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The Impact of Instrumented Gait Analysis on Surgical Planning: Treatment of Spastic Equinovarus Deformity of the Foot and Ankle

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Abstract

Background: Despite the logic behind instrumented gait analysis, its specific contribution to clinical and surgical decision making is not well known. Our purpose in this study was to determine the influence of gait analysis with dynamic electromyography upon surgical planning in patients with upper motor neuron syndrome and gait dysfunction.

Methods: Two surgeons (MAK and DAF) prospectively evaluated 36 consecutive adult patients with a spastic equinovarus deformity of the foot and ankle. After an initial history and physical exam, each surgeon independently formulated a surgical plan. Surgical treatment options for each individual muscle/tendon unit crossing the ankle included lengthening, transfer, release or no surgery. After the initial clinical evaluation and surgical planning, all patients then underwent instrumented gait analysis collecting kinetic, kinematic and poly-EMG data using a standard protocol by a single experienced physiatrist (AE). Each surgeon reviewed the gait studies independently and again formulated a surgical plan. The surgical plans were compared for each surgeon before and after gait study. The agreement between the two surgeon’s surgical plans was also compared before and after gait study.

Results: Overall a change was made in 64% of the surgical plans after the gait study. The frequency of changing the surgical plan was not significantly different between the more and less experienced surgeons. The agreement between surgeons increased from 0.34 to 0.76 ($p=0.009$) after the gait study. The number of surgical procedures planned by each surgeon converged after the gait studies. Correction of the varus deformity was seen in all patients that underwent surgical treatment.

Conclusion: Gait studies alter surgical planning for patients with equinovarus deformity of the foot and ankle and can produce higher agreement between surgeons in surgical planning.

Clinical Relevance: The equinovarus deformity is due to a variety of deforming forces and a single, best operation does not exist to correct all equinovarus deformities. Rather, a muscle specific approach that identifies the deforming forces will produce the best outcomes when treating the spastic equinovarus deformity.

Introduction:

Limb deformities and gait dysfunction are common consequences of the upper motor neuron (UMN) syndrome which is seen commonly after stroke and traumatic brain injury. UMN is characterized by impaired motor control, muscle paresis and muscle spasticity. A net imbalance of muscle forces across joints can lead to both dynamic and static joint deformities. Surgery has been used to treat the limb deformity and attempts to restore balance through selective muscle lengthenings, transfers and releases[1-3]. Surgical intervention is typically muscle specific. The objective of presurgical planning is to understand muscle activity and to predict the functional behavior after surgical intervention.

Clinical examination and observational gait analysis have been the mainstay of evaluation. Observational gait analysis, however, has been identified as an inadequate diagnostic method in the evaluation of gait abnormalities[4,5]. Instrumented gait analysis can provide dynamic electromyographic, kinetic and kinematic data to help characterize movement disorders and is collected and analysed frequently[6-10]. Despite the logic behind instrumented gait analysis, its specific contribution to clinical and surgical decision making is not well known. Because of associated cost and lack of proven benefit, the use instrumented gait analysis has been recommended against when planning the surgical reconstruction of spastic lower extremtiy deformities[11-13]. Other authors have found instrumented gait analysis to provide valuable diagnostic information, alter treatment considerations and possibly even improve outcomes[2,14-16]. Currently the clinical utility of instrumented gait analysis remains contoversial.

The purpose of this study was to determine the impact of instrumented gait analysis in surgical planning in patients with UMN syndrome and a spastic equinovarus deformity. We sought first to determine whether gait analysis changed a given patient's surgical treatment plan for each of two surgeons. This aspect of the study evaluated the accuracy of the clinical examination in determining which muscles were causing the deformity. Secondly, if the gait analysis did change the treatment plan, then we sought to determine whether there was a change in the degree of agreement between surgeons regarding details of the surgical plan. As a measure of outcome we used increased agreement between surgeons as a positive outcome. Third, the two surgeons involved in the study were of different levels of clinical experience and we sought to determine whether greater clinical experience was correlated with less impact of the instrumented gait analysis upon surgical planning.

Materials and Methods:

Two attending neuro-orthopaedic surgeons (DAF and MAK) prospectively evaluated 36 consecutive adult patients with UMN syndrome with an equinovarus deformity of the foot and ankle over an 18 month period. The deformity was bilateral in 5 patients therefore a total of 41 equinovarus deformities were evaluated. The demographic information and etiology of the deformity for the patients are presented in Table 1.

