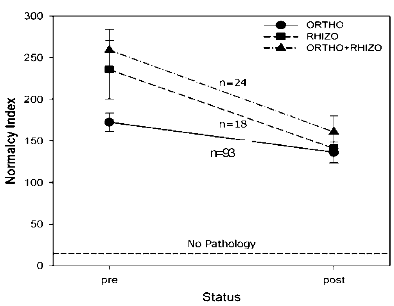

Figure 1. Improvement in overall gait pathology as measured by the normalcy index. All changes significant at the p < 0.05 level.

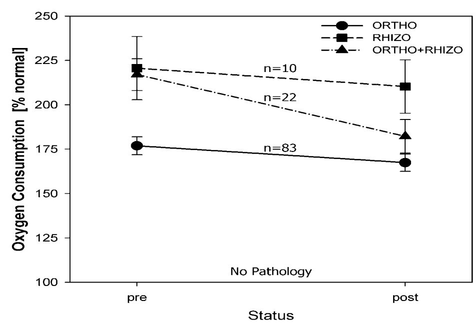

Figure 2. Improvement in overall gait efficiency as measured by normalized oxygen consumption. All changes significant at the p < 0.05 level.

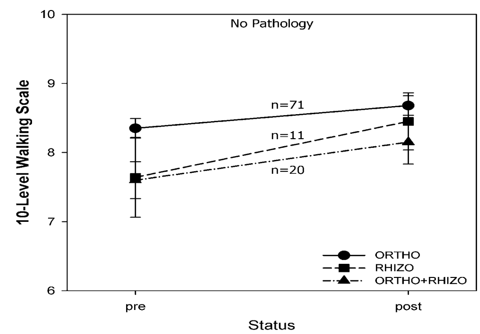

Figure 3. Improvement in community function as measured by the FAQ 10-level walking scale. All changes significant at the p < 0.05 level.

Discussion

This retrospective study shows that a comprehensive approach to diagnosis, treatment planning and surgery results in significant improvements in gait (NI), energy efficiency (O_2) and overall function (FAQ) of ambulatory children with CP. Improvements were seen for each surgery regimen and measure. Generalization of findings to a wider population must be done with caution. While this retrospective design is not ideal, there are no obvious sources of selection bias. In addition to a comprehensive treatment plan for ambulatory children with CP, this study demonstrates the strength of a comprehensive approach to outcome assessment that includes quantitative gait analysis as well as functional gait measures.

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Knee kinematics in spastic diplegic children before and after multilevel surgery

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Introduction

Quantified gait analysis permits an objective evaluation of pre and postoperative outcomes (1,3). This study was based on the evaluation of knee kinematics and aimed to present the results and the limitations of our method of treatment.

Patients and methods

The study involved 19 consecutive spastic diplegic children who were ambulatory (14 boys, 5 girls: mean age 10 years, range 5–16 years) admitted to the Physical Medicine and Rehabilitation Department between 1995 and 2002 for postoperative rehabilitation after a one-stage multilevel surgical treatment.

Inclusion criteria: to have a quantified gait analysis pre-operative and at least 1 year after the surgery. Each patient had pre-operative evaluation, surgery and physical therapy done by the same teams according to standardized protocols.

Exclusion criteria: previous neuro-orthopaedic surgical procedures or botulinum toxin type A injections of lower limbs.

Analysis of results: angular measurements and qualitative analysis of curves.

Evaluation criteria: knee flexion at initial contact (IC), knee flexion at loading response (LR), maximal knee extension in stance, maximal knee flexion in swing, knee flexion amplitude and flexion slope.

Thirty-eight curves were analysed. All the patients underwent multilevel surgery (mean 10 procedures per patient, range 5–17). The procedures included rectus tenotomy or transfer (38), hamstrings lengthenings (37), patellar advancements or releases (8) femoral derotation osteotomies (15), tibial derotation osteotomies (8), Dwyer 3, Evans 7, psoas lengthenings (l7), gastrocnemeus lengthenings (21), soleus lengthenings (1), tibialis anterior hemi-transfer (6), peroneus longus lengthenings (3).

Results

Knee flexion at initial contact: all knees showed an increased flexion at IC. Curves that averaged 50° of flexion at IC decreased to a mean of 20° after surgery. Eight knees had more than 50° of flexion at IC and the level of improvement was not enough to correct the forefoot weight-bearing.

Knee flexion at loading response: 19 knees improved, 1 deteriorated, 2 remained stable and flexion was absent in 16.

We did not find a significant relation between the changes in flexion at IC and at LR.

Knee extension at mid-stance: 5 knees were normal and did not change (5–7°), 27 showed a lack of extension. Changes regarding knee flexion were: twenty knees with a mean flexion below 40° improved to a mean of 11 degrees and 7 knees with flexion above 40 degrees had analytical improvement (mean 56° to mean 27°), but it was insufficient to correct crouch gait. Six knees showed hyperextension, 4 became normal and 2 did not change.

Knee flexion in swing: a maximal flexion of 55° was considered sufficient. Thirteen knees with insufficient flexion improved 8° in average. Those knees with flexion less that 40degrees maintained a stiff knee gait (5 knees: mean 30° to mean 38°). Twenty-five knees with sufficient flexion lost 14° in average, but remained close to 55°.

Total flexion amplitude: improved in 24 knees, remained abnormal or stable in 9 knees, and deteriorated in 5 knees.

Slope: 11 knees were normal and did not change, 21 improved, 3 remained abnormal and 3 deteriorated.

Slope's continuity: 24 knees were normal and did not change. Nine improved, 2 remained abnormal and 3 deteriorated.

Discussion

Preoperative knee flexion of more than 50° at initial contact, at least 40° at mid-stance and less than 40° during swing, correlated with poor postoperative functional results. Clinically, this description corresponds to a population using a kaye-walker with limited perimeter. However, improvement of slope and its continuity can explain our clinical observations of easy limb advancement in spite of our limited results on maximal flexion (2). The limited angular variation (2–4°) in excessive extension at mid-stance implies that the study of torques is a more reliable criterion.

Conclusions

One stage multilevel surgery followed by a rehabilitation program leads to good results when knee flexion at initial contact is less than 50°, less than 40° in mid-stance and more than 40° in swing. We suggest that these values constitute the objective of rehabilitation management of spastic diplegic child before surgical treatment

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Hip extensor muscle activation during crouch gait in spastic diplegia

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Introduction

Surface electromyography (sEMG) is able to provide information regarding the relative timing of muscles during motion. There is little published research on the sEMG activity of the hip musculature in normally-developing children or in children with cerebral palsy. Gotteschalk et al. (1989) proposed that gluteus medius (GMed) and minimus in healthy adults act to stabilise the femoral head in the acetabulum during stance. Gluteus maximus (GMax), primarily a hip extensor, is reported to be active for a brief period around initial contact (Sutherland et al., 1973; Tokuhiro et al., 1985). Perry and Newsam (1991) found the hamstrings to be active for a prolonged period during stance in children with spastic diplegic cerebral palsy (SDCP). We hypothesised that gluteal muscle activation would be prolonged during stance in children with SDCP walking in a crouch pattern, when compared to a normally developing population.

Materials and methods

A group of 5 children with SDCP (mean age: 9.4 years, range 6–16) undergoing routine gait analysis, who walked with greater than 15° of knee flexion (mean: 38.8°), and 5 normally developing (ND) children (mean age: 7.4 years, range 4–12), were invited to participate in this study. sEMG data from both groups was collected from barefoot walking trials using integrated sensors (MA-317 Motion Lab Systems, Baton Rouge, USA) at a sampling rate of 1080 Hz/s. Electrodes were positioned on the GMax, GMed and medial hamstring muscle group (Ha) following SENIAM recommendations (Hermens, 1999). We integrated the smoothed rectified envelope (SRE) of the signal over the stance period. We found the duration from initial contact to a point in stance where half the area under the curve was represented (we called this the integrated half-width, IHW). We measured IHW for each muscle under test. Differences between the subject groups were assessed using a Student's t-test (significance value of 0.05).

Results

There was no significant difference in IHW for GMax ($p = 0.271$), GMed ($p = 0.210$) and Ha ($p = 0.147$) between the two groups.

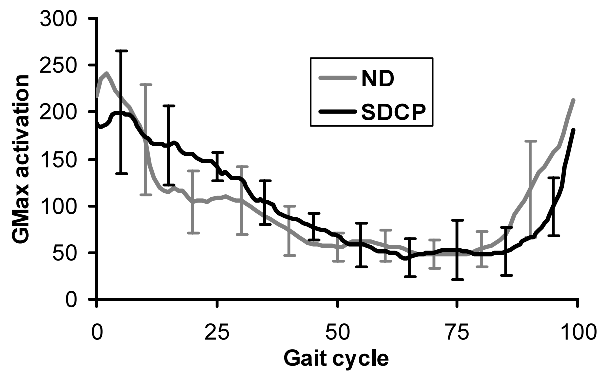

Figure: SRE of GMax in ND and SDCP groups expressed as a % of the mean signal ± 1SD over the gait cycle.

Discussion and conclusion

Our results showed that there was little difference in the activation patterns of GMax, GMed and Ha between the two groups although the power of the study was limited due to the small number of subjects. Prolonged GMax activation in ND group is not a feature of adult gait (Tokuhiro et al., 1985). Our findings contradict those of Sutherland et al. (1988) who reported GMax activation in children to be restricted to the first 15% of stance, irrespective of age. Perry and Newman (1991) observed somewhat variable but prolonged Ha activation in children with SDCP. We found no significant difference between the timing of the Ha EMG signal between ND and SDCP children. We normalised our EMG data to the stance period of the gait cycle, whereas typically activation timing is reported as a percentage of the gait cycle. When stance phase is prolonged, as we found the SDCP group, the timing of muscle activation in stance may be overestimated by normalising to the gait cycle. Our results suggest that the gluteal muscles contribute to hip extension throughout stance in children with SDCP walking in a crouch gait pattern. Strengthening of Gmax may be advocated for children with SDCP, to assist in extending hips in crouch gait.

Acknowledgements

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Muscle strength and passive and dynamic hip rotation in cerebral palsy: differences between right and left legs

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Introduction

The exact mechanisms for the often excessive internal hip rotation in children with cerebral palsy are still not well understood. Although authors have attempted to identify the abnormal muscle activity responsible for increased internal rotation in gait, the role of muscle weakness has not been investigated in much detail. The aim of this retrospective study was to investigate the linear relationship between hip rotation in gait (IRgait) and the strength of the hip extensors and abductors, in addition to passive measures of hip rotation.

Materials and methods

Kinematic and physical examination data collected during routine clinical gait analysis of 101 patients with diplegic cerebral palsy were studied retrospectively. After initial analysis the patients were divided into two groups: those who were clearly more affected on the left side (group L, $n = 41$) and those on the right (group R, $n = 38$). The remaining 22 patients were not clearly asymmetric. Hip internal rotation data of any limb for which the range of knee ab/adduction, averaged over at least three trials, exceeded 13° were discarded from the analysis. This left 18 right legs and 22 left legs in Group R and 16 right legs and 20 left legs for Group L for evaluation. The physical examination data analysed included the manual estimation of muscle strength and the limits of passive hip rotation. Left and right sides were analysed separately for both groups. A t-test was used to evaluate the differences between the left and right side, with $p < 0.05$ as level of significance.

Results

Table
Average physical examination and kinematic parameters for group R and L

	Group R			Group L		
	Right mean (std)	Left mean (std)	t-test p-value	Right mean (std)	Left mean (std)	t-test p-value
Peak internal rotation in gait (°)	16.7# (10.0)	6.4* (9.2)	0.000	7.7 (11.6)	9.8# (9.7)	0.479
Mean pelvic rotation (°)	−1.5(5.4)	1.5 (5.3)	0.092	4.2 (6.7)	−3.9* (6.1)	0.000
Limit of passive internal rotation (°)	59.9# (13.2)	62.2 (15.0)	0.141	50.5 (12.5)	66.5#* (12.0)	0.000
Limit of passive external rotation (°)	24.1 (14.3)	29.6* (14.0)	0.004	33.7 (13.3)	28.3* (13.9)	0.006

*Difference between left and right $p < 0.05$. #Difference between the most affected legs in groups R and L $p < 0.05$.

Table
Coefficient of determination (r^2) between IRgait (abd–add knee < 13°) and passive measures

	Group R		Group L	
	Right ($n = 18$)	Left ($n = 22$)	Right ($n = 16$)	Left ($n = 20$)
Limit of passive internal rotation (°)	0.099	0.000	0.338	0.065
Limit of passive external rotation (°)	0.275	0.060	0.624	0.345
Gluteus maximus strength	0.009	0.004	0.000	0.207
Abductor strength	0.001	0.179	0.008	0.382

Discussion

This study showed that both the average values of the passive measures related to hip rotation and their strength of correlation with IRgait, depended on the side and which side was more affected. For example, IRgait was significantly higher on the right in group R than on the left in group L, while group L was more retracted on the left. Further, the limit of passive internal rotation on the left in group L was significantly higher than on the right in group R. Muscle strength only showed values of $r^2 > 0.20$ with IRgait for the left leg in group L. In general, values for r^2 were higher in group L than in group R. One possible explanation for these differences may lie in the pre/postnatal position of the legs, often more windswept to the right, i.e. more adducted and internal rotated on the left (Fulford and Brown, 1976).

These results could be of importance when deciding on management of excessive internal rotation of the hip in gait.

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An assessment of the outcome of distal rectus transfer surgery in cerebral palsy

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Introduction

Distal rectus femoris (RF) transfer is commonly performed in conjunction with hamstring lengthening in ambulatory children with spastic cerebral palsy (CP) (Gage et al., 1987). Previous studies on the outcome of RF transfers have reported improvements in sagittal plane knee range of motion (e.g. Ounpuu et al., 1993). A recent study on the effects of hamstring lengthenings without RF transfers analysed the dimensionless gait temporal parameters which were normalised for body height (van der Linden et al., 2003). We have extended this analysis to compare hamstring lengthening with and without rectus transfer from two centres who use a similar approach in planning multilevel surgery based on gait analysis. The data on hamstring lengthening and rectus transfers from one centre were compared with the data on hamstring lengthening without rectus transfer from the other centre.

Materials and method

A retrospective study on the outcomes of multilevel surgery in 36 diplegic CP children were compared between two centres. Results from three dimensional gait analysis data taken within 1 year before surgery and approximately 1 year post surgery (range: 10–19 months) were reviewed. Gait analyses were performed for barefoot walking at self-selected walking speeds. All children had undergone hamstring lengthenings; 21 children (41 limbs), average age 11.8 years (range: 6.7–16.8), also had a distal rectus femoris (RF) transfer and were compared to 15 children (27 limbs), average age 11.8 years (range: 6.9–21.1), who had no surgery to RF. Other soft tissue and bony procedures had also been performed. Kinematic and temporal parameters for pre and post operative data were compared for each group using a paired t-test where a p-value of 0.05 was used as the threshold for significance. Temporal parameters were normalised for height to account for growth changes (Hof, 1996).

Results

Table
Pre and post operative gait parameters for the two groups of CP children (* indicates a significant change).

Gait parameter	Rectus transfer group ($n = 41$ legs)			No rectus transfer ($n = 27$ legs)		
	Pre	Post	p-value	Pre	Post	p-value
Max knee extension stance (°) (flex. +ve)	25(20)	16(10)	0.0009*	36(14)	23(13)	< 0.001*
Peak knee flexion in swing (°)	58(12)	57(8)	0.26	65(11)	55(9)	< 0.001*
Knee ROM (°)	33(15)	40(10)	0.0004*	29(9)	32(10)	0.29
Hip ROM (°)	45(10)	40(8)	0.0006	37(9)	38(8)	0.70
Time of peak knee flexion (%gait cycle)	84(5)	81(5)	< 0.001*	83(5)	83(6)	0.61
Peak knee ang. Vel. In swing (°/%gc)	150(72)	183(41)	< 0.001*	145(55)	164(59)	0.21
Peak hip ang. Vel. in swing (°/%gc)	183(41)	177(36)	0.28	170(43)	183(47)	0.28
Absolute speed (ms^{-1})	0.96(0.27)	0.82(0.32)	0.14	0.76(0.27)	0.73(0.26)	0.80
Absolute stride length (m)	0.91(0.18)	0.89(0.01)	0.67	0.78(0.21)	0.81(0.20)	0.69
Dimensionless speed	0.25(0.07)	0.22(0.08)	0.049*	0.21(0.07)	0.20(0.07)	0.63
Dimensionless stride length	0.66(0.14)	0.60(0.13)	0.102	0.59(0.14)	0.59(0.10)	0.92

Discussion and conclusion

The results (Table) show that in both groups knee extension in stance improved as a result of hamstring lengthening. The peak knee flexion reduced in both groups, though not significantly in the RF transfer group. No change in knee flexion in the RF transfer group is consistent with previous results (Ounpuu et al., 1993). The range of knee flexion/extension improved in both groups but only significantly in the RF transfer group. This corresponds to the greater improvement in the rate of knee flexion in swing and earlier peak knee flexion. Despite improvements in sagittal knee kinematics in the RF group, this group also had a significant reduction in normalised walking speed compared to the non-RF group, where the walking speed was unchanged. The reasons for this reduced walking speed and the speed effects on the kinematics warrants further study.

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Cerebral palsy: when will fixed ankle foot orthoses improve gait?

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Introduction

Fixed ankle foot orthoses (AFOs) are commonly prescribed for children with cerebral palsy but do not always produce the desired gait improvement: toe contact may be eliminated but knee hyperextension or excess flexion at midstance may persist, even if attempts are made to optimise the ground reaction vector (GRV) alignment at the knee using the methods described by Butler and Nene (1991) and Meadows (1995). A review was undertaken of children previously referred for optimisation of knee extending forces to identify criteria indicative of improvement and to define those children unlikely to benefit.

Materials and methods

Twenty-two children, mean age 7 years 3 months (range 4 years 2 months to 10 years 7 months), were selected showing a range of barefoot gait problems. All were able to walk independently without aids and all showed the common feature of an extending GRV at the knee occurring during the stance phase of gait associated with either knee flexion or full extension/hyperextension. Clinical information noted included passive joint movement at the hip, knee and ankle at the time of video recording. Video based sagittal plane kinematic and kinetic data was available both barefoot and with fixed AFOs with best-attempted GRV optimisation. Data was taken from one limb of each child, randomly selected if AFOs were used bilaterally. Knee angles, moments and moment arms were calculated from manually digitised stance phase video, using a previously described and validated method (Butler et al 1992). This enabled a clinical judgement to be made on the efficacy of GRV optimisation, dividing the children into two groups of 'tuned' or 'not tuned' with AFO. Maximum barefoot knee flexion in the first third of stance and minimum knee flexion in the second third of stance was determined for each child and analysed using a scatter plot to determine any differentiation between the two groups.

Results

Eight of the 22 limbs 'tuned' using the criteria of normal or near normal knee kinematics and kinetics. Seven of these children had spastic cerebral palsy while the remaining child showed an additional element of dyskinesia. There was no obvious difference in physical parameters between the two groups of 'tuned' and 'not tuned' although it was noted that no child with a hip flexion contracture in excess of 15° 'tuned'. Those who 'tuned' showed the identifying sharp increase in knee extending moment and moment arm around mid-stance when barefoot (Butler and Nene, 1991). Scatter plot analysis showed a clear distinction between the two groups based solely on knee kinematics. There was a strong association with the gait benefits of 'tuning' in those who showed flexion of no more than 20° in the first third of stance combined with movement towards extension in the second third of stance to a minimum of 10° flexion or less.

Discussion and conclusion

This study has confirmed that not all gait parameters can be improved in some children even if careful attention is paid to GRV alignment as well as to fit of the device. For those who show most improvement by 'tuning' there are potential long-term benefits (Butler et al., 1992) and thus identification of these children is critical. This study has provided guidelines to assist in identifying these children by simple kinematic analysis, which could be carried out in the community with subsequent referral to a Gait Laboratory for AFO tuning. For those children less likely to benefit by attempted force optimisation, fixed AFOs may continue to have a role in correction of deformity but realistic treatment goals with respect to the role and contribution of orthoses in walking can now be defined.

Acknowledgments

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Movement analysis in early diagnosis of a developing spasticity in newborns with infantile cerebral palsy

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Summary

In this paper preliminary results are presented for a procedure which aims at the objective and quantitative evaluation of spontaneous motor activity in newborns for the early diagnosis of a developing spasticity. Kinematic data are recorded by a 3-dimensional movement analysis system. Several characteristic normal parameters are defined.

Conclusion

Utilising 3D motion analysis in newborns with infantile cerebral palsy, an objective interpretation of spontaneous motor activity seems possible. Essential parameters for the evaluation of motion have been defined. Data of a norm collective and several pathologic cases have been acquired using the described methodology.

Introduction

The early diagnosis of a developing spasticity in preterm newborns with infantile cerebral palsy is based at present on the visual evaluation by the treating physician. The diagnosis is based on observations of the spontaneous motor activity of the baby. Reason for the application of this procedure, which is characterized by the subjective impressions of the examiner, is the absence of a methodology for the objective evaluation of spontaneous motor activity. In the institute for biomedical technologies therefore a procedure for the objective evaluation of the spontaneous motor activity in babies which will develop infantile cerebral palsy has been devised.

Patients and methods

The pathologic group consists of 6 preterm newborns with cerebral hemorrhage. The norm collective consists of 13 normal newborns. Measurements are carried out during the first, the third and the fifth month of life, calculated with respect to the target date of delivery. The spontaneous motor movement is recorded three-dimensionally with the baby lying on its back. Infra-red light reflecting markers are attached to the respective body segments (Fig. 1). From the retrieved marker trajectories different characteristics of the movement can be calculated using a biomechanical rigid body model consisting of segments for head, trunk, arms, legs and hands. Range of movement, speed and acceleration of individual body segments or the change of joint angles between two segments are major indicators for the quality of motor activity. Another important factor is the correlation of these parameters between left and right as well as upper and lower part of the body.

