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3D PATELLOFEMORAL JOINT KINEMATICS DURING A COUNTERMOVEMENT JUMP: FEASIBILITY OF A MODEL BASED ON EXTERNAL MARKERS

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SUMMARY
A model based on external markers was tested to detect the linear and angular patellar motion relative to the femur coordinate system, during a countermovement jump. Mean values for trajectory of patellar center of mass relative to the femur coordinate system were 12.9mm (±4.1) and 30.5mm (±3.9) for transversal and longitudinal trajectory, respectively. During a knee flexion of 0 up to 60º, patellofemoral joint minimal and maximal mean values were 16.1º and 32.4º for flexion/extension, 2.4º and 6.5º for adduction/abduction and 16.0º and 18.1º for internal/external rotation, respectively. This method seemed to be able to detect the patellar motion during a real dynamic situation, although it still needs a validation for the entire cycle of countermovement jump.

INTRODUCTION
For movement analysis in Biomechanics, external markers over the skin are generally used. However, the analysis of patellar motion is difficult due to its small dimensions, when compared with the rest of the body, and to skin movement artifacts. In order to further investigate the patella movements, methods based on cadavers has been applied generally fixing clusters on the patella and analyzing its motion during passive knee flexion/extension. The main drawback of such an approach is the lack of muscle contraction. Medical images such as magnetic resonance, fluoroscopy and tomography are able to provide reliable data, however they are not able to be applied to analysis in dynamic situations [1,2,3].

Another difficulty to accost this topic is about the validation of using markers on the patella bone. This stage is necessary due to skin movement artifacts, which are well known as the main source of error in biomechanics movement analysis. The problem is that the gold standard for measurements of 3D kinematics is medical image and most of those equipments do not allow dynamic exams. Thus, to the best of our knowledge, a complete validation of using external markers to track the patella motion has not yet been accomplished. Nevertheless it is important to verify the feasibility of such an approach, so the model proposed in this study addresses an important part of this problem, however do not intend to be a full validation of such a method.

Thus the aim of the present work is to verify the feasibility of a model based on external markers to describe the basic movements of the patella during a countermovement jump (CMJ). The rationale of this study was to perform a kinematical analysis of the lower limbs of subjects during CMJ applying a marker set to the patella, describing its motion related to the femoral coordinate system and comparing the results to the available literature, mainly those obtained under static or quasi-static conditions using cadavers or medical images (MRI or fluoroscopy).

METHODS
This study was approved by the university ethics committee and informed consent was obtained from all participants. Twenty four patellar trajectories of four young, healthy physically active women, with no history of pain and/or injury on lower limbs, were analyzed in this study. The subjects characteristics were: mean age 27.7 years (±4.6), mean weight 58.3kg (±3.2) and mean height 1.63m (±0.05). Each one performed three CMJ with no upper limbs movements. The DVideo kinematical analysis system was used for the 3D analysis of lower limbs and patella motion [4]. The system used six industrial cameras (Basler A602fc), working at 100Hz.

Markers protocol for segments tracking and orientation consisted of 16 spherical retrorreflexive markers, with 15 mm diameter for pelvis and lower limbs, and four markers on each patella, with diameters of 5 mm.

In order to model and calculate the body segments linear and angular motion the Visual3D® software (4.96.11) was used. All joints were modeled with six degrees of freedom. The pelvis was orientated according to the Coda model, for thighs, shanks and feet default Visual3D models were used. An additional patella segment was created with a conic geometry and the center of mass was assumed to be located at 50% of longitudinal axis (proximal to distal). The patella location was described by its center of mass and the orientation was defined as: the origin was set in marker 1, the Y axis was perpendicular to the plane defined by markers 1, 2 and 3, the Z axis defined from marker 3 towards to the marker 1 and finally the X axis was obtained by the cross product of the Y and Z axis. The forth marker was used only for tracking (Figure 1).

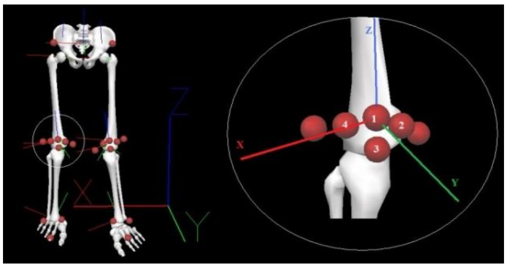

Figure 1: Model of body segments created by the Visual 3D software with zoom in PFJ model. Markers on anterior and

posterior superior iliac spines, medial and lateral condyles of femur, medial and lateral malleolus, calcaneus and second metatarsus, base midpoint (1), medial protuberance (2), apix (3) and lateral protuberance of patellas (4).

