Re-attachment of the tuberosities of the humerus following hemiarthroplasty for four-part fracture

This study evaluated the effect on movement under load of three different techniques for re-attachment of the tuberosities of the humerus using test sawbones. In the first, the tuberosities were attached both to the shaft and to each other, with one cerclage suture through the anterior hole in the prosthesis. The second technique was identical except for omission of the cerclage suture and in the third the tuberosities were attached to the prosthesis and to the shaft. An orthogonal photogrammetric system allowed all segments to be tracked in a 3D axis system. The humeri were incrementally-loaded in abduction, and the 3D linear and angular movements of all segments were calculated. Displacement between the tuberosities and the shaft was measured.

The first and second techniques were the most stable constructs, with the third allowing greater separation of fragments and angular movement. Separation at the midpoint of the tuberosities was significantly greater using the latter technique (p < 0.05). The cerclage suture added no further stability to the fixation.

Fractures of the proximal humerus account for 4% to 5% of all fractures,\(^1\)\(^2\) the most severe subgroup being the four-part injury. In the majority of cases the treatment of choice is a hemiarthroplasty because of the high risk (25%\(^3\) to 75%\(^4\)) of avascular necrosis of the head of the humerus.

Hemiarthroplasty of the shoulder was first described by the French surgeon Péan in 1893\(^5\) but was subsequently largely forgotten. Neer\(^6\) introduced his humeral head prosthesis in 1955, and subsequently reported the first results for its use in trauma.\(^3\) Since then it has evolved in both prosthetic design and surgical technique. Complications relating to the fixation of the greater and lesser tuberosities remain a major challenge, and the majority of poor results relate to failure of their fixation or malposition.\(^7\)\(^-\)\(^9\)

This study examined three different techniques of re-attachment of the tuberosities, looking specifically at their stability under a constantly-applied load in abduction.

Materials and Methods

Biomechanical test sawbones (Sawbones Europe AB, Malmö, Sweden) were used. A custom-built jig was created to allow a reproducible four-part fracture to be simulated and to standardise the holes for passage of the sutures in all specimens. A Neer 3 (Smith and Nephew, Memphis, Tennessee) prosthesis cemented with Palacos cement (Heraeus Kulzer, Wertheim, Germany) was used for all tests. A simulated rotator cuff of polypropylene webbing was bonded to the tuberosities over the anatomical footprint of the insertion of the rotator cuff with a methylmethacrylate resin. This allowed load to be applied by the mechanical testing machine. The Neer prosthesis is a non-anatomical monoblock device that has two lateral fins with four suture-wire holes and one medial fin with one hole.

The different techniques for re-attachment of the tuberosity that have been described, are all based on the principles of combined horizontal and vertical fixation with or without a cerclage element. In our study three different suture techniques were performed (Fig. 1), using a number 5 Ethibond suture (Ethicon, Livingston, United Kingdom). In technique 1, both the greater and lesser tuberosities were attached to the shaft using two separate sutures. The second suture again passed through the lateral fins of the prosthesis and the other in a cerclage fashion round the prosthesis and through the medial fin. Technique 2 was identical to technique 1 but with no cerclage suture. The second suture again passed through the lateral fins of the prosthesis. In technique 3, the lesser tuberosity was attached to the shaft by the
same technique as previously described, but the greater
tuberosity was attached using a figure-of-eight suture, and
the tuberosities were attached to the lateral fins of the pros-
thesis but not to each other. Technique 3 is the recom-
mended technique in the manual of surgical technique for
the Neer 3 prosthesis.

The specimens were securely fixed in 20° of abduction
within an Instron Universal Testing Instrument (Instron
Corporation, Canton, Massachussetts), using a custom-
designed test rig. This consisted of a T-shaped cage (the
load applicator) attached to the load cell of the Instron,
which had a concave indent for articulation with the pro-
thetic head. A pulley was positioned on the moving cross-
head below this cage, to allow equal distribution of load
between the greater and lesser tuberosities. The sawbones
were transected 10 cm from their distal ends and secured to
the Instron by means of two semi-rings attached to the fixed

Techniques of re-attachment of the humeral tuberosities. Technique 1: Tuberosities attached to each other with the inclusion of a cerclage suture through the medial fin distally. Tuberosities attached to the shaft by two individual sutures. Technique 2: as per technique 1 but without the cerclage suture. Technique 3: tuberosities attached to the lateral fins of the prosthesis, and to the shaft but not to each other.
Markers were attached to the shaft and to both tuberosities of the humerus, and calibration markers were attached to the rig itself. The Instron test set-up can be seen in Figure 2. The Instron was run at a speed of 10 mm/minute. Three tests were performed using each technique of fixation, and new bones were used for each test.

