VALIDATION OF MODEL-BASED IMAGE-MATCHING TECHNIQUE WITH BONE-PIN MARKER BASED MOTION ANALYSIS ON ANKLE KINEMATICS: A CADAVER STUDY

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Krosshaug (2005) introduced a model-based image-matching (MBIM) technique for 3D reconstruction of human motion from uncalibrated video sequences. The aim of this study is to validate the MBIM technique on ankle joint movement with the reference to bone-pin marker based motion analysis on a cadaver. One cadaveric below-hip specimen was prepared for performing full-range plantarflexion/dorsiflexion, inversion/eversion and relative circular motion between two segments. The videos were recorded and analyzed by the MBIM technique and bone-pin marker based motion analysis. The results are presented as the qualitative visual evaluation and the root mean square (RMS) error. In general, the validation results showed good agreement between the MBIM estimation and bone-pin marker based motion analysis results. This technique will contribute to the motion measurement of ankle joint kinematics in the future, for instance, the motion analysis in real game situations and understanding the injury mechanisms of real injury cases.

KEY WORDS: video analysis, ankle joint movement

INTRODUCTION: Skin marker based motion analysis is the most common method to calculate joint kinematics. However, skin marker based motion analysis is not always available in all situations. Sportsmen will not wear skin markers in real game situations and the target motion happens unexpectedly (Fong, 2009). In order to develop a novel biomechanical analysis to produce continuous estimates of joint kinematics from video recordings, Krosshaug and Bahr (2005) introduced a model-based image-matching (MBIM) technique for investigating human motion from uncalibrated video sequences. For the MBIM technique, only the validations on hip and knee joint movements were done, thus the validation on ankle joint movement is needed. Skin marker based motion analysis was regarded as the golden standard in previous validations. However, the results from skin marker based motion analysis were influenced by the skin artefact (Reinschmidt, 1997). The kinematics data deduced from skin markers is not a prefect standard for validating the MBIM technique. Thus, bone-pin marker based motion analysis was utilized to calculate the ankle joint kinematics in current study. The aim of this study was to validate the MBIM technique on ankle motion measurement with reference to bone-pin marker based motion analysis on cadaver.

METHODS: One cadaveric below-hip specimen was prepared for testing. Achilles tendon was cut to increase the joint flexibility. Hofmann II external fixation 5.0mm bone-pins (Stryker, US) were inserted into the posterolateral side of the calcaneus and into the lateral tibial condyle in the cadaver (Reinschmidt, 1997). Triads of reflective markers (14.0mm diameter spheres) were attached to the bone-pins (Figure 1). Skin makers were attached to lateral femoral epicondyle, medial femoral epicondyle, lateral malleolus and medial malleolus for defining knee and ankle joint center (Wu, 2002). After that, the specimen in upright position was mounted on a jig. Four high speed cameras (Casio EX-F1, Japan) were utilized to record the ankle motion in 30Hz with 640x480 resolutions from different views. A static calibration trial in the anatomical position served as the offset position to determine the segment embedded axes of the shank and foot segment. The foot segment was embedded with the Laboratory Coordinate System (LCS). The line connecting knee joint center and ankle joint center was the longitudinal axis of the shank segment (X1). The anterior-posterior axis of the shank segment (X2) was the cross product of X1 and the line joining the lateral femoral epicondyle and medial femoral epicondyle. The medial-lateral axis of the shank segment was the cross product of X1 and X2. Full-range pure plantarflexion/dorsiflexion, pure inversion/eversion and shank circular motion were performed on the ankle joint manually. A motion analysis system (Ariel Performance Analysis System, USA) was used to calculate the reflective marker's 3D coordinates by direct linear transformation. A singular value decomposition method was employed to calculate the transformation from triad reference frame to anatomical shank and foot reference frame (Soderkvist, 1993). Joint kinematics was deduced by the Joint Coordinate System (JCS) method (Grood, 1983). On the other hand, the videos were analyzed by the MBIM technique (Krosshaug, 2005). Using a commercialized animation software Poser (Poser4, Curious Lab, US), a virtual environment was built and matched with the video images in every camera view by adjusting the camera calibration parameters. A skeleton model (Zygote Media Group Inc, USA) was customized to match the anthropometry of the specimen. The skeleton matching started with the shank segment and then distally matching the foot, and toe segments frame by frame. The joint angle time histories were read into Matlab (MathWorks, USA) with a customized script for data processing. The kinematics results from both MBIM technique and bone-pin marker based motion analysis were filtered by Butterworth low pass filter with 5Hz cut-off frequency, in order to filter out the high frequency white noise.

