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Short communication

Effects of radiograph projection parameter uncertainty on TKA kinematics from model-image registration

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Abstract

Model-image registration techniques have been used extensively for the measurement of joint kinematics in vivo. These techniques typically utilize an explicit measurement of X-ray projection parameters (principal distance, principal point), which is easily done for prospective studies. However, there is vast opportunity to derive useful information from previously collected clinical radiographic films where the projection parameters are unknown. The purpose of this study was to determine variation in measured knee arthroplasty kinematics when the X-ray projection parameters were unknown, but bounded. Based on the clinical radiographic protocol, a nominal principal point was chosen and eight additional points ± 2 and ± 5 cm in the horizontal and vertical directions were defined. Tibiofemoral kinematics were determined for all nine projection parameter sets for a series of 10 lateral radiographs. In addition, the principal distance was varied ± 15 cm and tibiofemoral kinematics were determined for these two projection sets. Measured joint kinematics varied less than 0.6° and 0.4 mm for ± 2 cm variations in principal point location, and 0.7° and 0.6 mm for ± 5 cm variations in principal point location. Measured joint kinematics varied less than 0.6° and 0.7 mm for ± 15 cm variations in principal distance. Variation in X-ray principal point and principal distance over clinically bounded ranges has a small effect on knee arthroplasty kinematics computed from model-image registration with high-quality clinical radiographs.

Keywords: Radiograph; Kinematics; TKA; Model registration

1. Introduction

Model-image registration techniques have been used extensively for the measurement of joint kinematics in vivo (Banks et al., 2003a, b; Komistek et al., 2003; Dennis et al., 2003). A wide range of techniques for fluoroscopy and radiographic images (Incavo et al., 2004; Delport et al., 2006; Coughlin et al., 2007) have been reported, all employing an explicit calibration step to determine the X-ray projection parameters (principal distance, principal point). This step is easily performed for prospective studies. But what about the vast collection of clinical radiographs acquired over the past century acquired without explicitly recording the projection parameters? Assuming appropriate permissions could be obtained, it seems that useful information could be gleaned from retrospective kinematic analysis of radiographs from a wide variety of clinical populations having specific diagnoses, implant designs and treatments, cultural backgrounds, etc. The first step toward this goal would require a demonstration that kinematic measurements are little affected by significant uncertainty in projection parameters.

Jain et al. (2005) reported a theoretical and experimental analysis of reconstruction errors with fluoroscope mis-calibration. They concluded that, for mis-calibration up to 50 mm in the principal point, 3D reconstruction errors for small objects would be negligible. Given this proof-of-principle, the purpose of this study was to determine variation in knee arthroplasty kinematics measured from clinical radiographs when X-ray projection parameters were unknown, but bounded by a specific clinical protocol.

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2. Materials and methods

Clinical radiographs from a single knee arthroplasty patient were obtained according to institutional protocols. The patient had a cementless, mobile-bearing, cruciate-retaining knee arthroplasty (INNEX Anterior-Posterior Glide, Zimmer). The patient had radiographic examinations at 2 and 19 months of follow-up that included five lateral views according to standard clinical protocol: weight-bearing radiographs at full-extension, 30° flexion and maximal flexion; anterior and posterior drawer following Lerat's protocol (Lerat et al., 2000). The X-ray tube was placed 1 m from the film cassette, rotated to a fixed orientation perpendicular to the wall, and translated to aim at the center of the knee. The films were digitized on a flat-bed scanner at 150 pixels/in., and the digital images were cropped to 800 × 800 pixels. The principal distance was not standardized or recorded for the drawer images.

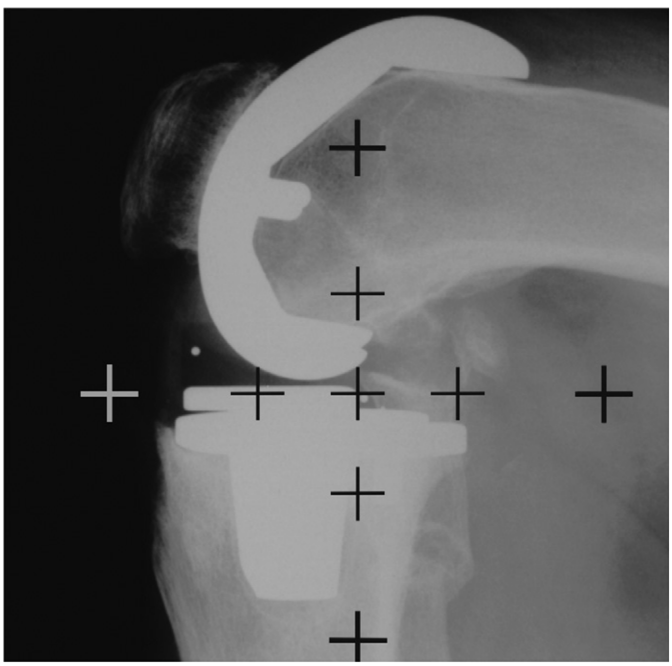

Fig. 1. Image showing nominal (center), ± 2 cm and ± 5 cm locations for the radiographic projection center or principal point.