Using a two-camera orthogonal photometric system, photos were taken at every millimetre of crosshead movement. An example of such a photo is seen in Figure 3, demonstrating the marker system and the simulated rotator cuff. Scion Image imaging software (Scion Corporation, Frederick, Maryland) was used to map the position of each marker in two dimensions. The two-dimensional data from the two cameras were then combined to create 3D linear and angular movements for each segment, and also corrected for parallax. These were all taken relative to the axis of the humeral shaft, as seen in Figure 4.

Measurements were taken from two points. Point 1 was the intersection of all three segments, separation between the tuberosities and from the shaft were measured, and point 2 was at the midpoint of the tuberosities where intertuberosity separation was quantified (Fig. 5).

The data were sampled at three points on the loading curve. The first of these was at 680 N (approximately 1 x body weight), the second was at 1200 N (the maximum load that all nine tests achieved), and the third at 1500 N (the maximum load achieved by all tests of techniques 2 and 3). Displacements were measured between the greater tuberosity, lesser tuberosity and shaft, in the z-axis (intertuberosity separation) and the x-axis (tuberosity-shaft separation). Rotation around the x-axis was also measured to represent the intertuberosity angular separation. The data are shown as the mean of all tests with 95% confidence intervals (CI).

Statistical analysis was performed using Minitab Statistical Software for Windows (Minitab Inc., State College, Pennsylvania). A one-way analysis of variance (ANOVA) was used to compare different groups of variables, with a significance level set at 0.05. Statistical differences were confirmed using Tukey’s pairwise comparisons.

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<td>Technique 1</td>
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<td>Test 1</td>
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Results

All tests were loaded to failure. Table I shows the maximum loads achieved in each group. Failure occurred in all the tests at a soldered joint between a metal bracket sewn into the simulated rotator cuff to allow load to be applied by the Instron testing machine.

Figure 6 shows the results of humeral shaft-lesser tuberosity displacement in the x-axis. Displacements were very small and similar for each technique, consistent with fixation of all techniques in the same way. Table II shows between-technique p-values for this and all other tests. No significant differences were seen between the tests for humeral shaft-lesser tuberosity displacement. The displacements between the greater tuberosity and humeral shaft (Fig. 7) were small, reaching a maximum of 2.9 mm, and the three techniques did not differ. This is consistent with the identical method of fixation employed in techniques 1 and 2, very similar to that used in technique 3.

Separation of the greater and lesser tuberosities at their base showed the greatest displacement, up to a maximum of 5.8 mm (Fig. 8). The mean displacement was greatest in technique 3 throughout the loads tested, although this did not reach statistical significance. Figure 9 shows the displacement at the midpoint of the tuberosities. It is clear that the mean values were considerably higher in technique 3 than in techniques 1 and 2, up to a maximum of 4.8 mm. These differences were statistically significant throughout the loads tested. Tukey’s pairwise comparisons confirmed this difference between technique 3 and the other two techniques.

The final displacement examined was the angular displacement, between the tuberosities rotation around the x-axis (Fig. 10). The values in technique 3 were higher than in the other two techniques but not significantly so.

