

Literature Review

# The Effect of Shoulder Immobilization Position on Outcomes Following Rotator Cuff Repair: A Scoping Review

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## Abstract

**Introduction:** There has been growing interest in determining the influence of post-operative immobilization posture and rehabilitation protocol on healing rates and clinical outcomes. Current consensus calls for the use of an immobilization device post-operatively, which commonly comes in the form of a standard sling or an abduction brace with the arm positioned in varying degrees of abduction. There is a lack of high-level evidence in the literature to recommend one type of immobilization device or arm position over another.

**Objectives:** This study aimed to summarize the current clinical and biomechanical evidence for the optimal postoperative positioning and bracing of the arm following arthroscopic rotator cuff repair.

**Methods:** A comprehensive search of the electronic databases EMBASE, MEDLINE, and PubMed was performed using a combination of the following keywords and medical subject heading (MeSH) terms: 'arthroscopic', 'rotator cuff repair', 'sling', 'brace' and 'immobilization'. This systematic review was conducted following the Preferred Reporting for Systematic Reviews and Meta-analysis (PRISMA) guidelines. Two reviewers performed an independent assessment of the methodological quality of each eligible clinical study using the Methodological Index for Non-Randomized Studies (MINORS).

**Results:** Based on current biomechanical evidence, placement of the arm into an abducted position following rotator cuff repair was found to be favorable. An abduction angle of 30° was associated with lower strain on the repair while maintaining appropriate contact pressure at the footprint. However, the use of an abduction brace did not result in a clinically significant improvement in long-term PROM, ROM, and re-tear rates when compared to a traditional sling in clinical studies.

**Conclusion:** Despite observing favorable outcomes with abduction bracing after rotator cuff repair in biomechanical studies these findings were not reproduced in clinical studies. However, current clinical studies are comprised of small sample sizes, varying tear sizes, and significant heterogeneity in both, the degree of abduction and forearm rotation. Future studies should be directed towards prospectively investigating the effect of immobilization position among patients with similar rotator cuff tear sizes.

## More Information

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**Keyword:** Abduction brace; Sling; Rotator cuff repair



## Introduction

Rotator cuff tears are the most common source of shoulder pain and disabilities [1-3]. As a result, arthroscopic rotator cuff repair has become one of the most frequently performed orthopedic procedures [4,5]. However, rotator cuff repairs have historically been associated with high re-tear rates ranging up to 70% [6-10]. A variety of biomechanical and clinical studies have attempted to identify factors influencing outcomes following rotator cuff repair. As such, there has been growing interest in determining the influence of post-operative immobilization posture on healing rates and clinical

outcomes [6,7,11-20]. Current consensus calls for the use of an immobilization device post-operatively, which commonly comes in the form of a standard sling with the elbow flexed to 90° and the arm internally rotated at the side of the body or an abduction brace with the arm positioned in varying degrees of abduction. However, there is a lack of high-level clinical evidence in the literature to recommend one type of immobilization device or arm position over another [21]. This study aimed to summarize the current clinical and biomechanical evidence for the optimal postoperative positioning and bracing of the arm following arthroscopic rotator cuff repair.

## Materials and methods

This systematic review was conducted following the Preferred Reporting for Systematic Reviews and Meta-analysis (PRISMA) guidelines [22]. Ethics board approval was not required as the study was based on a review of already published literature.

### Literature search & study selection

A comprehensive search of the electronic databases EMBASE, MEDLINE, and PubMed was performed using a combination of the following keywords and medical subject heading (MeSH) terms: 'arthroscopic', 'rotator cuff repair', 'sling', 'brace' and 'immobilization'. Titles, abstracts, and full texts were screened in duplicate by two independent reviewers (JL and US). References of included studies were reviewed for additional relevant articles that met the criteria for inclusion. Duplicates were manually excluded. Disagreements were resolved by a consensus decision with a third reviewer (PH).

