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Original article

Effectiveness of CT for the detection of glenoid bone graft resorption following reverse shoulder arthroplasty

L.M. Ferreira [a,b,c,*], N.K. Knowles [a,b], D.N. Richmond [a], G.S. Athwal [a,c]

[a] Roth|Mcfarlane Hand and Upper Limb Centre, Surgical Mechatronics Laboratory, St. Josephs Health Care, London, ON, Canada
[b] Department of Mechanical and Materials Engineering, University of Western University, London, ON, Canada
[c] Schulich School of Medicine and Dentistry, University of Western University, London, ON, Canada

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ABSTRACT

Introduction: Glenoid bone grafting is often used in cases of reverse shoulder arthroplasty (RSA) with glenoid deficiency. Additionally, bony increased-offset RSA (BIO-RSA) uses a cylindrical bonegraft harvested from the humeral head and is positioned beneath the glenoid baseplate to increase lateralization. Postoperative computed tomography (CT) has been used to detect glenoid bonegraft resorption, which is typically identified by a gap between the bonegraft and baseplate; however, CT images are often degraded by implant metal artifact. The purpose of this CT imaging study was to determine if a simulated bonegraft resorption gap is detectable following RSA with glenoid bone grafting.
Hypothesis: CT is unable to detect bone graft resorption following reverse shoulder arthroplasty conducted with bone grafting beneath the glenoid baseplate.
Materials and methods: RSA with glenoid bone grafting was performed on four cadaver shoulders. Glenoid bonegraft resorption gaps were simulated by fixing the implant at six different gap widths (0, 1, 2, 4, 6 and 8 mm). Clinical CT scans were acquired for each gap resulting in 6 scans per specimen. Two experienced observers (blinded) analyzed DICOM images in the axial and coronal directions, and measured gap widths using Mimics® software. Each observer had access to approximately 200 images per condition per specimen.
Results: The sensitivity of CT imaging to positively identify bonegraft resorption was 38%, with an accuracy of 46%. Inter-observer agreement was 92%. Observers tended to visualize no-gap for most conditions. Resorption gap width measurements were consistently underestimated.
Discussion: Metal artifact prevented identification of simulated bonegraft resorption gaps and observers most often determined that there was bonegraft-to-implant "healing" on CT, when in fact a gap was clinically present. This study illustrates the need for more effective imaging techniques to determine if bonegraft resorption has occurred following RSA.
Level of evidence: Level IV. Basic Science; Cadaveric Study.

1. Introduction

Reverse shoulder arthroplasty is an effective treatment for rotator cuff tear arthropathy, massive irreparable rotator cuff tears and comminuted proximal humerus fractures. Bone grafting of the glenoid is a commonly used technique to address glenoid bone deficiency and to assist with glenoid component lateralization. In cases of severe glenoid bone deficiency, the humeral head can be used as a structural bonegraft secured to the native glenoid, with fixation obtained from the glenoid component baseplate. Additionally, glenoid bone grafting has been used as a method to increase glenoid component lateralization to decrease the common complication of scapular impingement and notching. The use of a cylindrical bonegraft harvested from the humeral head, and positioned beneath the glenoid baseplate has been termed "bony increased-offset reverse shoulder arthroplasty (BIO-RSA)" [1].

The long-term stability and survivability of these bonegraft constructs is in part due to osseointegration of the bonegraft with the native glenoid bone. Additionally, bone on-growth between the implant baseplate and the bonegraft is believed to be beneficial for long-term survivability. For bone on-growth to occur, contact between the baseplate and the bonegraft is required. Failure to

* Corresponding author at: Roth|Mcfarlane Hand and Upper Limb Centre, Bioengineering Laboratory, St Joseph's Health Care, 268, Grosvenor Street, London, Ontario, Canada, N6A 4L6. Tel.: +519 646 6000x61351; fax: +519 646 6049.
E-mail address: Louis.Ferreira@uwo.ca (L.M. Ferreira).

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achieve this on-growth may occur due to bonegraft resorption, micromotion due to poor initial implant stability, or insufficient compression of the bonegraft-implant interface.

Bone on-growth of porous coated implants has shown promising results in increasing the life of implants [2–6]. Bonegraft resorption may result in increased localized stresses and a degrading of implant fixation, which may potentially compromise implant survivability [7–9]. Postoperative computed tomography (CT) is an imaging modality used by surgeons to detect bonegraft incorporation or resorption. Although CT can be an effective imaging tool, image quality is often degraded by implant metal artifact. While algorithms for reducing implant metal artifact exist [10–12] and can be used clinically, these methods do not completely eliminate artifact. Given that the bony region of interest for structural glenoid bone grafting and the BIO-RSA is adjacent to the metal implant, it is reasonable to postulate that metal artifact may decrease the ability of surgeons to detect bonegraft incorporation or resorption.

