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Hemiarthroplasty of the elbow: the effect of implant size on kinematics and stability

Sagar J. Desai, MD, FRCSC[a,b], George S. Athwal, MD, FRCSC[a,b], Louis M. Ferreira, PhD[a,b,c], Emily A. Lalone, PhD[a,b], James A. Johnson, PhD[a,b,c], Graham J.W. King, MD, MSc, FRCSC[a,b,*]

[a]*Bioengineering Laboratory, Roth McFarlane Hand and Upper Limb Centre, Lawson Health Research Institute, St Joseph's Health Care, London, ON, Canada*
[b]*Department of Surgery, Western University, London, ON, Canada*
[c]*Department of Mechanical and Materials Engineering, Western University, London, ON, Canada*

Background: Distal humeral hemiarthroplasty is a treatment option for distal humeral fractures, nonunions, and avascular necrosis. The biomechanical effects, however, have not been reported. The purpose of this in vitro study was to quantify the effects of hemiarthroplasty and implant size on elbow joint kinematics.
Methods: Eight fresh-frozen cadaveric arms were mounted in an in vitro motion simulator. An electromagnetic tracking system quantified elbow kinematics. A custom distal humeral stem was implanted by use of navigation, and 3 humeral articular spools were evaluated: optimally sized, undersized, and oversized. Statistical analysis was performed with repeated-measures analysis of variance.
Results: Distal humeral hemiarthroplasty altered elbow kinematics, regardless of implant size. In the valgus position, the optimally sized implant resulted in a mean increase in valgus angulation of $3^\circ \pm 1^\circ$ ($P = .003$) as compared with the osteotomy control. In the varus position, the optimal and undersized implants both resulted in significant increases in varus angulation: $3^\circ \pm 1^\circ$ ($P = .01$) and $3^\circ \pm 1^\circ$ ($P = .001$), respectively. The undersized implant had the greatest alteration in kinematics, whereas the oversized implant best reproduced native elbow kinematics.
Conclusion: This study showed a small but significant alteration in elbow joint kinematics with placement of a distal humeral hemiarthroplasty implant, regardless of implant size. This could be due to errors in implant positioning and/or differences in the shape of the humeral implant relative to the native elbow. These changes in joint tracking may cause abnormal articular contact and loading, which may result in pain and cartilage degeneration over time.
Level of evidence: Basic Science, Kinematics, Cadaveric Model.
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Keywords: Elbow hemiarthroplasty; implant design; elbow kinematics

Though described and reported many years ago, there has been recent interest in elbow hemiarthroplasty as a less invasive alternative to total elbow arthroplasty. Hemiarthroplasty may be ideal in situations in which only one

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*Reprint requests: Graham J.W. King, MD, MSc, FRCSC, Roth McFarlane Hand and Upper Limb Centre, 268 Grosvenor St, London, ON, Canada N6A 4L6.
E-mail address: gking@uwo.ca (G.J.W. King).

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portion of the elbow joint is affected, such as distal humeral fractures not amenable to open reduction–internal fixation, nonunions, or avascular necrosis. Hemiarthroplasty has the advantage of less invasive surgical approaches, less patient morbidity, avoidance of polyethylene wear concerns, and preservation of bone stock for future reconstructive procedures.[2]

There is a paucity of literature regarding hemiarthroplasty of the elbow. Clinical studies to date are few, with limited sample sizes, short-term follow-up, inconsistent indications for surgery, and variable implant materials and designs.[1,3,14,17,19,21-23] In addition to the lack of clinical information, there is a complete void of information regarding the biomechanics of these devices. Altered elbow kinematics may result in symptomatic instability from maltracking, implant loosening, and accelerated wear of the native articulation. Given that surgeons estimate the optimal implant size at surgery, the effect of incorrect implant sizing on joint kinematics and mechanics is unknown. Therefore, the purpose of this study was to determine the influence of distal humeral hemiarthroplasty and implant size on joint kinematics and stability in vitro.

Methods

This in vitro study quantifying the effects of hemiarthroplasty on elbow joint mechanics used 8 fresh, previously frozen male cadaveric arms (aged 76 ± 6.4 years) amputated at the mid humerus. Each arm underwent 64-slice, computed tomography (CT) (GE LightSpeed Ultra; General Electric, New Berlin, WI, USA). A three-dimensional (3D) surface model was generated (Visualization Toolkit [VTK]; Kitware, Clifton Park, New York, NY, USA) from CT scan DICOM (Digital Imaging and Communications in Medicine) data.

