

REVIEW ARTICLE

Application of computer-assisted imaging technology in human musculoskeletal joint research



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Summary Computer-assisted imaging analysis technology has been widely used in the musculoskeletal joint biomechanics research in recent years. Imaging techniques can accurately reconstruct the anatomic features of the target joint and reproduce its *in vivo* motion characters. The data has greatly improved our understanding of normal joint function, joint injury mechanism, and surgical treatment, and can provide foundations for using reverse-engineering methods to develop biomimetic artificial joints. In this paper, we systematically reviewed the investigation of *in vivo* kinematics of the human knee, shoulder, lumbar spine, and ankle using advanced imaging technologies, especially those using a dual fluoroscopic imaging system (DFIS). We also briefly discuss future development of imaging analysis technology in musculoskeletal joint research.

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Introduction

With the advancement of biomedical imaging technology, computer-assisted imaging analysis has been widely used in *in vivo* measurement of human joint kinematics [1]. The techniques include magnetic resonance imaging (MRI), computed tomography, X-rays, and fluoroscopy. In recent years, a two-dimensional (2D)–3D image matching

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procedure, that combines the information of the 3D joint model and the captured 2D X-ray/fluoroscopic images of the joint, has been proven to be accurate in reproducing the various human joint spatial positions during various dynamic functional activities [2]. Due to the different features of these imaging techniques, their applications involve different technical challenges, as well as radiation exposure [3].

Because of the easy accessibility and relatively low radiation dosage, the fluoroscopic image system has been extensively used to assist in orthopaedic surgeries, such as bony fracture reduction, total joint replacement, and spinal operations [4]. In the area of *in vivo* joint kinematics measurements, there are two different applications of the fluoroscopic image technique: single-plane fluoroscopy image system (SFIS) [5,6] and dual fluoroscopic image system (DFIS) [7]. SFIS has the advantage of being easy to use and has been widely used in tibiofemoral joint kinematics. However, this technique could not accurately determine the joint motion in the degrees-of-freedom related to the in and out of imaging plane direction [9]. To improve the accuracy of joint kinematics measurements, Li et al. [7] designed the DFIS using a combination of two fluoroscopic systems. The accuracy and repeatability of this system have been validated using a series of static and dynamic experiments [2,10]. The DFIS has been widely used in musculoskeletal joint research. This paper systematically reviews the *in vivo* kinematics studies of the knee, shoulder, spine, and ankle using the DFIS technique and discusses the advantage/disadvantage and future development of the technique in musculoskeletal joint research.

The DFIS

The DFIS consists of two fluoroscopes, with their image intensifiers positioned orthogonally so that an individual can freely move his/her knee within the DFIS and the two fluoroscopes can capture the images of the target joint simultaneously (Fig. 1A[8]). The *in vivo* poses of the knee are recorded as a series of paired fluoroscopic images. These images are corrected for distortion and automatically segmented using the Canny edge detection method [11]. A virtual DFIS is then created in a solid modelling

program (RhinoCeros, Robert McNeel & Associates, Seattle, WA, USA) to replicate the geometry of the actual DFIS (Fig. 1B). The two fluoroscopic images (labelled as F1 and F2 in Fig. 1B) are positioned to represent the two virtual image intensifiers. Two virtual cameras are created to represent the two actual X-ray sources. A global coordinate system is created in the virtual DFIS, where the X–Y plane coincides with the plane of a fluoroscopic image intensifier (F1 in this study; Fig. 1B).

Measurement of knee joint kinematics

The kinematics of tibiofemoral joint

DeFrate et al. [10] and Li et al. [12] carried out a normal tibiofemoral joint contact analysis during a single leg lunge from full extension to 90° of flexion, using a combined DFIS and 3D MRI-based knee modelling technique. The results indicated that the medial femoral condyle remained in the central portion of the tibial plateau and the lateral condyle translated posteriorly with increasing flexion. The flexion angle was not shown to have a statistically significant effect on the location of the contact points on the medial tibial plateau surface. The total translation of the contact point from full extension to 90° flexion was <1.5 mm in the anteroposterior direction, whereas the translation in the mediolateral direction was >5.0 mm. On the lateral tibial plateau, there was a statistically significant difference between the location of the contact point at full extension and the locations of the contact points at other flexion angles in the anteroposterior direction. The overall range of contact point motion was about 9.0 mm in the anteroposterior direction and about 4.0 mm in the mediolateral direction. Li et al. also found that on the medial condyle, the cartilage-to-cartilage contact regions were up to 40% thicker than regions with no contact. On the lateral femoral condyle, the maximum difference between these regions was 20%. On the tibial plateau, the maximal differences between regions with and without cartilage-to-cartilage contact were found to be 40% on the medial side and 50% on the lateral side [13].

In 2008, Bingham et al. [14] found that in both medial and lateral compartments, minimum peak compartmental contact deformation occurred at 30° of flexion and

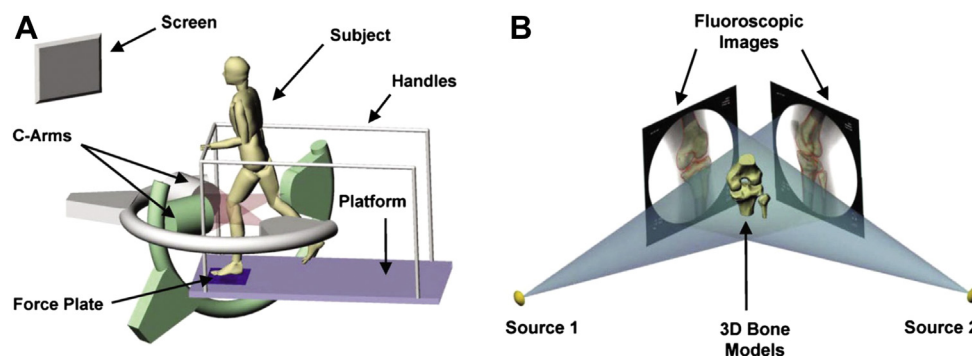


Figure 1 (A) Schematic of the dual fluoroscopic imaging system; (B) Virtual dual fluoroscopic system created based on the geometry of the actual experimental system. *Note.* From "Estimation of *in vivo* ACL force changes in response to increased weightbearing," by A. Hosseini et al, 2011, *J Biomech Eng*, 133, p. 05114–2. Copyright 2011. American Society of Mechanical Engineers. Reprinted with permission.

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