Effect of the soft tissue artefact on knee joint angles obtained by magneto-inertial measurement units during squat

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Summary

Motion capture and, for instance, the study of the 3D kinematics of the knee during squat can be carried out with magneto-inertial measurement units (MIMUs). The effect of the soft tissue artefact (STA) in this case remains unknow. The joint angles obtained by MIMUs are compared to those obtained by biplane X-rays in five postures (0 to 70 deg of knee flexion) performed by nine osteoarthritis patients. Errors ranged between less than 7 deg for extension-flexion and adduction-abduction in posture #2 (i.e. 15 deg of knee flexion) to more than 30 deg for internal-external rotation in posture #5 (i.e. 70 deg of knee flexion).

Introduction

MIMUs are a valuable alternative to marker-based motion capture. MIMUs are portable, can be used outside of the laboratory, and are less expensive. In terms of accuracy, sensor-to-segment calibration can be an issue, as well as the STA due to the movement of the skin relative to the skeleton. The effect of the STA on joint kinematics obtained by MIMUs has not been widely studied in the literature. The objective of this study is to quantify the errors in the 3D joint angles by comparing MIMUs with medical imaging, namely biplane X-rays.

Methods

Retrospective data from nine patients with severe medial knee osteoarthritis (OA) were analysed [1]. Six females and three males (55 ± 16 years, 86 ± 26 kg, 171 ± 9 cm) performed quasi-static squats in the EOS system (EOS Imaging),), at five controlled knee flexion angles: 0, 15, 30, 45, and 70deg (i.e. postures #1-5). 3D reconstructions of the femur, tibia, and fibula were generated, and 3D coordinate systems were defined according to ISB standards [2]. Two Noraxon MIMUs (Ultium) were placed on the lateral side of the thigh and shank and were secured by straps. They were used to control the knee postures in the EOS system. MIMUs orientation was estimated using accelerometer and magnetometer data (ecompass, Matlab). Sensor-to-segment calibration was performed in posture #1 (i.e. 0 deg of knee flexion). Knee joint angles were calculated using a ZXY sequence, following ISB standards [2], and root mean square errors (RMSEs) were computed between MIMUs and biplane X-rays kinematics.

Results and Discussion

RMSEs increased with knee flexion, being higher for internal-external rotation (Table 1). Errors ranged between less than 7 deg for extension-flexion and adduction-abduction in posture #2 (i.e. 15 deg of knee flexion) to more than 30 deg for internal-external rotation in posture #5 (i.e. 70 deg of knee flexion). RMSEs were higher than those reported with skin markers [4]. The patterns of knee kinematics obtained by biplane X-rays showed internal rotation coupled with flexion and constant adduction, as expected for a squat movement in OA patients [3]. With MIMUs, flexion is underestimated, internal rotation is reversed, and adduction is progressively amplified. Internal rotation and adduction also displayed larger variabilities. The patients' overweight could have maximised STA, but the static postures (i.e. without impacts) may have simultaneously minimised it. With MIMUs, extension-flexion could have demonstrated fewer instrumental errors as it is based on the gravity, as opposed to internal-external rotation which relied more on the Earth's magnetic field.

Conclusions

The errors in 3D knee kinematics obtained by MIMUs can largely exceed a clinically acceptable threshold of 5 deg. Errors are due to both STA and instrumental errors (excluding here any additional sensor-to-segment calibration error). MIMUs may not be reliable for monitoring knee static postures in OA patients.

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References

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Table 1: RMSEs (in deg) between joint angles obtained by MIMUs and biplane X-rays in two of the static postures

Squat posture	#2 (i.e.15 deg of knee flexion)	#5 (i.e.70 deg of knee flexion)
Extension-flexion	6.5	20.8
Adduction-abduction	6.6	19.7
Internal-external rotation	15.8	30.1