Fig 1: Marker based motion analysis of newborns for the evaluation of spontaneous motor activity

Results and discussion

Preliminary results show, that a number of parameters extracted from motion analysis can be used to objectively evaluate the baby's movement. As one example, the acceleration for the left and right foot of a healthy baby during spontaneous motor movements reveals points in time with high acceleration that are differing for each foot. Thus verifying the ability of the baby to independently control its two feet. In contrast, in affected children, this acceleration pattern can not be observed. On the basis of expert knowledge of treating physicians the characteristic parameters are to be extracted automatically in a further step from the data retrieved. In this way a second independent opinion is offered to the treating physician, which is not based on subjective impressions, but on a quantitative evaluation of the movement.

Friday 12th September 2003 11:04–11:52
Oral Session 5: Muscle

Efficiency of work production by spastic muscles

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Introduction

The energetic cost of locomotion is markedly increased in post-stroke hemiparetic spastic patients. This increase must be related to an augmentation of the mechanical work done by the muscle or to a reduction of the efficiency of work production by the muscle (η). A decreased η is expected because of excessive muscle co-contractions or an increase in muscle tone, for instance. Efficiency has rarely been measured in spastic patients and only during walking or bicycling where normal and spastic limbs were engaged together. The aim of the present study is to compare η when either the spastic or the healthy limb realize mechanical work.

Materials and methods

Sixteen chronic post-stroke hemiparetic and spastic patients (58.5 ± 13.6 years) were recruited from our outpatient rehabilitation unit. Neurological impairments were objectified by Ashworth scale and Stroke Impairment Assessment Set. Sixteen healthy subjects (50.9 ± 18.5 years) were recruited as controls. All subjects were submitted to a submaximal stepwise exercise testing on a bicycle ergometer (Monark 818E). They seated on a chair at the rear of the ergometer to avoid effort related to posture difficulty. They pedalled with only one leg at a constant frequency. Energetic expenditure was computed from oxygen consumption (Quark b^2). Each workload was maintained until a steady state of O_2 consumption was reached and maintained for at least 2 min with a respiratory quotient less than 1. Electrical activity of agonist muscles (tibialis anterior-lateral gastrocnemius, rectus femoris-lateral hamstring) was recorded (Telemg-BTS) and co-activation was defined as the percentage of pedalling cycle when both agonist and antagonist muscles were active. Both legs were evaluated successively in patients and only one leg was examined in controls. The efficiency was calculated as the ratio between the work done on the ergometer and the net energetic expenditure (oxygen consumption above resting value).

The elastic and viscous stiffness of the ankle plantar flexor muscles was recorded following the method described by Detrembleur (2000).

Multiple linear regression analysis was used to study the influence of co-contractions, stiffness of the ankle plantar flexor muscles on energetic expenditure and η. Analysis of variance was used to study difference of co-contractions, stiffness of the ankle plantar flexor muscles between groups.

Results

The patients working capacities were very low (< 40 W). The energy expenditure increased linearly as a function of work intensity. There was no statistically significant effect of muscle stiffness and co-contractions on energy expenditure. The efficiency was not statistically different between the three groups ($p = 0.095$). The co-contractions between TA and LG were statistically greater in patients hemiparetic legs than in the healthy subject leg ($p < 0.05$), and in patients normal legs than in healthy subjects legs ($p < 0.05$), but not between the normal and the paretic limb of patients ($p > 0.05$). There was no statistically significant difference between the three groups for the co-contractions of the RF and LH ($p = 0.344$). The ankle flexor muscle stiffness was statistically greater in hemiparetic limbs than in normal subjects ($p < 0.05$).

Discussion and conclusions

The efficiency of work production by leg muscles of our spastic subjects was normal, despite significant neurological impairments. This confirms our previous results obtained during walking where the increase of the mechanical work explained the increase of energy expenditure, while the efficiency of work production by the muscle was normal (Detrembleur et al., in press).

References

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Electrical stimulation for strengthening quadriceps femoris in children with cerebral palsy

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Introduction

Essentially two variations of electrical stimulation are utilised for strengthening and improving motor function in the paediatric cerebral palsy population: neuromuscular electrical stimulation (NMES) and therapetic (or threshold) electrical stimulation (TES). NMES is the application of an electrical current of sufficient intensity to elicit muscle contraction whereas TES is a low level, subcontraction electrical stimulus applied at home during sleep (Pape, 1997). In order to determine the efficacy of both forms of stimulation a randomised placebo controlled trial was carried out to investigate the effects of TES and NMES in strengthening the quadripceps femoris in children with cerebral palsy.

Materials and method

Sixty children with bilateral cerebral palsy were randomised by minimisation on the basis of age, sex and quadripceps strength into one of three groups; NMES ($n = 18$), applied for 1 h per day at maximum tolerable intensities; TES ($n = 20$), applied at a threshold intensity for 8 h at night; or placebo ($n = 22$), applied for 8 h at night. Electrode placement on the quadriceps muscles and treatment parameters were standardised in the TES and NMES groups; frequency = 35 Hz, pulse duration = 300 μs, on time = 5 s, off time = 12 s. Treatment was carried out 5 days per week for 16 weeks and compliance was recorded on the unit.

Peak torque (PT) of the quadriceps, the Gross Motor Function Measure (GMFM) and the Lifestyle Assessment Questionnaire (LAQ-CP) (Mackie et al., 1998) were used as outcome measures, and recorded by a blinded assessor at baseline, end of treatment and 6 weeks follow-up. An exit questionnaire was completed by parents at the end of the trial.

Results

While 6 children withdrew from treatment during the trial, an 'intention to treat' analysis was carried out on all 60 subjects using non-parametric statistics. Results showed no statistically significant differences between the groups over time. Average compliance was 67% in the NMES group and 38% in the TES group. Information with regards to treatment satisfaction and further treatment was obtained from 49 completed exit questionnaires and is summarised in the Table.

Table
Summary of 2 responses from the exit questionnaire

Groups	Were you satisfied with the treatment given?			Would be happy for your child to receive this form of Rx again?	
	Not satisfied (%)	Satisfied (%)	Very satisfied (%)	Yes (%)	No (%)
NMES ($n = 16$)	0	56.3	43.8	93.8	6.3
TES ($n = 15$)	6.7	40.0	53.3	86.7	13.3
Placebo ($n = 18$)	5.6	66.7	27.8	83.3	16.7

Discussion

Despite good reports of satisfaction from parents, a lack of significant treatment effect was demonstrated. However some trends in the data, which showed improvements in the mean and median scores of strength and function, suggest that further study with greater subject numbers is warranted.

Acknowledgements

This study was funded by the Wellcome Trust (Project Grant 061312).

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The accuracy of a practicable EMG-force model to estimate knee muscle moments in four functional movements

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Introduction

Quantitative knowledge of co-contraction during functional movements, would be of great clinical importance. It may serve to evaluate therapeutic interventions, e.g. to assess the amount of spasticity [1] or to measure active stability about the knee in ACL-deficient patients [e.g. 2,4]. Co-contraction does not follow straightforward from a mechanical analysis of movement, but requires an estimation of the contribution of both agonist and antagonist muscles to the net joint moment is. This seems possible with surface EMG, so the accuracy of this source of information should be investigated. In an earlier study, a practicable model of EMG to force processing, was suitable to assess the amount of active stabilization of the knee joint in ACL deficient patients in jumping [2]. Since no independent standard method exists to assess co-contraction, the accuracy of EMG-to-force processing should be evaluated at the level of the net joint moment. In this study, in addition to vertical jumping, the accuracy of EMG-to-force processing for three other movements: walking, ascending and hopping, are evaluated.

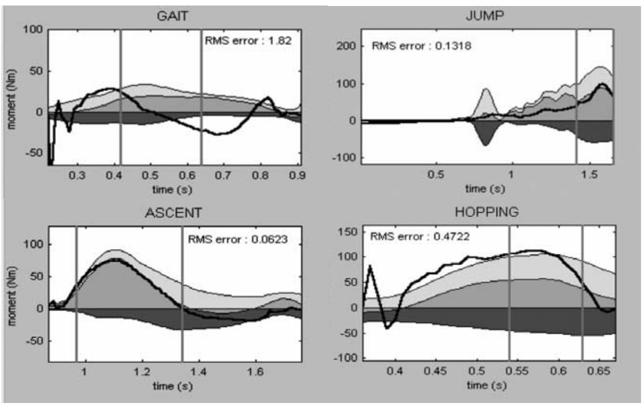
Methods

Thirty-nine (ACL-deficient and healthy) subjects (9 female; 30 male; age: 32.9 ± 6.8 years; height 180.4 ± 7.9; weight 76.8 ± 10.1) participated in this study. All subjects completed the following experimental protocol after a warming up:

I) Calibration measurements for EMG-to-force model: maximal knee extension and flexion contraction at different constant velocities on an isokinetic dynamometer. Knee angle, exerted moment and surface EMG of five leg muscles (VM, VL, RF, BF, ST) were simultaneously recorded. II) Functional measurements of the following movements: walking, hopping, jumping and ascending one step. For each trial, ground reaction forces, kinematics of the movement by means of a 3D opto-electric system (Optotrak 3020) and surface EMG of five leg muscles were recorded. For both parts of the experiment, EMG was processed into its linear envelope. To calibrate the EMG to force, EMG envelopes were linearly scaled to the isokinetic measured joint moments and fitted as a function of joint angle and angular velocity for knee flexors and knee-extensors independently [2]. Of the four functional movements, net knee moment was calculated in two ways: i) using standard inverse dynamics, the net joint moment about the knee (M_K) was calculated for reference. ii) application of the EMG-to-force model with EMG and knee joint kinematics as input resulted in the moment contribution for flexors and extensors, its difference being the estimated net knee moment (M_M) The accuracy of the estimation of knee moment derived with the EMG-to-force model was evaluated using RMS error values [3] of the difference in net joint moment over the concentric knee extension phase in each movement.

Results

Fig. 1 shows the net knee moments M_K and M_M (y-axis) for one subject during all four different movements. In each plot, the black line shows M_K; the dark gray area is the moment of flexor group; the light gray area of the extensor group; summation of the latter two results in $M_{M.}$ (the mid-gray area). The vertical lines indicate the concentric phase of knee extension. For this part of the movement, RMS errors were calculated [3], indicated in the plot for this subject. Averaged for all subjects, mean RMS values for vertical jump: 0.11 ± 0.03 (range 0.05–0.18); for ascending 0.12 ± 0.05 (range 0.06–0.24). For hopping and gait, RMS errors showed large variances with high values (range from 0.21 to 1.54 for hopping and 0.55 to 2.91 for gait).



Discussion

The first analysis showed that for jumping and ascending a stair, the model works quite well. However, for gait and hopping, the muscle moments M_M are largely underestimated compared to M_K derived with the inverse dynamic model. This could not be ascribed to a different velocity, since for ascending and walking, a similar angular velocity is present, while the two other movements are quite explosive. The common factor in gait and hopping to explain the bad performance is the small range of angular joint changes. Apparently, the present model with its calibration procedure is suitable to estimate individual muscle moments from EMG, only when sufficient knee joint motion is present, as is the case during jumping and ascending a stair. For generalization of a practicable EMG-to-force model to be applied in clinical practice, e.g. in quantifying co-contraction in CP children during gait, further study is required to find the most optimal calibration measurements for this purpose. In this process, it should be realized that aim of looking for such a model is not fully determined by its accuracy to replace inverse dynamics to calculate the net joint moment. The clinical aim is find indices of co-contraction by the estimations of antagonistic contributions to a net joint moment that are sensitive to assess clinically relevant changes.

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Architecture of the medial gastrocnemius in spastic hemiplegic cerebral palsy

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Introduction

Little is known about the physical nature of muscle deformity in spastic cerebral palsy but recent work (Shortland *et al.* 2002) has cast some doubt on the widespread belief that contracture is secondary to fibre shortness (O'Dwyer *et al.* 1989). Using 2D ultrasound imaging, Shortland and co-workers demonstrated that there was little difference between the length of medial gastrocnemius (MG) fascicles in children with spastic diplegia and those of normally-developing children. They speculated that contracture of the medial MG was caused primarily by a reduction in the length of the aponeurosis (internal tendons) secondary to a failure of muscle fibres to grow in diameter. It is possible that muscle deformities in children with spastic hemiplegic cerebral palsy (SHCP) are different in structure, partly because these children load their unaffected limb preferentially. Here, we use a 3D ultrasound technique to measure fascicle length and muscle belly length in the medial gastrocnemius of a small number of children with SHCP on their affected and unaffected sides. Our hypothesis is that fascicle- and muscle belly-lengths of the MG are shorter on the affected side.

Methods

Five children with SHCP (6–11 years) and limited passive dorsiflexion range with the knee extended on their affected side (-10 to $+5°$; mean $0°$) were invited to participate in this study. These children had not undergone previous lower limb surgery. We used a 3D ultrasound system consisting of standard B-mode scanner with a 7.5 MHz linear array probe and a magnetic-sensor based unit (Tomtec Gmbh, Germany) that can track the position and orientation of the ultrasound probe and interpolate a stream of 2D images to form a structured volumetric image. The child was invited to lay prone on a wooden treatment couch with their ankles overhanging the plinth. The angle of maximum dorsiflexion was measured by manual goniometry. A nominal leg length (lateral malleolus to fibular head) was measured with a dresser's tape. Longitudinal scans of the medial gastrocnemius were performed with the probe held perpendicular to the direction of the scan. A volume of interest was prescribed within the 3D reconstructed ultrasound data that contained the MG. The length of a fascicle within the central portion of the muscle was measured using proprietory software. The length of the muscle belly from its most distal fibre insertion to the most superficial location on the medial femoral condyle was also obtained. Muscle- and fascicle- lengths were normalised to nominal leg length. Test of significance between the affected and unaffected limbs were made using paired t-tests.

Results

At maximum passive dorsiflexion, the medial gastrocnemius muscle belly length was shorter on the affected side in all cases ($p < 0.05$) by a mean of 1.2 cm. There was no difference between the length of muscle fascicles in the affected and unaffected limb ($p = 0.717$).

Discussion and conclusion

Fascicle lengths of the MG were not significantly different on the affected and unaffected sides, and similar to data reported previously for normally-developing children and children with spastic diplegic CP (Shortland *et al.* 2002). Muscle belly lengths were significantly smaller in the affected limb in spite of the mild deformities recorded clinically. Our results suggest that plantarflexion contractures in SHCP are not caused by fibre shortness.

Derived muscle dimensions, such as the ones reported here, may be very useful to the clinician who wishes to assess muscle deformity and mechanical capacity before deciding upon an intervention, such as musculotendinous lengthening, splinting or tendon transfers. What is more, the effect of focal interventions on muscle morphology could be evaluated.

Acknowledgements
Nicola Fry was supported by a grant from the Wishbone Trust. The authors gratefully acknowledge the contributions of the One Small Step Charitable Trust and the Charitable Foundation of Guy's & St. Thomas' Trust for the providing funds to purchase our ultrasound system.

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Friday 12th September 2003 11:52–13:04
Oral Session 6: Technology

A simple tool for the identification of virtual anatomical landmarks during a static subject calibration

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Introduction

A common technique for quantitative movement analysis in a clinical setting involves the use of a camera-based motion measurement system and reflective markers placed on the patient's skin. This requires that the relationship between the markers placed on the skin and the underlying (segmentally fixed) anatomical coordinate axes be well established. Cappozzo (1990) describes the use of a pointer device to identify the additional anatomical landmarks required to accomplish this "anatomical axes calibration." In his technique, the tip of a straight rod with two markers mounted along the rod some fixed distance apart is held on an anatomical landmark while marker position data are captured. The fundamental disadvantage of this technique is that the clinician must hold the tip of the pointer on the landmark of interest during the entire static data capture. Consequently, separate static data capture trials are required for each landmark, thereby increasing the time required for data collection and reconstruction. The goal of the project described in this abstract was to develop a tool and technique that exploits the strengths of the pointer technique while addressing this shortcoming.

Method and results

The device shown in Fig. 1 represents an extension of Cappozzo's pointer technique. The two markers A and B on the pointer allow for the computation of a vector (the unit vector from A to B combined with length L) that points from marker B to the anatomical landmark of interest. Note also that the design of the pointer is telescopic such that the distance D between markers A and B can vary.

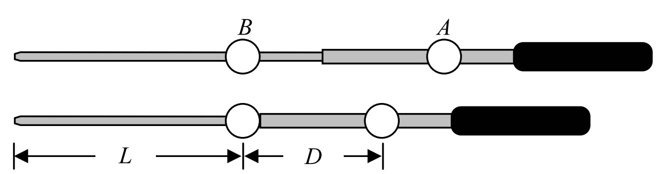

Figure 1. Dynamic Pointer

That is, as the pointer tip is pressed against a landmark, D decreases. At all other times, a spring in the pointer handle keeps the pointer extended and D maximized. The utility of this innovation is illustrated in Fig. 2. As the clinician presses the tip of the pointer against anatomical landmarks, the distance between the pointer markers drops below a predefined threshold of 220mm at points 1 and 2 thereby identifying frames 676 and 1211 as data consistent with the clinician pointing to an anatomical landmark. In effect, this decrease in inter-marker distance allows the clinician to "communicate" to the motion measurement system that a landmark is being identified.

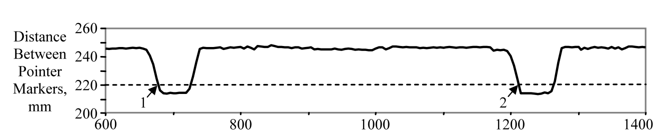

Figure 2. Data collected while the clinician was "pointing" to two different anatomical landmarks.

Discussion and conclusion

With this "dynamic pointer," the advantage of Cappozzo's pointer technique is maintained, i.e. the tip of the pointer can be placed directly on a palpated bony landmark. Soft tissue that might otherwise displace a skin-mounted marker can be compressed by the pointer tip to yield a more accurate determination of the relative position of the anatomical landmark. The requirement in Cappozzo's technique to capture a series of static trials has been addressed with this new technique. As illustrated in Fig. 2, multiple anatomical landmarks can be identified by the clinician in a single static subject calibration.

Currently, the dynamic pointer is being used in routine clinical use to address the challenge of determining the location of the right and left anterior superior iliac spine (ASIS) in patients with obesity. In this application, two reference (or technical) markers are placed on the patient's skin (right and left iliac crest) along with one anatomical marker (posterior superior iliac spine). The virtual relative locations of the right and left ASIS are then measured during the static subject calibration using the dynamic pointer. This clinical illustration will be described further during the presentation of this paper at the meeting.

Reference

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In vivo trapezometacarpal joint kinematics: a preliminary study with Polaris® system

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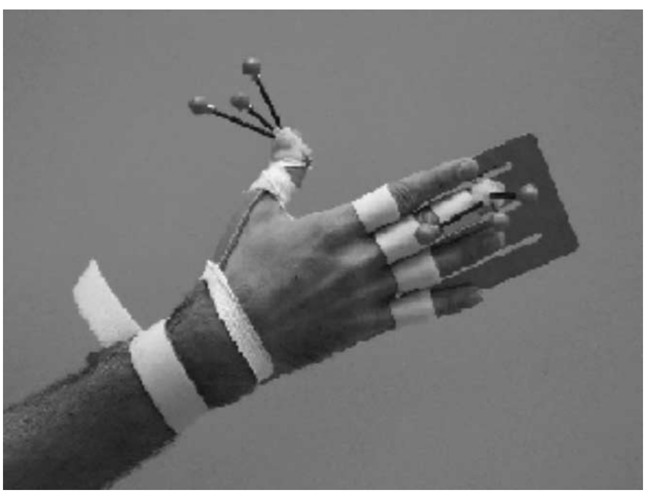
Introduction

Function of the trapezometacarpal joint is important in range-of–motion of the thumb (Kauer, 1987). Only a few articles studied in vivo kinematics of the trapezometacarpal joint (Cheze et al., 2001). The goal of our study is to perform an in vivo kinematics analysis protocol with Polaris system for clinical practice.

Materials and methods

Movement analysis is performed with optoelectronic Polaris® system using only two fixed cameras. The hand of the patient is placed in a hard splint which allows to immobilize the wrist and fingers (except the thumb). A notch is made on the radial side of the splint to let Thenar muscles free and avoid limitation of thumb motion (Fig. 1). Metacarpophalangeal joint is immobilized with a dorsal splint only, to analyze trapezometacarpal joint movements.



Retroreflective markers are placed on the dorsal splint of the thumb. Three anatomical bony landmarks (lateral tuberosity of the second and fifth metacarpal head and base of the fifth metacarpal) are located with a pen, on the hand. Four other points are palpated on the thumb (lateral and medial tuberosity of the first metacarpal and phalangeal head). Maximum range-of-motion is evaluated in different postures (abduction, flexion, adduction, extension). The center of rotation of the thumb and the position of rotation axis with mobiles axis and helicoidal axis are calculated. A reliability study is performed to assess the variability of the different protocol stages (palpation of anatomical points, captures, splint…).

Results and Discussion

Optoelectronic systems are commonly used for kinematics study and clinical practice especially in computed assistance surgery. However, many systems are proposed to biomechanical and clinical teams. The Polaris® system may be easily used in clinical applications. As a matter of fact, size and compact design of the system allow an easy installation. Moreover, the possibility to analyze a small volume is perfectly adapted to hand kinematics. No calibration is necessary before kinematics sessions. At last, the accuracy of Polaris system has been found for point palpation 0.6 mm (2 RMS).

The immobilization with a splint of wrist fingers and metacarpophalangeal joint of the thumb allows to analyze only the trapezometacarpal joint. Moreover, these splints can easily fit different hand morphologies.In order to know the exact position of bones (particularly metacarpal bone) anatomical marking with at least three palpated points is necessary. These anatomical marks are easy to find with the special pen.

