Effects of Abduction Pillows on Rotator Cuff Repair: A Biomechanical Analysis

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Abstract *Background:* After rotator cuff repair, some surgeons use abduction pillows to unload or protect the repair construct, while others do not. *Question/Purpose:* The aim of this study was to determine which type of sling—one with a small or large abduction pillow or one without a pillow—places the repaired rotator cuff in the best position to reduce tension on the supraspinatus. *Methods:* An X-ray study was performed on asymptomatic subjects to determine what position the shoulder is placed in when wearing a sling with or without an abduction pillow. Positions were then reproduced in human cadaveric shoulders using a custom-made testing jig, and tension on the repaired supraspinatus was measured. *Results:* X-rays showed that abduction of the glenohumeral joint with a sling was only 4°, with a sling with a small pillow was 13°, and with a sling with a large abduction pillow was 25°. Placing the cadaveric shoulders in the position of a sling with a small abduction pillow caused a reduction in tension on the supraspinatus of 27% anteriorly and 55% posteriorly compared to placing the shoulder in the position of a sling without an abduction pillow; a large abduction pillow caused a further reduction in tension, of 42% anteriorly and 56% posteriorly. *Conclusion:* These findings show that abduction pillows reduce tension on the repaired supraspinatus tendon.

Keywords rotator cuff repair · shoulder · biomechanical study · abduction pillow

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Introduction

Rotator cuff tears are common and can lead to disability and pain. Rotator cuff repairs are effective at restoring shoulder function and reducing pain; however, they may re-tear after surgery. Following a rotator cuff repair, some surgeons insist their patients use a sling with an abduction pillow [6]. Several studies have evaluated the effect of glenohumeral joint abduction on the supraspinatus tendon following rotator cuff repair. Rathbun and Macnab found when the humerus was abducted, the vessels at the insertion of the supraspinatus tendon were almost completely filled with blood, compared to when the arm was by the side, where there is a large area of avascularity [12]. Reilly et al. found loading on the repaired supraspinatus was reduced at 30° of abduction compared to 0° by a mean of 34 N in a human cadaver model [13]. Andres et al. also found footprint contact pressure decreased as the repair is abducted in an ovine rotator cuff repair model [4]. Hershe and Gerber measured the passive tension in the supraspinatus muscle at the time of surgery of four patients with long-standing ruptured tendons compared to those with intact tendons and found the tension in the tendon was considerably reduced at 60° of abduction compared to neutral in both groups [8]. Conversely, a magnetic resonance imaging (MRI) study by Bey et al. concluded that increasing the angle of abduction increased strain on the supraspinatus tendon, most notable at 60° abduction [5].

There is, however, limited evidence on the effectiveness of abduction pillows clinically [11]. A study by Bigliani et al. found that an abduction pillow allowed the arm to slide into extension, which could lead to an increase in tension on the sutures rather than relief of it [6]. Furthermore, to our knowledge, there are no studies evaluating what position the glenohumeral joint is placed in when wearing commercially available abduction slings and pillows. The American Academy of Orthopaedic Surgeons could not recommend for or against the use of an abduction pillow instead of a sling after rotator cuff repair [2].

The aim of our study therefore was to evaluate the tension on the supraspinatus tendon at positions produced

by three clinically available slings, with the ultimate aim to determine the best position for minimizing tension on the repaired supraspinatus.

Materials and Methods

This study involved two goals: (1) to determine the glenohumeral abduction and internal rotation produced by clinically used abduction pillows and slings in humans and (2) to evaluate the forces on the repaired supraspinatus at these abduction angles in fresh frozen cadavers. Ethics approval was obtained from relevant regulatory bodies (HREC STG 14/130; Public Health Unit, South Eastern Sydney and Illawarra Health Districts).