### Eligibility criteria

Studies were eligible for inclusion if they evaluated the influence of postoperative immobilization technique on clinical and radiological outcomes following arthroscopic rotator cuff repair. Biomechanical and clinical studies were included. Review articles, expert opinions, and technique studies were excluded. The search was limited to English-language articles.

### Data extraction

Data was extracted independently by two reviewers (JL and US). Data collected from clinical studies included: author, year of publication, demographic variables, immobilization technique and device used, postoperative rehabilitation protocol, mean length of follow-up, patient-reported outcomes, and other notable results. Data collected from biomechanical studies included tear characteristics, repair technique, and tension and strain at various arm positions.

### Assessment of risk of bias of eligible studies

Two reviewers performed an independent assessment of the methodological quality of each eligible clinical study using the Methodological Index for Non-Randomized Studies (MINORS) [23]. The MINORS criteria is a validated 12-item scale designed to assess the methodological quality of non-randomized surgical studies, including both non-comparative and comparative studies [23], Appendix A.

### Statistical analysis

Statistical analysis was performed to summarize all continuous and categorical data. No inferential statistical testing was performed.

## Results

### Study characteristics

Among the 32 full-text articles reviewed, a total of 15

studies were deemed eligible based on our inclusion and exclusion criteria (Figure 1). The included studies comprised nine biomechanical studies [6,24-31] (Tables 1,2) and six clinical studies [32-37] (Table 3) examining outcomes with sling and abduction brace use following arthroscopic rotator cuff repair.

## Clinical outcomes

### Study characteristics

Among the six clinical studies included in our review, there were a total of 1868 patients [32-37]. A total of three randomized controlled trials [32,34,37], two prospective cohorts [33,36], and one retrospective cohort study [35] were included. The mean age of patients was  $58.7 \pm 2.2$  years, while 54.4% were male. Four studies [33,34,36,37] had a minimum follow-up of 12 months. Two studies reported at least 6 months of follow-up [32,35]. All included studies permitted pendular exercises during the immediate postoperative period, with the initiation of active range of motion at the 6-week postoperative time point (Table 3). The overall risk of bias in clinical studies was low. MINORS score ranged from 19 to 22 out of a maximum score of 24 in comparative studies and 11 to 15 out of a maximum score of 16 in non-comparative studies [32-37].

### Patient reported outcomes

A double-blind randomized controlled trial by Conti, et al. [32] found no significant difference in the UCLA, DASH, SST, and Constant scores between patients immobilized in an abducted and externally rotated position when compared to those immobilized in  $15^\circ$  of internal rotation.

Similarly, Hollman and colleagues [34] found no significant differences in function and quality of life between groups at all

