Estimating Anterior Tibial Translation From Model-Based Image-Matching of a Noncontact Anterior Cruciate Ligament Injury in Professional Football: A Case Report

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INTRODUCTION

Although video analysis is the only method available to extract kinematic data from real injury situations to clarify the mechanisms for noncontact anterior cruciate ligament (ACL) injury, most studies have been limited to simple visual inspection,[1,2] the accuracy of which has been shown to be limited.[3] As an alternative, a model-based image-matching (MBIM) technique has been developed to extract joint kinematics from uncalibrated video recordings.[4–6] This technique has been validated in noninjury situations in a laboratory environment[4] and has also been found to be feasible for use in actual ACL injury situations.[5,6] This study presents a noncontact ACL injury situation in a male footballer recorded during a television broadcast using 4 high-definition cameras from different views, including 2 high-speed recordings. We have used the MBIM technique to describe the detailed joint kinematics, including tibial translations.

CASE REPORT

A 26-year-old male elite football player experienced a noncontact ACL injury to his right knee during a national team match, when he tried to stop after having passed the ball with his right leg (see **Video 1, Supplemental Digital Content 1**, http://links.lww.com/JSM/A15). After written informed consent had been obtained from the player, anthropometric data were measured and the clinical information was obtained from his physician. Physical examinations, magnetic resonance imaging, and arthroscopic surgery confirmed the ACL rupture. The videotape was obtained in HDCAM format. The quality of the videotape was high definition (1080i) with 2 regular recordings and 2 high-speed recordings (from dedicated slow-motion cameras). After video editing, effective frame rates of 50, 100, and 300 Hz were obtained. No body part was occluded in all camera views.

To reconstruct the 3-dimensional kinematics of the injured player, we used a new photogrammetric MBIM technique.[4–6] The matching was performed using the commercially available program Poser 4 and the Poser Pro Pack (Curious Labs, Inc, Santa Cruz, California). We used a skeleton model from Zygote Media Group Inc (Provo, Utah) for the player matching. This model consisted of 21 rigid segments with a hierarchical structure, using the pelvis as the parent segment. Pelvic motion was described by 3 rotational and 3 translational degrees of freedom. The motion of the remaining segments was then described with 3 rotational degrees of freedom relative to their parent, except for the shank that was described with 6 degrees of freedom relative to the thigh. One person performed the matching. To minimize the bias resulting from single-operator judgment, 3 experts gave their opinion on the goodness of the fit. The matching was then adjusted accordingly until we reached a consensus. The matching procedure has been described in detail in previous studies,[4–6] and in this case, we especially focused on the matching of the tibial translation, using the patella, the tibial tuberosity, and the anterior margin of the shank as key landmarks. A frame of a matched video is shown in Figure 1 (see also **Video 2, Supplemental Digital Content 2**, http://links.lww.com/JSM/A16).

Body segment parameters were based on direct anthropometric measurements obtained from the player. The skeleton model segment dimensions were set based on the measurements. The knee angles were converted into the joint coordinate system convention of Grood and Suntay.[7] The tibial translations were calculated based on the coordinate system of the shank. The midpoint between the femoral condyles was used as the reference point for tibial translation. The tibial translation was defined as zero in the anatomical neutral position. Initial contact (IC) was defined as the first frame where the foot contacted the ground before the injury. The calculations were done using customized Matlab scripts (MathWorks, Natick, Massachusetts), and knee joint angles and tibial translations were extracted.

The extracted knee joint kinematics are shown in Figures 2A and B. The knee was flexed 35 degrees at IC, with initial extension (26 degrees of flexion) until 20 milliseconds after IC, after which flexion angle continued to increase. The knee abduction angle was neutral at IC but had increased by 21degrees after 30 milliseconds. The knee was externally rotated 11 degrees at IC but abruptly rotated internally by 21 degrees during the first 30 milliseconds, then changed its direction to external rotation after this. Anterior tibial translation started to occur at 20 milliseconds after IC, where the