Table I. Patient Demographics

Number of Patients	36
Number Bilateral	5
Number of Males	21
Number of Females	15
Mean Age	41.9 years
Injury Type:	
Anoxia	1
Cerebrovascular Accident	14
Static Encephalopathy	2
Spinal Cord Injury	2
Traumatic Brain Injury	16
Familial Spastic Paraparesis	1

At the beginning of the study, surgeon (1) had less than one year's experience treating patients with neurologic disorders while surgeon (2) had 15 years of experience. Every patient in the study was evaluated independently by both surgeons who performed a full history and physical examination. Radiographic examination was used selectively to evaluate bone and joint anatomy. Each surgeon independently formulated a surgical plan for correction of the deformity of the foot and ankle prior to the gait analysis.

As part of the surgical plan the 11 muscle-tendon units crossing the ankle were included: tibialis anterior and posterior, extensor hallucis and digitorum longus, peroneus longus, brevis and tertius, flexor hallicus and digitorum longus, gastrocnemius and soleus. The evertor and invertor moment arms for the muscles crossing the ankle have been descibed to help understand a muscle's contribution to varus or valgus[17]. A reommendation for each of 11 muscle tendon units crossing the ankle was recorded for lengthening or transfer (reconstruction), release or no surgery. Reconstruction was considered possible if the deformity was supple and the forces could be re-balanced. Lengthening was considered for muscles that were overactive but demonstrated functional activity. Transfers were considered for muscles that were expendable with adequate strength, demonstrated phasic activity in the gait cycle or could be split and transferred. Release was considered for muscles that were spastic, contracted and without phasic control. Lengthening, transfer or release were all considered surgical procedures.

Also included in the surgical plan were treatment recommendations for 3 structures in the foot: the abductor hallucis brevis, the short toe flexors and the plantar fascia. The planter fascia was considered for release as part of a Steindler stripping of the plantar aspect of the foot. Patients with rigid deformities were considered for triple or ankle arthrodesis and were excluded from this study. The surgical plans were recorded on standardized checksheets that were transferred into a computerized database.

After the initial surgical plans were completed patients were referred for an instrumented gait analysis. At our institution gait analysis is performed routinely for all patients under consideration for surgical reconstruction of complex lower limb deformities and gait disorders. Gait studies utilized a standard protocol and were performed by a single experienced physician (AE). Gait studies collected kinetic and kinematic data using a CODA mpx30 optoelectronic active marker system and two AMTI force platforms and dynamic EMG data with surface and wire electrodes[18]. Dynamic EMG data was routinely collected for extensor hallucis longus, anterior and posterior tibialis, flexor digitorum longus, peroneus longus, lateral gastrocnemius, soleus and in some cases flexor hallucis longus. The dynmaic EMG of lateral head of the gastrocnemius was recorded only as it has been shown to correlate with the medial head[19]. 10 gait cycles were completed by the patient during the examination and 3 representative cycles were included in the printed report.

Both neuro-orthopaedic surgeons reviewed each gait study independently and reformulated their surgical plans. The surgeons reviewed dynamic EMG data, kinemtic data and kinetic data and they frequently reviewed videotapes of the gait study. The patients were seen again at the time of reformulation of the surgical plan. Surgical plans reformulated after gait analysis were recorded on standardized checksheets and then transferred into the database. The surgeons were blinded to each other’s plans. Each surgeon completed 41 surgical plans before and after gait analysis for a total of 164 surgical plans.

All patients included in the study that underwent surgical treatment for the equinovarus deformity were scheduled for clinical evaluation at 1, 3, 6 and 12 months after surgery by both surgeons. A physical examination and observation gait analysis were performed for patients at these intervals. The position of the foot and ankle were evaluated at rest and during activity for evidence of recurrence of the equinovarus deformity. Recurrence was considered positive if any evidence of varus or equinus was apparent, even less than 5 degrees. Examinations also noted any development of a valgus or calcaneus deformity. 25 patients (26 deformities) underwent surgical correction and 24 patients (25 surgeries) returned for clinical evaluation. The average length of clinical follow up was 7.2 months (range 1-20 months) The one patient unavailable for examination became incarcerated after his reconstructive surgery.

