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ESTIMATION OF THREE-DIMENSIONAL TORQUES ALONG THE FEMUR SHAFT IN A GROUP OF HEALTHY VOLUNTEERS DURING ACTIVITIES OF DAILY LIVING

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SUMMARY

The direct attachment to the skeleton of lower limb prosthetics for transfemoral amputees is a recent innovation with great potentials. A comprehensive knowledge of the loads applied to the femur nearby the osseointegrated implant is fundamental to optimize the mechanical design. In particular, load patterns of the implant to the bone at the point of anchorage are not established yet.

A standard gait analysis protocol with external skin markers was utilised to estimate the three components of the torque about points along the femur shaft. Twenty healthy young volunteers were asked to perform three repetitions of a number of activities which includes straight-line level walking at three different speeds (low, self-selected and high) and with sudden changes of direction, to the right and to the left, stairs ascending and descending, squat, rising from a chair and sitting down. During these tasks, kinematics and kinetics data were recorded for the main joints, and for nine additional equally distributed points along the femur shaft. Relevant average patterns were calculated over subjects for each point, about the three anatomical axes, and for each motor task.

These patterns of torque were found very different among the motor tasks. In general torque was higher for more proximal points, in the frontal than in the sagittal plane, and affected by progression speed. The highest torque was found at the proximal femur, in the frontal plane during walking at high speed. The present results are valuable directly for prosthesis design and relevant operative technique, i.e. for a most suitable level for amputation, but also for in-vitro mechanical tests and finite element models.

INTRODUCTION

Direct anchorage of a lower-limb prosthesis to the bone through an implanted fixation (osseointegration) has been suggested as an excellent alternative for transfemoral amputees experiencing complications with the conventional socket-type prosthesis attachment. An accurate estimation of the loads experienced nearby the level of bone amputation and implant fixation is a crucial step to optimize the design of the overall prosthesis system. There is currently no in-vivo and non-invasive measurements of the torques acting along the femur shaft during daily life activities. The aim of this study was to design and implement a gait analysis protocol with external skin markers to obtain these measurements averaged over a large group of healthy young volunteers and for a large number of motor tasks.

METHODS

Twenty healthy volunteers (9 males, 11 females; mean ± standard deviation: age 26.9±4.1 years, mass 63.9±14.5 kg, height 171.3±8.5 cm) were instrumented with a standard marker set [1]. Marker trajectories were collected by an eight-camera motion capture system (Vicon Motion Systems, UK); two synchronized force plates (Kistler Instrument AG, Switzerland) measured the ground reaction forces and the positions of the center of pressure. Motion capture was performed during three consecutive trials of eleven different motor tasks: straight-line level walking at three different speeds (low, self-selected and high), walking with sudden turn both right and left, i.e. sidestep and crossover, ascending and descending stairs, with alternating feet and also with the same foot, squat without lifting heels from the floor, rising from a chair and sitting down.

Ten equidistant points were identified along the femur anatomical axis of the dominant lower limb, from the knee joint centre (P1) to the midpoint (P10) between the great trochanter-marker and the hip joint centre [2]. Between these two extremes, P4 is the distal and P7 is the proximal thirds. The instantaneous torques about each of these points were computed in the femur anatomical reference frame [3], as the cross-product of the position and the reaction force vectors. The three torque components on the sagittal, frontal and transverse planes (respectively flexion/extension, ab/adduction and intra-extra rotation torques), were indicated as a percentage of the product of body weight in Newton and height in millimeters (BW*H%) so that these all were adimensional values. Their time-histories were re-sampled at a percentage of the stance phase for walking motor tasks, and of the support phase for ascending and descending stairs. Finally, these torque patterns about each femur point were averaged for each subject over the three single trials of each motor task, and then over all subjects (see for example Figure 1). All these calculations were performed by customized Matlab programs (Version 7.1, The Mathworks, Inc). For the intra-subject variability, one volunteer was asked to repeat walking at self-selected speed ten times.

RESULTS AND DISCUSSION

A good intra-subject repeatability was obtained; the maximum over the stance for standard deviations of the mean torque over these ten walking trials increased gradually along the femur anatomical axis in the proximal direction but these values remained smaller than 1.8 for all three components.