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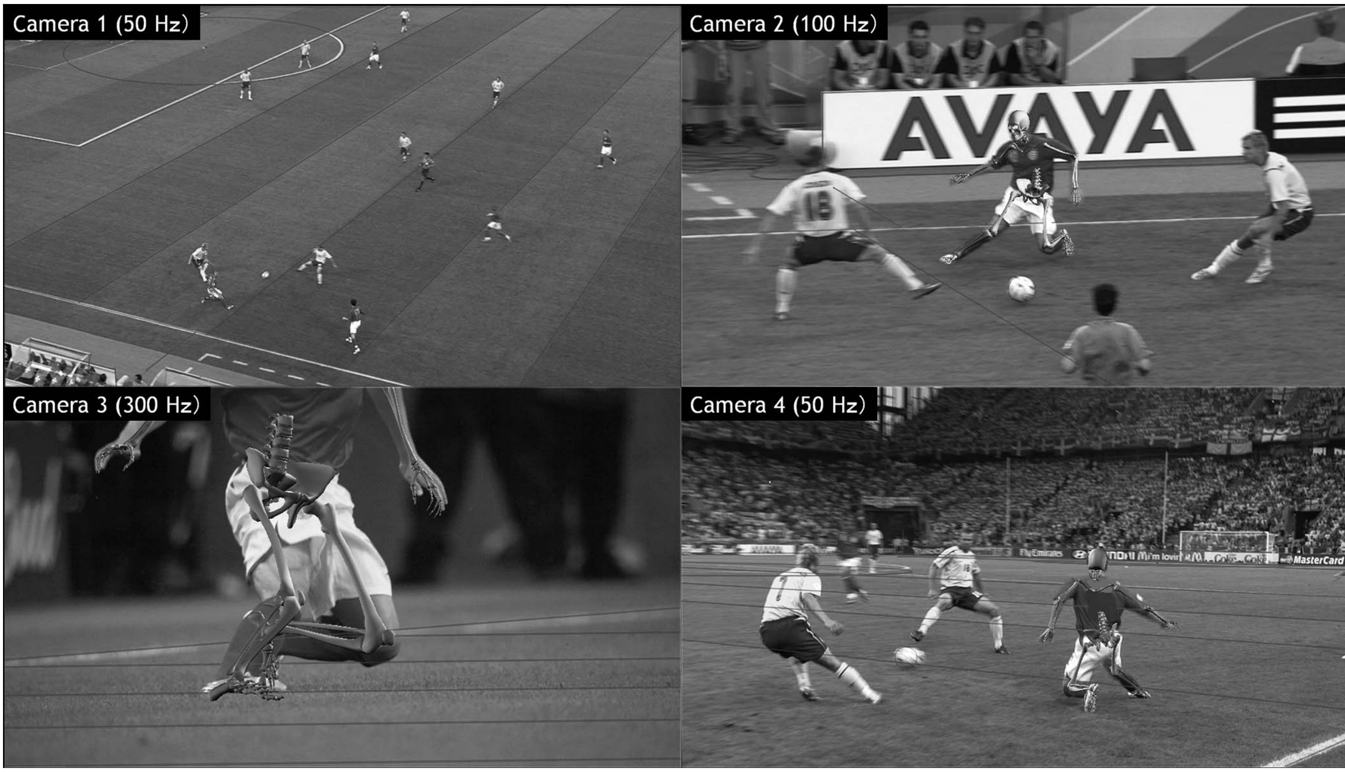

FIGURE 1. A frame of the matched video in Poser. The injury situation 30 milliseconds after IC. Each panel shows the customized skeleton model and the football pitch model superimposed on and matched with the background video image from each camera. Cameras 1 and 4 had an effective frame rate after being deinterlaced of 50 Hz, camera 2 had 100 Hz, and camera 3 had 300 Hz.

knee was the most extended, and by 30 milliseconds after IC, approximately 9 mm of anterior translation had occurred. The translations plateaued by 150 milliseconds and then shifted back to a reduced position between 200 and 240 milliseconds after IC.

To examine the accuracy of the anterior tibial translation estimates, 2 other matchings with 10 mm more and 10 mm less anterior tibial translation were compared with the final matching. The skeleton model of the tibia in the final matching matches much better than the 2 alternate matchings, showing that the final matching is the most accurate (Figure 3).

