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PEAK KNEE ADDUCTION MOMENTS & MEDIAL CONTACT FORCES – RELATIONS ACROSS SUBJECTS AND ACTIVITIES

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SUMMARY

This study establishes for the first time a robust relationship between the peak knee adduction moment (EAM) and the medial tibiofemoral contact force (F_{med}) Moreover, our results on the variation of the relation between the two measures provides critical, previously unavailable information for the interpretation of the EAM in the many studies that have no direct access to the contact forces transmitted across the knee joint.

INTRODUCTION

Although the external knee adduction moment (EAM) is generally considered a valid surrogate measure for the medial tibiofemoral contact force (F_{med}), supporting factual evidence for this widely accepted assumption has been limited to analyses in a single patient during walking only [1; 2]. To investigate the hypothesis that the peak EAM is indeed a reliable indicator for F_{med} across a spectrum of subjects and activities, this study investigated the relationship between EAM and F_{med} across a range of 10 activities in 9 patients with telemetric knee implants.

METHODS

Motion analysis was performed in 9 TKR patients, each implanted with a telemetric knee prosthesis [3], while recording the in vivo forces during repetitions of walking, stair climb/descent, chair rise/sit down, 3 squat variants, one-legged stance and weight transfer between legs. All subjects provided written informed consent to the procedures and the study was approved by the local ethics committee. The external loads were measured using two force plates (AMTI, MA, USA) while the 3D kinematics of the lower limbs were measured using a 10 camera optical motion capture system (Vicon, UK). Functional methods and patient specific anatomy fitting procedures [4] were used to accurately determine skeletal kinematics, which were then used to compute the EAM by inverse dynamics. Linear regression was applied to investigate the relationship between the peak EAM and the in vivo measured F_{med} at the same time point. Coefficients of determination (R^2), RMS errors and the slope of the regression were evaluated to assess the relationship between the two measures.

RESULTS AND DISCUSSION

The maxima of EAM did not act at exactly the same instant of time as the maxima of Fmed. (Table 1). Considering all 430 trials, the peak EAM explained 70% of the variance of the F_{med}, measured at the instant of peak EAM. The RMS error of Fmed was 35% bodyweight (BW) (Fig. 1a).

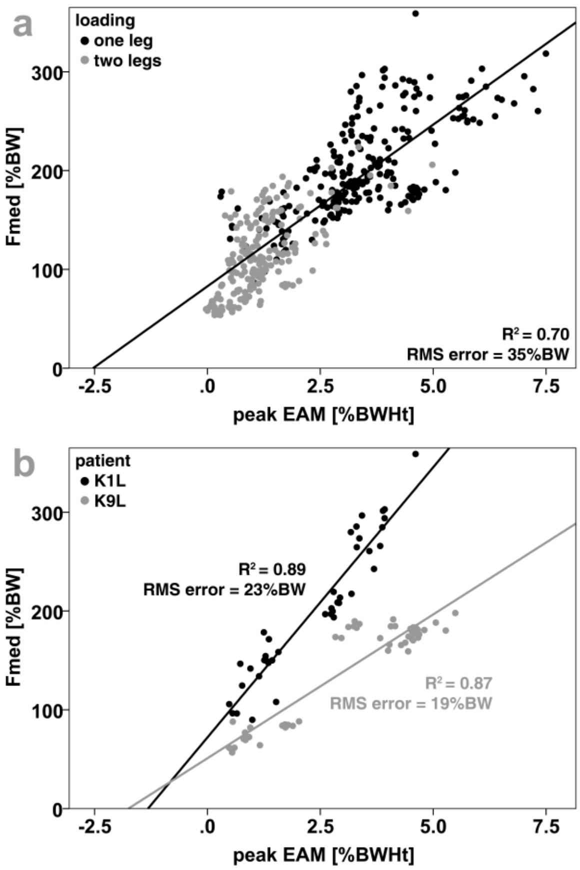

Figure 1: a) Peak EAM vs. simultaneously acting Fmed for all 10 activities & 9 patients (430 trials). Activities with predominant loading on one/two legs are shown in black/grey. b) Peak EAM vs. simultaneously acting Fmed across the 10 activities, shown for 2 exemplary patients.

For each individual, F_{med} was even more strongly correlated with the peak EAM across all activities, with a mean R^2 value of 0.81 and RMS errors ranging from 16 to 33%BW. However, the slope of the regression varied considerably between patients with values ranging from 21 to 55 bodyheight^{-1} (Fig. 1b). Generally, larger EAMs and medial forces were observed during the activities with predominant loading on one leg.

By assessing the relationships of the peak external adduction moments and the simultaneously acting medial contact forces in the knees of 9 subjects over 10 activities with a range in peak EAM of more than 7%BWHt, we found a substantial (R^2=0.70) correlation between peak EAM and the corresponding $F_{med.}$. This result supports our hypothesis and provides the first in-depth understanding of the relationship between external and internal loading conditions, as partially observed previously [1]. Here, when considering the relationships between the two measures of medial compartment loading for each patient individually, we found that peak EAM explained up to 89% of the variance in F_{med} (Fig. 2). While this finding indicates that a robust relationship between those measures might exist in a single subject, the variation in the slope of patient specific regressions was large, differing by a factor of more than 2. Therefore it seems likely that variable neuromuscular strategies to load the soft tissues and produce the internal joint forces for balancing the external moments and stabilizing the knee are employed by the subjects, and even seem to be maintained across different activities. As a result, estimations of changes in F_{med} based on changes in EAM alone, which do not specifically consider the contribution of the soft tissues to the forces acting across the knee, might exhibit only limited accuracy.

CONCLUSIONS

The findings of this study call for more detailed investigations into the soft-tissue related mechanisms that modulate the internal forces at the knee, but also indicate that EAM should be used only cautiously as a surrogate measure for F_{med}.

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Table 1: Peak EAM and peak Fmed values and the corresponding knee flexion angles for each activity (mean ± standard deviation).

activity	peak EAM [%BWHt]	peak F_{med} [%BW]	knee flexion at peak EAM [°]	knee flexion at peak F_{med} [°]
walking	3.05 ± 0.99	195.68 ± 35.81	20 ± 5	16 ± 7
stair climbing	2.97 ± 1.08	214.54 ± 41.55	41 ± 9	41 ± 11
stair descending	4.47 ± 1.38	236.63 ± 43.59	36 ± 14	37 ± 17
sit-to-stand	0.79 ± 0.37	121.50 ± 31.20	46 ± 25	71 ± 29
stand-to-sit	1.38 ± 0.56	137.11 ± 30.73	62 ± 21	73 ± 16
squat	1.06 ± 0.57	123.30 ± 34.71	53 ± 24	76 ± 25
squat varus	1.34 ± 0.64	140.29 ± 30.15	58 ± 23	88 ± 11
squat valgus	0.78 ± 0.49	105.43 ± 29.91	69 ± 26	86 ± 13
weight transfer	3.25 ± 1.05	197.73 ± 30.72	10 ± 6	8 ± 5
one legged stance	3.44 ± 1.46	214.40 ± 56.61	14 ± 5	14 ± 6