DESIGN AND IMPLEMENTATION OF AN INSTRUMENTED ULNAR HEAD PROSTHESIS TO MEASURE LOADS IN-VITRO

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INTRODUCTION

Quantifying joint loads has always been a challenging pursuit in biomechanics due to the indeterminate nature of the loading scenario. Such information is necessary; however, to test and improve the design, wear and fixation stability of orthopaedic implants, in addition to gaining knowledge of articular mechanics and degenerative changes. Excision and more recently arthroplasty of the ulnar head has been commonly employed in patients with pain and dysfunction at the distal radioulnar joint (DRUJ) due to arthritis or post-traumatic complications. Despite the frequency of these treatment procedures, which either replace or remove the ulnar head, few studies have been conducted to quantify the role of the ulnar head in load transfer at the DRUJ.  

Therefore, the objectives of this study were: 1) to develop an instrumented ulnar head prosthesis to measure load in the DRUJ, and 2) to measure the load transferred across the DRUJ following arthroplasty during simulated active forearm rotation in-vitro.

MATERIALS AND METHODS

A modular, axisymmetric (stainless steel) ulnar head replacement system consisting of a head, stem and sleeve component was developed (Figure 1). The stem incorporated eight strain gauges to measure bending moments about the anterior-posterior (AP), medial-lateral (ML) and inferior-superior (IS) axes of the ulna. A protective sleeve was included to protect the strain gauge circuitry from the in-vitro environment.

An upper extremity joint simulator was used to produce active simulated forearm rotation. 2,3 Seven fresh-frozen cadaveric upper extremities (mean age 74 ± 8 years) were prepared and mounted in the simulator as outlined previously. 1 Six degree-of-freedom kinematic data of the radius and ulna were recorded using an electromagnetic tracking device (Flock of Birds, Ascension Technology, Burlington, VT, USA). At the completion of testing, bony and implant landmarks were digitized to establish coordinate systems. This allowed later transformation of the loading data into the relevant ulnar coordinate system.

Active and passive pronation and supination trials were conducted in the intact forearm (kinematic data collected only), and following insertion of the instrumented implant (kinematic and loading data collected simultaneously). Kinematic data were described using a 2-dimensional algorithm, 1 that depicts the dorsal and volar position of the radius relative to the ulna as well as the joint diastasis. Two-way repeated measures ANOVA’s were conducted on kinematic data and loading data to determine differences due to forearm position, and pronation or supination trials.

RESULTS

There were no differences between pronation and supination trials for any of the three bending moments (p>0.05). There was a higher magnitude (negative) moment about the ML and IS axes when the forearm was in the supinated position compared to the pronated position (p<0.001). There were also no differences in bending moments between active and passive trials (p>0.005).

DISCUSSION

Similar patterns of loading and kinematics were obtained regardless of the type of motion (i.e., pronation vs. supination or active vs. passive). This suggests that the loading scenario experienced by the ulnar head is due to the position of the articulating sigmoid notch of the radius. Simulation of supination agonists (i.e., biceps and supinator muscles) compared to the pronation agonists (i.e., pronator teres and pronator quadratus muscles) did not have an effect on the bending moments. This information has implications with respect to simulator design and in-vitro testing methods for the forearm.

The ML and IS axis bending moments increased in magnitude when the forearm was positioned in supination, demonstrating both an anteriorly directed moment as well as a torsion moment tending to further supinate the forearm. These results may have clinical implications with regard to the standard rehabilitation protocol to position the forearm in supination following ulnar head arthroplasty.

The results of this study illustrate a joint load through the DRUJ ranging from 3-10 N for simulated unrestricted forearm rotation (Table 1). This information is valuable with regard to modeling upper extremity and wrist activity, and for determining implant specifications for ulnar head replacement.

The main limitation of this study is that by utilizing an instrumented implant stem, no comparison can be made to the loading environment. This device has generated a characteristic loading profile of the distal ulna during forearm rotation. The information presented in this study has valuable ramifications related to modeling and implant design in the distal radioulnar joint.


![Figure 1: (A) The implant with three components, the replacement ulnar head, instrumented stem and protective sleeve. (B) The orientation of the implant and the three axes about which bending was measured following insertion in the DRUJ.](image1)

![Figure 2: Averaged bending moments about the three anatomic axes of the ulna during simulated active pronation and supination trials (n=7).](image2)

| Table 1: Averaged Joint Loads (± 1 SD) with Forearm Position |
|---------------|----------------|----------------|
|               | Pronated        | Neutral        | Supinated      |
| Pronation     | 3.54 ± 13.80 N  | 3.62 ± 14.05 N | 3.99 ± 16.50 N |
| Supination    | 3.88 ± 11.14 N  | 3.81 ± 11.78 N | 6.36 ± 14.95 N |

Kinematic results (not shown) illustrated a dorsal translation of the radius when the forearm was in the supinated position (p<0.05). The radius was translated volarly during active supination compared to active pronation (p<0.003) and the joint experienced greater convergence during pronation compared to supination (p=0.028).