Accuracy of a Novel Method for Assessing Glenoid Micromotion in Mechanical Testing of Reverse Shoulder Arthroplasty

Lawrence F. Torkan[1, 3], Kristen MacKinnon[3], John T. Bryant[1, 3], Ryan T. Bicknell[1, 2, 3], and Heidi-Lynn Ploeg[1, 3]
[1] Human Mobility Research Centre, Queen's University, Kingston, ON, Canada, [2] Department of Surgery, Queen's University, Kingston, ON, Canada,
[3] Department of Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada
Email: lawrence.torkan@queensu.ca

DISCLOSURES: Lawrence Torkan (N), John T. Bryant (N), Ryan Bicknell (DePuy Synthes, Zimmer Biomet), Heidi-Lynn Ploeg (N)

INTRODUCTION: Reverse shoulder arthroplasty (RSA) is typically performed in patients with cuff tear arthropathy. The Delta XTend Reverse Shoulder System (DePuy Synthes) is fixed by means of a central peg and up to four peripheral screws inserted into the scapula at the glenoid. Loosening remains one of the principal modes of implant failure [1] and the main complication leading to revision [2]. In order to achieve long-term fixation, a hydroxyapatite coating facilitates osseointegration but the micromotion between the baseplate and the bone must not exceed a threshold of 150 µm for this to occur [3]. Excess micromotion contributes to glenoid loosening. When assessing factors contributing to RSA glenoid baseplate micromotion, a reliable measurement system is needed when mechanically testing the implant in multiple orientations. The purpose of this investigation was to perform a calibration study and assess the precision and accuracy of an experimental system designed to assess factors contributing to RSA glenoid baseplate micromotion.

METHODS: Four Linear Variable Differential Transducers (LVDTs; Solartron™ Metrology, West Sussex, United Kingdom) recorded micromotion from a 126mm diameter, stainless steel disc surrounding a modified glenosphere. A Delta XTend baseplate was implanted according to surgical guidelines, without the inclusion of peripheral screws. A 25 PCF density Sawbones™ block represented good quality cancellous bone and was loaded along the long axis of the column (Pacific Research Laboratories, Vashon Island, WA, USA). Varying force-controlled loads were applied via a materials testing system (Bionix Servohydraulic Test System, MTS Systems, Eden Prairie, MN, USA. A circular reference ring secured to the sample was used to support the four LVDTs. The configuration was arranged orthogonal to the MTS crosshead. A three-dimensional Cartesian coordinate system was used, where the z-axis was the axis of loading. During assembly, the measuring plate and reference ring were set parallel in the xy-plane. The LVDTs were positioned at a radius of 52.5 mm from the center of the baseplate at relative angles of 0^0, 120^0, 280^0 and 200^0 clockwise. Three load cases simulated distinct loading conditions of the shoulder. The lowest force, 250 N, represented the force of unloaded active shoulder abduction [4] and the midrange force, 500 N, was an approximate average for a moderately loaded shoulder during activities of daily living (ADLs) [4,5]. The maximum loading condition of 750 N represented maximum shoulder loading, consistent with protocols by Formaini *et al.* [3] and Stroud *et al.* [6], as well as ASTM standards [7]. Each force was applied at two frequencies, 0.2 Hz and 1 Hz, for 1,000 sinusoidal cycles. Displacement data were collected during three phases using a sampling rate of 20 Hz. First, a total of 500 data points were taken with no load as the initial calibration. A second sampling of 500 data points was taken halfway through the cyclical loading phase. At the end of this phase, a third set of 500 data points was taken with no load as the final calibration. The x-y coordinates for each LVDT were determined from their polar coordinates and measured displacements along the z-axis were used to determine the position of the measuring plate with respect to the reference ring. A reference position was determined by taking the minimum measured displacement value for each LVDT during the cyclic test and subtracting this value from the measured displacements. The position of three LVDTs were used to compute two vectors. The cross product was calculated to find planar coefficients in order to establish the equation of the plane. The displacement of the fourth LVDT was used to determine a predicted z-value, which was compared to the measured value for each sample.

RESULTS: The displacement measurements yielded an accuracy of 2% to 10% between the predicted and measured values for an average absolute error of 6% with a mean of -4.4µm and a standard deviation of 8.8 µm. Values fell within 95% confidence intervals of +11.6µm and -20.4 µm.

DISCUSSION: The purpose of this study was to determine an accurate, precise, and repeatable calibration protocol for measuring glenoid baseplate micromotion. Due to the exclusion of peripheral fixation, the conditions of this study are considered severe in comparison to clinical cases. Additional fixation using various combinations of locking and non-locking screws in different qualities of cancellous bone and substitution of the central peg for a central screw are planned to provide clinically comparable results. The results of this anticipated study are expected to have measurement uncertainties within the confidence interval reported here. The LVDT fixture is intended to undergo a redesign to minimize the tilt that occurred between the Sawbones™ block and the baseplate.

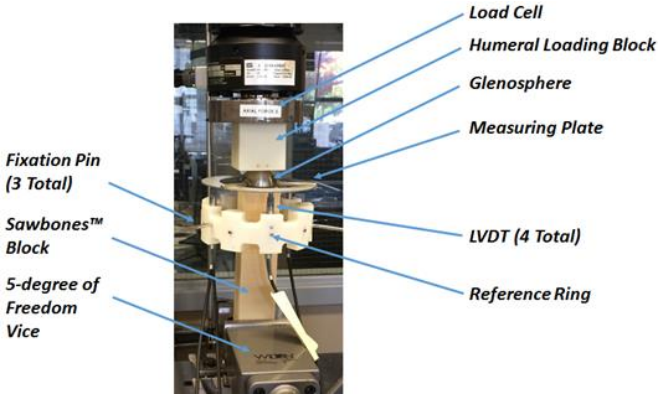

Figure 1. Testing Apparatus

CLINICAL RELEVANCE: These findings quantified the accuracy of a novel micromotion measurement method for mechanical testing of a reverse shoulder arthroplasty glenoid implant. This system is sensitive to biomechanically significant motions and will support future investigations to assess key factors contributing to glenoid baseplate micromotion such as the effects of central fixation (peg vs. screw), peripheral screw configuration (nonlocking vs. locking), bone density, and central cortical engagement.

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