Conclusion

In vivo analysis of trapezometacarpal joint with the Polaris® system will enable simple clinical applications. It allows to study the variability of thumb range-of-motion in normal individuals. Moreover, a precise comparison of range-of-motion will be possible before and after surgical treatment. At least, the comparison of range of motion and rotation axis after the implantation of trapezometacarpal prosthesis may be analyzed in order to know the kinematics of a prosthesis and eventually modify its design and components.

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Determination of residual errors in three-dimensional videography using still, moving and panning camera techniques

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Introduction

Significant technological advancements have been made in the study of human motion over the past few decades. There are three known video capturing techniques for collecting three-dimensional kinematic data: static, panning and mobile camera set-ups. The panning and mobile camera techniques allow for the cameras to follow a subject throughout the entire length of the skill, while maintain a close-range view of the subject. Something the static camera set-up does not allow. Accuracy of the panning and mobile camera techniques has not yet been well documented. The main objective of this study is to determine residual errors of three-dimensional coordinates in a 5.5-m filming volume using static, panning and mobile camera techniques using three specific testing conditions.

Methodology

All three camera set-ups used two digital video cameras (JVC model GRDVL 9800). Three testing conditions were set-up in order to verify the ability of each camera system (static, panning and mobile) to collect accurate data over a 5.5 meter filming volume. The first testing condition involved the simple linear movement of a moving calibration frame with reflective markers ($n = 7$). The second test condition involved angular movement using a pendulum, where three vectors were precisely measured from three markers placed on the pendulum and recorded by the three camera set-ups. The final test condition involved standard gait data collection. Reflective markers ($n = 9$) on the subject were positioned in a fashion to create triads on each of the three segments on the right leg (thigh, shank and foot). Three segment lengths were precisely measured from the marker set on each segment for a total of nine segment lengths. All marker positions were tracked and reconstructed using the APAS system. Residual errors were calculated for the collected three-dimensional positions and vector lengths were compared to the reference measurements made with the microscribe or anthropometer.

Results

The results obtained from the moving calibration testing condition showed that the mobile camera set-up produced the lowest residual error with a value of 0.2 ± 0.1 cm. The static and mobile camera set-ups proved to produce the lowest residual errors during the second testing condition (pendulum vector length measurement) with error values of 0.1 ± 0.1 and 0.2 ± 0.1 cm, respectively. Finally, the mobile camera set-up, once again, produced the lowest residual error during the segment length testing condition with an error value of 0.4 ± 0.4 cm, while the panning and static camera set-ups posted mean errors of 0.5 ± 0.3 and 0.9 ± 0.6 cm, respectively.

Discussion

Although the three camera techniques showed acceptable residual errors throughout the three testing conditions, the mobile technique produced the lowest residual error for two of the three test conditions. For the panning and mobile camera set-ups, camera-to subject distance is much smaller than the static camera technique for a 5.5 m filming volume. This supports a study done by Lamontagne et al. (2000) where it was reported that residual errors could be minimized when camera-to-subject distance is reduced. The mobile technique was believed to be capable to produce acceptable accuracy in video analysis (Lafontaine et al., 2000). This technique did reduce the residual errors, of positional coordinates of markers and the vectors length measurements by 85% and 56%, respectively from errors obtained using the static camera technique.

Conclusion

This study allowed for a comparison of three video capturing techniques abilities to collect accurate data over a large filming area. The results show that, although all three camera set-ups produce low residual errors, the mobile camera set-up offers the best accuracy while maintaining a small camera-to-subject distance, allowing for close range studies to be performed successfully.

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Reliability of evaluation of mechanical quality of gait under real conditions with the aid of GPS and accelerometer

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Introduction

A simple observation of the patient by a trained physician is often sufficient to evaluate gait disorder. However, a more quantitative and standardized evaluation of gait is required for research protocols and outcome studies. For this purpose, measurements are generally assessed under artificial laboratory conditions which may disturb the gait pattern. Hence, there is a lack of simple, rapid, reproducible methods to assess functional gait under real conditions (Terrier P 2001). The aim of this study is to develop a simple analysis of global mechanics of walking in a real live condition (i.e. the patient is not disturbed by the measurements and walks freely). Five healthy subjects were enrolled to measure a) displacements of the centre of mass (COM) (Cavagna GA 1976) with a small accelerometer and b) walking speed with a light portable satellite positioning system (GPS).

Materials and method

Subjects and methods: Five healthy subjects were instructed to walk outside on an flat asphalt road at eight different speeds (from 0.5 to 1.8 m/s, at least 20 cycles per speed). Each speed was not strictly imposed in order to keep movements as free as possible. All the measurements were repeated 2 days later. Measurements. A 3-D-accelerometer (Physilog™, Swiss Federal Institute of Technology, Lausanne, measurement frequency 200 Hz) was fixed directly on the skin at the L3-L4 level. It is commonly admitted that the COM can be modelled as a fixed point in the lumbosacral region (Saini et al., 1998). The mean sagittal speed was measured and controlled with a GPS (Etrex, Vista). Calculations: Half-cycles (i.e right or left) were defined as intervals between two sagittal peak speeds (Seichert et al., 1997). At each walking speed mean accelerations of 20 cycles allowed the calculation of the speed vector (by integration), the displacement (by double integration), the external work (right or left, Seichert et al., 1997) as well as the recovery i.e. the fractional potential energy recovered as kinetic energy at each half-cycle (left, right) (Cavagna et al., 1976; Seichert et al., 1997). Results of displacements were compared to those taken with a kinematic device (ZEBRIS Medizintechnik GmbH, Tübingen, D), which measures the displacements of an ultrasound source (Vogt and Banzer, 1999) with an accuracy of 0.1 mm. Calculations and statistical analysis were performed with matlab 6.0, Signal Processing and Statistic Toolbox.

Results

All variables were calculated at each velocity. For example, at a speed of 1.214 ± 0.005 ms^{-1}, results amounted to $70 \pm 2\%$ (mean$\pm$1 S.E.) for recovery. Respective results were for right recovery, $71 \pm 2\%$; for left recovery, $70 \pm 2\%$; for cycle period, 1.10 ± 0.01 s, for right half-period: 0.55 ± 0.01 s, for left half period: 0.55 ± 0.01 s, for standardized external work: 0.75 ± 0.06 Jkg^{-1} m^{-1}; for power, 57 ± 6 W; for vertical COM range, 4.2 ± 0.2 cm and for anterior-posterior COM range, 3.4 ± 0.2 cm.

Coefficient of variation (CV) due to measure repetition was 2% for recovery, right and left phase-recovery, for period, right and left half-periods, 3% for standardized external work and power, 5% for power of right and left half-periods, 3% for anterior-posterior and vertical COM displacement range, 5% for the other variables.The zero lag cross-correlation of COM displacement data between kinematic and accelerometer measure was 0.996 for vertical, 0.995 for sagittal and 0.899 for lateral movements.

CV due to between-subject variation was 1% for velocity, 6% for recovery, 19% for standardized external work, 14% for power, 16% for vertical, 21% for sagittal COM range and 32% for lateral COM range.

Discussion and conclusion The presented tool permits a quantification of gait symmetry and economy in a reliable manner for healthy subjects. This simple method (only 10 min needed per patient) can be used on large cohorts of patients for research protocols and/or outcome studies. Further research with different pathological gaits will be necessary to examine possible limitations of this tool.

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A skiagraphy method using for lumbar vertebras movement delimitation

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Introduction

The replacements of intervertebral discs with a controlled rigidity and items for dynamic dorsal spine fixation (e.g. pedicular srews, ...) are developed at present in our laboratory. The purpose of this project is to find out mobility of lumbar vertebras for optimization of spine replacements design. Assessment of kinematic parameters of vertebras during normal locomotion (walking, running) and assessment of range of vertebras movement is fundamental.

Materials and method

Because the vertebras are under skin and are invisible for classical visual movement analysis, was a skiagraphy method and supplementary 3Dmovement analysis used for the assessment of movement kinematic parameters. The skiagraphy is modern X-ray method. From the X-ray image amplifier are image information scanned with CCD camera. Each image we can obtain by means of pulse mode, the image is procured by very short X-ray pulse (duration is 3–40 ms). Advantage is high quality image, that is not defaced by scanned object movement and better drawing of details, and resolution of image is about 0.2 mm. According to short purchase time of image is major advantage to record movement of "invisible" bones. Because by skiagraphy we could have record a small area (circle with diameter 15″) and only in one plane (frontal or sagittal plane) we have used supplementary 3D movement analysis with 4 cameras. By skiagraphy was record 2D movement of lumbar vertebras and pelvis, and by 3D motion analysis system was record movement of processus spinosus of vertebras and pelvis. Both of these measurements has been synchronized with clappers. The inspected was vertebrae L5, L4 and L3. A recording frame rate for skiagraphy was 6, 9 and 12 frames per second, and for 3D movement analysis was 50 frames per sec. used. An investigated movement of experimental man was walking, running and bending in lumbar part of spinal column. All movement was record by skiagraphy in frontal and sagittal plane. For walking and running was treadmill used. From each X-ray frame was significant points of vertebral body and process detected. From thus acquired data about movement was computed velocity and accelerations of investigated vertebrae.

Results

From positions of vertebral body and process from skiagraphy images in frontal plane was detected: i) rotation in frontal plane, ii) rotation in horizontal plane (from the position of processus spinosus) and iii) displacement of vertebral body in horizontal (lateral) and vertical direction. Similar information we have gained from positions of vertebral body and process from skiagraphy images in sagittal plane: i) rotation in sagital plane, and ii) displacement of vertebral body in horizontal (anterior-posterior) and vertical direction. Data, obtained from bending and bending with loading, have helped us to estimate marginal and mutual position between adjacent vertebras. Data, obtained from walking and running, have helped us to estimate frequency of vertebras motion and to acquire concept about vertebras and intervertebral discs loading. A frequency of vertebras motion in lumbar spine is corresponding with motion of pelvis, but upward vertebras motion is changed and retrenched.

The obtained movement is small, but for spine replacements design and precise function development is very necessary. Due obtained data from bending of spine have been determined utmost positions.

Discussion and conclusion

The results would be better, if the frame rate during skiagraphy were higher, at least 24 frame rate per sec. and using of this method for 3D motion analysis of "invisible" bones. With implanted metal markers into the significant points of each vertebra would be arrived better detection of these points. In this manner obtained data about movement of lumbar spine are used as a part of input data for development of new spine replacements, for example intervertebral cages and intervertebral disc with a rigidity control.

Acknowledgements

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Assessment of sub-division of plantar pressure measurement in children

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Introduction

Measurement of plantar pressure is currently poorly defined. There is a lack of consistency in both measurement technique and reporting of results. This is particularly apparent when describing sub-sections of the plantar surface of the foot. The aim of this study was to assess repeatability of plantar pressure measurement in healthy children, using a new automatic technique of sub-area definition, in order to provide a baseline for comparison with children with foot deformity resulting from cerebral palsy (CP) and to supply a tool for the objective assessment of the outcome of treatment.

Materials and method

Seven healthy children were examined on 3 occasions. Fifteen children with hemiplegic CP were also assessed and compared to the healthy data. Each child had reflective markers placed on specific anatomical landmarks (Carson et al, 2001) on their dominant/affected foot. Data were collected from a pressure platform rigidly mounted to and time synchronised with an AMTI force plate (Giacomozzi et al, 2000). A 12 camera VICON 612 system was used to collect 3D motion data. The footprint was divided into 5 sub-sections by using the position of the markers on the foot projected onto the pressure footprint at mid stance (Fig. 1). Both inter-trial, and inter-day repeatability for peak pressure and peak force were assessed using SPSS.

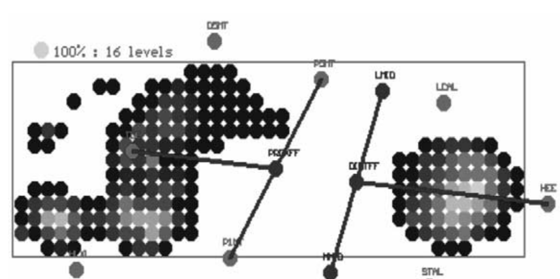

Figure 1 Sub-division of the foot into 5 areas (medical heel: MH, lateral heel: LH, midfoot: MF, lateral forefoot lFF, medical forefoot: MFF)

Results

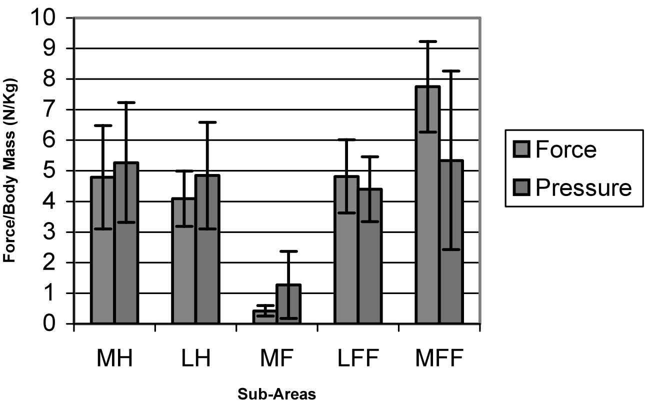

Figure 2 Comparison of repeatability of peak force and pressure for sub-areas showing within subject standard deviations

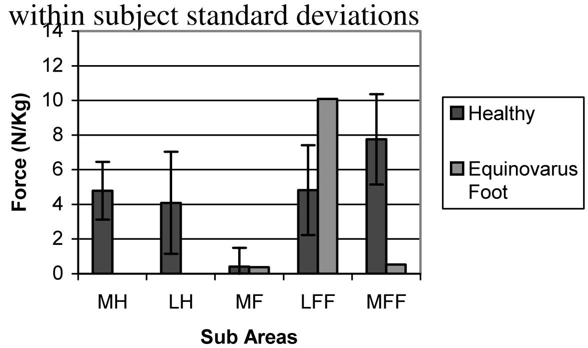

Figure 3 An example equino-varus foot from a CP child compared to healthy 95% confidence intervals

Discussion and conclusion

Automatic sub-area definition based on marker placement was found to be effective in healthy children and those with CP. A comparison of results revealed that peak vertical force was a more consistent measure than peak pressure for each of the five sub-areas (Fig. 2), possibly due to the variable nature of plantar surface contact when walking. This suggests that force may be the more appropriate measurement for outcome studies. There was consistency in the sequence of foot contact in all healthy children, where heel contact preceded fore foot contact. The mid foot was the only sub-area not always present in the healthy population. CP children did not always conform to this sequence of heel to forefoot contact, and frequently displayed a complete absence of either heel contact or forefoot contact (Fig. 3). Despite some variability in force values across the healthy population, measurements taken from children with CP still fell outside the 95% confidence interval of healthy children's feet (Fig. 3). This study revealed that force measurement and sequence of foot sub-area contact can help classify foot deformity in CP and has the potential for objective evaluation of treatment.

Acknowledgements

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Friday 12th September 2003 14:34–15:34
Poster Session 2

Cerebral Palsy

Construction of a device for the evaluation of kinematic features of motor induced passive cycling in children with normal motor behavior and with cerebral palsy

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Objectives

The objectives of this study were: 1. To develop a device for measuring the kinematic features of motor induced passive cycling in normally developed children (ND) and with Cerebral Palsy (CP). 2. To study the validity of the device.

Participants

Fifty-six children and teenagers were studied during passive induced cycling, 29 of who had been diagnosed as having CP and 27 who were developing typically. There was no significant difference between the two groups in age and anthropometric parameters (height, wheight, leg length). The functional level of the children with CP was classified according to the Gross Motor Function Classification System (GMFCS) for Cerebral Palsy.

Measurements and main results

The APT-TZORA (Tzora, Israel), an electrically powered was used to induce passive cycling in every subject at three different speeds.

Kinematic parameters including velocity and acceleration in cycling were measured by the V-Scope (Litek Advanced Systems, Israel).

The results obtained showed that at a passive constant speed of 47 rpm negative correlations were demonstrated in the ND children between mean velocity and height ($r = -0.479$, $p = 0.01$) weight ($r = -0.513$, $p = 0.006$) leg length ($r = -0.498$, $p = 0.01$). No correlations were found for these parameters in the CP group.

At 71 rpm no correlations were found between mean velocity and the above parameters for the ND children, nor for the children with CP. The mean velocity in the ND children was 7.1 ± 0.35 and 6.44 ± 0.7 rad/s in children with CP ($p < 0.001$). Negative correlations were demonstrated: GMFCS/71 rpm ($r = -0.623$, $p = 0.001$), Ashworth/71 rpm ($r = -0.631$, $p = 0.002$), Adductor spasm scale/71 rpm ($r = -0.614$, $p = 0.002$).

Conclusions

The results demonstrated that the new developed device could identify normal and abnormal kinematic features of passive cycling. It was shown that mean angular velocity is influenced by anthropometric parameters in the normal group but has no influence on the CP group. These results suggest that in children with CP the resistance to passive cycling is due to their pathological characteristics more than their anthropometric features.The negative correlation between the mean angular velocity as against functional status (GMFCS), Ashworth spasticity scale and Adductor spasm scale is higher with increased speeds. These measurements provide an objective quantification of the passive characteristics of rhythmical motor behavior.

The relationship between heart beat cost and functional status of children with cerebral palsy

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Objectives

To develop a method of representing a functional status by the heart beat cost of a particular external work in children with cerebral palsy (CP).

Design

Controlled quantitative study. Correlational analyses and mean difference comparison between groups.

Participants

Nine normally developed children (ND) (age 6–13) and 14 children with CP (ages 6–12 years). The functional level of the children with CP was classified from II to IV according to the Gross Motor Function Classification System (GMFCS) for Cerebral Palsy.

Measurements and main results

All the participants passed successfully the self-paced stair-climbing test after 5 min of rest. The count of heart beats was accumulated from Polar heart rate monitor while ascending and descending 4 steps repeatedly over approximately 4 min during the test. The performed external work was calculated by multiplying the body weight by total climbed height and added 1/3 of the total height for descending. The net heart beat cost (HBC index) (amount of heart beats after subtracting the resting heart rate level) was normalized by the external work performed during the test. The obtained results of HBC were compared to the GMFCS and GMFM-66 scores. The mean HBC of ND and CP children was 0.19 ± 0.07 and 3.55 ± 3.18 beats $kg^{-1} m^{-1}$ ($P < 0.01$), respectively. The HBC significantly correlated with GMFCS ($r = 0.82$, $P < 0.01$) and GMFM-66 ($r = -0.93$, $P < 0.01$).

Conclusions

The HBC index considers the dynamic pattern of heart rate changes in children as calculated from heart beat count over time.

The obtained results demonstrate the possibility of using the HBC as an index to calculate energy cost in a locomotion task, related to the functional status of children with CP. Its accuracy may be allied to the ability to calculate the exact amount of external work, i.e. take into account the child's weight and the vertical displacement.

Extracting diagnostic gait signatures for cerebral palsy patients from kinematic data

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Introduction

Abnormal gait may be due to an injury, disease, pain or problems of motor control. The subject's ability to compensate for the abnormality determines the amount of functionality retained. When these compensations are introducing penalties in joint strain or muscle overuse, lack of normal muscle growth and soft tissue contractures, clinical intervention becomes a necessity. In determining appropriate intervention, gait analysis is used to identify gait defects.

Gait analysis instrumentation based on infra-red (IR) cameras and computer-aided systems recording the 3D positions of markers attached to the subject has been used to record gait cycles of the patient and produce patterns and plots for clinicians to assess and to aid the planning of surgical and therapeutic intervention. The number of graphs plotted for gait analysis is immense and extracting useful information from such graphs is a demanding and challenging task due to various reasons, e.g., the complexity of the walking process itself, variability of patients' response to treatment, uncertainty in data quality and the difficulty in distinguishing between primary abnormalities and compensations in the gait pattern.

Some artificial intelligence methods, namely artificial neural networks, due to their inherent abilities of generalisation, interpolation and fault tolerance offer new means to assist in dealing with the challenge of processing huge amounts of data, classifying it through extracting generic features. Hybrid techniques of AI, e.g. neural net knowledge-based systems, have proved to be successful in building medical diagnostic tools. In this research, we use Kohonen Self-Organising Maps (SOM) [Kohonen, 1997] for classification and an algorithm to extract rules from these maps to characterise different groups of CP.

Data collection and method

The data of twenty four pathological cases of CP included symmetrical diplegias (dp), left and right asymmetrical (la,ra) diplegias and left and right hemiplegias (lh, rh) were used in our experiments.A method to extract salient features from hip, knee and ankle angles to characterise normal and pathological cases is proposed. The algorithm is based on transforming the spatio-temporal trajectories of the joints using the continuous wavelet transform and then training a SOM to cluster the input feature vectors according to their internal spatio-temporal structures. Based on the self-organisation of the patterns, rules are extracted for uniquely representing and characterising each cluster. Features that contribute in characterising a cluster and in differentiating it from other clusters are selected as *significant* features of that particular cluster. These salient features are automatically extracted.

Experiments and result

The objective of the set of experiments carried out in this research is to investigate and extract diagnostic signatures for different CP subgroups. In addition to the complexity of CP as an impairment affecting more than one joint and the coordination of the overall motion, one technical difficulty of the CP cases is the uniqueness of almost each case. However, clinicians are concerned that patients with CP are sometimes incorrectly diagnosed as hemiplegic when they are in fact diplegic, which consequently affect their management.The map was trained with features of the right and left hip joints combined together. The map self-organised as follows: right asymmetrical diplegias and right hemiplegias clustered together, and so did the left asymmetric diplegias and left hemiplegias while the symmetrical diplegics grouped between these clusters pulled by their attraction regions in different directions. A couple of unexpected results visualised in the map is the clustering of diplegia 6 (dp-6) with left hemiplegia 4 (lh-4), whilst right hemiplegia 3 (rh-3) lies close to diplegia 7 (dp-7).On a review of the patient files by the clinicians, dp-6 was found to have upper limb signs on the left indicating more involvement of the left side, explaining the clustering with the left hemiplegias. More importantly it appeared that rh-3 had been incorrectly diagnosed as a hemiplegia, having clear signs of bilateral involvement with spasticity in the lower limbs of both sides. The system therefore placed rh-3 correctly with the diplegias.