Determining Glenohumeral Abduction and Internal Rotation Angles of Various Abduction Pillows and Slings

Abduction

Three shoulders of three healthy subjects with no previous shoulder pathology were X-rayed in true anterior-posterior (AP) view using a Fluoroscanner InSight machine (Hologic, Inc., Bedford, MA, USA). Subjects wore three commonly used slings and abduction pillows. To be included in this study, subjects had to be healthy adults over the age of 18 years with no history of injury, surgery, or structural or functional abnormalities of the shoulder.

The sling and abduction pillows used included the following:

1. A sling with no abduction pillow: Donjoy Ultrasling II (DJO, Normanhurst, New South Wales, Australia: product number, 11-0449-3-06000)
2. A sling with a small abduction pillow: Donjoy Ultrasling II (DJO: 11-0449-3-06000)
3. A sling with a large abduction pillow: ProCare Shoulder Abduction Kit (DJO: 79-84500)

Each was applied according to the manufacturer's instructions.

The sling with or without a small pillow was treated as two different types of sling for easy identification and also for differences in generating different abduction and internal rotation angles. Therefore, in total there are three different "types" of sling used in this experiment, for a clearer distinction between the groups.

True AP X-rays were used to measure the angle of abduction at the glenohumeral joint. The glenoid surface was determined by a line joining the most superior and inferior points of the glenoid. The angle of the humerus was determined by finding the mid-point of two separate lines, drawn perpendicular to the outer cortices of the humeral shaft. Abduction of the glenohumeral joint was calculated from the intercept of these two lines (θ) (Fig. 1). A reliability study of this measurement technique with nine asymptomatic subjects (18 shoulders) showed an intraclass correlation coefficient of 0.82 for inter-rater testing and 0.92 for intra-rater testing (unpublished data).

Fig. 1 X-ray of normal shoulder for measurement of abduction angle of the glenohumeral joint.

Internal Rotation

The same shoulders were used to determine internal rotation angle produced by each of the three slings. A laser level (BDL220s, Black and Decker, Mooroolbark, Victoria, Australia) was secured to the sling and positioned next to the dorsal surface of the distal forearm. This laser guide produced a beam parallel to the forearm. A second laser guide (Craftech, 3 mW, Craftech, Australia) was positioned on the most lateral surface of the upper arm parallel to the humerus and perpendicular to the ground. A photograph was taken of the projected laser lines on the floor. Internal rotation angle (ϕ) was measured from the intercept of these two laser beams using a protractor on this photograph. A reliability study of this measurement technique with seven asymptomatic subjects (14 shoulders) showed an intraclass correlation coefficient of 0.87 for inter-rater testing and 0.95 for intra-rater testing (unpublished data).

Biomechanical Studies

Specimen Preparation

Four human cadaveric shoulders were used to assess the effect of abduction on loads experienced by the repaired supraspinatus tendon. Each specimen was dissected free of all soft tissues, except the supraspinatus muscle and tendon. The scapula and humerus remained intact. A 2-mm bone tunnel was created in the acromion (most lateral aspect) with an electric drill, and a second 2-mm bone tunnel was created on the surgical neck of the humerus. Two stainless steel pins were inserted into these holes as guiding posts for determining the internal rotation angle.

Testing Apparatus

Each shoulder was mounted onto a steel frame via two 10-mm bolts through the scapula. Each scapula was mounted such that the glenoid surface was perpendicular/vertical to the ground, confirmed with an angle finder protractor. The corresponding humerus was secured to a custom made U-shaped frame via bolts, to facilitate control of abduction and internal rotation of the humerus during the study. An angle finder was mounted to the U-shaped apparatus to allow precise determination of the abduction angle of the glenohumeral joint (Fig. 2a).

Two metal pins were inserted into previously drilled holes in the lateral acromion and mid-shaft of the humerus

at the surgical neck. Viewing superiorly, the neutral position for medial and lateral shoulder rotation was defined as these two pins aligned together.

