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# Towards a better assessment of patients with anterior cruciate ligament injury using smartphone videos and multibody dynamics.

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## EXTENDED ABSTRACT

## 1 Introduction

The multibody approach (MBS) is increasingly used to model the human body in the frame of movement analysis. The range of applications is wide, from the movement analysis for the performance of athletes to the gait analysis of children with cerebral palsy to better target medical interventions. traditionally, kinematics is acquired by an optoelectronic system composed of several infrared cameras and external forces are measured by force measurement devices such as force platforms. A current trend is the attempt to make this analysis available outside the research settings, to trainers and health care professionals. For this purpose, a large number of studies have been based on different measurement tools such as inertial measurement units, video cameras or pressure-sensing insoles. Then the processing of the raw data and the translation into clinically relevant biomarkers is often performed by either inverse dynamics or artificial intelligence [1].

In patients with anterior cruciate ligament injuries, the dynamics of movement during single leg jumps is interesting to evaluate. Indeed, asymmetries are thought to be related to the risk of recurrence and other adverse health effects. The biomarkers that seem most relevant are the knee flexion angle and range of motion, the vertical component of the ground reaction force (GRF) and the net knee extension torque [2]. The kinematic biomarkers can be obtained based on a video of the movement in the sagittal plane. This procedure is facilitated by the development of deep learning techniques for human pose detection. Very high performances are achieved by 2D single-person pose estimation methods.

The objective of the present study is to investigate whether a relatively simple 2D MBS could be used to obtain the clinically relevant dynamic biomarkers based on the kinematics measured in the sagittal plane during single leg jumps.

## 2 Materials and method

Six young healthy men (mean age: 23.5 years old, height: 1.8 m, body mass: 70.4 kg) were asked to perform 10 vertical and 10 forward single leg jumps in a direction such that the X-Y plane of the lab coordinate system corresponds to their sagittal plane while keeping their arms crossed in front of their chest. Eighteen reflective markers were placed over anatomical landmarks and their coordinates were captured using a height-cameras optoelectronic system. The GRF data were collected by a time synchronized force platform. Markers trajectories and GRFs were filtered using the same low-pass, zero-lag, fourth-order Butterworth filter. Three different cut-off frequencies (cof) usually used in studies focusing on jumps dynamics of ACL patients were investigated.

The MBS model of the patients (see Figure 1A) was developed with the multibody software Robotran [3] and is made of seven rigid bodies: (1) Middle and upper part of the trunk, neck, head and two upper limbs, (2) lower part of the trunk and pelvis, (3) contact thigh, (4) contact shank, (5) contact foot, (6) non-contact thigh and (7) non-contact shank and foot. The bodies characteristics were extracted from an anthropometric table [4]. The segment "lower part of the trunk and pelvis" has two prismatic and one revolute joints to represent the three degrees of freedom (DoF) of the MBS with respect to the inertial frame. Each body has one revolute DoF with respect to its parent body, corresponding in the sagittal plane to flexion/extension movements. Experimental values for all the DoF were extracted from the optoelectronic system data.

The only external forces acting on the MBS except gravity is the GRF. Therefore, its components in the sagittal plane can be obtained either as the inverse dynamic solutions for the two translational joints associated with the pelvis motion (see Fig. 1 A) or using Newton's law (equation (1) ).

$$F_x = \sum_{i=1}^{7} m_i a_{xi} \qquad , \qquad F_y = \sum_{i=1}^{7} m_i (a_{yi} + g) \tag{1}$$

Where $F_x$ and $F_y$ are the GRF in the antero-posterior and vertical directions respectively, $m_i$ is the mass of the $i^{th}$ segment, $a_{xi}$ and $a_{yi}$ are the accelerations of the $i^{th}$ segment center of mass in the x and y directions and $g$ is the acceleration due to gravity ($9.81 m/s^2$).

The peak vGRF are defined as the highest value in the vertical direction during the propulsion and the landing phases. The propulsion phase is defined as $400ms$ prior to take off until take off and the landing phase from initial contact to peak knee flexion. The propulsion and landing impulses are calculated as the integral of the vGRF curve with respect to time over each phase. These outcomes were extracted from both the multibody simulation results and the force platform measures for comparison. The reliability of the model for the prediction of the above-mentioned outcomes was assessed using a Two-way random Intraclass correlation coefficient (ICC 2,1).