Data were filtered by Butterworth digital low pass filter, with a cutoff frequency of an 8Hz. Joint angles were calculated using a XYZ Cardan rotation sequence. The following variables were calculated: knee joint angles (shank to femur orientation); trajectory of the patella center of mass and joint rotation angles related to the femur reference frame.

RESULTS AND DISCUSSION

Trajectory of patellar center of mass relative to the femur coordinate system is showed in Figure 2. Range mean and standard deviation values for all 24 patellar tracking were 12.9 mm (±4.1) and 30.5 mm (±3.9) for transversal and longitudinal trajectory, respectively. Mean, standard deviation, minimal and maximal values of patellar rotation relative to the femur reference frame in specific knee flexion angles are shown in Table 1. Until 60º of knee flexion, PFJ minimal and maximal mean values were 16.1º and 32.4º for flexion/extension, 2.4º and 6.5º for adduction/abduction and 16.0º and 18.1º for internal/external rotation, respectively.

Laprade et al. (2007) by using a patella thermoplastic mold and fluoroscopy images, found a mean value for transversal patellar trajectory of 12.8 mm for both sides and for longitudinal axis of 32.5 mm for right patella and 31.8 mm for the left one, between 0 e 60º of knee flexion. Therefore, data obtained in this present study corroborate those found by this group [5].

CONCLUSIONS

This study evaluated the feasibility of using external markers in order to track the patella linear and angular motion in the countermovement jump. The absence of directly comparable studies requires furthers efforts toward a complete validation. However, the experimental results were coherent in terms of range of motion across subjects and with the most similar study found in the literature suggesting that the approach is promising and should be further investigated.

ACKNOWLEDGEMENTS

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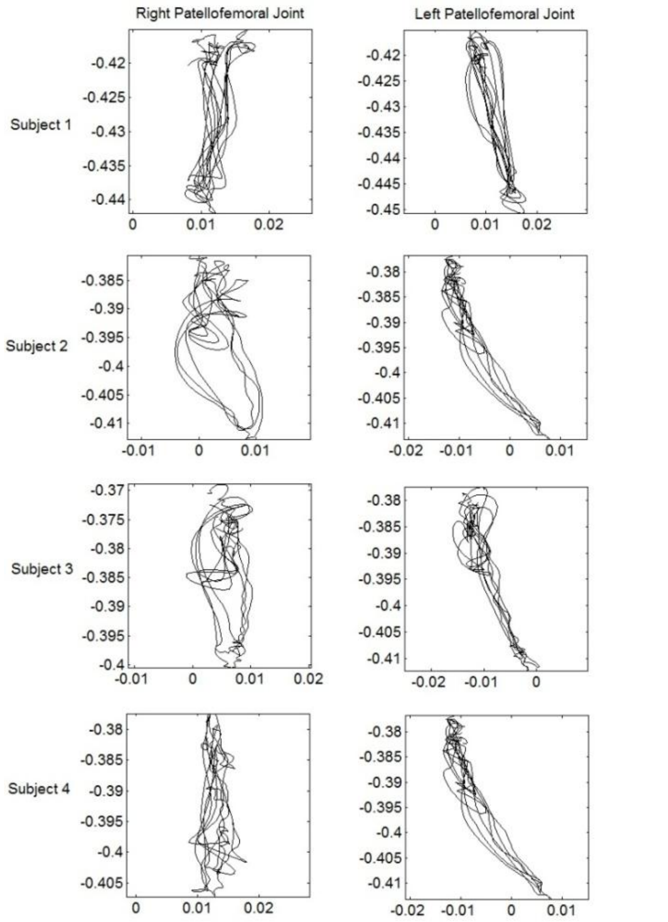

Figure 2: Trajectory of patellar center of mass in the femur reference frame. All value in meters.

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Table 1: Mean, standard deviation, minimal and maximal values of obtained for patellar rotation relative to the femur in specific knee flexion angles.

	flexion/extension(°)				aduction/abduction(°)				patellar tilt(°)			
Knee angle	mean	std	min	max	mean	std	min	max	mean	std	min	Max
15°	16.1	2.3	13.5	21.9	2.4	6.4	-4.1	11.1	18.1	7.1	5.1	30.8
30°	22.0	2.6	18.3	26.4	3.7	7.5	-4.4	13.6	17.9	6.3	7.1	27.6
45°	26.9	2.7	22.9	31.4	5.4	7.4	-3.4	15.2	17.4	4.3	9.5	24.3
60°	32.4	2.6	29.0	36.4	6.5	7.0	-1.3	16.1	16.0	3.5	10.0	20.7