Statistical Methods:

Data were analyzed after the collection period was completed. Changes in the surgical plan created before and after the instrumented gait analysis were analyzed for each surgeon. The procedure (lengthening/transfer, release, no surgery) recommended for each muscle was compared between the pre and post-gait analysis assessments for a given surgeon. The proportion of changes in treatment plan was defined as the proportion of ankles for which *any* muscle's treatment was altered. Agreement on the treatment plan was defined as the proportion of ankles for which *all* muscles' proposed treatments were identical between surgeons. Thus, the proportion of treatment changes and proportion of procedural agreement could range from 0 to 1. Data collection and analysis were performed by independent researchers (JW, RFS).

Differences between surgeons in the rate at which they altered their recommendations in response to the gait analysis were analyzed using the Chi Square Test. Rates of agreement prior to and after the gait analysis were compared using the Fisher's Exact Test. Two-way analysis of variance was used to assess the impact of surgeon, the gait analysis (pre vs. post), and the interaction between surgeon and gait analysis.

Results:

Surgical plans for correction of the equinovarus deformities were changed on average 64 % of the time after the instrumented gait analysis. For surgeon (1) the proportion of ankles for which some aspect of the surgical plan changed was 0.56 and for surgeon (2) the proportion was 0.71. This difference between the two surgeons was not statistically significant (Chi Square = 1.89, 1 d.f., $p=0.17$). Within the overall surgical plan, the treatment of the tibialis posterior was the changed most frequently by the two surgeons. After the instrumented gait analysis surgeon (1) changed the treatment plan for tibialis posterior with a frequency of 0.27 and surgeon (2) changed the plan with a frequency of 0.30. Data for each muscle are summarized in Table II.

Table II. Frequency of change in surgical plan after gait study

	Surgeon (1)	Surgeon (2)
Tibialis Anterior	0.12	0.17
Tibialis Posterior	0.27	0.32
ExtensorHallucis Longus	0	0
Extensor Digitorum Longus	0	0
Flexor Hallucis Longus	0.27	0.27
Flexor Digitorum Longus	0.17	0.15
Peroneus Longus	0	0.05
Peroneus Brevis	0	0.05
Peroneus Tertius	0	0
Gastrocnemius	0.15	0.02
Soleus	0.12	0.05
Short Toe Flexors	0.07	0.22
Abductor Hallucis Brevis	0.02	0.05
Plantar Fascia	0	0
Frequency of Change to any part of surgical plan	0.56	0.71 p = 0.17

Note: 3 treatment options existed for each muscle/tendon unit in the surgical plan: reconstruction (lengthen/transfer), release, no surgery. A single surgical plan may have had multiple changes within it.

Overall agreement for the two surgeons for muscles specifically studied with dynamic EMG increased significantly from 0.34 to 0.76 (Chi Square = 6.86, 1 d.f., $p < 0.01$). Overall agreement between the two surgeons, that is identical surgical plans for all 14 tendon/muscles (14^3 or 2,744 potential surgical plans for each patient), including those not evaluated with dynamic EMG also increased significantly from 0.17 before the gait analysis to 0.29 after the gait analysis (Chi Square = 7.25, 1 d.f., $p = 0.01$). The greatest increase in agreement was observed for tibialis posterior. Prior to the instrumented gait study the frequency of agreement of management of tibialis posterior was 0.71 and after the gait study there was complete agreement on management of tibialis posterior. The lowest agreement was observed for flexor hallucis longus both before and after the gait analysis. A summary of the agreement between the 2 surgeons before and after gait study is shown in Table III.

Table III. Agreement between Surgeon (1) and Surgeon (2) before and after gait study

	Before Gait Study	After Gait Study	
Tibialis Anterior	0.86	1.00	
Tibialis Posterior	0.71	1.00	
Extensor Hallucis Longus	0.90	1.00	
Extensor Digitorum Longus	1.00	1.00	
Flexor Hallucis Longus	0.34	0.46	
Flexor Digitorum Longus	0.66	0.85	
Peroneus Longus	1.00	0.95	
Peroneus Brevis	1.00	0.95	
Peroneus Tertius	1.00	1.00	
Gastrocnemius	0.88	0.95	
Soleus	0.85	0.98	
Short Toe Flexors	0.73	0.73	
Abductor Hallucis Brevis	0.85	0.90	
Plantar Fascia	0.95	0.95	
Overall agreement in surgical plan for muscles individually studied with gait analysis dynamic EMG	0.34	0.76	$p < 0.01$