Discussion

Hemiarthroplasty may be the treatment of choice for four-part fractures of the proximal humerus, with good clinical results reported in the literature.\textsuperscript{10-12} Accurate and secure re-attachment of the tuberosities is vital for a good outcome. Bigliani et al\textsuperscript{9} described 28 failed prosthetic shoulder replacements and found the greatest cause of failure to be detachment of the greater tuberosity. Similar problems were also highlighted by Demirhan et al\textsuperscript{13} in 32 patients; six had a complication related to the tuberosities, with five of these having an unsatisfactory outcome. Bono et al\textsuperscript{14} showed that malreduction of the greater tuberosity of 5 mm resulted in a significantly greater deltoid abduction force, demonstrating the importance of the tuberosities on the normal biomechanical function of the shoulder.
The use of biomechanical sawbones has disadvantages in that a simulated rotator cuff was required for which the sutures could not be applied at the tuberosity-cuff junction and allowed to ‘bed-in’ as in clinical practice. The site of failure in all tests was also related to the attachment of the artificial cuff which had a metal D-ring soldered to a metal bracket sewn into the cuff to allow attachment to the pulley for load transmission. Following failure in the tests for technique 1, the remaining specimens had their soldering reinforced. This is why only techniques 2 and 3 reached 1500 N. The reinforced soldered joint was still the point of failure in the remaining tests. Another potential disadvantage could be the use of the Neer 3 prosthesis. In recent years there has been increasing use of modular as well as fracture-specific prostheses. These implants have reduced the bulk of metal in the metaphyseal area to allow for re-attachment of the tuberosities. However, the Neer prosthesis has been in use for many years and has produced good clinical results.10,11 The advantages of using biomechanical test sawbones relate primarily to the minimising of problems associated with cadaveric specimens, such as size and the quality of the bone and cuff. All the bones were exactly the same anatomically, with identical biomechanical properties. This allowed a jig to be created to ensure that all bones had identical fracture patterns. Sutures were passed through holes positioned in the same location every time, standardising the fixation. It also allowed an identically-sized prosthesis to be used in all tests; a new specimen was used for each test.

Previous work on fixation of the tuberosities15,16 has looked at load applied in external rotation. Our study looked at load applied in abduction. External rotation is the primary...
passive movement worked on in early rehabilitation before healing of the tuberosities has commenced, and so this would be an appropriate loading mode. However, initial rehabilitation consists only of passive movements, which are likely to be small owing to pain and stiffness, and therefore the loads applied are likely to be very small. By testing in 20° of abduction a physiological loading was applied through the cuff. It has been shown that the subscapularis, which is attached to the lesser tuberosity, applies a similar force to that of the other three cuff muscles, attached to the greater tuberosity, combined. During early abduction, all the cuff muscles are active and depress the humeral head against the glenoid. Previous work has shown that between the initiation of abduction and 30° the resultant force is directed towards the centre of the glenoid. Therefore, the load applied by the pulley would recreate normal physiological conditions. During the early phase of rehabilitation the shoulder is immobilised. In order to wash under the arm and dress it is likely that some abduction will be required, and if any accident were to occur as part of a natural reflex response, abduction might occur. Hence, abduction was a suitable and useful loading to test.

Frankle et al. have demonstrated the importance of a single cerclage suture to resisting loads applied in external rotation. Good rates of healing and functional results have also been noted using a cerclage suture. The results in our study suggest that the cerclage suture does not confer a great deal of increased stability to loads applied in abduction, but it does not have a negative effect on the fixation, and it is therefore a valuable technique in view of its advantages in other loading movements. Boileau and Walch have advocated the use of multiple cerclage sutures for osteosynthesis, and it may be that a single cerclage as described here may not provide the same level of fixation, thus explaining the lack of demonstrated advantage in our study.

Displacement between the lesser tuberosity and the shaft of the humerus was the least of those tested. In all tests the lesser tuberosity was secured to the shaft with two sutures. This appears to be a stable and reproducible form of fixation, as the results were similar for all tests. It also demonstrates the reproducibility of the experimental techniques used.

Technique 3 consistently performed poorly for all intertuberosity measurements, although the differences only reached statistical significance for point 2. In techniques 1 and 2 the tuberosities were sutured together, allowing them to move as one unit when rotating around the x-axis. In technique 3 the tuberosities were only sutured to the prosthesis and were capable of independent rotation. This might account for the increased intertuberosity and the increased linear displacements. However, technique 3 is the method advocated in the surgical technique for the implant.

In conclusion, our study has shown that using a two-suture technique between the lesser tuberosity and the humerus provides a stable and reproducible form of fixation. Secondly, the tuberosities should be sutured to each other and to the shaft to confer maximum stability and minimise potential intertuberosity separation. Finally, in our study a cerclage suture appears to confer no increased stability against load applied in abduction.

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References