

Title

Retaining Or Excising The Supraspinatus tendon in Complex Proximal Humeral Fractures Treated With Reverse Prosthesis? A Biomechanical Analysis In Two Different Designs

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DISCLAIMER: None

The final publication is available at Springer via <http://dx.doi.org/10.1007/s00402-018-3016-8>

1 ABSTRACT

2 Purpose

3 We aimed to biomechanically evaluate the effect of the supraspinatus tendon on tuberosity stability using
4 two different reverse shoulder arthroplasty (RSA) models for complex proximal humeral fractures (PHFs)

5

6 Methods

7 Four-part proximal humeral fractures were simulated in 20 cadaveric shoulders. Two different RSA
8 designs were implemented: a glenosphere medialized model and a glenosphere lateralized model.
9 Tuberosities were reconstructed, and displacement of bony fragments was measured (mm) by placing three
10 sensors: in the humeral diaphysis (D), in the greater tuberosity (GT) and in the lesser tuberosity (LT). Axial
11 forces were induced and measured in Newton (N). The test was performed twice in each specimen, with
12 and without the supraspinatus tendon. The regression line (RL) was measured in mm/N.

13 Results

14 In the medialized model, the GT-D displacement was greater in the supraspinatus preserving model than
15 that in the tendon excision model ($p<0.001$), as well as for the LT-D distance ($p<0.001$).
16 In the lateralized model, GT-D displacement and GT-LT distance was greater in the preserving model than
17 that in the excision model ($p<0.001$, $p=0.04$).

18 Conclusion

19 The supraspinatus tendon excision had a positive biomechanical effect on tuberosity stability when
20 performing RSA for PHFs.

21

22 Keywords: tuberosity reconstruction, reverse shoulder arthroplasty, supraspinatus, cadaveric study, rotator
23 cuff excision, complex proximal humeral fractures.

24 Level of evidence: Basic Science Study. Cadaveric Study

25 INTRODUCTION

26 Reverse shoulder arthroplasty (RSA) has emerged as a viable treatment for complex proximal humeral
27 fractures (PHFs) in the elderly, and many studies have supported its use [1-3]. However, no consensus
28 exists regarding the need for tuberosity reattachment when treating complex PHFs with RSA.

29 The Grammont concept of reverse arthroplasty shifts the glenohumeral center of rotation (COR) inferiorly
30 and medially from the native joint, improving the efficiency of the deltoid [4, 5]. Lateralization of the COR
31 in RSA has been recently suggested as a potential benefit to limit the degree of scapular notching and
32 improve the range of motion. This can be achieved by designing extended or thicker glenosphere
33 components [6, 7] or using autograft bone spacers [8].

34 In the early reports on the use of RSA for acute fractures, tuberosities were not routinely reattached and
35 were even resected [9]. Technical efforts have recently been performed to anatomically reattach the
36 tuberosities[10], and this represents the current trend as described by several publications [2, 3, 11-13].
37 Tuberosity healing after RSA for PHFs has been shown to contribute to external rotation strength
38 restoration [12, 13]. However, some controversy exists in the literature concerning the influence of
39 tuberosity healing on outcomes [14].

40 The effect of the supraspinatus tendon on the greater tuberosity may represent a stress force that potentially
41 affects tuberosity healing. Because RSA was designed to work without a rotator cuff, the surgeon has the
42 option to preserve [3, 11] or excise [2, 12, 14] the supraspinatus tendon in complex PHF scenarios.

43 The objective of this study was to biomechanically test the effect of the supraspinatus tendon on tuberosity
44 displacement using a medialized glenosphere design and a lateralized glenosphere design for the treatment
45 of PHF with RSA. We hypothesized that the supraspinatus tendon may play a negative role in the stability
46 of tuberosities when fixed to the humeral stem.

47

48 MATERIALS AND METHODS

49 Twenty fresh-frozen cadaveric shoulders were used for this study, with a mean age of 62 (54-72) years.
50 Specimens had not had previous shoulder surgery.

51 Preparation of the specimens was performed according to a previous study description [15]. Two-thirds of
52 the distal clavicle, the entire scapula and the entire arm were initially included. Soft tissue superficial to the
53 rotator cuff was removed. All shoulders were dissected, and gross examination showed no evidence of
54 rotator cuff tears, arthritis, fracture or prior surgery. The medial third of the scapula was rigidly fixed to a
55 customized apparatus.