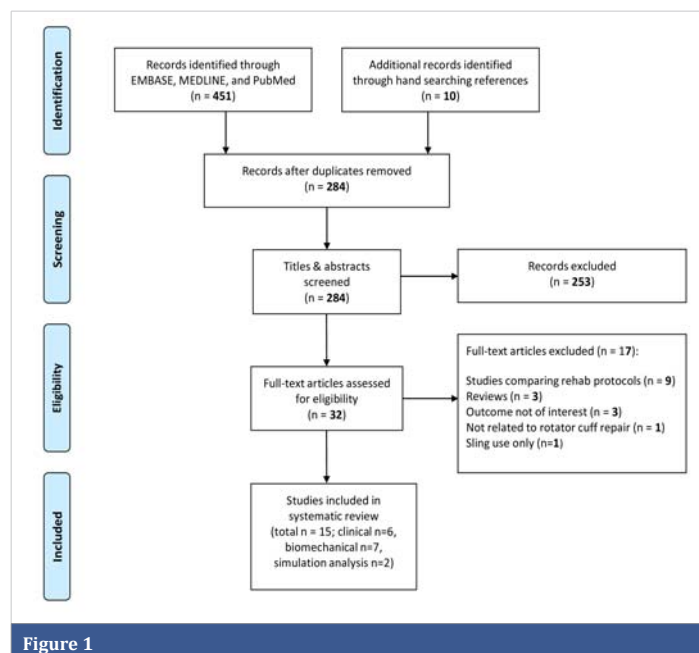


Figure 1



Appendix A

Study	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss of follow-up less than 5%	Prospective calculation of the study size	Additional Criteria for Comparative Studies				
									An adequate control group	Contemporary group	Baseline equivalence of groups	Adequate statistical analysis	Total (/24)* (/16)^
Hollman et al 2017 (32)	2	2	2	2	1	2	2	2	1	2	2	2	22
McColl et al 2019 (33)	2	2	2	1	1	0	1	2					11
Conti et al 2014 (34)	2	2	2	1	1	1	2	2	1	2	1	2	19
Ghandour et al. 2019 (35)	2	2	2	2	2	2	1	2	2	2	2	2	22
Silverio et al 2014 (36)	2	2	2	2	2	2	1	2					15
Pandey et al 2020 (37)	2	2	2	2	1	2	1	2	2	2	2	2	22

\*Maximum possible score for comparative studies

^Maximum possible score for noncomparative studies

Table 1: Summary of biomechanical studies examining effect of shoulder position on rotator cuff repair strain.

Authors	Year	Specimens	Tear Characteristics	Rotator Cuff Repair Technique	Findings
Zuckerman, et al. [24]	1991	12 fresh frozen human shoulders	"Small": Entire width of tendon + 1 cm length of supraspinatus (full-thickness)	Open; #2 Mersilene tape; horizontal mattress	Unchanged tension (N < 2) with abduction 30,60,90,120° Increase in tension with Abduction decreased to 15° (p < 0.01)
			"Large": Entire width of tendon and + 2 cm length of infra and supraspinatus (full-thickness)	Open; #2 Mersilene tape; horizontal mattress	Stable strain regardless of rotation, at flexion/extension above 30° degrees abduction.
Hatakeyama, et al. [25]	2001	14 fresh frozen human shoulders	2 cm width X 1.5 cm length, full thickness of supraspinatus	Open; #2 braided non-absorbable sutures, trans-osseous	Increased strain with decrease in elevation in scapular plane 30 to 15° and 15 to 0° (p < 0.01). With arm elevated 30 degrees in scapular plane, average tensile force < 0.3 kg at any rotation.
Reilly, et al. [26]	2004	3 cadaveric human shoulders	Full thickness supraspinatus tendon tears with 2 cm retraction	Open; #2 Ethibond, transosseous Mason-Allen	Mean reduction of tension by 34.1N as shoulder taken from 0 to 30° abduction
Andarawis-Puri, et al. [27]	2009	10 fresh frozen human shoulders	33% bursal, 66% bursal, full thickness supraspinatus tendon	Open; 1) #2 fiber-wire; Modified Mason-Allen transosseous 2) horizontal mattress with 2 suture anchors	Lowest strain at 30° abduction for all types of supraspinatus tears. Lowest strain of both infra and supraspinatus tendon at 30° abduction.
Howe, et al. [28]	2009	6 fresh frozen human shoulders	Full thickness supraspinatus tendon tear	Open; #2 Ticron, transosseous horizontal mattress	Arm externally rotated 30°: tension in the anterior suture 10X posterior suture (p < .001). Arm internally rotated 30°: tension in the posterior suture 10X that of anterior suture (p < .0005). No significant difference in the suture tension with arm in neutral rotation.
Park, et al. [38]	2009	6 fresh frozen human shoulders	Entire width of tendon + 1cm length, full thickness of supraspinatus	Open; #2 Fiberwire suture anchors 1) Modified double row 2) Double-row 3) Single row	Decreasing footprint contact pressures and contact area with increasing abduction Abduction < 30 and internal rotation to 60 most optimal footprint contact. Overall, the results favour the arm in 0° to 30° of abduction.
Hawthorne, et al. [29]	2018	4 fresh frozen human shoulders	Full thickness supraspinatus tendon	Open, Two knotless anchors, single row, inverted mattress	Decrease in anterior and posterior tendon strain and posterior increasing abduction angle. 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

Table 2: Summary of simulation studies examining the effect of shoulder position on rotator cuff repair strain.