## 3 Results and discussion

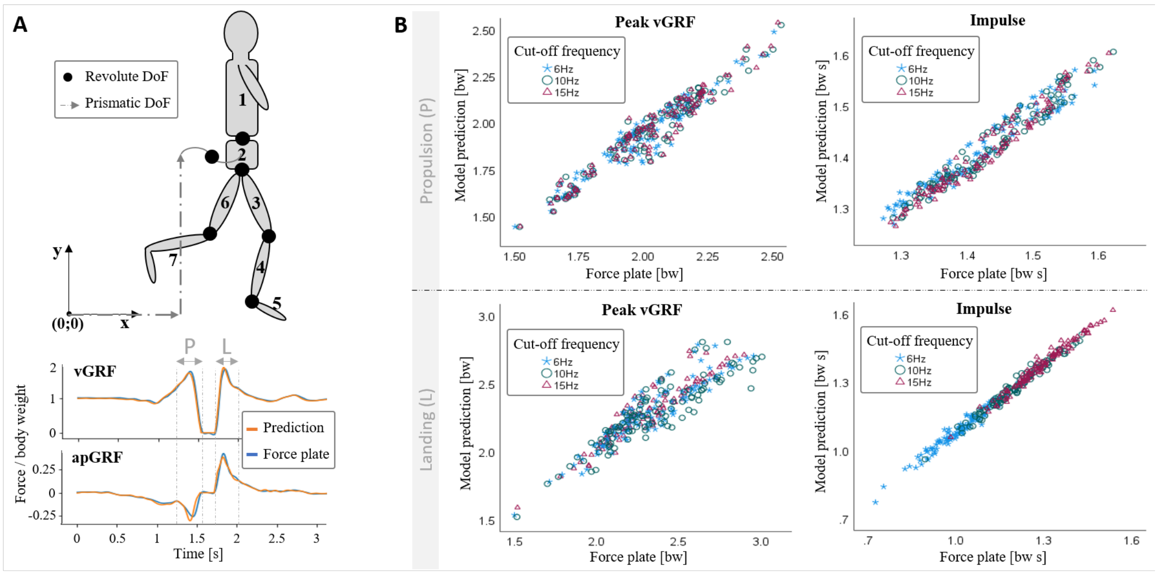

Figure 1: **A.** Schematic representation of the developed 2D MBS and example of external forces measured by the force platform and calculated by the model based on the kinematics during a single leg jump. apGRF and vGRF stand for antero-posterior and vertical components of the ground reaction force. **B.** Scatter plots of the model predicted values versus the force platform measurements for the different outcomes normalized by participants bodyweights (bw).

Figure 1B shows the model predicted values versus the actual ones measured by the force platform for the different outcomes. During the propulsion phase, the multibody model prediction showed excellent agreement with the force platform values with ICC above 0.96. During the landing phase, the reliability of the model to predict the outcomes was either good or excellent ($ICC > 0.87$) depending on the filter cof used on both kinematics input data and force platform measures.

In the context of ACL patients' assessment, the knee internal net torque seems to be a relevant biomarker. It is usually computed by inverse dynamics using a multibody system, the bodies kinematics and measurement from a force platform. The force and movement data have to be filtered with the same filter so that the torque is not affected by artefacts due to inconsistencies in the equations of motion. Consequently, the joint net torque could be computed by inverse dynamics using the developed multibody model, the body kinematics and applying the predicted GRF on the contact foot. Nevertheless, since the exact location of the external force point of application on the foot over time is not known, it would be only possible to calculate an estimate of the lower limb internal net joint torques. This estimate might already give a valuable information to the clinicians.

## 4 Conclusion

The developed 2D MBS allows the prediction of dynamic biomarkers based on kinematics in the sagittal plane. The kinematics was extracted from an optoelectronic system but might be computed from a smartphone video. Results are encouraging and call for further work to provide the health care professionals with a simple and user-frienly tool to better assess ACL patients in their clinical practices.

## References

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