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Short communication

The effect of patient positioning on the precision of model-based radiostereometric analysis

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ABSTRACT

A repeatable method for in vivo and in vitro measurement of polyethylene wear in total knee replacement (TKA) is needed. This research examines the model-based radiostereometric analysis' (MBRSA) in vitro precision under different patient-radiograph orientations and flexion angles of the knee using a TKA phantom. Anterior–posterior and medial–lateral imaging orientations showed the highest precision; better than 0.036 mm (3-dimensional translation) and 0.089° (3-dimensional rotation). Flexion of the knee did not affect MBRSA precision. Medial–lateral imaging is advantageous as it allows for flexion of the knee joint during an RSA examination, thus providing greater information for wear measurement.

1. Introduction

Aseptic loosening is the main cause of long-term failure of total knee replacements (Callaghan et al., 2004; Mulhall et al., 2006). Osteolysis resulting from polyethylene wear particles is a common cause of this loosening process (Carr et al., 2012). Higher volumes of wear particles have been shown to increase the incidence of osteolysis and subsequent implant loosening, resulting in revision surgery (Purdue et al., 2007). Precise and accurate measurement of polyethylene wear is important for determining improved wear resistance between different types of polyethylene. Model-based radiostereometric analysis (MBRSA) is one of only a few clinical tools that have previously been used to estimate polyethylene wear in total knee replacements (Simpson et al., 2010; Short et al., 2005; Gill et al., 2006). This research examined only MBRSA precision, which indicates repeatability of measurement, and did not assess accuracy, which is the presence or absence of bias in the measurement.

Radiostereometric imaging of the knee joint is typically centered about the antero-posterior axis of the patient (Baad-Hansen et al., 2007; Kaptein et al., 2007; Seehaus et al., 2009; van Ijsseldijk et al., 2011). MBRSA precision studies have reported the in vitro and in vivo limits of this system in this configuration (Baad-Hansen et al., 2007; Kaptein et al., 2007). However, the effect of patient positioning on MBRSA precision remains largely unknown. The primary purpose of this study was to examine the effect of patient-radiograph orientation as well as flexion of the knee joint on MBRSA precision in a controlled, in vitro phantom experiment.

2. Materials

A set of size 3 Genesis II TKA components were obtained from Smith & Nephew (Kalamazoo, MI) and were reverse engineered (RE) using a 3-dimensional laser scanner (SG102, ShapeGrabber Inc., Ottawa, ON). The component models were reduced to 5000 polyhedral elements (Medis-Specials, 2011) and were converted by RSACore (Leiden, The Netherlands) for use in the model-based RSA software (mbRSA, RSACore).

The TKA components were cemented to rigid foam Sawbones (Pacific Research Laboratories Inc., Vashon, WA) prepared by an orthopaedic surgeon (TT). Five tantalum 1.0 mm diameter marker beads (Halifax Biomedical Inc., Mabou, NS, Canada) were inserted into the Sawbones surrounding each of the TKA components to serve as the gold-standard of measurement; however, frequent marker occlusion was encountered and therefore marker-based analyses are not presented in this research. A phantom frame was constructed using medium-density fiberboard (Fig. 1) and designed with a large open-air space to facilitate different patient-radiograph orientations with minimal obscuration. The Sawbones tibia was mounted to micromanipulators and fixed to the base-plate of the phantom. The femur was fixed to the top-plate via an acrylic T-groove system, which facilitated anterior–posterior and superior–inferior positioning. The femur and tibia mounts were designed to rotate in the transverse plane about a common pivot point (Figs. 1B and C) such that relative positioning was well maintained between the different orientations.

Two ceiling mounted X-ray sources (Varian Medical Systems RAD-92) were positioned horizontally at 60° to each other and 160 cm from two digital imaging