56 *Fracture preparation*

57 Two orthopedic surgeons reproduced a four-part proximal humeral fracture through the bicipital groove
58 using an oscillating saw to separate the greater tuberosity (GT) from the lesser tuberosity (LT) by splitting
59 the humeral head, as previously reported [16]. The rotator interval was also split to allow access to the
60 articular surface. A surgical neck horizontal osteotomy of the proximal humerus was performed that
61 preserved the subscapularis tendon fibers to reproduce the division of the humeral diaphysis (D) from the
62 tuberosities. The split humeral head was excised, and the tuberosities were then trimmed to obtain the
63 anatomic relationship when reduced around the humeral stem.

64 *Reverse arthroplasty and the tuberosity construct*

65 Two different RSA designs were employed. A Grammont medialized COR design RSA was implemented
66 in 9 specimens (Delta Xtend™, DePuy, Warsaw, IN) with the following implants: a standard 27-mm
67 baseplate, a 42-mm centered glenosphere, a 10-mm monoblock humeral stem in a neutral position, with
68 155° of humeral inclination and a standard polyethylene insert sized according to the tension.

69 The remaining 11 specimens were used for the lateralized COR model with a 3.5-mm thicker glenosphere
70 (Humelock Reversed®, FX Solutions, Viriat, France). The specific implants included a 24-mm baseplate,
71 a 36-mm centered glenosphere, a 10-mm humeral stem with 145° of humeral inclination and a polyethylene
72 insert sized according to the tension.

73 The humerus was then transected distal to the deltoid tuberosity to fix the specimen to an aluminum bench
74 vice. The tuberosities were reduced around the proximal humeral stem and sutured to the humeral shaft
75 according to Boileau's suture technique [10] using #5 Ethibond Excel® (Ethicon, Somerville, NJ).

76 *Sensor implantation and measurement technique*

77 Three sensors were implanted in the final construct: one in the humeral D, one in the GT and one in the LT.
78 The sensor placement was guided by digital calipers to reproduce the same setup distances for each
79 specimen. Calibration was then performed to obtain a reproducible model to compare multiple analyses.
80 Consequently, three measurements were obtained for each experiment: the greater tuberosity to diaphysis
81 (GT-D) distance, the lesser tuberosity to diaphysis (LT-D) distance and the greater tuberosity to lesser
82 tuberosity (GT-LT) distance.

83 Progressive axial forces were induced through the supraspinatus, infraspinatus and subscapularis tendons
84 using #5 Ethibond Excel® (Ethicon, Somerville, NJ) sutures and measured in Newtons (N). A customized
85 traction device with a digital dynamometer (Dillon ED Junior Red Dynamometer®, Data Weighing
86 Systems, Elk Grove, IL) was used to apply force.

87 Displacement of the sensors was analyzed using a digital tracker that included position sensors and a digital
88 signal processor (Polhemus Liberty®, Polhemus, Colchester, VT). The test was performed twice on each
89 specimen: first with retention of the supraspinatus tendon and, second, after supraspinatus tendon resection.

90 *Statistical analysis*

91 Linear mixed models were applied to determine the effect of the supraspinatus tendon on the relationship
92 between the increase in distance and force. These models, fitted separately for each combination of implant
93 type and sensor, included the interaction of the supraspinatus tendon type and force as a fixed effect and
94 the individual as a random effect.

95 The slope of the regression line was measured in mm/N for each configuration to determine the effect size.
96 Both regression lines (with and without the supraspinatus tendon) were forced to pass through the origin
97 because the distance cannot be increased if no force is applied. The difference between the two regression
98 slopes was considered the effect size measure. A positive value indicated a larger distance increase with
99 the supraspinatus tendon given the same force as without the supraspinatus tendon. The level of significance
100 was set at $p < 0.05$. All statistical analyses were performed with R (R Foundation for Statistical Computing,
101 Vienna, Austria.), version 3.3.1.

102 RESULTS

103 For both the medialized and lateralized COR models, all interfragmentary distances increased according to
104 the forces applied, resulting in a positive regression line in all experiments (Fig. 1 and Fig. 2).

105 The medialized COR RSA model showed significant differences in the GT-D interfragmentary
106 displacement when the supraspinatus tendon was preserved compared to that when it was resected (Fig. 1).

107 The model showed a higher regression line (RL) when the supraspinatus tendon was preserved than that in
108 the model where the supraspinatus tendon was resected ($p < 0.001$) (Table 1). The LT-D interfragmentary
109 distance (Fig. 1) exhibited a smaller regression line for the supraspinatus tendon excision model (RL: 0.047)
110 than that for the tendon preserving model (RL: 0.065, $p < 0.001$). Regarding the displacement between
111 tuberosities (GT-LT distance), the construct showed small non-significant differences for the excision and
112 preserving models ($p = 0.07$) (Table 1).