DISCUSSION

The superior quality video available for the current study enabled us to assess femorotibial translation for the first time in an ACL injury situation. The results provide additional evidence in support of the timing of ACL injury and the injury mechanism proposed in a recent study[6] based on MBIM matching of 10 noncontact ACL injury videos from female team handball and basketball players. Koga et al[6] reported that sudden valgus motion combined with internal knee rotation occurred within 40 milliseconds after IC and that the peak vertical ground reaction force occurred at 40 milliseconds after IC. The present case shows strikingly similar patterns, with a rapid knee valgus and internal rotation increase within 30 milliseconds after IC, followed by external rotation. In addition, anterior tibial translation started 10 milliseconds before the peak knee internal rotation angle was obtained and reached approximately 9 mm at 30 milliseconds after IC, which corresponds to the maximum anterior tibial translation in intact knees.[8] The large anterior tibial translation that is clearly seen indicates that there must be forces driving the tibia forward relative to the femur. Consequently, these observations strengthened the previously proposed hypothesis that noncontact ACL injuries seem to occur approximately 30 to 40 milliseconds after IC and that valgus loading and lateral compression generate internal tibial rotatory motion and anterior tibial translation, due to the joint geometry, resulting in ACL rupture.[6,8,9]

It must be acknowledged that although a validation study has been performed to assess the accuracy of estimates for knee flexion/extension, abduction/adduction, and rotation,[4] the accuracy of femorotibial translation is not known. However, we believe that the unique video material available in this case could provide for acceptable estimates because we had 4 camera views with higher frame rate and higher quality images, as well as larger relative surface area of the player to the total video frame size in the lateral high-speed view (camera 3). Sensitivity tests using 5 (data not shown) and 10 mm more and less anterior translation also showed that the current matching was the most precise. Nevertheless, although the 9-mm estimate seems reasonable, an exact measure of anterior translation is not possible. It should also be noted that the current case may be exceptional, and further research is needed to determine if significant anterior translation occurs regularly.

