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Improvement of joint reaction forces and moments calculation during a step up and over task using a 4D scanner data

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1. Introduction

Joint forces and moments are relevant for the assessment of knee pathology [1], however, they cannot be observed directly, since they are dynamic variables that depend on the masses and inertias of body parts. Body segment inertial parameters (BSIP) are normally estimated from tables, scaled by simple equations to account for variations in subject's anthropometry (height, weight, and limb lengths). "4D scanners" (body shape in motion) allow to capture more details of human motion, including precise volumes and shapes of body segments that can be used to make more accurate calculations.

2. Research question

Can "4D scans" provide a significant improvement in the calculation of joint reaction forces and moments in the functional assessment of knee injuries?

3. Methods

A male subject with knee arthrosis in pre-operatory phase and twelve healthy subjects (7 male, 5 female) participated in the study. The patient performed an instrumented step up and over task [1], and tabulated BSIP [2] were scaled as in Ref. [3], in order to calculate flexion moments and reaction forces of lower limb joints in the anterior-posterior (AP), medial-lateral (ML) and vertical (Vert) directions of the distal segment.

The healthy subjects were measured with a 4D scanner [4] during ground level walking. The BSIP of feet, shank, thigh and pelvis were calculated from tabulated data, and from the 3D meshes at each instant [5]. The differences between "observed" and "tabulated" BSIP were characterized by averages and standard deviations, and those statistics were used to estimate expected differences in joint forces and moments of the stair test performed by the injured subject, if his BSIP diverted from the tabulated ones as in the observed sample.

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4. Results

Table 1 shows the expected maximum differences in moments and forces of the injured leg (absolute and relative to the peak of the curves), separating the gestures of stepping up and stepping down with that leg. Those differences varied across joints in agreement with previous studies for gait [6]. At the knee joint, the discrepancies were between 2% and 5% of the subject's body weight (scaled by leg length for the flexion moment), which was a small fraction of the vertical force, but more than 10% of AP force and flexion moment.

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Table 1
Expected maximum differences in joint moments and reaction forces of the injured leg, between calculations made with tabulated BSIP and with their observed values in 4D scans. Maximum differences in scale normalized by body weight - and leg length for the flexion moment.

		Flex. moment		AP force		ML force		Vert. force	
		Up	Down	Up	Down	Up	Down	Up	Down
Ankle	Max diff.	0.009	0.010	0.010	0.008	0.005	0.006	0.012	0.009
	% peak	6.2%	7.7%	7.7%	3.0%	9.4%	4.3%	1.3%	0.5%
Knee	Max diff.	0.025	0.021	0.039	0.046	0.019	0.025	0.030	0.027
	% peak	16.9%	14.4%	12.7%	19.0%	5.4%	6.4%	3.3%	1.5%
Hip	Max diff.	0.049	0.055	0.040	0.061	0.042	0.039	0.067	0.104
	% peak	29.1%	34.9%	14.2%	24.3%	18.5%	8.9%	9.0%	7.1%

5. Discussion

These results show that 4D scans may reduce uncertainties in the calculation of joint forces and moments due to inaccuracies of BSIP estimated from tables, in order to support clinical decisions.

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