Tension on the Repaired Tendon

Rotator Cuff Repair Method

The supraspinatus tendon was detached completely from its humeral insertion to replicate a full-thickness tear. The torn tendon was then repaired using a single-row inverted-mattress construct with two knotless suture anchors. A tension band repair was performed using two 5.5-mm anchors (SwiveLock® C; Arthrex, Inc.; Naples, FL, USA). Prior to

Fig. 2. **a** Set-up allowing abduction and internal rotation of glenohumeral joint to be fixed. **b** Experimental set-up involving an external suture attached to the suture of the rotator cuff repair in order to determine tension on the sutures of the repair. **c** Experimental set-up testing tension in sutures.

placing the anchors, two inverted mattress sutures (FiberWire®, Arthrex, Inc.) were passed through the supraspinatus 13-mm medial to the torn edge of the tendon using a suture passer (CapsuleClose Scorpion™ Suture Passer, Arthrex, Inc.). Two pilot holes were created on the greater tuberosity 5 mm lateral to the supraspinatus footprint with a 4.5-mm diameter punch, 15 mm apart. The free ends of each suture were delivered over the tendon and through an eyelet of a knotless anchor, forming a tension-band construct. Each knotless anchor was placed in the appropriate pilot hole. The suture was tensioned until the tendon

covered the bony footprint, and then the anchor was screwed into bone for fixation. One limb of each suture was connected through a load cell (HFG-45, Transducer Techniques, Temecula, CA, USA) to a ratchet device to allow manual tensioning of each suture.

Testing Procedure

Both the anterior and posterior suture of the supraspinatus repair was tensioned to 10 N by two separate ratchet devices while the glenohumeral joint was at 0° of

Fig. 3. **a** True abduction angles from X-ray. **b** Internal rotation angle produced by three different slings.

Table 1 Intraclass correlation (2-way random model) mount 1 vs. mount 2 average

Abduction angles	Intraclass correlation coefficient	
	Anterior suture	Posterior suture
0°	0.834	0.889
4°	0.982	0.780
13°	0.707	0.982
25°	0.738	0.675

abduction (Fig. 2b). The 10 N load was determined in a pilot study to best represent the load seen in a typical rotator cuff repair. In the pilot study, the torn supraspinatus was mobilized to cover the footprint insertion on the greater tuberosity. Sutures from the repair were fastened with the ratchet device until the suture began to cut through the tendon. This load (10 N) was recorded via the load cell and used as the standard tensioning load throughout the experiment.

The humerus was then abducted to the three corresponding abduction angles (4°, 13°, and 25°) as measured on X-ray, and the tension was recorded at each abduction angle. This experiment was repeated three times on each of the four shoulders at four corresponding internal rotation angles measured previously (i.e., internal rotation of 29°, 20°, and 11°).

The following was the sample test sequence for each specimen:

- Step 1) internal rotation 0°; abduction (4°, 13°, and 25°)
- Step 2) internal rotation 29°; abduction (4°, 13°, and 25°)
- Step 3) internal rotation 20°; abduction (4°, 13°, and 25°)
- Step 4) internal rotation 11°; abduction (4°, 13°, and 25°)

Post-repair Suture Tension

A second method was used to assess post-repair suture tension. Upon completion of the measurements above, the same cadaveric shoulders were used to examine the tension in both the anterior and posterior suture of the repair. A small metal swivel was passed through each suture, then both limbs of the suture were reattached to the humeral head in an inverted mattress fashion with anchors (SwiveLock® C; Arthrex, Inc.) (Fig. 2b, c). A separate suture was threaded through the metal swivel with one limb attached to the load cell and the other attached to the ratchet device for manual tensioning. The humerus was then abducted and internally rotated to angles measured on X-ray, and tension in both the anterior and posterior sutures was recorded.

Statistical Analysis

Data in this study were reported as mean $\pm$ standard error of mean. Differences in tension in the supraspinatus tendon and the sutures were analyzed using paired Student's *t* tests. Correlation between tension on the repaired tendon and tension in the sutures were analyzed using Pearson's correlation coefficient.