Author	Year	Model	Tear Characteristics	Findings
Jackson, et al. [30]	2013	Computational shoulder model	Gap length 0 mm - 20 mm of (1) full-thickness supraspinatus tears, (2) full-thickness supraspinatus and infraspinatus tears, and (3) full-thickness supraspinatus and subscapularis tears.	Optimal position for isolated supraspinatus tear: humeral elevation 61 to 109 degrees as tear 13 to 37° anterior to the coronal plane with neutral or internal rotation (76% to 90% stress reduction). Optimal position for supra + infraspinatus tears: elevation between scapular and coronal plane 61 to 106 degrees with neutral to limited internal rotation (76% - 83% stress reduction for the supraspinatus and 29% - 47% for the infraspinatus). More anterior elevation plane optimal with subscapularis tear
Saul, et al. [31]	2011	Computational shoulder model	Gap length 5mm to 30mm of supraspinatus	Passive force from 28.5N to 518.1N when shoulder position was changed from 60 to 0° of shoulder abduction, for rotator cuff with 0.5 cm gap



**Table 3:** Clinical studies investigating sling and abduction brace use for rotator cuff repair.

Study	Year	Level of Evidence	Immobilization Method	Duration of immobilization (weeks)	Sample Size (N)	Age (SD)	Sex (M:F)	Minimum Follow-up (months)	Rotator Cuff Repair Technique	Rehab Protocol	Outcomes
Conti, et al. [32]	2015	I	Internal Rotation (15°) Sling	6	20	62.3 ± 5.8	NR	6	Single Row	Immediate: Pendulum and pROM; aROM 6 weeks	ROM, UCLA, DASH, VAS, SST, Constant
			External Rotation (15°) + Abduction Brace (15°)	6	20	59 ± 7.0	NR	6			
Silverio, et al. [33]	2014	II	Abduction Brace	6	45	64 ± 17.3	20:25	12	NR	Pendulum for 6 weeks, 1 hour out of brace	ASES, SST, UCLA, Adherence
Hollman, et al. [34]	2017	I	Anti-Rotation Sling	6	16	62.5 ± 9.76	5:11	12	Double Row (29); Single Row (7)	Immediate: Pendulum, restricted passive ROM; aROM starting 6 weeks	VAS, CMS, WORC, ROM, satisfaction, EQ-5D-3L
			Abduction Brace (30-40°)	6	20	60.2 ± 6.84	11:9	12			
McColl, et al. [35]	2019	III	Abduction Brace	6	1600	59 ± 0.3	883:717	6	Single Row	Initially immediate pROM, and aROM at day 8; Less aggressive as study progressed	Retear Incidence (ultrasound)
Ghandour, et al. [36]	2019	II	Open Pouch Sling	6	55	50.8 ± 12.0	28:27	12	Double Row	pROM 6 weeks, aROM after	VAS, CMS
			Abduction Brace	6	51	50.4 ± 11.7	25:26	12			
Pandey, et al. [37]	2020	I	Open Pouch Sling	6	21	55.5 ± 10.5	9:12	12	Single Row (18); Double Row (24)	pROM at 6 weeks, aaROM at 8 weeks	VAS, CMS, Vascular Flow, Healing (ultrasound)
			Abduction Brace (30°)	6	21	55.8 ± 7.8	13:8	12			

Abbreviations: SD: Standard Deviation; M:F: Male to Female; NR: Not Reported; Prom: Passive Range of Motion; aROM: Active Range of Motion; ROM: Range of Motion; DASH: Disabilities of the Arm; Shoulder & Hand; VAS: Visual Analog Scale; SST: Simple Shoulder Test; ASES: American Shoulder & Elbow Society; CMS: Constant-Murley Score; WORC: Western Ontario Rotator Cuff

follow-up time points. Pandey, et al. reported no significant difference in Constant scores at 1-year follow-up between the sling and abduction brace groups in their study [37].