The patterns of sagittal, frontal and transverse plane torques averaged over all volunteers were very different among the motor tasks, but consistent among subjects within the same femur point, i.e. a good inter-subject repeatability was observed.

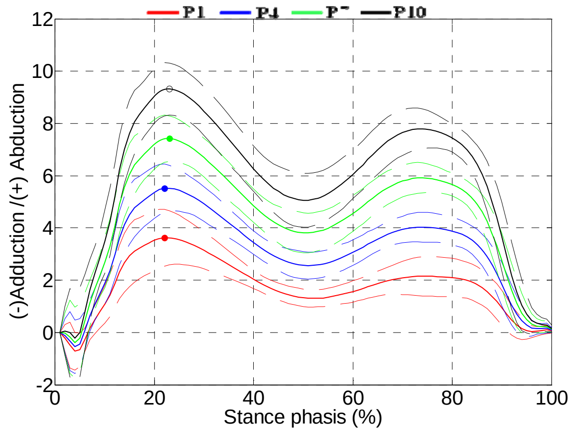

Figure 1: Adduction/abduction torque [BW*H%] about four points distributed over the femur shaft. Mean (solid lines) ± one standard deviation (dashed) patterns over the twenty healthy volunteers during level walking at high speed. The peaks also represented in Table 1 are identified with dots.

In all five walking motor tasks, the more proximal was the femur point, the higher were the mean torques across all subjects in all three anatomical planes. Particularly, the flexion/extension torque at the knee center (P1) was 80% smaller than that at the most proximal point (P10) in walking at high speed (Table 1). In ascending with alternating feet, this was 90% smaller already at P7, but more than twice the value in P10 at P1, though in the other direction.

Higher torques were in general transmitted in the frontal plane: in both stair descending tasks these exceed by three times those transmitted in the sagittal plane. These were influenced by the walking speed: among all motor tasks analyzed the highest peak torque was achieved in the frontal plane in walking at high speed (Table 1), 9.3 BW*H%.

The mean patterns of each component of torque are here reported for a large group of healthy volunteers at ten different femur points along its shaft. With the present technique however, this resolution can be enlarged to many more points, or the torque calculated even at any point of special clinical or surgical interest, and also for a single specific patient. The torque estimation was based on healthy volunteers; in transfemoral amputees the magnitude of torque can be smaller, likely because of the smaller velocity, but the present results shall be taken as an appropriate upperbound for the loads to be carried by the implant-to-bone interface.

CONCLUSIONS

This study is the first attempt for in-vivo non-invasive evaluation, by a gait analysis based technique, of torques about a number of points along the femur shaft during daily life activities. The results suggested that the overall technique was robust enough to obtain consistent patterns over the volunteers, and this for each femur point and each motor task. The highest torque was observed at the most proximal femur point, in the frontal plane, and during walking at high speed (99.9 Nm). The present results can be exploited for in-vitro mechanical tests and finite element models in analyses of relevant implant-to-bone interface.

ACKNOWLEDGEMENTS

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Table 1: Torques in flexion/extension (FE), ab/adduction (AA) and intra-extra rotation (IE) about the knee centre (P1), and the distal (P4) and proximal (P7) third points. These are expressed as percentages of the corresponding values of the peak on the patterns at the midpoint between the great trochanter-marker and the hip joint centre (P10), the latter being expressed here in BW*H%. These are reported for the four motor tasks with the overall highest torque values. The row in bold reports these values taken from Figure 1.

Motor tasks:	Torque Components:	P1 [%]⁺	P4 [%]⁺	P7 [%]⁺	P10 *
Walking at high speed	FE	20	40	68	5.0
	AA (as from Fig. 1)	**39**	**59**	**80**	**9.3**
	IE	67	80	87	-1.5
Walking with sidestep	FE	30	54	76	-4.6
	AA	36	58	79	8.5
	IE	45	64	82	1.1
Ascending stairs, alternating feet	FE	-214	-110	10	-2.9
	AA	37	57	79	6.8
	IE	54	71	83	-2.4
Descending stairs, alternating feet	FE	58	69	85	-2.6
	AA	35	57	79	8.1
	IE	63	74	84	-1.9

*Values reported in percentages of the product of body weight and height, these are adimensional (as in Figure 1).

⁺Values were expressed as percentages of the corresponding peak values at P10.