INTRODUCTION: In elbow replacement surgery, optimal function is dependent on the accurate replication of the flexion-extension axis, defined by the geometric centers of the capitellum and trochlear sulcus\(^1\), yet no computer-assisted techniques are currently reported to determine this axis. Thus, the position and orientation of the axis are currently estimated from visual landmarks intraoperatively.

A surface-based registration technique, employing a hand-held laser scanner, was evaluated against a stand-alone paired-point method to determine whether it led to improved alignment of the flexion-extension axis of the elbow. Our hypothesis was that the laser scanner combined with a surface registration would contribute to a more accurate axis alignment.

METHODS: Twelve fresh-frozen cadaveric distal humeri, each with at least a 10-cm shaft, were selected for the study. CT images of each were obtained using a helical scanner (GE – Light Speed Ultra Medical Scanner). Three different registrations, one paired-point and two surface-based, were performed on each specimen. The two surface-based registrations incorporated different devices for data acquisition. To perform paired-point (PP) registration, key anatomical landmarks were digitized using a tracked probe instrumented with a receiver from an electromagnetic tracking device (Flock of Birds, Ascension Tech). These landmarks included the capitellum, trochlear sulcus, and the distal and proximal humeral shaft. Using the geometric centers of these landmarks, PP registration to the CT data was performed using a landmark registration technique\(^1\).

Surface registration was performed using the iterative closest point (ICP) least-squares algorithm\(^1\). Prior to this procedure, a paired-point registration was performed to achieve a coarse alignment. Two surface registrations were evaluated; registration employing the tracked probe (TP-ICP) and registration employing a hand-held scanner (HHS-ICP). To perform surface registration, the magnetically tracked probe and a hand-held laser scanner (FastSCAN\textsuperscript{TM}, Polhemus) were each employed to acquire surface data. A 3D surface model was reconstructed and registered to the CT model using the hybrid method described above. For surface registration, only the articular surface was used for alignment, to be consistent with clinical exposure.

Surface acquisition was performed once (for each tracking modality) on each specimen, while the process of registration was repeated five times. Registration error was computed as the RMS distance of a registered landmark from the same landmark on the CT scan. An analysis of variance (ANOVA) was used for a multi-group comparison to ascertain whether the means of the independent distributions were significantly different.

RESULTS: Registration error was highest for the PP method with a mean of 1.921.0-mm in translation compared with a mean error of 0.820.3-mm for the hand-held scanner surface-based registration (p < 0.001). Registration error for the tracked probe surface registration was 1.520.5-mm (Fig. 1).

DISCUSSION: Joint replacement surgery involves aligning an implant with key anatomical landmarks of the joint. While it has been documented that surface registration is more accurate than paired-point registration incorporating anatomical landmarks, the hand-held scanner was found to be an improvement over the tracked probe for this application. HHS-ICP registration led to a more consistent and accurate alignment of the source flexion axis to the target flexion axis, as evidenced by the small deviation and maximum error shown in Fig. 2 (C) and (F). Varus-valgus error was most prominent for the PP registration technique while internal-external error was most prominent for the TP-ICP registration technique.

A significant concern regarding computer assisted joint replacement surgery is the limited exposure of the joint intraoperatively. However, in most cases clinically, the majority of the articular surface will be available to the surgeon. Surface registration using the information of the articular surface was found to be consistent with surface registration studies focusing on other joints\(^1\). Limitations of this study include the use of each device by only one user and a simulated in-vitro environment. The tracked probe and hand-held scanner were only used once per user on each specimen. Future studies need to focus on the repeatability of surface acquisition as well as inter- and intra-user variability. The absence of tissues surrounding the articular surface may also need to be considered.

Overall, the high reliability of the surface-based registration combined with the implementation of the hand-held laser scanner show promise for providing the surgeon with a valuable clinical tool in the future. A reliable surface-based registration technique will lead to a more accurate determination of the flexion-extension axis of the elbow, allowing for proper placement of the implant. This may well improve clinical outcomes following elbow replacement surgery, as successfully targeting the flexion-extension axis is expected to lead to improved joint motion.