113 In the lateralized COR RSA model, the GT-D interfragmentary displacement (Fig. 2) was greater in the
114 supraspinatus preserving model than that in the supraspinatus excision model for the forces applied
115 ($p < 0.001$) (Table 1). The LT-D interfragmentary distance measurements (Fig. 2) showed no significant
116 differences with and without the supraspinatus tendon ($p = 0.97$) (Table 1). Regarding the GT-LT distance,
117 a significant difference in the RL was found between the two models. The RL value was significantly higher
118 for the excision model than that for the tendon retaining model ($p = 0.004$) (Fig. 2).

119 DISCUSSION

120 RSA has currently gained popularity in the management of acute PHFs. The present study showed that the
121 supraspinatus tendon is important for tuberosity stability in RSA performed for a PHF. This tendon excision
122 plays a positive biomechanical role in the stability of tuberosity reconstruction via RSA, especially affecting
123 the stability of the GT-D junction.

124 It is still unclear how tuberosity healing affects functional outcomes after RSA for PHF. In an early report,
125 Cazeneuve et al. [9] excised the remnants of the tuberosities to prevent limitation of adduction and possible
126 instability of the humeral component. Since then, different authors have reported their experience with the
127 use of reverse prostheses for fractures. Sebastiá-Forcada et al. [3] reported no differences between
128 tuberosity failure and healing subgroups according to the mean constant score of 31 patients. Chun et al.
129 recently reported no differences in functional outcomes regardless of tuberosity healing in 38 patients [14].
130 In contrast, Gallinet et al. [12] observed better clinical outcomes of patients with tuberosity healing among
131 a group of 41 patients.

132 Given the background, technical efforts have been made to enhance tuberosity healing, and consequently,
133 increased emphasis on tuberosity repair for the restoration of rotational shoulder function has been recently
134 noted [14, 17, 18]. Formaini et al. [11] proposed a hybrid cementation-impaction method with a cancellous
135 bone graft to improve tuberosity healing, and an 88% tuberosity healing rate was reported. In some
136 publications, the description of RSA for a PHF has included supraspinatus resection, but no clinical or
137 biomechanical evidence suggests that this will increase the healing of the tuberosities [2, 12, 14].

138 The present study confirmed the involvement of the supraspinatus tendon in GT- and LT-mediated stability
139 of the D in RSA. In the medialized model, resection of the supraspinatus tendon particularly has no effect
140 on GT and LT stability. In the lateralized RSA model, the greater impact of the supraspinatus tendon seems
141 to be focused on GT attachment stability to the D. However, when releasing the supraspinatus tendon, the
142 forces through both tuberosities seemed to increase, contrary to the medialized design. This may be
143 explained because the lateralized glenosphere may produce tension on the subscapularis tendon,
144 infraspinatus tendon and teres minor when the supraspinatus tendon is absent. COR lateralization seems to
145 significantly increase the joint loads, especially when the rotator cuff tendons are repaired [19]. In the
146 lateralization scenario, the rotator cuff tendons may act as antagonists after RSA [20].

147 Based on the results obtained, some clinical applications may be advised. The surgeon has the option to
148 either preserve or excise the supraspinatus tendon during the surgery. Preservation of the supraspinatus

149 tendon may jeopardize tuberosity stability around the humeral stem in RSA. Reinforcement of the
150 tuberosity sutures may favor bone fragment stability. Hence, the tuberosity stability may be favored when
151 excising the tendon from the GT. When a COR lateralized RSA is performed with a supraspinatus excision,
152 the surgeon must use a higher tension between both tuberosities. Then, the horizontal circumferential
153 fixation suture may play a more important role in tuberosity stability. This effect was previously described
154 by Frankle et al. [15] when studying the tuberosity reattachment stability in proximal humeral
155 hemiarthroplasty.

156 The aim of this study was not to compare the two different RSA techniques. Differences between the
157 designs are not limited to the COR. The authors do not consider the implants employed as comparable
158 designs. Differences include the humeral inclination, humeral stem diaphysis and baseplate diameter.
159 Therefore, a strict comparison of medialized and lateralized implants cannot be performed based on the
160 findings of the present study. Nevertheless, the aim of this study was to analyze the effect of the
161 supraspinatus tendon using two different RSA designs.

162 This study has several limitations. First, this is a biomechanical study. The clinical implications cannot be
163 fully determined, as the authors idealized the fracture pattern by obtaining good quality bone fragments and
164 reducing tuberosities with small fracture gaps. Second, cadaveric specimens were used with a mean age
165 and gender distribution that may not represent the target population for RSA treatment due to a complex
166 PHF. Third, the deltoid effect has not been analyzed. Lateralization and rotator cuff repair seem to interact
167 with deltoid action regarding joint load magnitudes [21].

