DUMAS, Raphaël, BRANEMARK, Rickard, FROSSARD, Laurent, 2017, Gait analysis of transfemoral amputees: errors in inverse dynamics are substantial and depend on prosthetic Design, IEEE Transactions on Neural Systems and Rehabilitation Engineering, 25, 6, Institute of Electrical and Electronics Engineers - IEEE, pp. 679-685, DOI: 10.1109/TNSRE.2016.2601378

Gait analysis of transfemoral amputees: errors in inverse dynamics are substantial and depend on prosthetic design

R. Dumas, R. Brånemark, and L. Frossard

***Abstract*—Quantitative assessments of prostheses performances rely more and more frequently on gait analysis focusing on prosthetic knee joint forces and moments computed by inverse dynamics. However, this method is prone to errors, as demonstrated in comparison with direct measurements of these forces and moments. The magnitude of errors reported in the literature seems to vary depending on prosthetic components. Therefore, the purposes of this study were (A) to quantify and compare the magnitude of errors in knee joint forces and moments obtained with inverse dynamics and direct measurements on ten participants with transfemoral amputation during walking and (B) to investigate if these errors can be characterised for different prosthetic knees.**

Knee joint forces and moments computed by inverse dynamics presented substantial errors, especially during the swing phase of gait. Indeed, the median errors in percentage of the moment magnitude were 4% and 26% in extension/flexion, 6% and 19% in adduction/abduction as well as 14% and 27% in internal/external rotation during stance and swing phase, respectively. Moreover, errors varied depending on the prosthetic limb fitted with mechanical or microprocessor-controlled knees.

This study confirmed that inverse dynamics should be used cautiously while performing gait analysis of amputees. Alternatively, direct measurements of joint forces and moments could be relevant for mechanical characterising of components and alignments of prosthetic limbs.

***Index Terms*—Osseointegration, Bone-anchored prosthesis, above-knee amputation, loading, kinetics, joint moments, artificial limb, transducer, load cell, validation.**

Manuscript submitted March 23, 2016.

This study was partially funded by the Australian Research Council Discovery Project (DP0345667), Australian Research Council Linkage Grant (LP0455481), Queensland University of Technology Strategic Link with the Industry and Institute of Health and Biomedical Innovation Advanced Diagnosis in Medical Device Grant.

R. Dumas is with Univ Lyon, Université Claude Bernard Lyon 1, IFSTTAR, UMR_T9406, LBMC, F69622, Lyon, France (raphael.dumas@ifsttar.fr).

R. Brånemark is with Centre for Advanced Reconstruction of Extremitites (C.A.R.E.), Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Sahlgrenska University Hospital, Gothenburg, Sweden. He is also with International Centre for Osseointegration Research Education and Surgery (*i*CORES), Department of Orthopaedics, University of California San Francisco, San Francisco, California, USA (rickard.branemark@orthop.gu.se).

L. Frossard is with Queensland University of Technology, Brisbane, QLD, Australia. He is also with University of the Sunshine Coast, Maroochydore, QLD, Australia (laurentfrossard@outlook.com).

I. Introduction

Clinical examinations leading to objective evaluations of ambulation abilities of individuals with lower-limb amputation are increasingly required. Typically, quantitative assessments of prostheses performances rely on spatio-temporal, kinematic and kinetic gait characteristics [1-6]. In particular, the analysis of lower limb joints kinetics (i.e., forces, moments, power) has become critical to compare mechanical performances between adaptive dissipation prosthetic knee units [7-19] and an anatomical knee joint [2, 3, 20]. Furthermore, the development of osseointegrated fixations for bone-anchored prostheses requires a better understanding and monitoring of implant and prosthetic loading during locomotion to increase walking abilities (e.g., speed of walking) while assuring safety (e.g., limitation of high loading, fall prevention, breakage of fixation parts) [6, 21-29].

One way to produce such knee joint kinetics is to rely on inverse dynamics computations. Unfortunately, joint forces and moments obtained this way tend to be prone to errors especially for prosthetic gait [30-35]. These errors could be mainly attributed to inaccurate measurements of prostheses inertial parameters and oversimplified modelling of prosthetic segments (i.e., rigid) and prosthetic joints (i.e., with constant centre/axis of rotation, without any damping nor friction). However, prosthetic gait provides a singular opportunity to validate the computation of knee joint kinetics by comparing knee forces and moments obtained with inverse dynamics equations with the ones measured directly by a transducer fitted within the prosthesis [36-40].

Previous studies comparing both methods involving participants fitted with various types of knees revealed errors close to 5% of body weight and 30% of body weight times height for knee joint forces and moments, respectively [38]. Interestingly, the magnitude of errors seems to vary between these studies involving various prosthetic components (e.g., one participant with a constant friction knee [36] *vs.* six participants with hydraulic microprocessor-controlled knees [38]). One could hypothesize that the range of these errors could be attributed to differences in absorption in the foot and dissipation in knee components that are hardly taken into account in inverse dynamic computations while, conversely, properly assessed by direct measurements.