With respect to the number of surgical procedures recommended per ankle, Surgeon (1) recommended significantly fewer procedures (5.2) than Surgeon (2) recommended (6.1) ($F = 21$, d.f. = 1, 40, $p < 0.001$). The average number of surgeries recommended per patient prior to the gait studies (5.6) did not differ significantly from the average number recommended after the gait studies (5.7) (F=0.11, d.f = 1, 40, p = 0.74). Surgeon (1) planned a total of 207 surgical procedures before the gait analysis and 219 surgical procedures after the gait analysis for the 41 patients. Surgeon (2) planned a total of 254 surgical procedures before the gait analysis and 246 surgical procedures after the gait analysis for the 41 patients. There was a significant 2-way interaction between surgeons pre and post surgical plans (F=2.44, d.f. = 1, 40, p = 0.035) indicating a tendency for the number of the two surgeons recommended surgical procedures to converge after the gait analysis. This convergence of surgical plans is show graphically in Figure I.

Figure I. Number of Surgical Procedures per Equinovarus Deformity

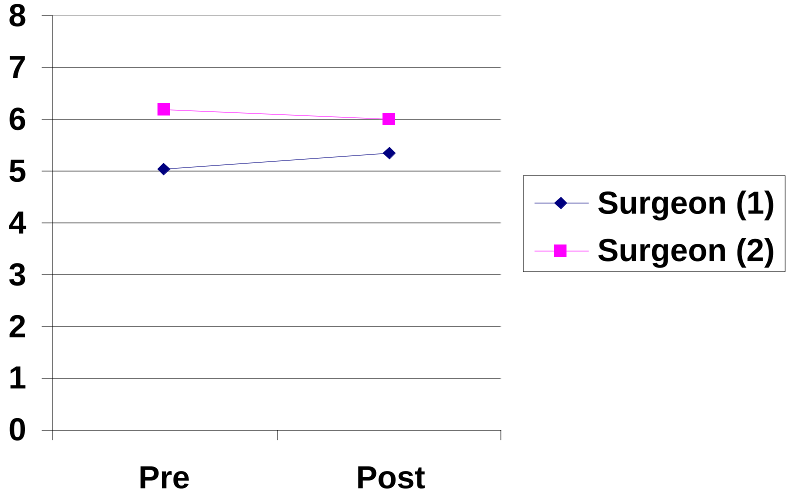

Figure 1 shows the average number of recommended surgical procedures per ankle on the Y axis and the time frame (pre or post gait analysis) on the X axis. Surgeon (1) (diamond) and Surgeon (2) (square) are shown separately.

In the 25 surgically treated equinovarus feet there were no recurrences of the varus deformity. All 25 feet were neutrally balanced with respect to inversion and eversion and were able to be placed flat on the floor at rest and during gait. 1 patient had a mild recurrence of a dynamic equinus deformity but overall had shown resolution of the varus component, improved gait velocity and orthotic free ambulation. No valgus or calcaneus deformities developed. All patients were satisfied with the correction of the equinovarus deformity and felt that their gait had improved.

Discussion:

The surgical plan was changed on average 64 % of the time by the two surgeons after the gait study. We conclude that clinical judgement alone is inadequate in understanding and planning surgical correction of the spastic equinovarus deformity. On average the surgical plan was changed most frequently for the tibialis posterior muscle (30 %). Unlike extensor hallucis longus and tibialis anterior, tibialis posterior is a deep muscle and not visible or easily palpable. Heel inversion can suggest spasticity of tibialis posterior but other muscles can cause this deformity. Flexor hallucis longus and flexor digitorum longus run parallel to tibialis posterior and can potentially contribute to heel inversion and equinus and their activity is also difficult to assess by clinical exam alone.

Agreement between the two surgeons increased significantly after the gait study. For the muscles studied with dynamic EMG the agreement more than doubled from 0.34 to 0.76. Agreement was seen to increase significantly in spite of the high frequency of change to both surgeon's plans. Complete agreement for the 14 muscle/tendons including those not studied with dynamic EMG also increased from 0.17 before the gait study to 0.29 after the gait study. The lowest agreement after gait analysis was observed for flexor hallucis longus and the short toe flexors, muscles for which dynamic EMG data is not routinely collected as part of gait analysis.