Results

Abduction and Internal Rotation of the Glenohumeral Joint with Abduction Pillows and Slings (X-ray Study)

The glenohumeral abduction angle of the sling, measured using X-ray, was only $4^\circ \pm 3^\circ$ (mean angle $\pm$ SD) with internal rotation of $29^\circ \pm 13^\circ$. The sling with a small abduction pillow placed the glenohumeral joint at $13^\circ \pm 6^\circ$ of

Table 2 Effect of tension in the anterior suture of the supraspinatus at 0° internal rotation

Abduction angles	Load experienced by anterior suture (N $\pm$ SD)	Percentage change				Significant levels			
		0°	4°	13°	25°	0°	4°	13°	25°
0°	10.4 $\pm$ 0.6		– 18%	– 42%	– 56%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
4°	8.6 $\pm$ 1.0	– 18%		– 30%	– 47%	$p < 0.0001$		$p < 0.0001$	$p < 0.0001$
13°	6.0 $\pm$ 1.7	– 42%	– 30%		– 25%	$p < 0.0001$	$p < 0.0001$		$p < 0.0001$
25°	4.5 $\pm$ 2.0	– 56%	– 47%	– 25%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	

Table 3 Effect of tension in the posterior suture of the supraspinatus at 0° internal rotation

Abduction angles	Load experienced by posterior suture (N $\pm$ SD)	Percentage change				Significant levels			
		0°	4°	13°	25°	0°	4°	13°	25°
0°	10.1 $\pm$ 0.9		– 20%	– 44%	– 59%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
4°	8.1 $\pm$ 0.9	– 20%		– 31%	– 49%	$p < 0.0001$		$p < 0.0001$	$p < 0.0001$
13°	5.6 $\pm$ 1.5	– 44%	– 31%		– 27%	$p < 0.0001$	$p < 0.0001$		$p < 0.0001$
25°	4.1 $\pm$ 1.9	– 59%	– 49%	– 27%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	

Table 4 Effect of tension in the anterior suture of the repaired supraspinatus at 0° internal rotation

Abduction angles	Load experienced by anterior suture (N ± SD)	Percentage change				Significant levels			
		0°	4°	13°	25°	0°	4°	13°	25°
0°	4.2 ± 0.3		– 38%	– 72%	– 86%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
4°	2.6 ± 0.3	– 38%		– 54%	– 77%	$p < 0.0001$		$p < 0.0001$	$p < 0.0001$
13°	1.2 ± 0.2	– 72%	– 54%		– 50%	$p < 0.0001$	$p < 0.0001$		$p < 0.0001$
25°	0.6 ± 0.1	– 86%	– 77%	– 50%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	

abduction with $20^\circ \pm 2^\circ$ of internal rotation. The sling with a large abduction pillow placed the glenohumeral joint at $25^\circ \pm 8^\circ$ of abduction with an internal rotation of $11^\circ \pm 1^\circ$ (Fig. 3a, b).

Reliability Study

Two additional human cadaveric shoulders were used to test the reliability of our testing apparatus. Our testing apparatus showed an intraclass correlation coefficient of at least 0.68 for mounting and re-mounting the same specimen during testing [7]. According to Fleiss, an intraclass correlation coefficient of 0.7 is considered excellent reliability (Table 1).

Effects of Abduction on Tension of the Repaired Supraspinatus

Load Experienced by the Tendon (Anterior Aspect)

Abduction of the glenohumeral joint from 4° to 13° resulted in a significant reduction in tension (30%) of the repaired supraspinatus tendon ($p < 0.001$) indicative of the position the glenohumeral joint is placed in by the small abduction pillow. There was a further reduction in tension (25%) of the repaired supraspinatus when the glenohumeral joint was abducted to 25° ($p < 0.001$) indicative of the position the glenohumeral joint is placed in by the large abduction pillow (Table 2).