The use of CT imaging has been reported as a means of observing healing of the bonegraft adjacent to a reverse shoulder arthroplasty [1]. However, the CT technique has not been validated in a controlled model. Thus, the purpose of this study was to determine if a simulated bonegraft resorption gap is detectable following BIO-RSA, using an in-vitro model imaged by CT. The accuracy and reliability of measuring the simulated bonegraft resorption gap width was quantified. We hypothesized that CT is unable to detect bone graft resorption following reverse shoulder arthroplasty conducted with bone grafting beneath the glenoid baseplate.

2. Materials and methods

Four fresh-frozen cadaveric shoulders (mean age: 56 ± 18 years) with preserved soft tissues and the humerus resected at the midshaft were used for this CT imaging study. An 8 mm thick cylindrical bonegraft was harvested from the humeral head and a BIO-RSA [13] was performed on each specimen by a fellowship trained shoulder surgeon with ten years of experience implanting RSA, using an Aequalis™ Reversed II Shoulder System (Tornier Inc., Bloomington, MN). A 29-mm diameter baseplate with an extended 25-mm post was implanted with a 36-mm glenosphere.

Six bone resorption gaps of varying width were simulated at the graft-baseplate interface of each specimen using precision custom fabricated (± 0.05 mm) plastic spacers. Resorption gaps were simulated in decreasing order (i.e. 8, 6, 4, 2, 1, 0 mm). To secure the baseplate and the bonegraft, only compression screws were used, with screws inserted parallel so that decreasing gaps were achieved by sequentially advancing the screws into the same existing holes. This method preserved bone integrity by avoiding repeated screw holes at varying angles. The plastic spacers were used to confirm the desired gap, but were removed prior to each CT scan. A clinical CT scan was done after each condition (6) for each specimen (4), for a total of 24 CT scans.

In order to avoid high air contrast, and artifact caused by large transitions in density, the density of joint fluid was simulated using buffered saline solution (Nerl Blood Bank Saline, Thermo Fisher Scientific Inc., Waltham, MA). The specimens were secured to avoid movement during CT scanning. Scanning was performed using a multi-slice scanner (GE Discovery CT750 HD) with clinical settings (140 KvP, 250 mm field of view, 1 mm slice increment, 1.25 mm slice thickness, resolution of 512 × 512 and 0.488 mm pixel size). These settings are standard at our centre to minimize metal artifact for patients with shoulder implants. Specimens were placed in the scanner in a manner consistent with patient placement. As such, the gap width dimension was oriented within the CT slice plane, where the pixel size is 0.488 mm, thus optimizing resolution of the gap width.

Fig. 1. A CT image in the coronal plane of a specimen with no gap (0 mm, full contact) between the reverse shoulder arthroplasty (RSA) baseplate and the bonegraft. The absence of the gap was accurately identified by both observers.

Computed tomography images in digital imaging in communications and medicine (DICOM) format were uploaded to medical imaging software (MimicsV. 15.01, Materialize, Leuven, BE). All identifying information was removed from the file names in order to blind observers (Figs. 1–4). Separately, two experienced observers viewed blinded and randomized specimen CT files. The observers were asked to review the imaging files to determine if a simulated resorption gap was present, and if present, to measure the gap width between the bonegraft and baseplate using the Mimics linear distance measurement tool. Observers were able to browse through DICOM images in the axial and coronal directions, which amounted to approximately 200 images per condition for a total of 4800 images for this study.

Statistical analysis was performed using a Fisher Exact test to determine if each observer could determine a simulated bonegraft resorption gap when present. A contingency table for diagnostic testing further indicated positive and negative identification of gap presence, from which we calculated sensitivity, specificity

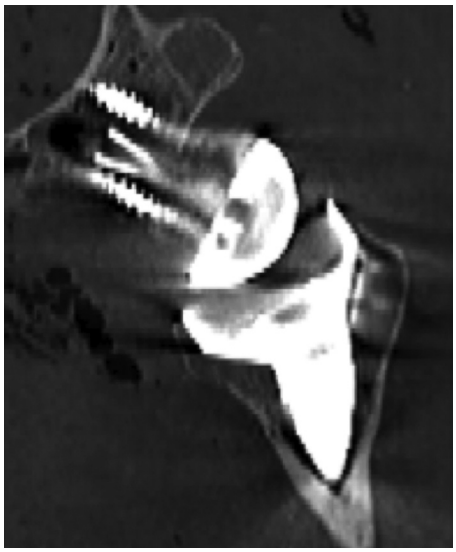

Fig. 2. A coronal CT image of a specimen with a 4 mm simulated resorption gap, which was incorrectly reported by both observers as having no gap (0 mm).