Eleven different projection parameter sets were created for model registration. A nominal set positioned the principal point at the radiographic center of the knee with a 1 m principal distance (Fig. 1). Eight additional projection parameter sets were obtained by varying the principal point ± 2 cm and ± 5 cm in the horizontal and vertical directions (Fig. 1). Two additional projection parameter sets were obtained by varying the principal distance ± 15 cm from nominal for the drawer radiographs.

For each image and projection parameter set, model-image registration was performed to determine the position and orientation of the tibial and femoral implant components in the radiographic coordinate system. Implant models were positioned manually into rough alignment and then non-linear least squares minimization was performed using an image edge-to-model edge criterion. Solutions for each image and projection parameter set were determined independently, i.e., the solution from one image or projection parameter set was not used as an initial guess for another. Joint kinematics were computed using standard rotation definitions (Tupling and Pierrynowski, 1987), and the anteroposterior (AP) translation of each femoral condyle was determined from the point on each condyle closest to the surface of the plane of the tibial baseplate (Fig. 2).

Model-image registration was performed, and joint kinematics computed, for five projection parameter sets using nominal and ± 2 cm principal point variations, five projection parameter sets using nominal and ± 5 cm principal point variations, and three projection parameter sets using nominal and ± 15 cm principal distance variations. The standard, or root mean square, deviation (RMSd $= \sqrt{\sum_{i=1}^{n}(x_i - \tilde{x})^2/(n-1)}$, where $n = 5$ and $\tilde{x}$ is the sample mean) in five joint kinematic parameters was determined for each projection parameter set (Tables 1 and 2).

3. Results

Variation in joint kinematics with ± 2 cm principal point variation averaged 0.3° for flexion (range 0–0.6), 0.2° for abduction (range 0–0.3), 0.6° for tibial external rotation (range 0.3–1.1), and 0.4 mm for AP motion of both condyles (medial range 0.2–0.8, lateral range 0.2–1.0).

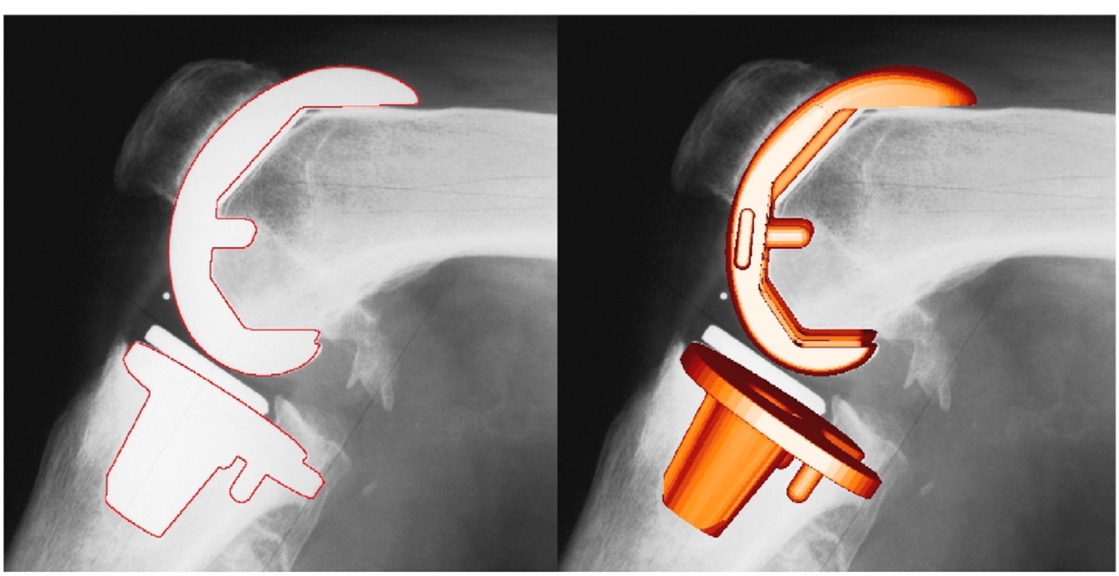

Fig. 2. Images showing the registered model edges (left) and rendered model (right) superimposed on a radiographic image. These images show the worst registration result of any image analyzed.