The study by Ghandour, et al. observed no differences in Constant-Murley scores between the abduction brace and sling groups at one year following arthroscopic rotator cuff repair [36] (Table 4).

**Range of motion**

A double-blind randomized controlled trial by Conti, et al. [32] noted significantly greater abduction and external rotation at 1-, 3- and 6-months post-operative for patients immobilized in an abducted and externally rotated position compared to those immobilized in 15° of internal rotation ( $p < 0.05$ ). Forward flexion was noted to be greater in this group at 1 month, however, no differences were noted between groups at 3- or 6 months postoperatively. On the contrary, a randomized controlled trial by Hollman, et al. demonstrated no significant differences between the anti-rotation and abduction sling groups (Table 4).

**Pain**

Conti and colleagues [32], found that patients immobilized in an abducted and externally rotated position had significantly less pain than those in a sling at all postoperative time points up to 6 months of follow-up ( $p < 0.05$ ). On the contrary, both Hollman, et al. [34] and Ghandour, et al. found no significant

difference in pain between groups at all post-operative follow-ups. Pandey and coworkers [37] reported lower VAS scores among patients in the abduction brace versus sling group, the difference approached but did not reach statistical significance ( $p = 0.06$ ) (Table 4).

**Re-tear rate**

Two studies commented on post-operative re-tear incidence. A case series of 1600 patients by McColl, et al. [35] reported a mean re-tear rate of 15% detected by ultrasonography at 6-month follow-up. The authors found postoperative abduction sling use to be a protective factor against re-tear. Anterior-to-posterior diameter of the tear size was the greatest predictor. Less aggressive rehabilitation, abduction brace use, and increased surgical experience were associated with a significant reduction in re-tear rates. Conversely, a randomized controlled trial by Hollman, et al. examined the effect of tear size, surgical technique, number of anchors, amount of retraction, and intraoperative tension on outcomes in both the abduction brace and sling group and found no significant differences between the randomized groups at short term follow up of 3 months. Pandey and coworkers [37] noted a combined partial and full re-tear rate of 9.5% (2 of 21) among the sling group compared to 14.3% (3 of 21) in the abduction brace group. This difference in re-tear rates between the groups did not reach statistical significance ( $p > 0.05$ ) (Table 4).



**Table 4:** Clinical measures of studies investigating sling and abduction brace after rotator cuff repair.

Study	Immobilization method	Adherence to therapy Yes: No	Pre-op ROM				1y Post-op ROM				Pre-op PROMS					Final Post-op PROMS					Retear	Complications							
			FF	AB	ER	IR	FF	AB	ER	IR	Constant	ASES	WORC	SST	VAS	UCLA	Constant	ASES	WORC	SST			VAS	UCLA					
Conti, et al. [32]	Internal Rotation Sling	NR	Only available in graphs																			NR	NR						
	External Rotation + Abduction Brace	NR	Only available in graphs																			NR	NR						
Silverio, et al. [33]	Abduction Brace	88% ± 10 (59.2 - 100)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Hollman, et al. [34]	Anti-Rotation Sling	15:01	NR	81.3 ± 12.97	68.7 ± 16.16	NR	Only available in graphs *				44.2 ± 20.62	NR	38.5 ± 21.91	NR	40.9 ± 26.30	NR	Only available in graphs^		NR	Only available in graphs^		NR	NR	NR	NR	NR	NR	No re-tears at 3 months	3/16 adhesive capsulitis
	Abduction Brace	17:03	NR	77.8 ± 15.52	65.9 ± 16.29	NR	Only available in graphs *				43.4 ± 13.72	NR	42.1 ± 15.46	NR	40.6 ± 30.6	NR	Only available in graphs^		NR	Only available in graphs^		NR	NR	NR	NR	NR	NR	No re-tears at 3 months	2/20 adhesive capsulitis
McColl, et al. [35]	Abduction Brace	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Ghandour, et al. [36]	Open Pouch Sling	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Abduction Brace	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Pandey, et al. [37]	Open Pouch Sling	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Abduction Brace	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

\*A significant improvement was observed in both groups in active forward elevation, glenohumeral abduction, and external rotation from 6 weeks to 3 months, from 3 to 6 months, and then 6 to 12 months after surgery ( $p < .001$  for all analysis).