Greater agreement was not achieved by the less experienced surgeon moving toward the more experienced surgeon’s plan but by both surgeons moving toward a common plan. Cases where differences of opinion existed were reviewed. Different functional expectations for the patients were a cause for disagreement. If one surgeon believed that a patient was going to achieve a high level of ambulation a flexor digitorum longus transfer to the os calcis was often recommended whereas if the other surgeon had lower functional goals this procedure was not included.

Despite the large difference in years of clinical experience between the two surgeons, no significant difference was observed between their frequencies of changing surgical plans after a gait analysis. Advanced clinical experience does not reduce the impact of an instrumented gait analysis on surgical planning. This further supports the concept that clinical judgement alone is not adequate in determining the deforming forces in the spastic equinovarus deformity.

The ultimate question of interest is whether gait analysis improves the functional outcome from surgeries of this type. To definitively answer this question would require randomizing patients to surgery with or without prior gait analysis and then evaluating their function post-operatively. Based on published and personal experience we did not wish to provide treatment to patients with a spastic equinovarus deformity without the information available in an instrumented gait analysis. Thus we used change in surgical plan and increased agreement between surgeons as surrogate indicators for improved quality of the surgical plan.

100 % correction of the varus deformity (25 out of 25) was achieved in the surgical treatment group. No opposite deformities, that is valgus or calcaneus, were created. Using the same muscle specific diagnostic and treatment strategy, similar success was reported previously by one of the co-authors of this research with no recurrences in 59 surgically corrected equinovarus deformities[8]. These results compare favorable with other published series of surgically treated equinovarus deformity. An array of surgical procedures have been described and reported in the literature to treat the equinovarus deformity. Almost all of these reports include poor results due to residual deformity, typically recurrent or uncorrected varus. Residual deformity ranges from 19 – 62 % in other reports[3,12,20-25].

In 1991, Barnes and Herring[11]reported a series of 20 children (22 feet) with spastic cerebral palsy and an equinovarus deformity. These patients all had a combined split anterior tibial tendon transfer and intramuscluscular lengthening of the posterior tibial tendon. 14 of the feet treated had an excellent outcome. 4 feet with mild residual deformity had a good result and another 4 had a poor outcome. These authors indicate that they may have eliminated the necessity for dynamic electromyography analysis by operating on both the anterior and posterior tibialis muscles simultaneously in all cases. Perhaps not all of the feet in the excellent outcome category required surgery on both the anterior and posterior tibial tendons however. Unnecessary surgery has been shown to be reduced with the use of instrumented gait analysis[15]. Unnecessary surgery can also increase operative morbidity and muscle weakness. A single,optimal operation does not exist for correction all equinovarus feet. Rather, treatment must be individualized and clinical examination alone is not adequate at identifying the underlying deforming forces.

The reproducibility of the surgeon's exam was not evaluated in this study. Conceivably the surgeons could create different surgical plans for the same patient at different time points. To provide a stable neurologic examination, all patients were more than one year beyond their neurologic injury. No patient underwent gait analysis and follow-up physical examination greater than 6 months after the initial examination and surgical plan were done. Each surgeon typically spent up to 60 minutes with the patient before a gait analysis and provided a comprehensive examination. The examination included a complete history and routinely included manual muscle testing, sensory testing and observational gait analysis with and without orthoses.

Nonsurgical treatment of movement disorders, in a similar fashion to the surgical treatment, is muscle specific. Intramuscular pharmacologic agents such as Botulinum Toxin A are being used with increasing frequency to treat spasticity. Treatment plans and outcomes for the spastic equinovarus deformity with muscle specific pharmacologic agents may be also be influenced by instrumented gait analysis in planning treatment. Improving upper extremity function in patients with UMN syndrome is also muscle specific and can impact on gait by improving balance, comfort and the use of walking assist devices. Surgical reconstruction of movement disorders in the upper extremity can be influenced by utilizing preoperative diagnostic motor control studies in an analogous manner to the gait analysis.

Instrumented gait analysis is more than a research tool. Gait analysis is currently a vital part of surgical decision making when reconstructing a spastic lower extremity deformity in patients with UMN syndrome and a gait disorder. Gait analysis has a significant impact on the treatment plan. Gait analysis altered surgical planning and produced increased agreement between surgeons. Greater clinical experience did not lessen the impact of gait analysis on surgical planning. The patterns of change and agreement that we found and review of other published reports suggests that instrumented gait analysis has a significant impact on surgical planning and outcome in treatment of the spastic equinovarus foot and ankle.

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