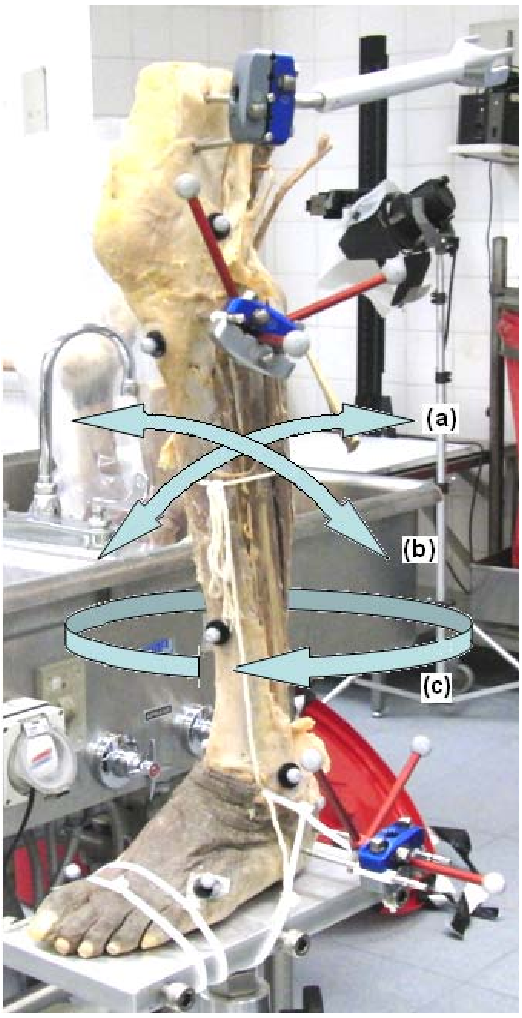

Figure 1. Three testing motions
(a) plantarflexion/dorsiflexion
(b) inversion/eversion
(c) relative circular motion between two segments

RESULTS: Figure 2 presents the curve fitting of the MBIM technique to bone marker based motion analysis method in measuring ankle kinematics. Good agreement was found for the plantarflexion/dorsiflexion and inversion/eversion. And internal/external rotation was less precise.

Table 1. Root mean square errors on ankle joint for the whole testing motion and the percentage differences to maximum range. Results from a similar study of comparing bony marker and skin marker (Reinschmidt,1997) are shown

	Plantarflexion/Dorsiflexion		**Inversion/Eversion**		**Internal/External Rotation**	
	MBIM	Skin marker	MBIM	Skin marker	MBIM	Skin marker
R.M.S. error (°)	4.6	4.7	3.1	4.6	4.5	3.6
Percentage difference to max. range (%)	10.7	14.1	11.7	34.7	30.5	51.2