Conclusion

Results obtained by this research verify the existence of kinematic diagnostic signatures that comprise generic and specific features distinguishing different subgroups within CP. These diagnostic signatures could be extracted automatically. The system also classified correctly cases that were incorrectly diagnosed by clinicians.

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Value of the Duncan–Ely test in patients with cerebral palsy and stiff knee gait

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Introduction

The present study evaluates the sensibility and specificity of the Duncan–Ely test in the determination of rectus femoris muscle spasticity in patients with cerebral palsy. The sensitivity of the test demonstrates its capacity in detecting the disease. The specificity demonstrates the capacity of the test in detecting the absence of the problem (disease).

The stiff knee gait in patients with spastic cerebral palsy is mainly caused by an inappropriate electric activity of the rectus femoris during the swing phase.

Material and methods

Thirty-five individuals (70 limbs) with spastic cerebral palsy were observed. Of the studied patients, 19 were female and 16 were male. The average age was 11.3 years old and ranging from 5 to 19.8 years.

The Duncan–Ely test was performed with graduation of the answer in agreement with Ashworth scale.The participants studied were analyzed during self-selected gait speeds on a seven meter track. The VICON 370 system (Oxford Metrics England), with six 60HZ infrared cameras, was used for data collecting; and the V.C.M. (VICON Clinical Manager) software was used for data processing. The dynamic surface EMG was performed with Motion-Lab MA 100/10 channels.

The following gait parameters were observed: peak flexion of the knee, time of peak flexion in the knee swing, movement of the knee arch and rectus femoris activity in the swing phase. The muscular electric activity and kinematic data were collected simultaneous during gait cycle.

Results

Of the 70 evaluated members (limbs), 61 presented positive EMG results during midswing. Of those 61, 51 responded positive to the Duncan–Ely test. Of the 9 limbs with no electric activity in the midswing, 3 had a negative Duncan–Ely at physical examination. Therefore, the Duncan–Ely test results present 83.61% sensitivity in detecting the presence of inappropriate electric activity in the rectus femuris during the swing phase and 33.33% of specificity for detecting the absence of the problem.

Discussion and conclusion

The data demonstrates that when the Duncan–Ely test is positive, 83.61% of the cases will have inappropriate activity of the rectus femoris during the swing phase. However, when the test is negative, only 33.33 are accompanied by a normal function of the rectus femoris. Marcks et al. described a sensibility of 98% and a specificity of 10.9% for the Duncan–Ely test when dynamic fine wire EMG of the rectus femuris were performed.

The treatment of stiff knee during gait in cerebral palsy patients is made by distal rectus femoris transfer. The assessment of effectiveness of the clinical test utilized for detecting the rectus femoris spasticity (Duncan–Ely test) demonstrates the importance of using others methods to improve accuracy in detecting the problem.

The correlation of the Duncan-Ely test with the kinematics data and EMG decreases the error rate of the indication of the rectus femuris transfer to the treatment of the stiff knee gait in patients with cerebral palsy.

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Intrathecal baclofen therapy and cerebral palsy
External programmable pump procedure in spastic diplegia

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Summary and conclusion

Intrathecal baclofen therapy is an effective treatment for spasticity in cerebral palsy. Clinical and functional tests have been improved as well as objective modifications of gait analysis parameters. The external programmable pump procedure facilitates a complete investigation and allows an outcome measure among homogeneous individuals (spastic diplegia).

Introduction

Some studies have shown that intrathecal baclofen (ITB) can be beneficent in the treatment of spastic Cerebral Palsy [Butler et al., 2000]. Clinicians have used this new surgical intervention only in the last decade and try to place it among other surgical procedures as selective dorsal rhizotomy, dreztomy, peripheral and partial selective neurotomy or multilevel orthopaedic surgery (MOS) [Morton et al., 1999]. ITB treatment effect must be firmly established by rigorous investigation.

Patient/materials and methods

Five patients with spastic cerebral Palsy were selected for ITB therapy (2 diplegic, 3 quadriplegic, 3 males and 2 females) and received baclofen boluses via a catheter-port system. In order to get a better understanding of the effect of baclofen therapy, the last diplegic CP patient (age: 15 years, apparent equinus in Rodda's classification) received a continuous intrathecal administration of baclofen (level of insertion of catheter tip in T11–T12 with a progressive increase from 80 to 130 μg per 24 h) via an external pump. An extensive assessment was achieved inlcuding a clinical evaluation (consisting of a range of motion, strength and spasticity), Physician's Rating Scale (PRS), Gross Motor Function Measure (GMFM), walking gait analysis (Vicon 250 with 5 cameras, 2 force plates, temporal-spatial parameters, kinematics, kinetics and dynamic electromyography—EMG, energetic cost Cosmed K4 and video-tape recording). The trials have been carried out at a self-selected speed without any assisting devices.

Results

The results showed that spasticity decrease 45 min after ITB administration with a permanent effect during continuous infusion, measured by a significant decline for the modified Ashworth score (from 3 to 1).Afterwards, a decrease of plantar-flexors strength and no significant objective differences in range of motion have been observed. Another effect was an improvement of functional assessment, 40% in the PRS and 9% in the GMFM (10% in section D, 17% in section E). The results of walking gait analysis showed an increase of the spontaneous speed and stride length. From the kinematic point of view, the anterior tilt, hip and knee flexion decreased. In dynamics, the extensor knee moment has been reduced and the first ankle absorption and the second peak of vertical force, grew up. The continuous pattern of dynamic EMG was transformed in a segmented pattern without modifications of the energetic cost. For the patient social integration was facilitated. Differences were observed with several dosages, the maximal effect is at 130 μg. No adverse effects were noticed.

Discussion

The continuous baclofen infusion via the external pump allows a complete objective assessment and facilitates the understanding of motor disorders (primary and secondary anomalies and compensations). The proximal positive effects of ITB (decrease of spasticity) were associated with negative distal symptoms (unmask plantar-flexors weakness) and underlined the effect of contractures. A complete surgical plan is finally foreseen by an implantation of an internal pump and a MOS. Probably, a ground reaction ankle foot orthesis will be installed. The suppression of spasticity with ITB can also affect changes in other dimensions (social activity or cosmetics).

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Gait analysis in cerebral palsied children, attempt of evaluation

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Introduction

The acquisition of the walking represents one of the main undertaking of the young child. It is the outcome of a whole series of slow and progressive alterations of the central and peripheral nervous system, neuromuscular structures under the influence of genetically scheduled processes but with interaction of the environment. Next to the development of postural static, we observe the implementation of the balance strategies.

Objectives

Objective assessment, reproducible evaluation of certain parameters of gait in a parallel to a classic clinical evaluations.

Materials and methods

Preliminary study realized since 2002 in the service of physical medicine of the Kassab institute concerning 12 patients of average age 9.1 years. 11 ambulant child with cerebral palsy and a child presents congenital lack of 2 upper limbs with delay of the acquisition gait. All the subtests of Balance Master were proposed.

Results

All the children present abnormalities in the postural control with overtaking of the balance strategies revealing to subtests CTSIB, limits of stability. Seven children have pathologic patterns of gait (length, width of the step and the speed) studied by the tandem walk, the step up/over, the forward lunge.

Conclusion

The analysis of various parameters allows to establish a physical therapy and possibly orthopedic better adapted, to there based only on clinical assessment. It also underlines the complementary of the clinical evaluation with a gait analysis.

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Orthopaedics

Assessment of hallux valgus correction in cerebral palsy using dynamic pedobarography

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Introduction

Children with cerebral palsy often have hallux valgus as part of a tri-dimensional foot and ankle malalignment. This results from a combination of intrinsic muscle imbalance and abnormal extrinsic loading during the stance phase of gait. The association of hallux valgus and metatarsus primus varus with a planovalgus foot leads to pain, hygiene problems, difficulty with shoe wear and abnormal gait. The goals of surgical correction of hallux valgus are to improve ambulation, decrease pain, improve shoe wear and correct deformity. This study aims to objectively assess the results of corrective surgery for hallux valgus using dynamic pedobarography.

Patients and methods

Thirty-seven children with cerebral palsy underwent either a first metatarsal osteotomy or soft-tissue correction at our institution between 1990 and 2000. Those patients who underwent a metatarsophalageal fusion were excluded from this study. Of these, 10 patients (14 feet) who underwent a full gait analysis including physical examination, temporal-spatial parameters, kinetics, kinematics, EMG, and dynamic pedobarography pre- and post-operatively were included in this study. The age of the patients at the time of surgery ranged from 5 to 16 years (Mean 11.4 years). There was 1 male and 9 female patients. 8 children had diplegic pattern cerebral palsy and 2 had hemiplegia. 9 patients were community ambulators and 1 was a household ambulator. Surgical procedures undertaken included bunionectomy and soft-tissue correction, proximal phalanx osteotomy or a proximal first metatarsal osteotomy. All patients except one had concomitant surgery for planovalgus foot deformity. Average time from surgery to follow-up gait analysis was 25.1 months (9–44 months). To evaluate the results, the following parameters were analyzed: peak of ankle power generation, ankle plantar flexion at toe-off, and foot pressures from dynamic pedobarography. The results were analyzed using paired t-test ($p < 0.05$). Preoperative and postoperative radiographs were obtained and the hallux valgus angle, 1-2 intermetatarsal angle and the hallux valgus interphalangeus angles were measured.

Results

Following surgery to correct hallux valgus, we found improved power generation at the ankle but the values did not reach statistical significance. There was a trend towards a more normal pressure distribution pattern within the foot. The only parameter that showed a significant improvement was the medial forefoot pressure ($p < 0.001$). Ankle plantar flexion at toe-off did not improve following surgery. There was a significant improvement in the hallux valgus angle from 33° (mean) preoperative to 14° (mean) postoperative (p value 0.013). The 1-2 intermetatarsal angle improved from 12° (mean) preoperative to 7° (mean) postoperative (p value 0.002). The hallux valgus interphalangeus angle improved from 13 to 8° (p value 0.17)

Conclusions

This is the first study that attempts to objectively document the changes in gait parameters and foot pressures following corrective surgery for hallux valgus in children with cerebral palsy. We found a significant decrease in medial forefoot pressures. This can be attributed, in large part to restoration of a more-normal weight-bearing pattern through the first metatarsal.

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Functional analysis of impaired ambulation following the foot reconstructive surgery

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Introduction

The study is aimed at the characterisation of the gait of subjects with complex traumas of the foot due to car crashes or accidents on the job submitted to surgical reconstruction. The reconstruction is focused on the morphological and gross functional recovery of the patient's foot. The clinical examination following the surgery is focused on a morphological description of the limb and on a qualitative analysis of the gait. However over time patient claims ambulation disturbances. This study is aimed at a functional evaluation of the patient's gait by means of 3-D movement analysis. This one integrates the patient's post-operative evaluation, providing quantitative parameters for the assessment of his/her ambulatory behaviour. These parameters can also provide useful information for suggesting surgical solutions aimed at improving the patient's functional recovery level. Moreover, the same instrumental methods (kinematics and dynamics) [1] associated to the clinical evaluation could reveal and/or quantify-"disability signs" not easily perceptible by the clinical examination.

Materials and methods

The population analysed is constituted by 20 subjects with traumas at the foot dorsum, at the calcaneal area and at the forefoot area. Each subject is asked to walk several times over the walkway wearing his/her shoes. The shod condition is adopted to allow the most comfortable situation for the subject. Specific footwear and/or the presence of special arch support is considered an exclusion criterion for the test. Moreover all the subjects have not pretraumatic vascular or metabolic pathologies nor degenerative invalidating pre-traumatic pathologies nor pre and/or post operative trophic ulcers of the sole or injuries of the main nervous trunks. The inclusion criteria are: 1) age between 16 and 60; 2) injuries limited to the tegument or complex traumas of the foot.The protocol is as follows (3-D bilateral gait analysis):

1) Ground reaction forces (BERTEC© force platforms) and the pressure distribution (Tekscan's F-Scan Pressure Assessment System) are examined. This would improve the understanding of the foot behaviour during the phase of weight acceptance, rolling and raising of the toe and would take into consideration the presence of some altered stance mechanisms [2,3].
2) Linear and angular kinematics (ELITE ($B|T|S$)) of ankle, knee and hip are measured for evaluating the locomotor ability of the subjects and to see eventual compensatory / corrective phenomena. For hip, thigh and shank kinematics clusters of markers are adopted. The insoles used for gathering the pressure distribution ask for single markers positioned at anatomical landmarks of the foot (first, fifth metatarsal head and heel). The second metatarsal head position is evaluated by pointing, according to CAST protocol. For each segment the anatomical reference system is defined as in [1].
3) Spatio-temporal parameters such as stride length, progression speed and duration of stance and double support phases are calculated for characterising the patients gait and to put into evidence asymmetries.

Results

Gait Analysis allows to evaluate if the recovery of a "normal" locomotor ability is gained by the examined subjects. In fact the preliminary results, here presented, show altered patterns of some variables with respect to the "normal" behaviour, as described into the literature [2]: subjects with traumas of the calcaneal area present an irregular behaviour of some dynamic and cinematic variables during the phase of weight acceptance, while subjects with forefoot traumas reveal such alterations during the terminal stance and pre-swing phase. The center of pressure trajectory, the vertical component of GRF, the double support duration and the kinematics of ankle and knee appear to be relevant for characterising the gait of subjects with these foot traumas typologies.

Discussion and conclusion

The 3D bilateral examination puts into evidence the presence of compensatory and/or corrective phenomena. In particular gait asymmetries during weight transfer phase between healthy and surgical limb (and vice versa) seems to provide useful indications about the post-operative evolution.

Therefore, the here described functional evaluation could help in improving re-education programmes of this kind of patients and could provide useful indication for adopting the best reparation surgical procedure.

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Pain, gait, and quality of life before and after knee arthroplasty

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Introduction

Early studies on the outcomes of total knee arthroplasty (TKA) were concentrated on the surgeon's view, i.e. knee pain and deformity, and gait. On the contrary, recent studies mainly evaluated the patient's view, i.e. the health-related quality of life (HRQoL). To our knowledge, no study combined these different points of view.

The main goal of our prospective study was to simultaneously assess knee pain, HRQoL, and gait among 9 patients suffering from severe unilateral knee osteoarthritis (OA) undergoing TKA.

Materials and methods

Nine patients (mean age of 68.8±4 years) diagnosed with unilateral degenerative knee OA were selected from our orthopaedic department. Pain, HRQoL, and gait were assessed, 1 day and 6 months after TKA. The outcomes of TKA were assessed by a knee pain visual analogue scale (VAS); the function score of the Knee Society (KS); the physical subscales of the Medical Outcomes Study Short Form-36 Health Survey (MOS SF-36); the gait speed; the external (W_{ext}), internal (W_{int}), and total (W_{tot}) mechanical work during gait; and the net metabolic cost of gait (C). The W_{ext}, the mechanical work done to move the whole body centre of mass (CM_b) relative to the surroundings, was computed from the measurement of the 3D ground reaction forces. The W_{int}, the mechanical work done to move the limbs relative to the CM_b, was computed from kinematics data. The W_{tot} was the sum of W_{int} and W_{ext}. The C was assessed on a motor driven treadmill and computed as the ratio between net oxygen rate (walking minus standing) and walking speed.

A Wilcoxon signed rank test was performed on the ordinal scales (VAS, function score of the KS, and MOS SF-36 subscales) and paired t-test on the gait variables (gait speed, W_{int}, W_{ext}, W_{tot}, C) in order to evaluate a significant difference before and after TKA.

Results

The median VAS score of knee pain was significantly decreased (from 4.6 to 0.5, $p = 0.004$) in postoperative. The median function score of the KS was improved (from 50 to 100, $p = 0.004$). About the MOS SF-36, Physical Functioning subscale score (from 35 to 70, $p = 0.004$), Role-physical subscale score (from 0 to 75, $p = 0.008$), and Bodily Pain subscale score (from 32.5 to 57.5, $p = 0.004$) were significantly improved in postoperative. Vitality and general health perception subscales scores were not significantly changed. No significant differences were found about the gait speed and mechanical gait variables (W_{ext}, W_{int}, W_{tot}). The metabolic gait variable, C, was significantly decreased (from 5.19 to 4.27 J kg^{-1} m^{-1}, $p = 0.034$) in postoperative.

Discussion and conclusions

Our VAS and HRQoL results are in agreement with previous studies (Kroll *et al.*, 1989; Bachmeier *et al.*, 2001). About the gait variables, the main result is the significant decrease of C 6 months after TKA surgery, despite a non-significant increase of gait speed and a non-significant decrease of W_{tot}. We hypothesize that this decrease could be related to: (1) the simultaneous increase of gait speed and decrease of W_{tot}; and (2) physical reconditioning status of the OA patients associated to knee pain decrease after TKA surgery (Ries *et al.*, 1996).

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Gait analysis in patients with osteoarthritis and rheumatoid arthritis of the knee

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Introduction

Understanding of the gait abnormalities in patients with osteoarthritis and rheumatoid arthritis of the knee joint is essential for the optimal management of these patients and for the evaluation of treatment outcomes. There are very few studies in the literature examine the use of quantitative gait analysis in evaluating gait characteristics in with osteoarthritis and rheumatoid arthritis knees (Kettelcamp et al., 1972; Györy et al., 1976; Stauffer et al., 1977; Messier et al., 1992) but the underlying mechanisms of these deviations have not been adequately addressed. In the present study a quantitative gait analysis of patients with osteoarthritis and rheumatoid arthritis of the knee was carried out.

Materials and methods

Ten patients (mean age 72 years) with osteoarthritis of the knee and ten patients (mean age 70 years) with and rheumatoid arthritis of the knee were studied. All patients were female. The patients and 10 age-matched control subjects were asked to walk at self-selected speed on a 10 walkway. The kinematics analysis was performed using an optoelectronic motion analysis system (Coda mpx30). Kinetic data were recorded using Kistler force plates. The activity of four muscles of the lower extremity was recorded using telemetered electromyography (EMG). The EMG data were integrated with the kinetic and kinematic data. The following gait parameters were collected. 1. Spatiotemporal parameters—walking speed, stride length, timing of mid stance, and mid swing in the gait cycle. 2. Kinematic parameters—the maximum range of hip motion during the stance phase, the maximum knee extension during loading response, the maximum knee flexion during swing phase, the maximum ankle plantarflexion in stance, and the maximum ankle dorsiflexion in swing. 3. Kinetic parameters—the maximum knee moments and powers during mid stance, the maximum ankle moments and powers in pre-swing.

Results

Analysis of the data confirmed that both groups of the osteoarthritis and rheumatoid arthritis patients walked more slowly and with a significantly reduced stride length compared to the age-matched control group. Mid-stance and mid-swing occurred later in the gait cycle in both patients' group. The range of motion at the knee and hip joints of the both patients group was also severely limited. Both patients group had increased moments and reduced powers at the knee and prolonged activation of the rectus femoris muscle. The differences between the two patients group were not statistically significant for all the parameters measured. The differences between the two patients groups and control group were statistically significant for all the parameters measured ($P < 0.05$).

Discussion

The walking speed and stride length were slow and the timing of mid-stance and mid-swing in the gait cycle were delayed in both patients groups with osteoarthritis and rheumatoid arthritis of the knee by comparison to the age-matched control group. This could be to avoid pain caused by abnormal increased movements at the knee. The reduced power generation may be due to the damage of the joint capsule and ligaments associated with severe arthritis. Generation of increased moments without corresponding powers would also be necessary to enable knee stability in stance. This hypothesis is supported by the EMG findings of this study, in particular the prolonged contraction of the rectus femoris muscle in both osteoarthritis and rheumatoid arthritis patients.

Conclusion

Knee osteoarthritis and rheumatoid arthritis patients adopt new gait pattern which is significantly different from the age-matched control subject. Due to psychological and physical factor the both groups patients alter their gait pattern which is significantly different from the control. The spatiotemporal and kinematic gait abnormalities observed in patients with both osteoarthritis and rheumatoid arthritis of the knee appear to be caused by instability of the knee joint. Increased joint moments help to stabilize the knee joint. Instrumental gait analysis, including the study of kinetic, kinematic and dynamic EMG, provide the clinician with detailed information about the underling causes of gait abnormalities in patients with osteoarthritis and rheumatoid arthritis of the knee joint. Such information is essential for the rational management of these patients.

Acknowledgments
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Gait analysis in Legg–Calvé–Perthes disease

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Introduction

Legg–Calvé–Perthes disease is a self-limiting, iuvenile osteonecrosis of the femoral head among children 4–10 years of age. The final outcome is dependant on the deformity of the femoral head and the congruity of the hip joint. Deformity of the hip joint will lead to early degenerative joint disease. Till now follow-up and outcome evaluations are analysing only subjective results, clinical parameters like range of motion measurements and radiological changes. There are no studies evaluating the functional impairments during gait.

Material and method

Twenty-one children (13 male, 7 female, average age 7.6 years) were included in the study. Inclusion criteria were: 1. unilateral hip involvement; 2. age > 6 years; 3. no previous surgical treatment at the hips; 4. no other disorder leading to gait deviations. All children were investigated clinically and radiologically. Three-dimensional gait-analysis was performed with a VICON 512 system. Patients walked at a self-selected speed—barefoot. Kinematic, kinetic and time-distance-parameters evaluation served to elucidate gait deviations compared to the non-involved side as well as to a group of normal children. The datas were also analysed depending on the Waldenstroems classification—a system for classifying the hips according to the stage of the disease. Data were averaged from five trials and these were included in the final analysis. Statistical analysis was performed using the pairwise t-test. Significance level was set at $p < 0.05$.

