Tracking Shoulder Implant Motion Using Biplanar Videoradiography: An Accuracy Study

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Introduction: The shoulder joint is a complex joint with multiple degrees of freedom in both translation and rotation, and substantial laxity. This complex joint is also one of the most vulnerable joints to pathology and injuries due to repetitive motions during recreational and occupational activities. Many of these pathologies and injuries result in functional impairment, leading to progressive degeneration and eventually arthroplasty. Quantifying in-vivo kinematics of the shoulder joint after arthroplasty should offer compelling insight into the mechanistic link between joint stability and arthroplasty related kinematic changes that can be used to advance implant design and replacement procedure. Current state-of-art techniques for in-vivo kinematics use non-invasive 3-D video-radiography measurement techniques that overcome limitations associated with skin-based motion tracking systems. Bi-planar videoradiography can track dynamic 3-D bone motion with high accuracy of 0.1 mm and 0.15° when tracking marker-less motion of distal femur, radius, and ulna [1]. This accurate tracking requires a CT image volume of the bone being tracked and the algorithms utilize the density variations within the bone to optimize registration. However, tracking implants that don’t provide density gradient, pose unique challenges. Therefore, the purpose of this study was to evaluate the systemic error of the bi-planar videoradiography (X-ray Reconstruction of Moving Morphology - XROMM) system while tracking dynamic motion of shoulder implant after arthroplasty in a cadaver bone model.

Methods: The biplanar videoradiography (XROMM) system was evaluated against a standard optical motion capture system (OMC) (Qualisys, Gothenburg Sweden). One cadaveric humerus bone was manually stripped of soft tissue, cleaned using teragzyme in a hot water bath, disinfected with hydrogen peroxide, and dried at room temperature. A press-fit humeral component with articulating head (T5559AC 17 & C 4326AD 8, Tornier Inc, IN, USA) was implanted in humerus bone and affixed using bone cement. The humerus bone was attached to a custom designed impact pendulum that was rigidly fixed to a concrete block. A reference marker assembly with seven retroreflective markers (4 mm diameter) was attached to the impact pendulum. Two pendulum drop-impact trials were captured. The pendulum was rotated about its axial bearing until it impacted a cement block, orientated to mimic planar- and scapular- abduction tasks. A third pendulum rotation trial was collected, where the bone was fixed in line with the axial bearing to provide pure rotation, mimicking internal-external rotation task. The XROMM and OMC systems were time synchronized and sampled at 250 Hz. The kinematic transforms of the XROMM data were computed using custom marker-less tracking (Autoscoper) software1. 3D CAD models (STL files) of the implant were acquired from manufacturer and imported in slicer3D software (Slicer3D, Harvard, MA) to create 2D slices representing the 3D volume. These 2D slices were binarized using NIH ImageJ (1.47v, USA) software such that the implant is white and the background is black. These binarized slices were exported as a stack of tiffs file and used for digitally reconstructed radiographs (DRRs). The Autoscoper software computed transformation for each frame by rotating and translating the implant volume such that the DRRs were optimally matched to the bi-planar videoradiography. The kinematic transforms of the XROMM and OMC markers were computed...
for each frame from the previous frame. Helical axes of motion (HAM) parameters were computed for comparison between the XROMM and OMC data. The pendulum motion was confined to planar rotation, hence, the rotation and translation about HAM was considered in the analysis. The absolute maximum rotation and translation errors between XROMM and OMC data were computed and the root mean square (RMS) errors were evaluated between each tracking methods for each task.

**Results:** We evaluated the accuracy of the bi-planar videoradiography (XROMM) system against a “gold standard” optical-motion capture (OMC) system. Marker-less tracking of an implant is challenging due to lack of any density gradient in the DRRs and its smooth and regular design. Banks et.al have previously utilised a single-plane fluoroscopy look-up table method to perform dynamic kinematic measurements on knee prostheses, where the shape matching techniques were used to align the shape of a 3D surface model of the implant with the experimentally acquired images of the knee and reported the rotational and translation accuracy of $1^\circ$ and 0.5 mm, respectively [2]. However, using single-plane images, the method produces satisfactory in-plane accuracy but limited accuracy in the out-plane direction, which was highlighted in their limitation. In contrast, we utilised bi-plane radiography system and, as per our findings, angular errors for implant kinematics are very small and similar to previously reported dynamic errors of approximately $0.14^\circ$ for skeletal bone motion[1].

**Discussion:** We evaluated the accuracy of the bi-planar videoradiography (XROMM) system against a “gold standard” optical-motion capture (OMC) system. Marker-less tracking of an implant is challenging due to lack of any density gradient in the DRRs and its smooth and regular design. Banks et.al have previously utilised a single-plane fluoroscopy method to perform dynamic kinematic measurements on knee prostheses, where the shape matching techniques were used to align the shape of a 3D surface model of the implant with the experimentally acquired images of the knee and reported the rotational and translation accuracy of $1^\circ$ and 0.5 mm, respectively [2]. However, using single-plane images, the method produces satisfactory in-plane accuracy but limited accuracy in the out-plane direction, which was highlighted in their limitation. In contrast, we utilised bi-plane radiography system and, as per our findings, angular errors for implant kinematics are very small and similar to previously reported dynamic errors of approximately $0.14^\circ$ for skeletal bone motion[1].

**Significance:** This study is a significant step toward understanding the ability of the bi-planar videoradiography system in answering functional questions for the in-vivo kinematic changes after arthroplasty. Our outcome reports the baseline accuracy of such a system and provides a foundation for interpreting findings of future in-vivo studies.

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