168 **CONCLUSIONS**

169 The supraspinatus tendon excision plays a positive biomechanical role in tuberosity stability when
170 performing RSA for treatment of a PHF. Tendon resection leads to a more stable tuberosity construct for
171 both medialized and lateralized RSA models.

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176 **CONFLICT OF INTEREST**

177 The authors, their immediate family, and any research foundation with which they are affiliated did not
178 receive any financial payments or other benefits from any commercial entity related to the subject of this
179 article.

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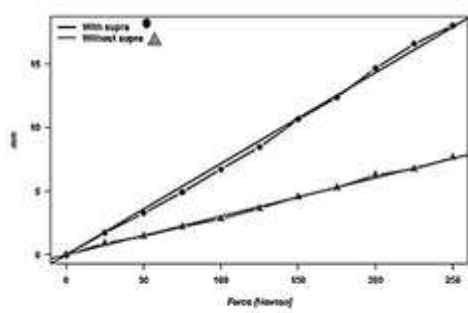
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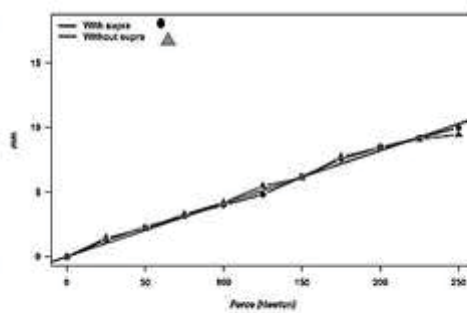
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Figure 1

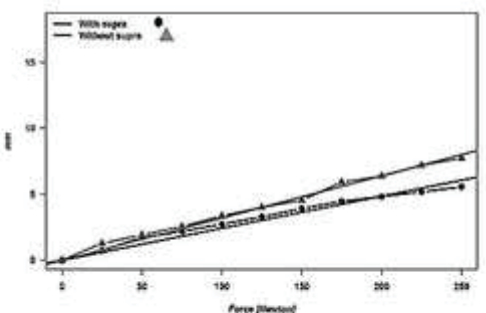
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GT-D interfragmentary displacement



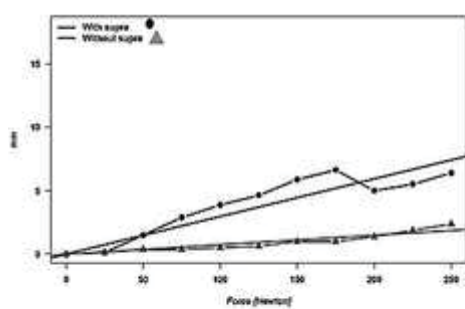
LT-D interfragmentary displacement



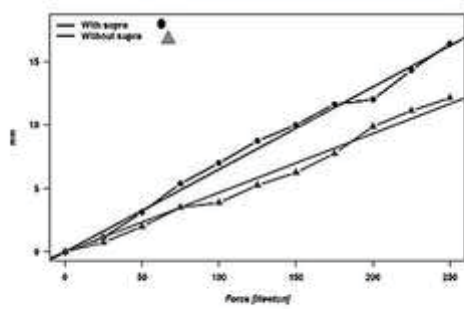
GT-LT interfragmentary displacement

Figure 2

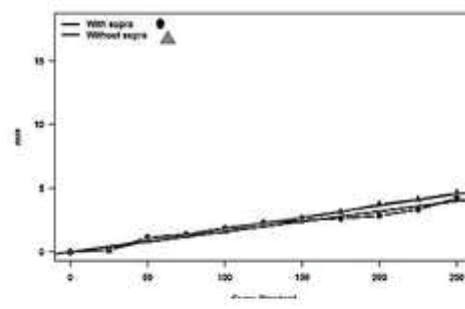
[Click here to download Figure FIGURE 2.power media player.windows.jpg](#)



GT-D interfragmentary displacement



LT-D interfragmentary displacement



GT-LT interfragmentary displacement

Table 1. Estimated slopes of regression lines for three different distances in both medialized and lateralized COR models.

	RL for supraspinatus preservation models (mm/N)	RL for supraspinatus excision models (mm/N)	P value
<i>Medialized model</i>			
GT-D distance	0,032	0,007	<0,001
LT-D distance	0,065	0,047	<0,001
GT-LT distance	0,015	0,018	0,07
<i>Lateralized model</i>			
GT-D distance	0,072	0,031	<0,001
LT-D distance	0,040	0,040	0,975
GT-LT distance	0,023	0,030	0,004

COR, Center of rotation; RL, Regression line; GT-D, Greater tuberosity to diaphysis distance; LT-D, Lesser tuberosity to diaphysis distance; GT-LT, Greater tuberosity to lesser tuberosity distance. The p values correspond to the null hypothesis that the slopes of the regression lines are the same.