The optimally sized distal humeral implant was determined by measurements taken from the 3D CT reconstruction. Points were defined on the surface of the trochlea and capitellum with a semiautomated algorithm by use of initial boundary points selected by a single user (Fig. 1). The geometric center of the capitellum and trochlea was found by sphere fitting of the capitellum and circle fitting of the trochlear groove. The distance from the geometric center of the trochlear groove to the geometric center of the capitellum was measured for each 3D model. To match the implant to the specimen, comparative measurements were taken from 3D models of the 6 distal humeral implants (Latitude Anatomic, Tornier, Stafford, TX, USA).

Specimens were thawed at room temperature (mean, 22°C ± 2°C) for 18 hours before testing. They were kept hydrated throughout the preparation and testing protocol with normal saline solution. The tendons of the biceps, triceps, and brachialis were sutured by a locking Krackow repair.[9] All skin incisions were closed with No. 2 Vicryl (Ethicon, Bridgewater, NJ, USA). A Steinmann pin was placed through the third metacarpal, through the carpus, and into the distal radius to fix the wrist in neutral flexion and extension. Two fully threaded 3.5-mm cortical screws were placed across the distal radioulnar joint to fix the forearm in neutral rotation.

The distal humerus was mounted in an in vitro, unconstrained elbow simulator previously developed in our laboratory.[7] The

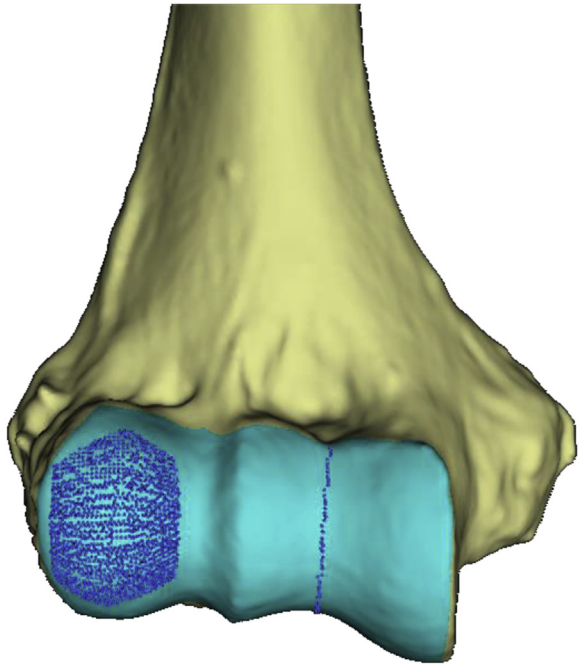

Figure 1 Three-dimensional reconstruction of distal humerus. Nine points were selected on the surface of the capitellum and 6 points along the trochlear groove. By use of a semiautomated algorithm, a point cloud was created over the surface of the capitellum and along the trochlear groove. These points were used to define the geometric center of the spherical capitellum and the circular trochlear groove.

sutures were connected to servomotors via braided Dacron cords. The servomotors applied forces to the tendons that moved the elbow from full extension to full flexion or vice versa at a controlled rate (10°/s). The motion simulation was based on electromyographic data and muscle cross-sectional area.[8,10] Established muscle load protocols were used during active motion, as reported by Ferreira et al.[7] The simulator allowed for testing in the dependent (vertical), horizontal, varus, and valgus positions (Fig. 2). The motion of the ulna with respect to the humerus was quantified with the use of an electromagnetic tracking system (trakSTAR; Ascension Technology, Burlington, VT, USA). Accuracy as reported by the manufacturer is 1.8 mm with 0.5° root-mean-square deviation. A tracker receiver was rigidly fixed to the ulna, and the tracking transmitter was mounted on the simulator rigidly with respect to the humerus.

Testing began with the intact arm. The various elbow orientations, including varus, valgus, dependent, and horizontal positions, were tested in random order both actively and passively in flexion and extension. Passive flexion was performed by 1 investigator (S.J.D.) slowly moving the arm through a full arc of motion. The elbow was then surgically exposed through a midline posterior incision. Medial and lateral fasciocutaneous flaps were created, and the subcutaneous border of the ulna was identified. A chevron-type olecranon osteotomy was performed to gain access to the distal humerus. The osteotomy was fixed with a precontoured olecranon plate and locking screws (Accumed, Hillsboro, OR, USA). The collateral ligaments were left intact. The testing protocol with the native articulation was

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