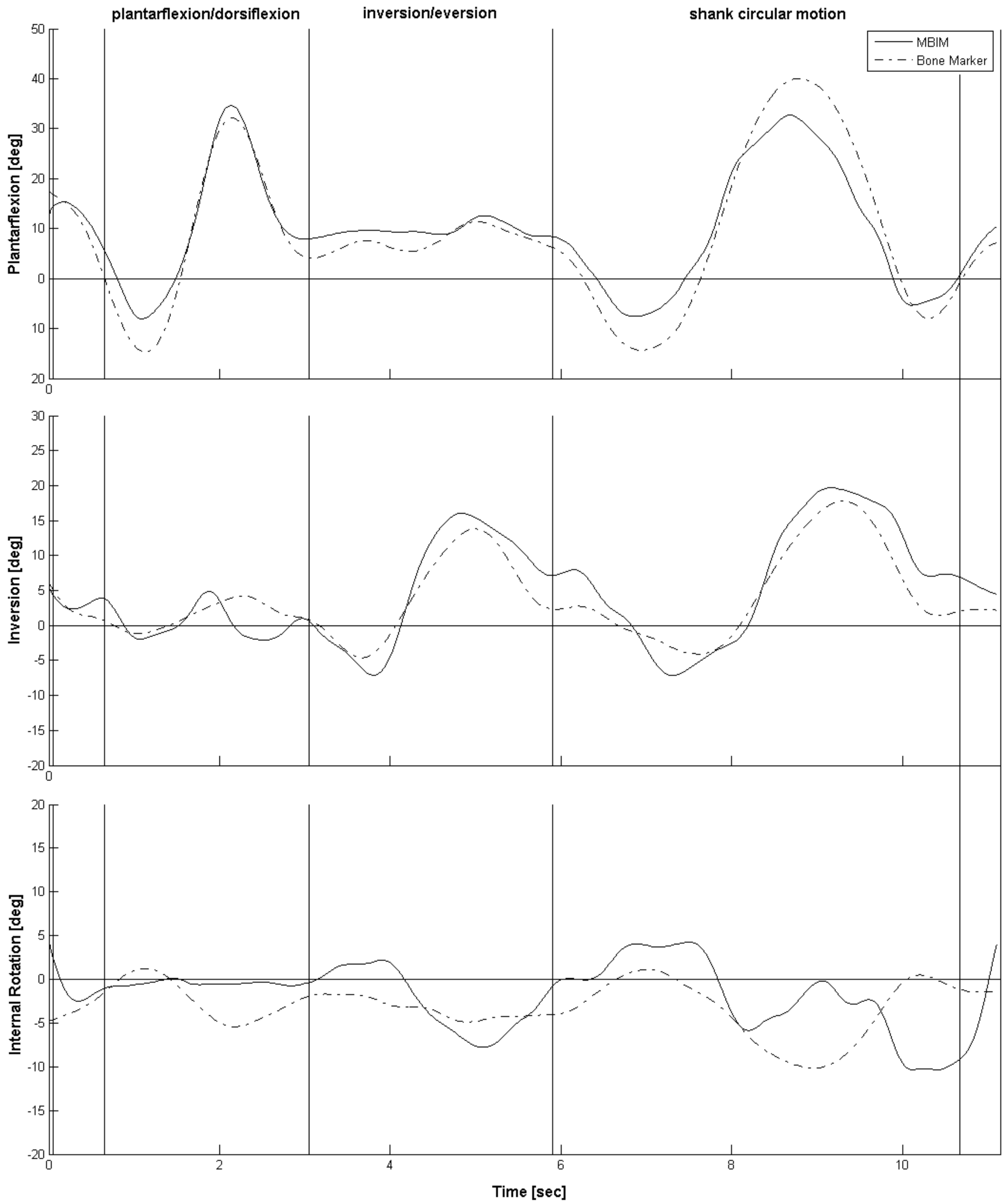

Figure 2. Ankle joint angles of the specimen, calculated with the bone marker based motion analysis (dotted lines) and the model-based image-matching (MBIM) technique (solid lines).

DISCUSSION: The aim of the study was to evaluate the MBIM technique for the estimation of ankle movements from uncalibrated video sequences. From the qualitative visual evaluation, good agreements were found in plantarflexion/dorsiflexion and inversion/eversion while internal/external rotation was less precise. The RMS errors of the three kinematic parameters were less than 5 degrees for the whole testing motion. The percentage differences to range are about 10% for plantarflexion/dorsiflexion and inversion/eversion results. The small RMS error coupled with good curve agreements, the MBIM technique was adequate to produce the ankle joint kinematics based on uncalibrated video recordings. Compared to a similar study of investigating the accuracy of skin-marker based motion analysis, MBIM technique performed relatively better than skin-maker based motion analysis (Table 1). However, it is not sufficient to conclude MBIM technique is more accurate because of the inconsistence of testing protocol.

Good agreement in plantarflexion/dorsiflexion was expected. The flexion axis of ankle joint was the cross product of the shank longitudinal axis and the foot longitudinal axis (Wu, 2002). As the longitudinal axis orientations of the shank and the foot could be accurately defined from the video images, plantarflexion/dorsiflexion result was expected to have a good fitting. Regarding the inversion/eversion result, it was highly depended on the orientation of the foot segment. Foot segment could be regarded as a flat rectangular board. And, the orientation of the plantar foot would be key information to match the foot skeleton on the video images. Using top view camera and front view camera in Poser, the detail orientation of the foot segment could be seen and further fine tuning was possible. For the shank, it was comparably difficult to be perfectly matched because it was in a cylindrical shape. The internal/external rotation result was highly depended on the internal rotation orientation of the shank segment. While only the patella position was a decisive landmark to define the internal rotation orientation of the shank. Therefore, it was understandable to have a less precise agreement on internal/external rotation.

The validation of the MBIM technique on ankle joint kinematics was considered achieved. The ankle kinematics information will contribute to different research areas in the future, for instance, the motion analysis in real game situations and understanding the injury mechanisms of real injury cases.

CONCLUSION: MBIM technique on ankle joint movements has been validated. This technique can produce ankle joint angle histories from uncalibrated video sequences. In the future, the MBIM technique would be regarded as a promising motion analysis approach for cases without skin marker based motion analysis in real game situations. Future works will be the investigation on the repeatability and reliability of MBIM technique.

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