Effects of Sampling Rates on Knee Kinematics and Kinetics during Single-leg landing

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INTRODUCTION:
Non-contact anterior cruciate ligament (ACL) ruptures frequently occurs during landing or deceleration. During those risky motions the knee joint experiences high loading rate and rapid translation/rotation within a short period of time. In particular, peak vertical reaction force during landing increases and then decreases within a few milli-seconds rapidly. Thus, it is necessary to accurately measure high speed movement such as landing or cutting to study ACL injury mechanism. Moreover, more accurate measurement data are required if we like to use them for patient-specific model simulation studies.

To date, popular motion capture system has chosen frame rate of 120 Hz for human movement. However, for high speed movement such as landing or cutting, it is worthwhile to capture movement with very high sampling rates, since capturing at 120Hz may omit high peak values of impact and mislead knee kinematics and kinetics accordingly.

The purpose of this study was to determine whether 3D knee kinetics and kinematics would be measured different between high (1200Hz) frame rate and low popular frame rate (120Hz). We hypothesized that the peak values are higher in higher frame rate captured.

METHODS:
In order to compare knee kinetic and kinematic differences of a subject between two frame rates of optoelectronic capture system, one healthy male subject (mass 70 kg, height 1.77m) was repeatedly tested in this study. The experimental protocol was approved by the IRB of our institution and written informed consent was obtained from the subject prior to data collection. Spherical reflective markers (12.5mm diameter) were attached to the lower limb of the subject. Ten markers were placed on bony landmarks: the bilateral greater trochanter, thigh, lateral and medial femoral epicondyles, lateral and medial edges of the tibial plateau, shank, lateral and medial malleoli, and second metatarsal head.

The subjects were instructed to perform single leg landing maneuvers by stepping off a 0.3m platform with the dominant limb. Ten trials were conducted each sampling rates and the results were averaged from trials. A 5-camera motion analysis system (Eagle; Motion Analysis Corp., Santa Rosa, CA, USA) was used to collect kinematic data at 120Hz and 1200Hz, and a force plate (Kistler, Winterthur, Switzerland) was used to obtain ground reaction force (GRF) data at 120Hz. Kinematic data was synchronized via GRF data.

The knee joint angles were calculated using Euler angle rotations of the tibia relative to the femur. The knee kinetics was calculated using inverse dynamics and normalized by bodyweight (BW) or bodyweight x height. The kinematics and GRF data were digitally smoothed by a zero-lag fourth-order Butterworth low-pass filter at a cut-off frequency correspond to half the sampling rate. Statistical analysis was conducted using Matlab (MathWorks, Natick, Massachusetts, USA). Mann-Whitney test was used to compare the parameters between the 120Hz and 1200Hz conditions. All significance levels were set at \( \alpha = 0.05 \).

RESULTS:
Peak knee kinetics, peak superior/inferior (3.52±1.85BW at 1200Hz vs. 2.64±1.21BW at 120Hz, p<0.001; Figure 1) force, peak medial/lateral (p<0.001) force, peak anterior/posterior (p<0.05) force, peak adduction/abduction (p<0.001; Figure 2) moment and peak internal/external rotation (p<0.05; Figure 3) moment were significantly higher at high (1200Hz) frame rate than low (120Hz) frame rate. However, peak flexion/extension moment were not found to be significantly different between sampling rates (p=0.968).

For the knee kinematics, peak flexion/extension (p<0.05), peak adduction/abduction (p<0.001), and peak external/internal (p<0.001) rotation angles were significantly different between the low and high frame rates. Peak medial/lateral translation (p<0.001), peak superior/inferior translation (p<0.05) were significantly different between the two sampling rate. However, peak anterior/posterior translation (p=0.143) was not different between the two frame rates.

DISCUSSION:
The results of this study have shown that most peak kinetic and kinematic parameters are significantly higher in higher frame rate capturing while the subject performs a single-landing maneuver. Low frame rate capturing appears to miss actual peak values in most of trials for high speed movement.

It is important to note that the peak value of impact force (Figure 1) differs by approximately one bodyweight (0.91BW). In addition, in higher sampling rate the observed peak abduction and internal rotation moments were 2.5 times and 1.6 times higher, respectively. Since abduction and internal rotation moments during landing substantially increase ACL strain, these differences may have greater impact while investigating ACL injury mechanism. Moreover, these differences seem to be more emphasized if we utilize those values for patient-specific model simulation inputs.

In conclusion, significant differences in knee kinematics and kinetics between two frame rates suggest that the high frequency capturing increases the accuracy of the knee kinematics and kinetics measurement for single-leg landing.

SIGNIFICANCE:
High risk maneuvers to ACL injury accompany rapid movement in the knee joint. High frequency capturing beyond current popular frame rate is suggested to measure knee kinetics/kinematics and to better investigate ACL injury mechanism.

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