Results

The analysis of the time-distance-parameters on the involved side showed-compared to the non-involved side-a significant reduced stance-phase and a significant reduced single-support time. The sagittal range of motion of the involved hip joint was significantly reduced (41 vs. 47° on the non-involved side, $p = 0.001$) as well as maximum extension in terminal stance (−1 vs. 6°, $p = 0{,}001$). At the knee joint sagittal kinematics showed a significant reduced range of motion (54 vs. 57°, $p = 0{,}038$) and a reduced maximum extension in terminal stance (10 vs. 5°, $p = 0{,}004$). The differences were more pronounced in the condensation and fragmentation stage.

Discussion

Gait-analysis showed significant changes in the gait pattern mainly in the early stage of the disease. The changes might be due to a hip-avoidance pattern. The results suggest that gait analysis is a valuable tool for detecting functional deficits in the course and in the outcome evaluation of Perthes disease.

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Technology and Consumption

Left-right step detection during walking using only acceleration sensors on the lower back

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Introduction

Methods for activity monitoring using body fixed acceleration sensors were developed since the early nineties. The idea behind these methods was to develop simple non-obtrusive methods to assess human movement under natural conditions (e.g. ADL). The first methods used sensors on the thorax and the legs (Veltink, 1996). Later methods were developed with sensors around the waist and legs (Busser, 1998). Sensors at the legs were used for detection of the left and right steps. This paper describes a new method of gait analysis that uses sensors at the lower back only.

Materials and method

Eleven students (mean age 22.6) walked a corridor of (37 m) up and down and a block (110 m) in both directions including 3 curves. A video camera registered the subjects. The videotapes were used to count left and right steps. Three acceleration sensors (Analog Devices, ADXL202) were mounted orthogonal in a small data logger (DynaPort, 5.5 × 3.5 × 2.5 cm). Data were sampled at 100 Hz and stored locally on a flash card with maximum 512 MB memory. The unit was attached to the dorsal side of the lower trunk by using elastic straps around the waist. Step detection was based on peak detection of trunk accelerations in the direction of walking, left and right step detection was based on the left to right movements of the lower trunk (Zijlstra & Hof, in press).

Results

From the 4529 counted steps 4517 were detected correctly (99.6%). Missed steps occurred during the start and stop phase of walking, especially the closing step. From these 4529 steps

4114 were assigned to the correct leg (91.8%), with a small difference in the corridor (93.21%) and the block (90.06%). Misdetections occurred mainly during the start and stop phase and during curves. Misdetections in left right were ranging from 4.1 to 10.9% except one subject with a misdetection of 37.4%.

Discussion and conclusion

The step detection is robust. Although left-right detection of some individual steps was incorrect, misdetections can be corrected assuming that left and right steps are alternating. The result is 100% detection. This accuracy is up to now only reached with sensors on both legs. The advantage of the present method is that no cables are necessary and interference with the subjects' movement patterns is minimized. The presented method for detecting left and right steps can be the basis for further gait analysis (Zijlstra & Hof, in press) and for detection of trunk posture. This approach is only possible with DC coupled sensors that are sensitive to kinematic and gravitational acceleration. The acceleration sensors on the lower trunk can also be used for posture detection, kinematical analyses, balance and energy monitoring.

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Accelerometric gait analysis for use in the assessment of knee osteoarthritis: a preliminary study

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Introduction

Knee osteoarthritis (OA) is the most common degenerative disease in the elderly population (Felson, 1990). The progression of OA has also been associated with impulsive gait (Radin et al., 1991). Although OA represents an important disorder affecting daily activities, there is currently no quantitative assessment to characterize pathological joint evolution due to physical treatment. Therefore, an accelerometric method based on twice differentiation of three-dimensional knee kinematics has been developed. The purpose of this study was, first, to compare 3D accelerations of the knee joint with data from literature during walking gait cycle and secondly, to understand impulsive gait pattern associated with OA population.

Materials and method

Three-dimensional knee biomechanical data were collected from 15 healthy subjects while walking at comfortable speed (average speed: 1, 1 m/s) on an instrumented treadmill (Adal, Med. Development, France). Knee kinematic values were acquired using a three-cameras optoelectronic system (Optotrak, Northern Digital, Canada). Eight markers (infrared light diodes) attached on a non-invasive knee harness (Sati et al., 1996; Ganjikia et al., 2000) were used to track 3D knee kinematics during walking. For each subject, data were collected during 30 s, divided into 20–30 gait cycles and averaged. 3D Accelerations of shank and thigh segments, as well as an index of shock loading (absolute acceleration with respect to global coordinate system), were estimated from 3D filtered kinematics data.

Results

The peak acceleration was estimated and averaged at shank and thigh levels for 15 healthy subjects during gait cycles. In medial-lateral direction, maximal values were 0.34 and 0.36 g for shank and thigh segments respectively. In anterior-posterior direction, maximal values were equal to 1.09 and 1.25 g, whereas in proximal-distal direction acceleration data decrease to 0.82 and 0.33 g for shank and thigh segments respectively. Fig. 1 shows typical polar diagram which represents mean shank acceleration data collected during walking gait cycles in proximal-distal and anterior-posterior directions.

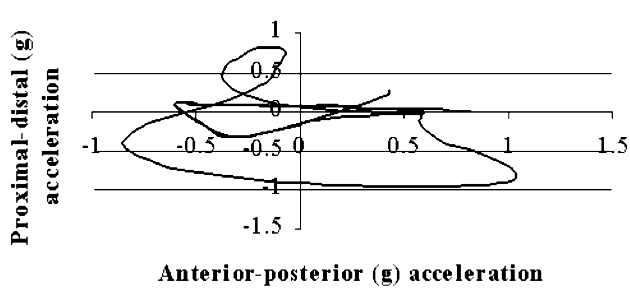

Figure 1. Polar diagram of a typical healthy subject. Shank acceleration (g) averaged from 23 gait cycles. Positive values indicate distal and posterior directions

Discussion and conclusion

An original and accurate method for the assessment of acceleration at knee joint during gait has been developed. In general, maximal ranges obtained from the method presented are comparable with the literature data which are based on accelerometers measurements. During gait, maximal acceleration was detected for thigh segment in the anterior-posterior direction (1.25 g). Similar findings were observed in literature (Wu and Ladin, 1996). The index of shock loading will be used, in further study, to monitor biomechanical progression of knee disorders such as osteoarthritis during and after physical therapy treatment.

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An ambulatory device for three-dimensional knee evaluation: comparison of anterior cruciate ligament deficient knee with healthy knee

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Introduction

It has been hypothesized that injury of the anterior cruciate ligament (ACL) leads to alterations in lower extremity joint kinetics, kinematics, and energetic patterns during gait [1]. Many studies have shown that injuries of the ACL causes degenerative long term changes at the knee joint and affect the performance of daily activities. Although some studies have compared the different movements, between healthy and ACL damaged knees, the new gait strategies occurring after ACL injury in all planes are not clearly understood. Additionally, these gait strategies have not been well characterized during daily activities based on outdoor measurements. The purpose of this pilot study was twofold: 1, to introduce an ambulatory system that enables the calculation of 3D knee kinematics performed during both indoor and outdoor daily activities; 2, to characterize the kinematics of the knee in order to compare the deficient knee with the healthy one.

Materials and methods

Seven young subjects (average age: 31 years with range 21–40 years) with symptomatic ACL deficiency participated in this investigation. Two kinematic sensors including each a 3D miniature gyroscopes, were attached on each shank and thigh of the subjects. This configuration enables 3D measurement of the angular velocity of the lower limbs during the walking. Physilog® system was used to digitize and record the data with a sampling rate of 200 Hz. This system also allows the calculation of the different phases of the walking cycle over daily conditions [2]. The subjects were asked to walk at a comfortable pace over a distance of 30 m in a well-lit room with regular walking shoes. 3D knee angles were calculated during walking based on the integration of the gyroscope signals. To cancel the drift due to integration, a high pass IIR filter with a cut of frequency of 0.25 Hz was used. In order to assess the accuracy of the angles calculated by the gyroscopes, a goniometer was used as a criterion standard. Spatio-temporal parameters of gait as well as knee kinematics were calculated during each gait cycle. Stride to stride variation of each parameter was estimated using its coefficient of variation ($CV = 100 \times$ standard deviation/mean). Wilcoxon rank-sum test was used for statistical comparison of the extracted parameters from the deficient and healthy knee of each subject. Moreover, for each subject, a knee laxity measurement was performed using a KT1000™ arthrometer (MEDmetric® Corporation).

Results

A high correlation was found between the angles calculated by the gyroscopes and measured by the goniometer ($r > 0.98$, RMSE < 1.4°). A significant increase was observed for the CV of the knee angle in pitch (flexion-extension) and roll (axial rotation) directions ($p < 0.02$). However, under yaw direction (aduction-abduction), the CV of the knee angle was decreased ($p < 0.02$). The decreasing rate for CV of the knee angle in the pitch direction reached more than 67% compared to the healthy knee. Moreover, a high significant correlation was observed between this parameter and the displacement measured by the KT1000™ for the knee rupture ($r > 0.9$, $p < 0.005$). Concerning the mean values of the knee angles, only a significant decrease was observed in the pitch direction ($p < 0.001$). Furthermore, maximum range of rotation was significantly decreased in the pitch direction ($p < 0.001$). However, there wasn't any tendency in other directions for this parameter ($p > 0.2$).

Discussion and conclusions

In this pilot investigation, we introduced an ambulatory device to extract the knee kinematics in particular 3D knee angles in daily conditions. This new methodology enables the comparison of gait patterns as well as 3D knee kinematics between deficient and healthy knees and consequently allows the study the long term gait changes occurring during daily activities caused by the rupture of the ACL. Although this observation has to be interpreted with caution given the small number of participants, these results suggest that the coefficient variation of stride-to-stride knee angle in all directions during walking might prove more sensitive to evaluate ACL injury. Whether these changes will also translate to clinically meaningful differences for these patients will need to be further investigated in larger sample.

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Gait-CAD—a MATLAB toolbox for application of data mining methods in gait analysis

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Introduction

In-depth analysis of gait data is a difficult task requiring extensive and specialised knowledge about the pathologies involved. The problem of extracting relevant information for specific patient groups arises from hidden coherences in the high number of measurement variables needed to fully capture the complexity of human gait. Computer based data mining methods seem to offer valuable tools to support clinical data evaluation [Sutherland 01]. Generally, such methods require highly specialized mathematicians or computer experts [Chau 01]. In this project a software toolbox was developed for systematic application of these sophisticated methods to large sets of gait data.

Materials and method

The Gait-CAD toolbox (gait computer aided diagnosis) is realised using the MATLAB environment. Its specific data structures comprise large sets of commonly collected gait variables (kinematic and kinetic data, patient information, clinical assessment scores). An interface is provided to a structured data base [Schablowski et al. 03] which ensures consistency of the data. The toolbox has a graphical user interface giving quick access to the data mining methods. The algorithms currently implemented include calculation and evaluation of characteristic features (statistical significance tests, mutual information, multivariate analysis of variance, regression models), fuzzy clustering, and fuzzy classifiers. The results obtained can be visualised in various graphical formats, numeric tables or textual descriptions.

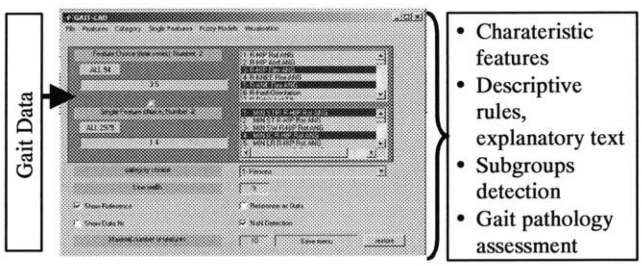

Figure 1: Gait data evaluation using the Gait-CAD toolbox

Results

Gait-CAD at its current stage contains various data mining algorithms that support the user in the solution of group specific analysis tasks. These tasks include searching for patient subgroups, finding characteristic features to separate the groups or assessing gait pathologies. The tool supports the evaluation procedure in clinical gait analysis by pointing out the most relevant data coherences for whole patient groups. Individual patients can be discussed in the context of multiple reference groups (other patient groups, normal data) and the results can be compared against each other. Particularly for poorly described pathologies this option is essential for promoting a better understanding of the underlying mechanisms.

Applications of the software include data based discovery of different gait patterns and detection of characteristic features to differentiate them [Loose et al. 02]. Sample features include reduced range of motion during particular gait periods or different curve slopes in certain phases of the step cycle. Such features are helpful in indicating on which details to focus when studying kinematic gait curves. Visualisation methods to highlight main abnormalities for a given patient group are included as well.

Discussion

The toolbox presented here forms the basis for application of data mining algorithms to huge sets of gait related patient data without detailed knowledge about the specific algorithms implied. While this opens up the way for making these methods accessible to a broader user clientele, emphasis is placed upon maintaining interpretability of the results for clinical experts. This is achieved for example through automated generation of fuzzy decision rules and results in a closer integration of the implemented methods with the clinically based manual evaluation procedure.

Conclusion

Data mining methods offer a valuable tool to analyse complex data. For medical acceptance, a comprehensible access has to be achieved to apply such methods in clinical routine.

Acknowledgments

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Assessment of temporal gait parameters in elderly people from trunk kinematic signals during walking

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Introduction

Since gait is repetitive in nature, measures of temporal gait parameters is a valuable tool for the clinician to analyze gait and quantify the timing of critical events in the gait cycle. Long term monitoring of these parameters can be used to evaluate mobility limitations, risk of falling, motor functions, and quality of life. Ideally, such a monitoring system should be light, simple to carry and should not interfere with the subject's daily activities. The number of sensors which can be fixed on the subject is a serious limitation to achieve this goal. In this study, we present a new ambulatory system based on only one kinematic sensor attached to the chest to measure temporal parameters of gait under daily living conditions. We hypothesized that gait events, such as toe-off and heelstrike would affect acceleration patterns of the trunk segment.

Materials and methods

Nine elderly (79 ± 8 years) subjects were asked to wear a kinematic sensor attached to their chest. Some of them used walking aid such as a cane or a walker. The signals were digitized at a sampling rate of 200 Hz by a portable data logger (Physilog®) and stored on a memory card. To assess the validity of the temporal parameters estimated by the kinematic sensor, information provided by two pairs of footswitches placed under the heel and beneath the big toe were used as criterion standard. Each subject performed two trials including at least 15 gait cycles at their comfortable pace. The kinematic sensor is composed of one miniature gyroscope, and two miniature accelerometers. Trunk angular velocity, measured by the gyroscope, enables the estimation of the trunk's angle during walking. The vertical and the horizontal axis were estimated by finding the projection of measured accelerations on the vertical and horizontal axis, respectively. Information extracted from the vertical acceleration was used to estimate the time of heelstrike and information extracted from the frontal acceleration was used to estimate the time of toe-off. Extracting the times of these events makes possible to measure temporal parameters such as stride, stance and double support durations for each leg. In order to cancel the drift of integration and to eliminate the noisy peaks, we used a Wavelet Transform approach.

Results

The 95% confidence interval for the difference between heelstrike detection by kinematic sensor and footswitch was [−0.044s, −0.023s]. Heelstrike detection based on kinematic sensor was systematically delayed compared to detection by footswitch (average overestimation 0.03 s). No systematic bias in detection of toe-off was observed. The 95% confidence interval for the difference between toe-off detection by footswitch and kinematic sensor was [−0.001s, 0.025s].

Discussion and conclusions

Our results demonstrate that a single kinematic sensor attached to the chest provides valid information on temporal parameters of gait in elderly people, even when they use a walking aid. Assessment of these parameters over a long period enables to measure gait unsteadiness (i.e., measure of inconsistency and arrythmicity of stepping), as well as to assess the risk of falling in elderly people[1]. Compared to most currently available systems, this new system based on only one light kinematic sensor has minimal interference with the subjects' daily activities and could therefore be used for prolonged monitoring. In addition, we previously showed that a system with the same configuration could provide information on daily physical activity of elderly people[2]. Combining both methodologies will result in a new ambulatory system based on only one kinematic sensor that could monitor daily activities and extract temporal parameters of gait when it detects the walking state. This combination would provide additional insight into motor activities during daily life.

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Energetic demands of walking in adults with poliomyelitis history

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Summary

Resting and walking energy expenditure were evaluated in adults with a poliomyelitis history and in healthy controls, using a high-technology portable metabolic system, the VmaxST.

Conclusion

Energy cost of walking in polio survivors is 27% higher than in matched able-bodied subjects.

Introduction

The energetic demands of walking in adults with a history of poliomyelitis have not been fully described. A thorough search through literature revealed a few studies about this topic. Reviewing these studies, their content was mainly focused on the effects of aerobic training programs. To the best of our knowledge there are no studies, which compared the walking energetics of adultery polio survivors with healthy controls. Such information seems important since some authors proposed that late onset symptoms, such as fatigue and walking difficulties, might partly be explained by severely reduced work capacity and increased energy expenditure of performing submaximal activities [1, 2].

The purpose of this study was to determine resting and walking energy expenditure in adults with a history of poliomyelitis and to compare their energetic demands with the demands of non-disabled healthy controls.

Method

Resting and walking energy expenditure were calculated using $EE = (4.960 \times RER + 16.040) \times VO_2$, [KJ]. The portable metabolic VmaxST system (Sensormedics, Bilthoven, The Netherlands) was used to measure VO_2 and RER. A group of 11 post-polio subjects (age: 36–68, body mass: 59–95 kg) and 12 healthy matched controls (age: 30–62, body mass: 53–94 kg.) volunteered to participate in the study. Measurements consisted of two blocks: 10 min of resting in a comfortable chair followed by 5 min of walking at a self-selected walking pace. For walking, on oval track of 50 m was used and walking pace was measured per round. The measurements were repeated four times on different days at the same time of day.

Results

All subjects, but one polio-subject, reached steady state (by visual inspection) during the period signals were analyzed. Consequently the results included data of 10 polio and 12 control subjects. The table shows the results.

	Rest P	Rest C	*Diff (%)*	Walking P	Walking C	*Diff (%)*	Net P	Net C	*Diff (%)*
Velocity (m/min)				65.9*	82.4	*25.9*			
VO_2 (ml/kg/min)	3.5*	3.2	*10.1*	14.7	13.7	*6.7*	11.1	10.5	*4.9*
VO_2 (ml/kg/m)				0.225*	0.166	*27.0*	0.170*	0.125	*27.7*
EE (kJ/min)	5.4*	4.9	*9.7*	21.0*	20.0	*8.8*	16.5	15.5	*5.9*
EE (kJ/m)				0.34*	0.24	*28.8*	0.25*	0.19	*26.9*
EE (kJ/kg/min)	0.072*	0.064	*10.9*	0.292*	0.268	*8.2*	0.219	0.205	*6.5*
EE (kJ/kg/m)				0.0045*	0.0032	*28.1*	0.0034*	0.0025	*27.2*

P = polio subjects ($n = 10$), C = control subjects ($n = 12$), * = significant different from control subjects ($p < 0.05$).

Discussion

The energetic demands of walking in adultery polio survivors were evaluated during a submaximal over-ground walking test at a self-selected speed. In addition, their demands were compared with healthy controls. The results showed significant higher values of walking expenditure for polio subjects and significant lower values of walking speed. The same result was found in the one other study that compared walking expenditure in health and polio in children [3].

Walking expenditure differences were greatest when expressed as energy used per unit of distance, i.e. not just looking at energy consumption, but also taking walking velocity into account. This is in line with a review of Fisher, in which the energetic demands of walking in health and disability were summarized [4]. He concluded that disabled persons reduce their walking speed so that energy consumption (kJ/min) decreases towards the normal range. Subsequently walking becomes less efficient in terms of energy cost (kJ/m).

Future research should focus on possible determinants of walking efficiency, such as number or extent of paralyzed muscles involved. Furthermore, research on the effect of therapeutic measures is recommended.

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The impact of ISO 9001 on the delivery of a clinical movement analysis service

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Introduction

Increasingly clinical staff, including doctors and physiotherapists, are being required to defend their gait laboratories to the outside world. Within the field concern over correct procedures has formed part of European initiatives including CAMARC, ABCMALE and ESMAC's peer review process. No mandatory accreditation process has yet been applied across Europe. ISO 9001 is a general standard for managing quality. It is not designed for clinical movement analysis laboratories, or even for measurement services. Its scope is broad so it can be applied to almost any organization. As a result it has been adopted very widely and accreditation to ISO 9001 is understood to provide a badge of good practice by professionals in many different sectors. ISO 9001 has a track record of use in the health services and industries. The Medical Devices Agency (MDA) in the UK strongly recommends the adoption of ISO 9001 and EN 46001 by manufacturers of Class 1 orthotic devices to ensure compliance with the European Medical Devices Directive. ORLAU's experience as an orthotic manufacturer revealed the appropriateness of the standard for application in movement analysis. The final decision to extend the system was made in 2001. This paper describes the implementation process and the results for the service.

Materials and method

To reflect the process approach introduced with the new edition of the standard, the whole movement analysis service, from the receipt of a referral letter to the delivery of the report and data archiving, was broken down into a series of flow charts. Each step clearly identified the input and outputs, the staff responsible, the resources needed and any records which should result. Operating procedures were referenced where necessary, typically defining more complex activities within the gait laboratory. Across the whole system paperwork and forms were standardized forming, along with computer files, records of activity. Around these core processes a series of supporting procedures was defined. These covered, for example, the calibration of lab equipment and the training of staff. Also included were 6 procedures compulsory under ISO 9001:2000, Nonconformance, Corrective Action, Preventive Action, Internal Audit, Quality Records and Document Control. The new system was introduced in stages over a period of approximately 12 months, with full implementation by July 2002. All the elements were documented in a manual, as required, mostly in the form of computer files with hard copies available where needed. Once in place the system continued to evolve under the requirements for auditing and continuous improvement.

