In Vivo Three Dimensional Motion Analysis of Kudo Total Elbow

Introduction

Since the introduction of total elbow arthroplasty (TEA), many different designs of prostheses have been developed. However, survivorship of prostheses of favorably used today still remains lower and their peri-operative complication rates higher than total knee arthroplasty and total hip arthroplasty. Since the early 1990s, numerous in vitro kinematic studies of TEA have been undertaken. The cumulative results indicate that component design, alignment, and ligamentous balance contribute to the high rates of aseptic loosening and complications. However, in vivo kinematic study has its limitation. And in vivo kinematic study is essential to functionally evaluate TEA. The aim of the present study was to clarify in vivo motion of TEA using a 2D/3D registration technique, a 3D kinematic measurement by fluoroscopy and computer-assisted design (CAD) modeling of metallic prostheses. This technique has been hitherto used mainly to assess in vivo kinematic after total knee arthroplasty and useful for development of a new design of prosthesis and surgical technique. The basic principle of the algorithm, proposed by Zuffi et al., of this technique is that the 3D pose of a model can be determined by projecting rays from contour points in an image back to the model surface.

Patients and Methods

Patients: Between March 2006 and June 2008, six elbows (six patients), those who agreed to participate in the present study under institutional review board approval, were included. All the patients were female and treated with Kudo Total Elbow Type 5 because of rheumatoid arthritis. The mean age at the time of surgery was 47.2 years (range, 29–72 years). The mean duration between the operation and fluoroscopic surveillance was 56.7 months (range, 2–151 months). All the procedures were performed by Campbell’s approach. Medial and lateral collateral ligaments were transected and radial head resection was performed. Components were fixed with cement and the ulnar nerve was transferred to an anterior subcutaneous position.

In vivo kinematic measurement technique (Figure 1): Under fluoroscopic examination in the sagittal plane, each patient was asked to bend his or her elbow from full extension to full flexion at a comfortable rate. Successive elbow motions were recorded as serial digital X-ray images (1024 × 1024 × 12 bits/pixels, 7.5 Hz, serial spot images saved as DICOM files). In vivo 3D poses of the humeral and ulnar components were estimated using a 2D/3D registration technique, which uses CAD models to reproduce spatial postures of the humeral and ulnar components from calibrated single-view fluoroscopic images. The registration algorithm utilizes a feature-based approach, to minimize distances between lines drawn from a contour found in the 2D image to the X-ray source, and a surface CAD model with iterative computations.

Coordinate systems and kinematic descriptions: In each component, X, Y, and Z axes were defined as the axis perpendicular to the coronal, axial, and sagittal planes, respectively. The magnitude of the rotation about the X, Y, and Z axes of the ulnar component relative to the humeral component were expressed as varus/valgus, internal/external rotation, and extension/flexion, respectively, using Euler’s method. All data were expressed as mean ± standard deviation.

Results

The minimum flexion angle between the components was 33.6° ± 18.5° (range, 11.1–57.0°). Four of the six elbows exhibited minimum flexions of >30° and the other two elbows exhibited <30°. One elbow exhibited excessive flexion contracture >50°. The maximum flexion angle was 126.7° ± 5.5° (range, 117.8–134.5°). Only one elbow demonstrated flexion angle <120° and all the others >120°. The arc of range of motion was 93.0° ± 19.4° (range, 75.4–118.0°).

Concerning the valgus/varus angles between the components, there was a variation among patients. And from 30 to 120° flexion, there was a tendency to incline valgus with the increase of flexion (Figure 2). The mean valgus angle through flexion was -4.1° ± 4.3° (range, -4.2–5.8°) and the magnitude of displacement of valgus angle was 9.5° ± 4.0° (range, 4.1–16.4°).

In a similar way, there was a variation among patients about the rotation between the components. And from 30 to 120° flexion, there was a tendency to incline external rotation with the increase of flexion. The mean internal rotation through flexion was -1.0° ± 4.3° (range, -8.6–3.3°) and the magnitude of displacement of internal rotation was 8.1° ± 3.3° (range, 5.3–14.0°).

Discussion

According to the past in vitro studies on the kinematics of total elbow arthroplasty, transaction of medial and lateral collateral ligaments and radial head resection had influenced valgus/varus and rotational laxity after total elbow arthroplasty. Others reported that the different articular design of components had caused the different intrinsic constraint.

In the present study, as to valgus/varus angle and rotation, there was a moderate variation among patients. It might have been caused by the surgical technique, such as transaction of collateral ligaments and radial head resection. However, this examination could analyze only the motion between the metallic humeral and ulnar components but not between the humerus and ulna bones. To clarify the effect of medio-lateral soft tissue balance on the kinematics of total elbow arthroplasty, analysis including the humerus and ulna bones will be needed. And this is our future challenge.

References


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