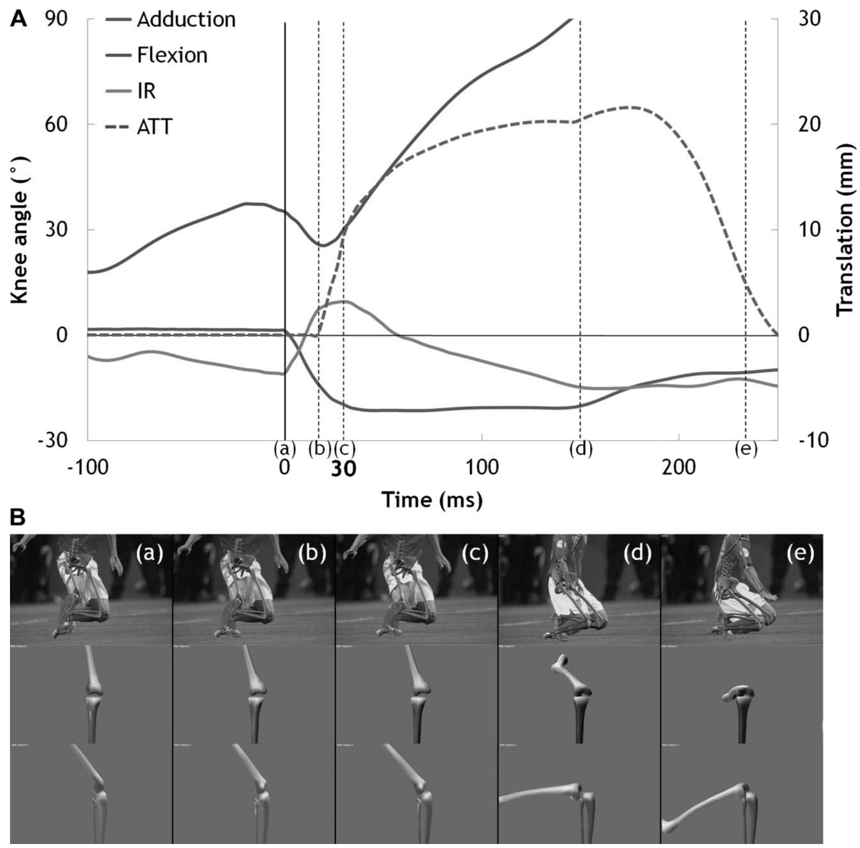

FIGURE 2. Knee joint kinematics extracted from an MBIM technique. A, Time sequences of knee joint angles (left axis) and anterior tibial translation (right axis). Time 0 (a) indicates IC, and the dotted vertical lines (b–e) indicate the time point 20, 30, 150, and 217 milliseconds after IC, respectively. B, Corresponding frames from camera 3 (300 Hz) (top panels), frontal views (middle panels), and side views (bottom panels) of the knee at 0 (a), 20 (b), 30 (c), 150 (d), and 217 (e) milliseconds after IC.

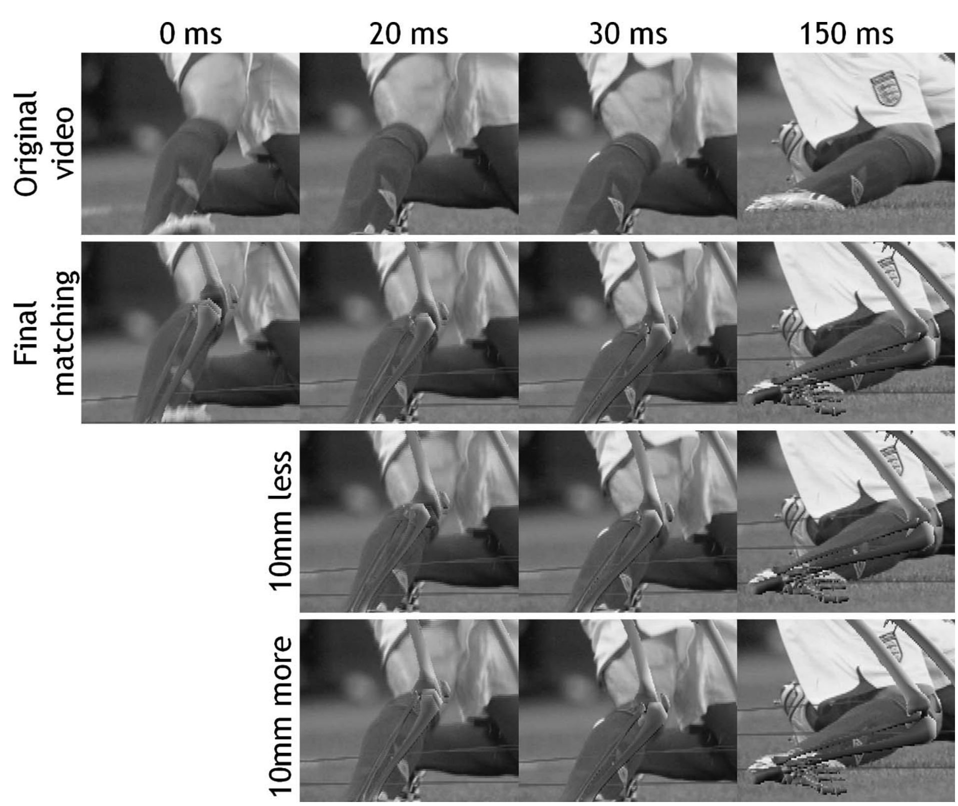

FIGURE 3. Accuracy of the anterior tibial translation. Two other matchings with 10 mm more and 10 mm less anterior tibial translation were compared with the final matching at 20, 30, and 150 milliseconds after IC.

In conclusion, the MBIM technique could describe the detailed joint kinematics, including femorotibial translations, of a noncontact ACL injury situation recorded using high-definition high-speed cameras. In addition to valgus motion coupled with internal tibial rotation, substantial anterior tibial translation was observed at the time of injury. These 3 motions seem to be important components of the injury mechanism. This study provides additional evidence in support of the injury mechanism proposed in the previous study[6] that valgus loading and lateral compression generate internal tibial rotatory motion and anterior tibial translation, resulting in ACL rupture.

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