Load Experienced by the Tendon (Posterior Aspect)

Abduction of the glenohumeral joint from 4° to 13° resulted in a significant reduction in tension (31%) of the repaired supraspinatus ($p < 0.001$), with further reduction in tension (27%) of the repaired supraspinatus when the

glenohumeral joint was abducted to 25° ($p < 0.001$) (Table 3).

Effect of Abduction on Suture Tension

The suture tensions were similar to the load experienced by the repaired tendon, with significant reduction in tension (54%) when the glenohumeral joint was abducted from 4° to 13° ($p < 0.001$), with a further reduction (50%) when abducted to 25° ($p < 0.001$) (Tables 4 and 5).

Correlation Between Muscle Tension and Suture Used for the Repair

There was a strong correlation between the load experienced by the repaired supraspinatus and suture tension (anteriorly, $r = 0.84$, $p < 0.001$; posteriorly, $r = 0.89$, $p < 0.001$), indicating that as the repaired tendon experienced greater load, the suture used for the repair also experienced a greater load.

Effects of Internal Rotation on Suture Tension

There was a significant reduction in repair tension anteriorly (50%) when the glenohumeral joint was internally rotated from neutral to 11° ($p < 0.0001$). Further internal rotation to 20° and 29° resulted in further reductions in repair tension compared to neutral ($p < 0.0001$). There was, however, no significant difference in repair tension when the joint was internally rotated from 11° to 20° (Table 6).

Conversely, there was a significant increase in repair tension posteriorly (35%) when the glenohumeral joint was internally rotated from neutral to 11° ($p < 0.0001$). Further internal rotation of the glenohumeral joint to 20°

Table 5 Effect of tension in the posterior suture of the repaired supraspinatus at 0° internal rotation

Abduction angles	Load experienced by posterior suture (N ± SD)	Percentage change				Significant levels			
		0°	4°	13°	25°	0°	4°	13°	25°
0°	4.2 ± 0.3		– 38%	– 70%	– 80%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
4°	2.6 ± 0.4	– 38%		– 52%	– 67%	$p < 0.0001$		$p < 0.0001$	$p < 0.0001$
13°	1.3 ± 0.4	– 70%	– 52%		– 32%	$p < 0.0001$	$p < 0.0001$		$p < 0.0001$
25°	0.9 ± 0.4	– 80%	– 67%	– 32%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	

Table 6 Effect of tension in the anterior suture of the supraspinatus at 0° abduction

Internal rotation	Load experienced by anterior suture (N ± SD)	Percentage change				Significant levels			
		0°	11°	20°	29°	0°	11°	20°	29°
0°	4.1 ± 0.2		– 50%	– 54%	– 59%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
11°	2.2 ± 0.3	– 50%		– 9%	– 19%	$p < 0.0001$		$p = 0.33$	$p = 0.34$
20°	2.0 ± 0.5	– 54%	– 9%		– 11%	$p < 0.0001$	$p = 0.33$		$p = 0.56$
29°	1.8 ± 0.5	– 59%	– 19%	– 11%		$p < 0.0001$	$p = 0.34$	$p = 0.56$	

and 29° caused further increases in repair tension compared to neutral ($p < 0.0001$) (Table 7).

Differences Between Anterior and Posterior Suture Loads

As both anterior and posterior sutures were tensioned to the same amount at the beginning of the experiment, there were no significant differences between tension in both sutures at 0° internal rotation and 0° abduction. As the humerus internally rotated to 11°, 20°, and 29°, there were increases in tension experienced by the posterior suture compared to the anterior suture at each of these angles ($p < 0.0001$).

Combined Effect of Abduction and Internal Rotation on Repair Tension

There was a significant reduction in tension anteriorly (27%) on the supraspinatus tendon when the glenohumeral joint was placed in a position indicative of a sling with a small abduction pillow compared to a sling only ($p < 0.05$). There was a 42% further reduction in tension on the supraspinatus repair anteriorly when the glenohumeral joint was placed in a position consistent with a sling with large abduction pillow ($p < 0.0005$) (Fig. 4a). These reductions were also observed in the posterior aspect of the repair (Fig. 4b).