Results

BSI accreditation to ISO 9001:2000 was obtained in September 2002. Benefits to the clinical service have included,

- Increased awareness of practice and confidence for clinicians in the results of data collection.
- Improved efficiency in the use of resources and the availability of patient information.
- Tighter control over procedures, of benefit in clinical practice and essential if the data are to be used in research.
- Better mechanisms for monitoring the service and making improvements.

Discussion

There is likely to be increasing pressure on clinical movement analysis services to implement standards and establish accreditation mechanisms. Whatever route is chosen labs will be required to make a considerable investment in time and money. Difficult decisions need to be made. Should an existing standard be adopted or an entirely new one designed? ISO 9001 has the advantage of its breadth of scope. It extends quality issues well beyond laboratory calibration and testing protocols, covering the whole management process. Being general in its requirements it does not address specific, detailed areas of concern within the field. This has the benefit of avoiding the heated controversy that arises with any attempt to agree common practice. There is, however, some potential for incorporating bad practice unchallenged within the implementation of the standard. This risk is minimized by the requirement for external assessment and the transparency required of the manual, making the whole movement analysis process open to inspection. ISO 9001 is understood by those outside the field of movement analysis, including those responsible for purchasing services. This is perhaps its greatest benefit.

Conclusion

ISO 9001 is an appropriate standard for application in clinical movement analysis laboratories. As such it provides a potential candidate for use in a future accreditation process.

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Muscle

The maximal isometric voluntary contraction manual testing of the upper limb muscles at the subjects with the spinal cord injury

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Introduction

Many biomechanics research at the propulsion in manual wheelchair combines the tools allowing the kinematics, dynamics and the muscular electric activity study [1]. The electromyographic (EMG) requires a standardization signal. The recording of a maximal isometric voluntary contraction (MVC) at the time of a manual testing does this standardization. Many studies use work of Kendall et al. (1993) to evaluate this MVC [2]. We propose a manual testing adapted to this population.

Materials and method

We chose to test the principal muscles intervening in the manual wheelchair propulsion [1]. The subjects consisted of 8 individuals with paraplegia or tetraplegia. We used the EMG ME3000P8 (1000 Hz) of Mega Electronics Ltd and respected the electrodes placement advised by the software MegaWin (Mega Electronics Ltd The 7 muscles were tested as follows: *Pectoralis major* (PM): The arm perpendicular to the trunk in the frontal plan, the elbow with 90° and the forearm positioned to that of the inspector. The inspector poses his hand on the subject elbow's on the level of the biceps and exerts a force towards the back and perpendicular to the frontal plan. *Latissimus dorsi* (LD): The arm perpendicular to the trunk in the frontal plan, the elbow with 90° and the forearm positioned to that of the inspector. The inspector poses his hand on the subject elbow's on the level of biceps brachiali, the second hand positioned on the elbow on the level of *epicondylus medialis* and exerts a force upwards and parallel with the frontal plan. *Deltoideus pars posterior* (DP): The arm is in extension complete and parallel with the trunk in the frontal plan. The inspector poses his hand on the level of *olecranon* and exerts a force forwards and perpendicular to the frontal plan. *Deltoideus pars anterior* (DA): The arm is in extension complete and parallel with the trunk in the frontal plan. The inspector poses his hand on the elbow on the level of the biceps and exerts a force towards the back and perpendicular to the frontal plan. *Triceps brachiali caput longum* (TRI): The arm parallel with the trunk in the frontal plan, the elbow with 90°, the forearm in supination. The inspector poses his hand on the internal face of the wrist of the subject and exerts a force downwards and parallel with the frontal plan. *Biceps Brachiali caput longum* (BI): The arm parallel with the trunk in the frontal plan, the elbow with 90°, and the forearm in pronation. The inspector holds the wrist with the level of *radial styloïd* subject and upwards exerts a force and parallel with the frontal plan. *Trapezus* (T): The arms parallel with the trunk in the frontal plan, the shoulders are in adduction. The inspector poses its hands on the level of the glenohumeral joint on the DP and exerts a force forwards and turned down and perpendicular to the frontal plan. This force is max when the shoulders are behind neck and turned up. This testing is different from the recommendations of Kendall [3] in the position of the subject for the test (seating/decubitus) for PD and LD, in the symmetrical effort for T, in the position of the arm in the relation to the trunk (BI, TI, DA, DP).

Results

The figures of root-mean-square (RMS) are calculated on periods of 1 s. This calculation has been made for the 7 muscles in each test. The results RMS for each muscle are standardized from the value achieved during the reference test. The analysis of the variation of RMS (Fig. 1) shows that the tests proposed enable to achieve a figure considered as maximal for the muscles BI TI DA DP T. For the muscles PM LD the tests emphasize how difficult it is for the subject to stabilize himself during the effort.

S 1	B I	TI	D A	D P	P M	L D	T	S 2	B I	TI	D A	D P	P M	L D	T
testBI	**100**	9	*110*	12	64	33	121		**100**	10	65	29	36	22	40
testTI	7	**100**	8	29	*132*	85	12		78	**100**	86	*113*	34	55	34
testDA	65	9	**100**	13	*111*	49	26		*326*	19	**100**	57	76	29	45
testDP	8	82	38	**100**	12	*102*	86		63	80	43	**100**	28	*214*	17
testPM	30	29	43	12	**100**	44	9		51	71	73	10	**100**	28	44
testLD	76	17	17	6	*108*	**100**	9		*121*	46	9	7	86	**100**	10
testT	4	24	4	7	16	13	**100**		51	17	46	*117*	21	59	**100**

Fig 1. Variation (%) of the tested muscle RMS when tested on the reference movement for each experimental condition

Discussion and conclusion

This study leads to the installation of a manual testing allowing the evaluation of the upper limb muscles force at the time of a voluntary maximum isometric contraction. The results show the difficulty to isolate a muscle in order to value it. We think this problem comes from the difficulty of the subject to stabilize himself during the effort. The maximal isometric contraction of PM and LD requires the stabilization of the trunk which is very hard for this population. We think that this testing is adapted to a population para and tetraplegia but it needs the watchfulness of the inspector about the stabilization of the trunk during the test. We think that it can be a tool interesting for the professionals working on the propulsion in manual wheel chair and using the EMG.

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Effect of isometric activity level on motion power

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Introduction

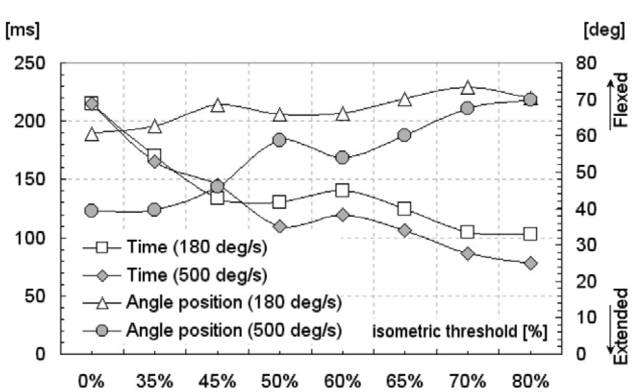
Hill results demonstrate that maximal muscle power can be developed under external loads in amount 30% of maximal muscle force or velocity. Motion preceded by an isometric muscle contraction can give significant influence by effect of elastic elements energy (result of a tendon stretching by contractile machinery) and a muscle potential elevation (Ettema et al., 1990; Jensen et al., 1991; Tis et al., 1993). Therefore, the aim of the study was to estimate the motion effect preceded by isometric contraction on muscle intensity transfer to higher possibilities and modification of force – velocity characteristic.

Material and methods

Six male competitors performed tests took part in this work: age 24±0.2 years, weight: 73±7 kg and height: 1.80±0.07 m. Subject were seated on a Biodex System 3 Pro stand in a position of 110° in hip and 90° in knee joints. They performed a knee maximal voluntary isometric contraction at the start angle (MVC), two isokinetic tests (180 and 500°/s) and isokinetic trials preceded by 2 s isometric knee muscle contraction. During all isokinetic trials muscles were contracted to the following MVC thresholds (IT): 35, 45, 50, 60, 65, 70 and 80%. The correction for the effect of gravity on the limb was then made with the mechanical lever in a horizontal position. Analogue signals of the muscle torque, the angle position in the knee joint (Biodex System 3 Pro) and EMG (ME 3000P4-Mega Electronics, Kupio Finland) were synchronized by ME4ISO with 1000 Hz sampling rate. EMG as the RAW signals was analogically frequency band-pass filtered in range of 20–500 Hz, amplified (differential amplifier, CMRR > 130dB, total gain 1000, noise < V), analogue to digital converted (12-bit) and stored in PC memory. Disposable Ag/AgCl electrodes (Medicotest, model M-00-s, Olstykke, Denmark) were attached over belly of rectus femoris (RF) and vastus lateralis (VL). Average EMG (AEMG) and spectral mean power frequency (MPF) were determined. The subjects were instructed to perform tests correctly, and they were allowed to warm up their muscles. All participants signed written consent form.

Results and conclusion

Mean value of maximal muscle torque under isometric test was 288±46 Nm, while both results of isokinetic trials were 39% (180°/s) and 72% (500°/s) lower. Tests presented in this paper show favourable effect of isometric stretch preceding isokinetic joint motion. Effect was clearly shown for lower velocities. During all isokinetic tests with IT value of motion power were 2–12% higher then without IT. Time (21–52%) and angle positions (4–21%) obtained



lower value for which maximal power values were achieved (Fig. 1). Insignificant lower values of power recorded during movement with the highest velocity were the result of slowing down by antagonistic muscles involved in stabilizing process during isometric contraction. Time values and angle position for which the maximal power values were obtained were also lower in this case. Results of AEMG and MPF for both examined muscles point at different work strategy as the effect of functions filled in the joints on which they affected. The increase of movement velocity is accompanied by the growth of muscle VL involvement. The significant effect of such activity is also the transfer of power muscles opportunities in given range of exercise intensity, what allows to modificate the Hill's force-velocity characteristic. The effect can be then the factor for better mobilisation of muscle system for dynamic exercises causing the new view on sport and rehabilitation exercises.

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Neuromuscular efficiency of the triceps surae in voluntary and electrically induced contractions in prepubertal children

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Introduction

The few studies related to muscle function in prepubertal children are often focused on changes in maximal voluntary isometric strength (Belanger and McComas, 1989) without considering the muscle activation capacities. The objective of the present study mainly concerns these activation capacities and their eventual changes for 7- to 11-year-old prepubertal children. For that purpose, neuromuscular efficiency, i.e. Torque/EMG ratio, was evaluated during isometric contractions, in voluntary or induced conditions.

Materials and method

Neuromechanical properties of the ankle plantar-flexor muscles were investigated using a specific ergometer (Pérot et al., 1999). In voluntary conditions, the activation capacities of the child were evaluated thanks to the analysis of EMG-Torque relationships. Electromyograms (EMG) were detected on each part of the triceps surae (TS) using surface electrodes. EMGs were rectified and summed up to get the triceps surae response. The tibialis anterior (TA) EMG was also recorded. Maximal voluntary isometric contraction was required three folds and the best value was taken as MVC. Then, the child maintained for 5 s an isometric torque at 10, 25, 50, 75 and 100% of MVC. One-minute rest was given after each trial. The slope of the EMG_{TS}-Torque relationship was used to obtain an index of neuromuscular efficiency (NME). The level of TA co-contraction was estimated by the slope of the EMG_{TA}-plantarflexion torque relationship. In induced conditions, NME was obtained by the ratio between the twitch amplitude (Pt) and the M-wave amplitude in response to a supra-maximal stimulus applied to the posterior tibial nerve (PTN). Stimulation electrodes were located at the popliteal fossa. The twitch amplitude was related to a muscle size evaluation obtained from the calf circumference measurement.

Results

In voluntary conditions, the EMG-torque relationships reveal that the youngest children overactivated their TS when maintaining submaximal isometric contractions. Consequently, a significant increase in the NME index with the age of the children was found. Furthermore, the level of co-contraction was also age dependent. In response to a supra-maximal stimulation of PTN, absolute and relative Pt values were significantly correlated with the age of the children. On the other hand, M-wave did not vary with the age of the children and presented already an adult value. Thus NME in induced conditions was also age dependent.

Discussion

In induced conditions, the constancy of the Mmax wave amplitude with the age of the children agrees with the fact that M-wave reaches its plateau value as soon as 3–4 years of age (Vecchierini-Blineau and Guiheneuc, 1981). The age dependent increase in the corresponding NME confirms that torque increases with age more than expected by changes in muscle size (Asmussen and Heeboll-Nielsen, 1954). In voluntary conditions, the increase of the slope of the NME index-age relationship was steeper than that found in induced conditions. This important increase in NME index may be due not only to changes in muscle contractile properties, already evoked, but also to an improvement of motor programs, with a better agonist-antagonist coordination.

Conclusion

The evaluation of neuromuscular efficiency in prepubertal children in induced and voluntary condition allows us to propose that the increase in NME with age is dual in origin, partly due to peripherical muscular properties and partly due to central mechanisms.

Acknowledgments

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Early recovery of walking after stroke

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Introduction

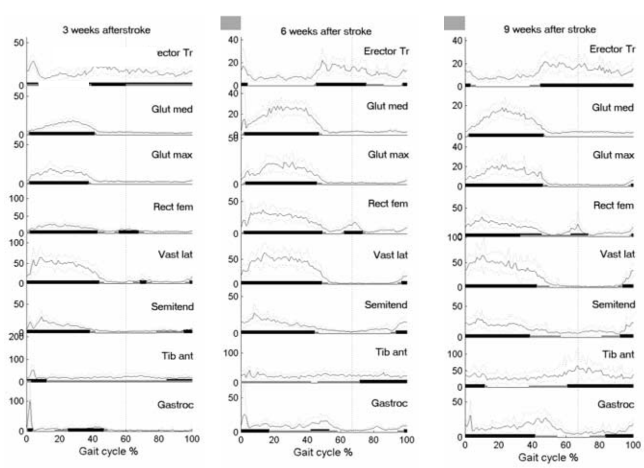
Many patients after stroke have a disturbed selective regulation of motor control. Movements cannot be performed or co-ordination of movements is disturbed. This situation is not stable. After a while new co-ordination patterns will develop. Little is known about the speed in which this happens and the type of patterns that come with it (Knutsson, 1981). One of the most important goals of rehabilitation of the motor deficits from stroke patients' point of view is the restoration of gait and improvement in function. The objective of this study is to gain insight in the development of new co-ordination patterns during the recovery of walking after stroke and its relationship to functional recovery.

Materials and methods

A longitudinal study was set up to study muscle activation patterns during early recovery of 15 patients who suffered a first ever ischaemic stroke. Muscle activation patterns are measured 3, 6 and 9 weeks after stroke using surface electromyography. Changes are quantified using the approximated generalised likelihood ratio test (Roetenberg). Functional recovery was measured using Barthel Index, Functional Ambulation Categories and walking speed.

Results

All patients showed improvement in functional ambulation category, Barthel Index and Walking Speed. However, only little individual changes in the development of muscle co-ordination were found. Most of these changes were seen in the tibialis anterior and gastrocnemius muscle (Fig. 1).



Discussion

Results indicate only little change in the development of muscle co-ordination of the affected limb. This raises the question whether these co-ordination patterns of the affected limb could be influenced at all through therapy. It would appear that the improvement in functionality is through improvement in compensation mechanisms of the unaffected side.

Conclusion

Coordination activation patterns of the affected side are only minimally affected by rehabilitation. Further analysis of coordination patterns of unaffected side is required to understand the discrepancy between the functional improvement and lack of improvement of the coordination patterns of the affected limb.

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Influence of hamstring lengthening on muscle activation timing

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Introduction

In the current clinical use of dynamic sEMG in CP children for preoperative planning it is hypothesized that timing of muscle activation patterns hardly changes through surgical intervention (Perry, 1977; Brunt, 1988; DeLuca, 1991). These findings are based on tendon transfer studies with intra muscular fine-wire electrodes and subjective visual interpretation of raw EMG signals. Little is known about the effect of muscle lengthening on muscle activation patterns of the lengthened muscles (Gueth, 1985) and their antagonists.

Aims: describe the changes in muscle activation patterns using sEMG during walking in CP-children after hamstrings lengthening.

Materials and methods

Fifteen CP-children comprising a total of 23 hamstrings lengthening (mean age: 13.8 years at operation date) were included. sEMG of semitendinosus and vastus lateralis was measured pre and post surgery. Timing parameters of the sEMG patterns were quantified, using an automatic and objective burst detection algorithm (Roetenberg, accepted) and statistically evaluated using the paired t-test.

Results

The activation, of the semitendinosus after hamstrings lengthening, shows significant delayed on-times (95% CI: −0.085, −0.00086) and off-times (95% CI: −0.141, −0.034). Burst duration did not change significantly (95% CI: −0.124, 0.0351). The activation of the vastus lateralis after surgery shows statistically significant delayed on-times (95% CI: −0.055, −0.0025) and earlier off-times (95% CI: 0.0049, 0.1199). Burst duration was significantly shorter (95% CI: 0.036, 0.1466).

Conclusions

Hamstring lengthening causes statistically significant differences in timing of both the semitendinosus and vastus lateralis. The significant decrease in burst duration of the vastus lateralis after surgery is considered to be the most important change.

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Saturday 13th September 2003 8:30–9:10
Lecture 3

Saturday 13th September 2003 9:10–10:22
Oral Session 7: Methodology

Automated classification and rule extraction from the gait pattern of CP-gait

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Introduction

Instrumented gait analysis allows the measurement and assessment of walking behavior, which facilitates identification of abnormal characteristics and recommendation of treatment alternatives. Interpretation of gait data in clinical routine is performed by looking at the whole set of parameters identifying functionally significant deviations from the normal, focusing on the most important features in respect of the clinical problem. The resulting classification into subgroups of gait abnormalities allows the formulation of a treatment plan.

In the last few years several computer-based approaches were used to overcome the limitations of manual and subjective evaluation of gait data. The aim of these approaches is to support clinicians in their decision making process towards categorizing patients according to different diagnoses by use of mathematical methods. These methods are not restricted to a few parameters for one patient at a time but can also handle large data sets from multiple patients. Such methods typically are based on the subjective expertise of the clinical experts involved [Weintraub, Bylander, Simon 1990], [Schutte et al. 2000], and they are therefore restricted to a specific problem. Fully automated classification of gait data without any prerequisite knowledge on the other hand suffers from lack of interpretability/transparency. A combination of methods is therefore presented to combine the power of automated systems with the descriptiveness of expert systems [Mikut et al. 2002].

Materials and method

In this study 43 children with diplegic cerebral palsy (6.4±1.5 years, 18.3±4.0 kg) were investigated. Pre-therapeutic (PRE) and post-therapeutic (6 weeks, POST) kinematics of a Botulinum toxin therapy were classified. For feature evaluation, the time series and their time derivatives as well as the intra-individual variances between strides in the pre therapeutic situation were compared to the corresponding data of 10 normal subjects. A fuzzy based method is used [Mikut et al. 2002] for an automated classification of pathologic/normal data and the features most relevant for this process are analyzed. A-priori factors of relevance are introduced (see the Table) to favor clinically highly descriptive rules. These factors favor for example the consideration of complete time series rather than specific time windows of this series.

Table
Automatically extracted features as CP-gait characterization sorted by information relevance, mean and standard deviation at different therapy stages and healthy walking behavior. Significant improvements are symbolized by * ($p < 0.05$)

Feature	Relevance		Mean ± STD (°)		
	Overall	Data a-priori	PRE	POST	Reference
1. ROM (PelvicTiltStride)	0.552	0.552 × 1	8.2 ± 3.3	8.0 ± 3.5	2.6 ± 0.7
2. MAX (PelvicTiltStride)	0.509	0.509 × 1	24.0 ± 7.4	25.1 ± 7.3	10.3 ± 4.4
3. MIN (DorsiFlex,Stance)	0.432	0.540 × 0.8	−28.0 ± 17.9*	−11.9 ± 13.0*	−4.0 ± 2.7
4. ROM (KneeFlex,Swing)	0.400	0.500 × 0.8	28.1 ± 12.6	29.4 ± 13.5	53.6 ± 2.9
5. MEAN (VarDorsiFlex-Stride)	0.362	0.904 × 0.4	4.8 ± 1.9	4.5 ± 2.6	1.5 ± 0.1
6. MIN (VelDorsiFlexSwing)	0.336	0.525 × 0.64	−1.2 ± 1.1	−1.1 ± 0.8	−3.1 ± 0.5
7. MIN (VelHipFlex,Swing)	0.312	0.488 × 0.64	−0.9 ± 0.6	−0.9 ± 0.5	−0.1 ± 0.4
8. ROM (PelvicRot,Stride)	0.293	0.366 × 0.8	17.8 ± 6.8	16.8 ± 7.6	7.7 ± 2.4

Results

The assessment of the relevance of automatically detected features describing CP-gait is subsumed in the Table. The four most relevant features are typical joint angle criteria regarded as clinically important [Schutte et al. 2000]. Number five in relevance describes the variance of the ankle dorsiflexion in an individual CP gait pattern which in clinical routine is not detected since small variance generally is taken as a prerequisite for a stable gait pattern and not quantitatively analyzed any further. The next two features in the order of relevance describe the time normalized joint ankle velocity of ankle and hip, respectively. In addition, the differences in the pre- and post-therapeutic situation of Botulinum toxin therapy are listed in the Table. Statistically significant differences are found in the peak dorsiflexion in stance, the characteristics which is addressed by the therapy predominantly.