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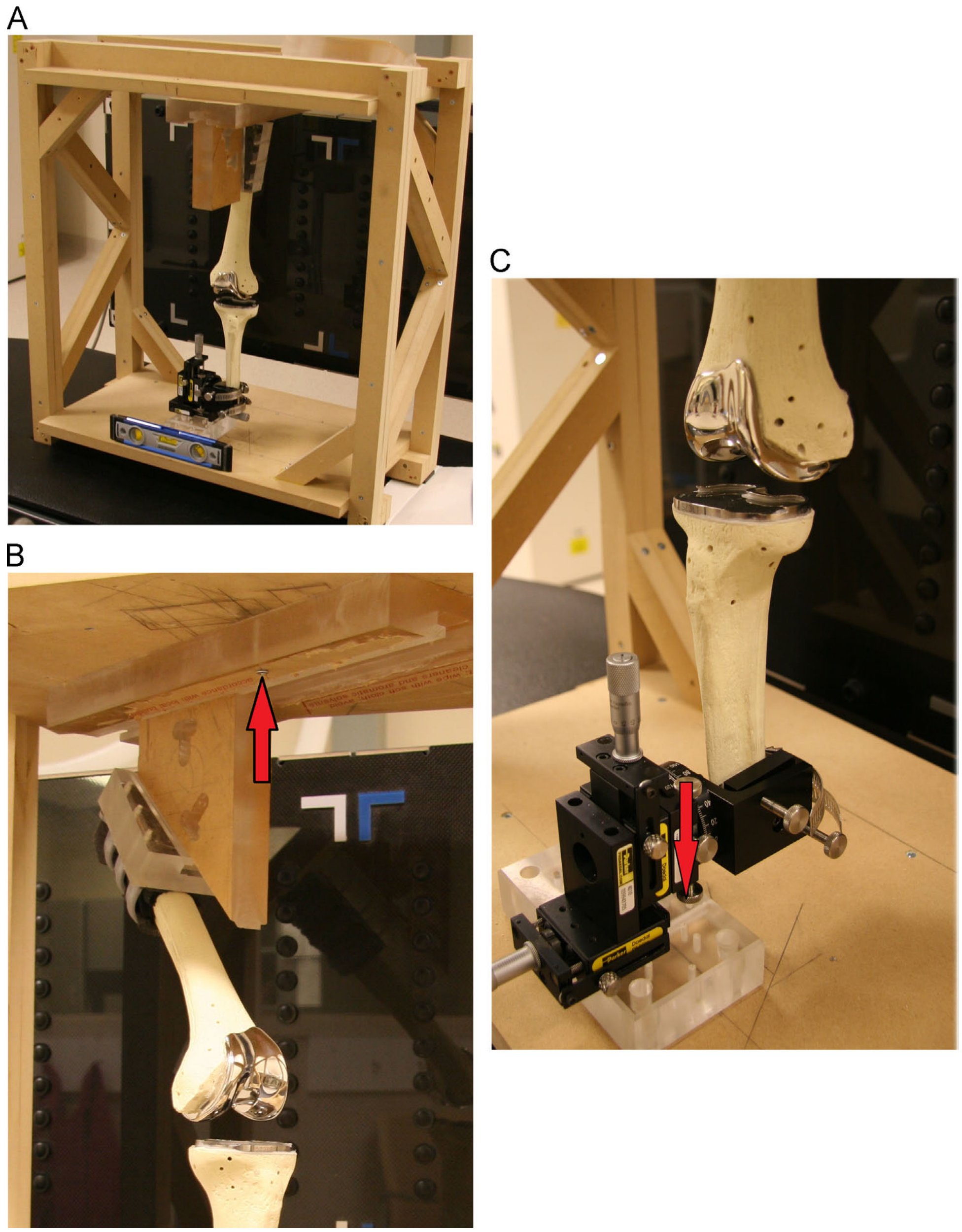

Fig. 1. (A) TKA phantom, (B) femur mounted to acrylic *t*-groove and (C) tibia mounted to micromanipulators.

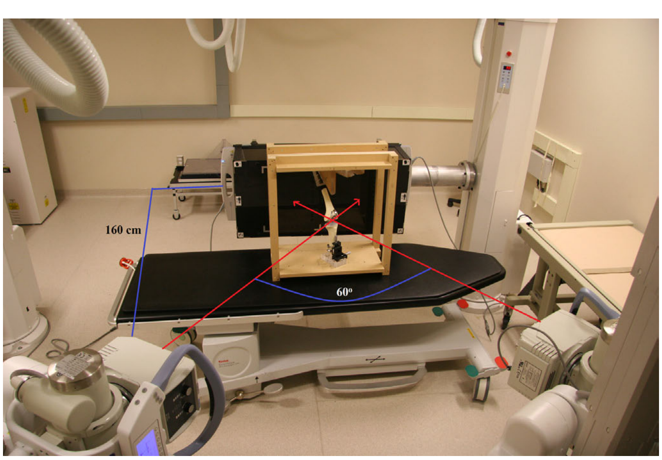

Fig. 2. Image and schematic of the RSA imaging setup.

plates (Canon CXDI-55C, Canon Inc., Lake Success, New York) that were slotted behind a carbon-fiber uni-planar calibration box (Halifax Biomedical) (Fig. 2). The TKA phantom was positioned at the crossing point of the x-ray beams. Radiographs were imported into mbRSA for analysis. Pose estimation was performed with the Iterative Inverse Perspective Matching (IIPM) algorithm in mbRSA utilizing 10% of the points on the contour. The pose algorithm was applied for a minimum of 200 iterations per component.

3. Methods

The inter-component distance (ICD), or spacing between the centers of mass of the femoral condyles and the tibial tray, was the focus of this research as this is the principal direction of polyethylene wear. The precision of measuring this centroid-to-centroid distance when no movement has occurred (zero displacement) was examined in a full-factorial experiment with 2 factors and 3 or 4 levels of each factor. Orientation of the knee joint was the primary factor; X-ray sources centered about the anterior–posterior axis of the joint (termed AP orientation), the joint turned 30° from this orientation (termed 30° offset), the joint turned 60° from this orientation (termed 60° offset), and X-ray sources centered about the medial–lateral