Discussion

This study showed that placing the shoulder at positions consistent with wearing a sling with small or large abduction pillows reduces tension in the repaired supraspinatus tendon. Tension on the supraspinatus decreased by 27% anteriorly and 55% posteriorly

compared with the sling only. A further reduction in tension was observed when the shoulder was placed in a position indicative of the sling with large abduction pillow of 42% anteriorly and 56% posteriorly.

A limitation of this study was a relatively small number of human cadaveric shoulders. However, a post-hoc power analysis showed only two shoulders were needed to achieve significant findings. When the specimens were being prepared, an artificial supraspinatus full-thickness tear was created, and this tear may not be completely indicative of tears seen clinically. It is possible that different repair constructs would result in different forces being detected with the abduction angles tested.

Our study also found the abduction angles produced by the abduction pillows were smaller than previously reported [3, 8–10, 14], with the small abduction pillow producing 13° and the large abduction pillow producing 25° of abduction at the glenohumeral joint. The study also found that the angle of internal rotation produced by wearing the sling to be only 29°, the sling with small abduction pillow to be 22°, and the sling with the large abduction pillow to be 11°.

Our findings of decreased tension on the supraspinatus repair with increasing shoulder abduction are consistent with the studies of Howe et al., Park et al., Reilly et al., and Andarawis-Puri et al. [3, 9, 10, 13].

We found that when the glenohumeral joint was internally rotated, tension on the anterior suture decreased, but tension on the posterior suture increased. This finding is consistent with data from Howe et al. and Ahmad et al., who found that the posterior suture was preferentially loaded during internal rotation [1, 9].

Our study is the first to examine tension on the supraspinatus after rotator cuff repair in shoulder

Table 7 Effect of tension in the posterior suture of the supraspinatus at 0° abduction

Internal rotation	Load experienced by posterior suture (N ± SD)	Percentage change				Significant levels			
		0°	11°	20°	29°	0°	11°	20°	29°
0°	4.2 ± 0.2		+ 35%	+ 58%	+ 63%		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
11°	5.8 ± 0.5	+ 35%		+ 18%	+ 21%	$p < 0.0001$		$p < 0.005$	$p < 0.05$
20°	6.8 ± 0.8	+ 58%	+ 18%		+ 3%	$p < 0.0001$	$p < 0.005$		$p = 0.8$
29°	7.0 ± 0.2	+ 63%	+ 21%	+ 3%		$p < 0.0001$	$p < 0.05$	$p = 0.8$

Fig. 4. **a** Tension on the anterior suture of the supraspinatus repair produced by different sling/pillow positions. **b** Tension on the posterior suture of the supraspinatus repair produced by different sling/pillow positions.

positions created by commonly used abduction pillows and slings. We found the small abduction pillow placed less tension on the supraspinatus compared to the sling only, and the large abduction pillow placed the least tension on the repaired tendon. The use of two separate methods to determine tension on both the repaired supraspinatus and the sutures used for the repair was a strength of this study.

In summary, this study showed abduction pillows and slings placed the shoulder in less abduction than previously reported. This study showed that an abduction pillow decreases tension placed on rotator cuff repair compared to no pillow (sling only). These findings support the use of an abduction pillow following rotator cuff repair. Reducing the tension should reduce the chance of re-tear while healing.

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Compliance with Ethical Standards

Conflict of Interest: Jacqueline R. Hawthorne, MD; Elise M. Carpenter, MD; and Patrick H. Lam, PhD, report that they have no conflict of interest. George A.C. Murrell, MD, DPhil, reports receiving grant support and fees as a consultant from ArthroCare Corporation.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: Informed consent was waived from all patients for being included in this study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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