Discussion and conclusion The series of gait characteristics listed in table 1 demonstrates that clinically well known features of CP gait can be reproduced in an automated algorithm without pre-requisite expert knowledge. Furthermore, the algorithm detects features which might draw the clinicians eye to other characteristics than commonly visualized in gait analysis plots.

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Gender recognition of children from gait data using artificial neural networks

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Introduction

The use of neural networks in the classification of human gait profiles has been in the past few years of interest to many researchers. Human gait has been used as a biometric measure to distinguish between known and unknown persons in cases where other biometric measures such as face are not available. In this research, we analyse simple gait data (cadence, cycle time, stride length, speed) of normal children of age range between 12 and 72 months. We examine how artificial intelligence, in the form of neural networks, can exploit such data with the objective to correctly identify a child's gender.

Data collection and method

We used the data set provided by Dr. Sang-hyun Cho for normal children available at http://guardian.curtin.edu.au/cga/data/index.html. We decided to concentrate only on primary gait parameters for simplicity and to examine the role the values of these parameters play in gender recognition. Thus, using the mean and standard deviations provided by Sang-hyun Cho for age, cadence, cycle time, stride length and speed, we generated data for females and males assuming a Gaussian distribution. We have normalised the data such that they would have a zero mean and a unit standard deviation.

Experiments and result

We have used two types of neural networks: multi-layer perceptron (MLP) and self-organising maps (SOM).

For the MLP, we have experimented with various architectures and parameters of the network to try to achieve the best recognition rate possible. With a two–layer network and a tanh activation function for the hidden layer and a sigmoid for the output layer, 5 neurons in the hidden layer and a learning rate of 0.9, we achieved a typical testing recognition rate of 57.89% with a mean square error of 0.012 after 17000 epochs of training. An optimum recognition rate of 63.16% was achieved with 10 hidden nodes and learning rate of 0.5.

We used the SOM on the same sets of normalised data as in the previous experiments with FFBP to examine how the same problem of gender classification, based on simple gait parameters, can be solved by this different type of neural network. A self–organising map does not need target outputs. It was trained only on inputs with the objective to learn their internal distribution and categorise them. We adopted a hexagonal arrangement as the topology of the neurons, since this is considered to avoid favouring of the diagonals. Then for the ordering phase, during which a rough order of the SOM is performed and the convergence phase which lasts much longer we chose the following values: Ordering phase learning rate = 0.9, Tuning phase learning rate = 0.02, Ordering phase steps = 1000, Tuning phase neighbourhood distance = 1.

A SOM of size 7 × 7 when trained for 24500 epochs showed an 84.4% recognition performance.

These percentages obtained by both types of networks were satisfactory in the sense that they were comparable to respective rates of human perception of motion as found by Cutting and Kozlowski (1977). Another remark elicited from the experiments is that SOMs on the whole proved to be better classifiers as exhibited by their achieved recognition rates.

Conclusion

Based on the series of experiments and the methodology described above we showed that machines can learn to determine the gender of children given simple gait parameters of the subjects.

We have shown that gender signatures do exist behind simple gait parameters and at an early age. We have also shown that machines, in the form of neural networks, can be taught to exhibit learning capabilities comparable and even better to those of humans in recognising gender from gait. We are now investigating the role of each gait parameter in determining gender and will present the results at the conference.

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Visualisation of gait quality using self organising artificial neural networks

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Introduction

One way of approaching the quality of gait is to describe how far the patient's gait lies from normal. The concept of detecting abnormality by learning the "normal state" was suggested by Kohonen (1997) as a possible application of his self organising map (SOM). Fernández et al. (2001) have successfully used the quantisation error (QE) of SOMs to recognise abnormal electrocardiograms. Barton (1999) demonstrated the use of SOMs to visualise abnormal gait patterns. The combination of quantification of abnormality and the identification of abnormal gait patterns provides a tool which captures the quality of gait by mimicking the unconscious competence of a gait expert (Flower, 1999). The aim of this study was to demonstrate the use of self organising neural networks to grasp the quality content of gait.

Materials and method

Full three-dimensional joint kinematics and kinetics of the ankle, knee, hip and pelvis of 10 healthy subjects were used to train a SOM. Values of the 43 curves were taken at n, $n+5$ and $n+10$ percent of the gait cycle providing a vector of 129 values. The values were normalised between 0 and 1 using the scales on the laboratory's printouts in order to keep the relative strength of curves identical to those in a laboratory setting. During training the SOM arranged the values representing normal gait on a 13 × 11 lattice of neurons. Following training, abnormal gait of randomly selected 26 patients were presented to the SOM. The neural network reduced the 129 dimensional data space into a two-dimensional curve by finding the series of neurons with the smallest Euclidean distances from the presented pattern. The Euclidean distance (i.e. QE) values were plotted through the gait cycle (Fig. 1).

In a second experiment the 10 normal and 26 abnormal gait patterns were all presented to a new SOM. Following training the topological relationships among sections of the resultant two-dimensional curves were assessed. This was used to compare normal and abnormal gait patterns (Fig. 2).

The SOM was sensitised to abnormalities around the ankle joints by multiplying the ankle related kinematic and kinetic variables by an arbitrary factor of 2. The resultant changes in the QE and the two-dimensional visualisation were examined (Figs. 3 and 4).

Results

The figures show the QE curves and the SOM projections of one normal, one slightly abnormal, and one considerably abnormal gait cycle (from the 10 normal controls and 26 patients).

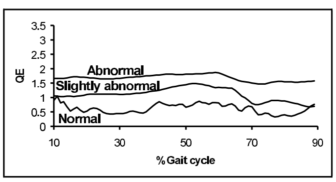

Figure 1: Quantisation error

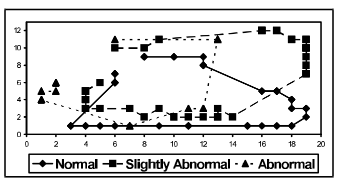

Figure 2: Som visualisation

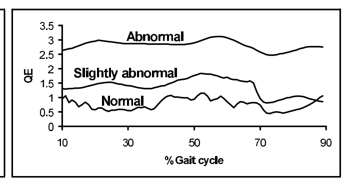

Figure 3: QE of sesitised net

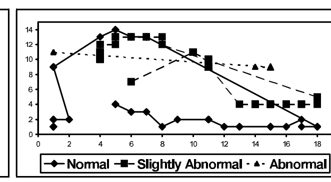

Figure 4: Sensitised curves

Discussion and conclusion

The SOM reduced the 129 dimensional data space into a single variable. Fig. 1 shows that the resultant QE is proportional to the deviation from normal gait. The deviation is quantified continuously during the gait cycle. Fig. 2 shows how the SOM projected the 43 curves into single trajectories. Similar gait patterns are located close to each other. Fig. 3 demonstrates that a SOM sensitised to ankle abnormality will separate the gait patterns dominated by abnormal ankle curves more clearly. The interpretation of the SOM trajectories of Fig. 4 together with those in Fig. 2 allow the identification of abnormal ankle patterns. The sensitisation factors can be applied to any groups of curves allowing a delicate tuning of the focus of visualisation.

The combination of the QE, SOM projections and sensitisation to groups of curves provide a well controlled set of tools which handle the whole of the gait patterns and so allow a direct visualisation of the quality of gait.

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The reliability of the normalcy index for quantifying gait pathology

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Introduction

The Normalcy Index (NI) is a statistical tool for assessing gait pathology [Schutte 2000, Romei 2003]. The NI measures the distance between the gait of a subject and that of a reference group (e.g. able-bodied) based on 16 kinematic variables derived from three-dimensional gait analysis. The validity of the NI has been assessed in several centers [Romei 2003], however, the reliability of the NI has not been published. The goal of this study was to estimate the reliability of the NI in a clinically meaningful manner.

Materials and methods

During a previous reliability study [Schwartz 2003], two able-bodied volunteers underwent 12 gait analysis sessions (3 sessions by 4 different physical therapists). Five walking trials were captured during each session. For the purposes of this study, the NI and each of its 16 constituent variables were computed for each walking trial. The inter-observer errors were estimated as the standard deviation (σ) of the appropriately pooled data. In their raw form, the standard deviations are difficult to interpret since (i) the NI is dimensionless, (ii) its constituent variables have different dimensions, and (iii) the raw numbers lack a clinical context. To arrive at a clinically relevant measure of reliability, normalized error was defined as follows.

Suppose x is a gait variable and pop is a patient population (e.g. x = mean pelvic tilt, pop = diplegia). The typical deviation in x presented by a patient drawn from pop is $\mu_x^{pop} - \mu_x^{ref}$. Normalized error ($\tilde{\sigma}_x^{pop}$) is computed as the estimated experimental error, as a percent of the typically observed deviation,

$$\tilde{\sigma}_x^{pop} = 100\% * \frac{v\sigma_x^{pop}}{\mu_x^{pop} - \mu_x^{ref}}$$

In this study, μ_x^{ref} was computed from the able-bodied reference data at the Gillette Center for Gait and Motion Analysis. For μ_x^{pop}, gait data from 145 hemiplegic, 331 diplegic, and 82 quadriplegic subjects previously seen for gait analysis were used.

Results

The NI was more reliable than any of its constituent variables (Table). The normalized error for the NI was less than 7% for any of the categories of cerebral palsy that were studied. The most reliable constituent variables had normalized errors on the order of 10–15%.

Discussion and conclusions

The NI is a reliable measure of overall gait pathology. The statistical nature of the NI results in a measure that is more reliable than its constituents (see [Schutte 2000] for details). Variables with large normalized errors are of questionable value as diagnostic or outcome tools. It is therefore imperative that treatment planning and outcome assessment employ reliable measures.

Table
The reliability of the NI and its constituent variables

Variable	Units	μ_{REF}	μ_{HEMI}	μ_{DI}	μ_{QUAD}	σ	HEMI	DI	QUAD
Normalcy Index	none	15.0	100.2	174.8	295.2	5.75	7	4	2
Pelvic tilt ROM	degrees	3.8	7.4	8.1	8.9	0.52	14	12	10
Knee flex/extension ROM	degrees	53.8	42.3	30.3	26.9	2.40	21	10	9
Knee flexion at initial contact	degrees	7.2	19.0	33.0	39.1	2.83	24	11	9
Time to max. knee flexion	% cycle	72.3	75.2	80.2	83.7	1.26	44	16	11
Max. hip extension (flex > 0)	degrees	−9.9	−0.2	3.3	12.4	3.42	36	26	15
Cadence	steps/min	59.4	67.0	64.2	48.0	1.61	21	33	14
Speed/leg length	s^{-1}	1.7	1.8	1.6	0.9	0.06	55	45	8
Mean pelvic tilt (ant > 0)	degrees	9.5	16.6	17.1	18.3	2.72	38	35	31
Max. stance dorsiflexion	degrees	13.0	10.3	6.5	4.9	1.91	71	29	24
Max. swing dorsiflexion	degrees	3.6	−1.5	−3.2	−3.3	2.50	49	37	36
Mean stance hip rotation (int > 0)	degrees	7.9	11.5	14.3	16.1	3.52	98	55	43
Time to foot off	% cycle	62.7	63.4	65.2	69.7	1.07	163	42	15
Mean stance foot progress. (int > 0)	degrees	−10.3	−6.9	−0.1	−4.3	5.24	154	51	87
Hip flex/extension ROM	degrees	44.9	46.7	45.8	39.5	1.77	95	188	33
Max. swing hip abduction	degrees	−0.4	−0.2	0.5	2.1	2.12	1234	224	85
Mean pelvic rotation (int > 0)	degrees	0.3	0.1	0.1	0.1	1.14	917	694	679

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Correlation of gait analysis data with static and dynamic clinical measurements, in children with cerebral palsy

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Introduction

Both gait analysis and physical clinical measurements are critical factors in the evaluation and treatment of gait disorders in children with cerebral palsy (CP). Previous studies (Damiano & Abel 1996; Damiano & Abel 1998; Orendurff *et al.* 1998; Aktas *et al.* 2000; Mcmulkin *et al.* 2000) only correlated a few clinical parameters and some gait analysis variables and no systematic study on the relationship between the complete set of commonly assessed clinical parameters (range of motion, spasticity, strength and selectivity) and gait analysis parameters (kinematics, kinetics, EMG, video data and time and distance parameters) could be found. This prospective study documents the correlation between objective gait analysis data and clinical measurements and evaluates the combined predictive value of static and dynamic clinical measures on gait data of children with CP.

Materials and mehods

Thirty four patients, with predominantly spastic CP (13 with hemiplegia and 21 with diplegia), were evaluated using a standardized set of measurements of ROM, alignment, spasticity, strength and selectivity, and by 3D gait analysis. Kinematic and kinetic measurements were collected using a six-camera VICON system and two AMTI forceplates. Muscle activity of seven lower extremity muscle groups were obtained using a 16 channel EMG system. Additional selective parameters were derived from normal video analysis. The relationship between 47 clinical measurements and 95 gait analysis parameters were explored by means of pearson or spearman coefficients. A series of multiple regression analysis was carried out to establish which combinations of clinical variables best predicts gait analysis parameters. The multiple regression analyses were done by a forward stepwise analysis with a significance level of 0.15 as the criterion for an independent variable to be included in the model.

Results

Low to moderate correlations were found between clinical measurements and gait data, with 27 moderate correlations (the overall highest correlation being 0.61). For the ROM, moderate correlation was only found with the kinematic data, with a total of 7 moderate correlations (for a total of 16 ROM parameters). ROM measurements of the hip were observed to be more correlated with gait data then other ROM and alignment measurements. The amount of clinically measured hip extension and abduction showed moderate correlations with hip rotation (0.61) and knee extension in stance (0.57). Unexpectedly, femoral anteversion was found to have low correlations with hip rotation in stance. Values of significant correlations between spasticity measures and gait data varied between 0.27 and 0.61. The highest correlation was found between spasticity of rectus femoris and rectus EMG activity at preswing. The lowest correlations were noticed between spasticity measures at the ankle and gait data. General comparison of all correlations revealed that strength and selectivity measurements correlated better with gait analysis data then ROM and spasticity measurements. The highest correlation was found between strength of hip extension and walking velocity. Multivariate analysis revealed that adding dynamic clinical measurements (spasticity, strength and selectivity) to a static model (ROM) improved the link between clinical measurements and gait data. The highest variance explained by clinical measurements was seen between ankle angle at initial contact and the dynamic model ($R^2 = 0.61$). High R^2 values (0.51–0.57) were also found for pelvic mean anterior tilt, hip rotation at terminal stance, ankle angle in swing and rectus femoris activity at pre swing.

Discussion and conclusion

The low to moderate correlations found in this study are in agreement with Orendurff *et al.* (1998) and Mcmulkin *et al.* (2000), however these studies only included ROM parameters. Time and distance parameters mainly correlated with strength and selectivity parameters. Damiano *et al.* (1998) also found moderate to good correlation between strength in the lower limb muscles and velocity and cadence in eleven children with CP. The variance of the gait was better explained by a combined model of static and dynamic clinical measurements, compared to a purely static model. We can conclude that, although several clinical measurements show moderate correlation with gait analysis parameters, multivariate regression analyses revealed that the majority of gait analysis parameters cannot be predicted by a combination of clinical measurements. Therefore it may be concluded that a in order to have a full view of the problems of a child with CP, clinical measurements have to be combined with objective gait analysis. We also conclude that a combination of clinical measurements of ROM, alignment, spasticity, strength and selectivity is a better predictor of gait analysis data than a combination of only ROM measurements.

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Introducing a new non-invasive method to study the anterior tibial displacement in ACL-deficient knees. A gait analysis study

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Summary and conclusion

Although this method does not provide a pure tibial translation and shows a combination of the tibial translation with other movements, but these do allow us to compare the healthy and injured knees with each other. Because of the consistency of the shape of the tibial translation, it can be concluded that this safe technique is a repeatable and reliable non-invasive method to study the stability of the knee joint in vivo situations particularly in sports activities

Introduction

Because of the small amounts of tibial translatory movement relative to the femur and the existence of the semi-circular locus of the instant center in the knee joint, finding an accurate non-invasive method to analyze tibial movement in vivo situation is very difficult and all of the available methods have their own inherent limitations (Rahimi and Wallace, 2000). The aim of this study was to introduce a new non-invasive method to directly study the excessive tibial linear movements relative to the femur in vivo situation in patients with an ACL-deficient knee.Statement of clinical significance:Since the available methods are either invasive or in vitro or static in vivo, they are not an appropriate method to assess the tibial translation, as some important issues will be overlooked (Lafortune et al., 1992). This method as a dynamic in vivo technique can help both researchers and clinicians to directly study knee stability without facing major confounding factors.

Materials and methods

A prospective experimental study was carried out on 15 ACL-deficient knee and 15 carefully matched amateur athletes as control group during walking on level ground, walking on the treadmill and running on the treadmill. Using a CODA 3-D gait analysis system with a clustering marker placement in conjunction with virtual marker feature, two virtual femur and virtual tibial points were defined at the lower femoral epicondyle and the upper tibial plateau. The distance between these two points was measured during a whole gait cycle and assumed as an index representing knee stability. This line was called ‘‘tibial displacement’’ and was compared in the normal and ACL-deficient knees.

Results and discussion

The ACL-deficient knee subjects showed an increased tibial displacement relative to the controls both in their stance and swing phases in all three tasks (↑30%). However, it was significant only in the swing phase ($P < 0.05$). The total tibial translation was also measured and showed a significant difference between the ACL-deficient subjects and the control group ($P = 0.01$). The remarkable translation in the ACL-deficient knees was noticeable in all modes, which was significant mostly in the swing phase. The shape of curves and the results of this study were in agreement with some researchers such as Lafortune et al. (1992) and Beynnon & Johnsson (1996).

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Saturday 13th September 10:52–11:12
Award Winner fo Poster presentation

Saturday 13th September 2003 10:52–12:48
Oral Session 8: Gait and Modelling

Gait patterns in patients with neuromuscular diseases: comparison between type II spinal muscular amyotrophy and Duchenne muscular dystrophy

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Introduction

Preserving gait autonomy is a major preoccupation in the management of neuromuscular diseases. Authors (Sutherland et al., 1981; Patte et al., 2000) have characterised the gait evolution of Duchenne muscular dystrophy (DMD). There is no study to our knowledge on the gait of type II spinal muscular amyotrophy (SMA). The two pathologies present a muscular weakness which imposes adaptations to prolong gait autonomy. The aim of this study was to compare two different gait patterns in order to highlight the adaptation mechanisms with muscular weakness.

Materials and methods

Three patients with DMD (7 years 9 months, 8 years and 9 years 8 months) and two patients with SMA (6 years 2 months and 5 years 11 months) were included in this study. All children received a full gait analysis including 3D kinematics and kinetics (with 5 camera VICON 512 and 2 AMTI force plates), combined with bilateral surface EMG (MA-100 system) of five muscles (gluteus maximus, rectus femoris, semi-membranosus, gastrocnemius, tibialis anterior). Clinical examination included ROM and muscle testing using the MRC scale. All patients walked barefoot at self-speed on a 12 m long walkway. A minimum of 3 trials per side were analysed for each patient. Data analysis included comparison of 35 curves with 46 gait parameters (spatio-temporal, means, peaks, ranges) for each side. With a low number of subjects, we considered a different parameter between the two groups (DMD and SMA) when the difference between these two was higher than two standard deviations.

Results

Major similarities between SMA and DMD

The muscle testing indicated a muscle weakness with the same order of magnitude for the two diseases. The cadence and pelvic tilt were similar in SMA and in DMD. Hip extension was lower than normal gait values in terminal stance. There was no knee flexion in loading response with a permanent flexor moment in stance phase. The EMG showed a premature and prolonged activity of rectus femoris, a prolonged activity of semi-membranosus and permanent activity of tibialis anterior.

Major differences between SMA and DMD

The stride length and speed were lower in SMA. Pelvis oscillation in frontal plan was higher in SMA. Hip flexion and knee flexion were higher in DMD during swing. The ankle plantarflexion at the initial contact and during swing phase was higher in DMD. The mean angle foot progression was more external in SMA. The hip extension moment at initial contact, the hip abduction moment in stance phase and the ankle extension moment in stance phase were higher in DMD. The energy exchange was higher in DMD for the sagittal plan but it was higher for the horizontal plan in SMA. The EMG showed a permanent activity of gluteus maxinus for SMA (prolonged activity in DMD), premature activity of gastrocnemius for SMA (correct or silence activity in mid-stance for DMD)

Discussion

For DMD, an excessive pelvis tilt during gait cycle, a reduced hip extension in stance phase, an excessive knee flexion in swing phase were in agreement with other studies (Sutherland et al., 1981; Patte et al., 2000). SMA used rotations to move forward whereas DMD moved essentially in the sagittal plan. SMA used all segments (trunk, head, arms) to create rotation around the hip in stance phase. DMD accepted higher flexion and abduction moments at the hip; SMA limited all moments, the ground reaction force line remained very close to each rotation center, even in the frontal plan. Several clinical hypotheses could explain these differences: the asymmetry of muscular weakness for extensor/flexor muscles was slightly different between SMA and DMD, a retraction of hip abductor muscles for DMD (allowing them to accept a higher hip abduction moment), a gastrocnemius fibrosis for DMD (a providential equinus).

Conclusions

From a better understanding of gait patterns in patients with muscular weakness can be derived their management to prolong gait autonomy. For example, it could be important for SMA to reinforce or to preserve at its most the strength of the hip abductor muscles (this in order to have the necessary hip abduction moment for a more efficient gait).

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Relationship between fear of falling and gait changes in elderly persons

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Introduction

Fear of falling is frequent in elderly people and has been associated with several adverse outcomes such as falling, decline in mobility, activity restriction, and permanent nursing home admission. Few studies investigated the relationship between fear of falling and gait performance in this population. The purpose of this pilot study was to determine the relationship between spatio-temporal parameters of gait and activity-related fear of falling in a cohort of elderly persons. Specifically, we wanted to assess the relationship between fear of falling and stride velocity, stride length, gait cycle, double support, and stance durations. In addition, we aimed to determine whether these relationships would be stronger under dual-task methodology (i.e. simultaneous walking with an attention-demanding task).

Methods

For this study, 34 community-dwelling elderly persons (median age 79 years, range 67–93) were enrolled. Participants completed two tests: 1) walking without performing a cognitive task (T1), and 2) walking while counting aloud backwards from seventy (T2). Each test was performed at comfortable pace on a 15 m length in a well-lit room, with regular walking shoes. Physilog® was used to extract the spatio-temporal parameters of gait. This system measures temporal and spatial parameters of gait during long period of walking, therefore providing stride-to-stride variability of these parameters. Falls Efficacy Scale (FES) was used to assess fear of falling. It assesses ones confidence in performing 12 activities of daily living without falling. Scores range from 0 to 120, with higher values indicating higher confidence. Correlation between total FES score and each gait parameters as well as its coefficient variation ($CV = 100 \times$ standard deviation/mean) were determined. In addition, we determined the correlation between each gait parameter and individual items of the FES to investigate possible differences. Finally, bootstrapping method with 1000 samples was used to assess the robustness of observed correlations.

Results

Under T1, significant correlations ($r > 0.40$, S.D. < 0.19, $p < 0.01$) were found between FES and stride velocity (SV), stride length (SL) and gait cycle (gct), while no significant correlation ($p > 0.05$) were observed with stance (ST) and double support (DS). Under T2, findings were similar for SV and SL, although variability in these coefficients were smaller ($r > 0.45$, S.D. < 0.16, $p < 0.005$). Under T2, correlations also became significant for ST ($r = -0.35$, S.D. $= 0.19$, $p < 0.05$) and DS ($r = -0.48$, S.D. $= 0.18$, $p < 0.005$). In contrast, no significant correlation ($p > 0.2$) were observed between FES and CV of SV, as well as CV of gait cycle under T2 while it was the case under T1. Finally, individual items of the FES with the highest correlations with gait parameters were those assessing activities requiring good mobility (i.e. shopping, walking around the house, answering the phone).

Conclusions

Our results demonstrate several significant relationships between spatio-temporal parameters of gait and fear of falling. As hypothesized, several of these relationships were stronger under dual-task testing conditions. In contrast, the discordance of findings under single- and dual-task for markers of gait unsteadiness (i.e. SV and gait cycle variability) is intriguing and should be further investigated. It supports the hypothesis that fear of falling and falling risk estimation might share some, but not all, predictors[2].

Finally, the stronger relationships between gait parameters and FES items that assess activities requiring good mobility probably reflect the relatively high mobility level of the study population. An alternative explanation could be that fear of falling primarily affects mobility-related rather than balance-related activities. Further study in elderly population with lower mobility is required to clarify this issue.

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Evaluation of gait pattern of children with hypophosphatemic rickets

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Introduction

Familial hypophosphatemic rickets (XLH) is most frequently occurring genetically caused rickets. Mode of inheritance is dominant X-linked. Affected mothers transfer the disorder to half of their offspring. All daughters of affected fathers inherit XLH, all their sons are healthy. Patients with XLH are short statured, have increasing with time varus deformity of the lower extremities, and high loss of phosphates in urine, which usually manifests itself around first year of age, when child starts to walk. Diagnosis is based on low level of phosphates in serum, high concentration in urine, and changes in knees detected in X-rays (similar to classic rickets or dysplasias). Early introduced pharmacological treatment prevents the occurrence of extreme deformations, but short stature remains. Patients require constant rehabilitation treatment. They should avoid the loading of lower extremities and spine: uneven calcification of bones could result in fractures in the weakest regions [Popowska et al.].

The aim of the present study was to assess the changes occurring in XLH patients' gait pattern, due to their short stature and varus deformities of lower extremities.

Materials and method

In the study participated 18 patients with XLH (12 girls and 6 boys), aged 7–23 years, treated for 4–15 in Dept. Metabolic Diseases. All patients had very high varus deformities of the lower extremities at the time of their admittance to the Department. At the time of the gait analysis 14 patients had normal lower extremities: in 3 cases due to corrective knee surgery, in 11 cases due to pharmacotherapy, 4 patients had still varus deformity of the lower legs.

Gait analysis was performed using VICON 460 system with six 6M cameras, EMG Motion Lab system and Kistler force plate. The EMG signals were recorded from the following muscles: rectus femoris, hip abductors, biceps femoris, gastrocnemius, tibialis anterior and gluteus maximus. Helen Hayes marker set was used for kinematic data. Data from 12 gait cycles were averaged.

Results

Gait of XLH patients could be characterised by the following features: limited range of motion in hips and knees in sagittal plane, increased rotation of the pelvis in horizontal plane, flexed knees in stance phase, decreased step length and gait velocity, increased medio-lateral shear of ground reaction force. The activation pattern of recti femori muscles and hip abductors were changed. In recti muscles there was no activation at the end of stance phase and at the beginning of the swing phase. Hip abductors were active during 3/4 of the stance phase and during the swing phase.

The difference between children with persistent varus deformity and patients with corrected deformity was quantitative, and not qualitative: all features were present in both groups, but in the second they were less pronounced.

Discussion

The limited step length was caused by limited range of motion in knees and hip and flexed knees, although increased rotation of the pelvis in the horizontal plane compensated to a certain degree these limitations. This compensation could be responsible for the early occurrence of lumbar spine pain in XLH patients (often around 20th–30th years of age).

The varus deformity of the legs caused changes in the ankle joint and feet orientation. This deformity caused additional, external torque (distance between the ground reaction force and knee joint depended on the degree of the deformity), which had to be balanced by the internal torques: this was done by hip abductors. The abnormal excitation pattern of hip abductors was still present in patients with corrected varus deformity. This could be responsible for the often observed phenomenon: already corrected deformity often came back at time of the child's puberty.

Conclusion

Children with hypophosphatemic rickets have characteristic gait pattern. This pattern acquired during period when child has lower extremities varus deformations remains after the correction of these deformations. This abnormal pattern could be responsible for the secondary problems of children with XLH.

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Relationship between gait biomechanics and inversion sprains

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Introduction

In order to increase knowledge of the aetiology of ankle sprains, a few prospective studies have investigated the underlying risk factors. Knowledge of the variables influencing and contributing to the risk of ankle sprains is important for the development of effective preventive strategies. Most probably, the aetiology of inversion sprains is multifactorial, in which intrinsic and extrinsic risk factors play their part. One of the causes that has been assumed, is biomechanical abnormalities in gait(1). Therefore, the purpose of our study was to prospectively determine gait related risk factors for inversion sprains.

Materials and method Plantar pressure data and alignment were collected from 93 (October 2001) and 130 (October 2002) healthy undergraduate physical education students without lower extremity injuries. 3D-kinematic data were collected from the first group ($n = 93$). A footscan pressure plate (RsScan nv., 2 m × 0.4 m, 16384 sensors, 480 Hz, dynamic calibration with AMTI) was mounted in the middle of a 16.5-m long wooden running track. Video data were collected at 240 Hz using 7 infrared cameras (Proreflex) and Qualisys software. Retroreflective markers were placed on the upper leg, the lower leg and the rearfoot. A multi-segment model was developed to investigate the three-dimensional motions of the knee and the ankle: rearfoot with respect to a laboratory frame, rearfoot to shank and shank with respect to thigh (Visual 3D, S. Selbie, USA). The subjects were asked to run barefoot at a speed of 3.3 m/s (±0.17 m/s). Prior to the measurements, all subjects performed habituation trials. Three valid left and three valid right stance phases were measured. After testing, the same observer placed 8 regions (medial heel, lateral heel, metatarsal heads I to V and hallux) on the footprints for all trials. Temporal data (i.e. time to peak pressure, instants on which the regions make contact and instants on which the regions end foot contact), peak pressure data and relative and absolute impulses were calculated for all 8 regions. Medio-lateral ratio's were calculated at five instants of the foot contact, namely initial contact (IC), midstance (Mst) i.e. contact of one of the metatarsal heads, foot flat (FF) i.e. contact of all metatarsal heads, heel off (HO) and last contact (LC). Excursion ranges of these ratio's were calculated over four intervals (IC-Mst, Mst-FF, FF-HO, and HO-LC). The X-component (medio-lateral) and Y-component (anterior-posterior) of the centre of pressure (COP) scaled to the foot width and foot length, were analysed. The positioning and displacements of the components were calculated at the five instants and in the intervals. From the kinematic data, initial position at heel-strike, position at push-off, maximal position, time to maximal position, excursion, maximal and mean velocity and time to maximal velocity were identified for rearfoot with respect to a laboratory frame, rearfoot to shank and shank with respect to thigh. Sports injuries were registered during a year and a half for the first group and a half year for the second group by the same sports physician.

Results

During this 1 year and a half, of the 93 subjects, 15 subjects had an inversion sprain of whom one subject bilaterally, and during half a year 6 subjects of the 130 had an inversion sprain (group 1, $n = 22$, 12 left and 10 right). As control group (group 0), 36 subjects were selected out of the first group who were followed during a year and a half. None of these subjects had injuries at the lower extremities. Statistical analyses revealed that total contact time is significant longer in subjects who sustained an inversion sprain compared to the non-injured subjects. In addition, the impulse underneath M1 is significantly higher in group 1 and the impulse underneath M5 is significantly lower. Relative contact time of M1 is earlier in group 1. Medio-lateral ratio's show that pressure distribution is more medially directed at midstance, footflat and heel off in subjects who sustain an inversion sprain. In addition, in the intervals of IC-Mst and Mst-FF, there is less displacement of the pressure from lateral to medial. From heel off until last foot contact, there is significantly less pressure displacement from lateral to medial. The X-component of the COP is situated significantly more laterally at last foot contact in subjects who sustained an inversion sprain. Although not significant ($p = 0.062$), but clinically relevant, the X-component is situated more laterally at first heel contact in group 1. Kinematic data show a significantly higher maximal pronation of the rearfoot with respect to the ground and the instant of maximal resupination velocity occurs significantly later in group 1. Time of maximal knee flexion is significantly later in these subjects, through which the flexion velocity is significantly lower. Alignment measurements show that subjects who sustain an inversion sprain, have a significantly higher metatarsophalangeal I extension range of motion.

Discussion and conclusion

Our results reveal that the gait of subjects who will sustain an inversion sprain has typical characteristics of a laterally situated COP at initial contact, which implies that the trust needed to invert the ankle is smaller in these subjects. In addition, at midstance, footflat, and heel off, these subjects show a mobile foot type, which is more pronated and accompanied with more pressure underneath the medial side of the foot and maximal knee flexion is later. Resupination starts later and the roll off does not happen across the hallux, but more laterally, probably because of the diminished support at the metatarsophalangeal I joint. Total foot contact time is also longer than in normal subjects. The findings of this study suggests that effective prevention and rehabilitation of inversion sprains should include attention for gait patterns and adjustments of the foot biomechanics.

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Functional electrical stimulation augmented partial weight bearing support treadmill training for acute incomplete spinal cord injured patients—a pilot study

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Introduction

The main barrier to early gait training of the incomplete spinal cord injured patient (ISCI) is the inability of the patient to stand or walk independently. Both partial weight bearing support (PWBS) treadmill walking and functional electrical stimulation (FES) have been proven to be effective in the rehabilitation of this patient group (Field-Fote, 2001). To date there have been no reports on the use of the combination of FES and PWBS treadmill training in patients during the acute phase of spinal cord injury. Early intervention with ISCI patients is essential in maximising their functional recovery. The objective of this study was to explore the combination of FES with PWBS treadmill gait training in the rehabilitation of acute ISCI subjects.

Materials and methods

Fourteen subjects were recruited to receive daily gait training on the treadmill for 4 weeks. Subjects walked on the treadmill for up to 25 min per day, for 5 days per week. This was compared with a control period of 4 weeks of standard physiotherapy. Two subjects withdrew from the study. Subjects were randomly assigned to either an AB (control – intervention) or BA (intervention – control) sequence. Outcome measures, including over ground walking speed, walking endurance (distance walked in 6 min) and observational gait analysis, were recorded prior to the first study period and in the final week of the control and intervention periods.

Results

All subjects showed an improvement in distance walked on the treadmill across the intervention sessions. This was accompanied by an increase in treadmill walking speed and a progressive decrease in PWBS as a percentage of body weight. A greater increase in over ground walking endurance was observed following intervention in the AB group (mean increase = 72.2 m following intervention compared to 38.4 m following the control period). Greater improvements following treadmill training were also noted in two subjects in the BA group, however the mean increases following control and intervention periods in the BA group were equal. A similar trend was observed in over ground walking speed.

Discussion

Improvements in walking speed and endurance were achieved following FES and PWBS treadmill training when compared to physiotherapy alone. Observational gait analysis revealed that quality of gait also improved following treadmill training in the majority of subjects in both groups. However, improvements in gait quality seen on the treadmill were not always automatically transferred to over ground walking. Two subjects in the BA group made further dramatic improvements in gait quality following the control period. This included learning to use walking sticks rather than more cumbersome walking aids. This indicated that FES and PWBS treadmill training may be a powerful adjunct to physiotherapy, but that conventional techniques are still required to enhance gait quality. Nine of the twelve subjects who completed the study had not commenced conventional gait training prior to beginning treadmill intervention. PWBS treadmill training minimised health and safety risks and enabled gait training to be commenced much earlier than would have otherwise been possible. The addition of FES also reduced the effort required by the therapists in assisting swing phase limb advancement and stance phase support.

Conclusions

Over ground walking endurance improved following FES and PWBS treadmill training. The random allocation of subjects into AB and BA groups suggested that these improvements were at least part due to the intervention and not solely to natural recovery in this small sample. Conventional gait training techniques are still essential in the transition from treadmill walking to over ground walking to enhance gait quality and teach the use of walking aids. A larger study is required to reinforce the results of this pilot study and to investigate the effects of the withdrawal and reinstatement of the intervention.

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Adal treadmill and school bag carrying

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Introduction

To the authors' knowledge, only one research study has investigated the impact of backpacks in children or adolescents using measurement of static posture and gait kinematics (Pascoe 1997). No work in the literature has been devoted to kinetic analysis of backpack carrying in children. So, the purpose of this study was to determine the impact of different methods of carrying book bags on gait kinetics in children aged 11 – 13 years and in that case to determine if the way of carrying affects the gait kinetics in children.

Materials and method

Ground reaction forces (GRF) of right and left feet were measured on a treadmill ergometer (Belli 2001). Forty-one healthy children, mean age 12 years, participated in this study. The 3 trials consisted in walking on the treadmill at the speed of 3.5 km/h, first without backpack (WO) and then carrying a 10-kg school bag on the right shoulder (1BP) and both shoulders (2BP). For each carrying condition, GRF were recorded, averaged, and analyzed for 30 steps. Stride, Stance, Double Stance, thirteen specific GRF parameters and the symmetry index (SI) were measured.

Results

The right leg produced higher propulsive fore-aft forces than the left one, whatever the walking conditions were. For the two maximum peaks and the average vertical force during Stance, a statistical difference was found between WO and 1BP and WO and 2BP (1BP > WO, 2BP > WO) but never between 1BP and 2BP. The children increased their Stance and Double Stance when walking with backpack (1BP, 2BP) compared with walking without backpack (WO). SI increased with 1BP (compared to WO/2BP) for Fy1 when it decreased for Fy2. No statistical difference appeared when comparing the SI for WO and 2BP conditions, whatever the considered gait parameters. A significant difference was found for Fy1 and Fy2.

Discussion and conclusion

When carrying a backpack the children walked with longer Stride, Stance and Dstance compared to walking without a backpack. In our study, we noticed a significant increase of Dstance when the children walked with a backpack. This was then not due to the use of a treadmill, and the backpack was therefore the cause of the increased Dstance. In our study, SI remained the same whether children walked with or without any backpack except for fore-aft forces. Carrying a 10-kg one-strap backpack induced an asymmetric gait for breaking and propulsive fore-aft forces. It's interesting to note that this asymmetric gait didn't existed with a two-strap backpack. The average force during propulsion and the propulsive impulse with 1BP were higher on the right side compared to WO/2BP probably because all the children carried their backpack on their right shoulder. Carrying a 10-kg backpack on one shoulder brought about an imbalance and, after the swing, children needed a greater propulsive force to get back in balance.

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Validation of joint rotation and translation calculations using a joint coordinate system approach

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Introduction

Various mathematical procedures are well known in the biomechanics community to compute joint kinematics in 3D space. Among these, the Joint Coordinate System (JCS) method (Grood & Suntay, 1983) is widely accepted and has been extensively used over the years. A popular reason cited when justifying the choice of this method is the anatomical relevance of the motion axes. The anatomical relevance of JCS axes is a key advantage of this computation approach over other techniques such as the helical or screw axis methods (Woltring, 1994). The main objective of the current project was to verify the validity of joint motions calculated using a JCS method implemented into a in-house joint motion calculation software.

Methodology

Using three digital video cameras (JVC model GRDVL 9800) laid out in a semicircle configuration, a lower-extremity model proportioned to a 178 cm male was recorded in a neutral position to establish joint axes as well as in many different joint attitudes to verify the calculations performed using the JCS. The neutral position trials served to establish the local reference systems for each segment. Reflective markers ($n = 17$) were installed on the model and their positions were tracked and reconstructed using the APAS system. The cameras were calibrated using a cage with twelve reflective markers mounted to it and dispersed evenly in its volume. The models' lockable spherical joints were moved to various attitudes and positions to assess the methods' capacities over a large range of motion. Due to physical limitations of the model that was constructed, translation assessments were limited to the knee joint and to antero-posterior and medio-lateral displacements. The computed values were compared to reference measurements made with a manual goniometer or a ruler built into the model.

Results

Results that were obtained show that the computation approach yields results that match up very closely with the reference measurements. As an example, when only the ankle joint was moved into 10° of dorsiflexion, the computed value for that motion was 10.2°. The same level of congruency was attained when complex model attitudes were measured. When the knee was set to 30° of flexion, neutral abduction/adduction and 25° of tibial external rotation, the computed results were of 29.4, 2.6 and 24.8°, respectively.

Translation measurements over a range of 2.3 cm in the antero-posterior direction and 2.5 cm in the medio-lateral direction proved to be as accurate as the rotations. The models' knee joint was moved to 3 different positions in both translation directions. For all translations, the measured error was limited to less than 2 mm (range: 0.01 – 0.18 cm).

Discussion

A very high level of accuracy was achieved in all calculations as demonstrated in the results cited above. Although these results are very encouraging, they must be interpreted with caution. The main source of this caution is the tool used to obtain the angular reference measurements. In an optimal setting, the tool is accurate to 0.5°. However, due to the way the model was built, it is unlikely that this level of accuracy was achieved. Nonetheless, we are confident that the computations provide very accurate angles throughout the models' range of motion. The translation were less affected by the reference tool since direct measurement of the model segment positions were obtained at an accuracy of 0.05 cm.

Conclusion

The current project allowed the verification of results computed by using a JCS approach. The results demonstrate that a high level of accuracy can be obtained for both translations and rotations. Further research on this topic should focus on refining the reference measurements for the angles.

References

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Gait model with anticipatory control of motion symmetry

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Introduction

A walking model with its motion control has been developed for the purpose producing a continuous and stable symmetrical gait motion. It follows from previous work [1] on a biped robot model. The algorithm implementation in a real biped robot is under way. This research is in line with previous developments such as those of McGeer [2] and Garcia [3]

METHODA system of rigid bodies, each with its own mass and inertia, consisting in legs, knees and upper body is shown on Fig. 1. Generalised impulsive external forces and torque as well as gravity forces are applied to the model.

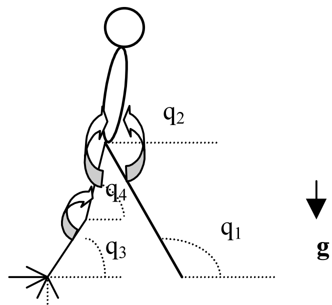

Figure 1: Four DOF Model

A stiff knee is assumed for the stance leg, and the four degrees of freedom resulting model leads to a symbolic system of four differential equations of motion using the Kane formalism. A polynomial solution in the form of $V_i = Ci_1 + C_{i\,2}t + C_{i\,3}t^2 + C_{i\,3}t^3$ is assumed for each body This solution is required to satisfy the initial conditions and the linearised equations of motion for various powers of t. Furthermore symmetry and gait velocity at mid-stance is prescribed thus requiring specific initial body angular velocities. The needed steps in angular velocities are then produced by the various impulses at propulsion time, which can be so tuned at the beginning of each gait cycle.

Results

A continuous gait motion can be obtained and visualised with an animation programme. A limit cycle involving primarily the leg variables is reached after a few steps. The propulsion impulses may vary somewhat from cycle to cycle depending on the amount of step angular velocity corrections that need to be applied. The stability of the system can be observed from the steadiness the limit cycles when perturbation impulses, such as tripping impulses, are purposely introduced at various time of the gait cycle. These tripping impulses may be increased until a complete instability of motion has occurred. Some stability margin can then be defined for the above algorithm in the presence of applied perturbations.

Discussion and conclusion

This model produces a simulation which displays symmetry, which is often claimed to be a general objective for a good gait. The method is general and can be adapted to a model displaying a larger number of degrees of freedom. For a pneumatic biped robot, the time over which the propulsion impulses are distributed may lead to a different behaviour and the algorithm might need some adaptation. The limit cycles are found to be very useful for the assessment of stability as for example when tripping impulse are accidentally applied. Applications are considered eventually for the design of active and semi-active intelligent prosthesis. The anticipatory algorithm with delay can be adapted with some delay additions to a walking robot or to an intelligent prosthesis.

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