^A significant improvement was observed in both groups in the CMS and WORC index from 6 weeks to 3 months, from 3 to 6 months, and then 6 to 12 months after surgery ( $p < .001$  for all analysis)

Abbreviations: ROM: Range of Motion; PROMS: Patient Reported Outcomes; FF: Forward Flexion; AB: Abduction; ER: External Rotation; IR: Internal Rotation; ASES: American Shoulder and Elbow Score; WORC: Western Ontario Rotator Cuff; SST: Simple Shoulder Test; VAS: Visual Analogue Scale; NR: Not Reported

### Biomechanical studies

A total of nine biomechanical studies were included in this review, comprising seven cadaveric studies involving 55 human shoulders (Table 1), as well as two computational shoulder models (Table 2). Zuckerman, et al. assessed strain levels after rotator cuff repair, focusing on small-sized tears (specifically supraspinatus tears) across cadaveric shoulders positioned in 36 distinct configurations [24]. Results indicated a significant increase in strain ( $p < 0.01$ ) with a lower angle of abduction from 30° to 15°. A comparable pattern was demonstrated in the large tear group (involving the supraspinatus and infraspinatus tears), with pronounced strain increases observed at 15° (20N) and 0° (> 50N) of abduction.

Hatakeyama, et al. and colleagues assessed 50 distinct shoulder configurations, incorporating various degrees of elevation in the scapular, coronal, and sagittal planes, as well as arm rotation relative to the scapular plane [25]. Statistical analyses demonstrated a significant ( $p < 0.05$ ) rise in rotator cuff strain with decreased humeral elevation from 30° to 15°, and from 15° to 0°, in both coronal and scapular planes. Internal rotation elicited a significant ( $p < 0.01$ ) strain increase, while external rotation produced the opposite effect. Strain remained low across all degrees of rotation at 30° of elevation in the scapular plane.

Reilly, et al. evaluated gap formation after rotator cuff repair and identified 30° of abduction as an advantageous position [26]. They noted a mean reduction in passive load of 34N among shoulders abducted at 30° compared to 0°. Andarawis-Puri, et al. studied the impact of arm positioning on differential strain within the infraspinatus and supraspinatus tendons [38]. The maximal strain on the infraspinatus tendon was observed at 0° abduction compared to 30° and 60°, while maximal strain in the supraspinatus tendon occurred at 60° and minimal strain at 30° of abduction. The authors also observed the greatest mechanical interaction between the infraspinatus and supraspinatus at 0° of abduction and the lowest at 30°, suggesting 30° of abduction as the optimal immobilization position post-rotator cuff repair to minimize strain on the repair.

Park, et al. investigated footprint contact area and pressure in human cadaveric models with full-thickness supraspinatus tears [38]. They found that the highest contact area and pressure occurred at 0° of abduction and the lowest at 60°, with no significant difference in contact area observed between abduction angles of 0° to 30°. Internal rotation was favored for contact area and pressure compared to external rotation.

Hawthorne, et al. observed that glenohumeral joint abduction of 4° was seen with a traditional sling. A small abduction pillow translated to 22° of internal rotation and

13° of glenohumeral joint abduction, while a large abduction pillow translated 11° and 25° of glenohumeral joint abduction respectively. Lower levels of anterior and posterior tendon strain were seen with increasing abduction angles from 0 to 25° ( $p < 0.001$ ). The use of a small abduction pillow reduced tension on the supraspinatus by 27% anteriorly and 55% posteriorly, while a large abduction pillow led to a further reduction in tension to 42% and 56% respectively.

Howe, et al. conducted a cadaveric study, finding that external rotation of 30° resulted in ten times greater tension in the anterior suture compared to the posterior suture ( $p < 0.001$ ), with the opposite observed during internal rotation [28]. The authors recommended neutral rotation as it may minimize tension at all suture locations, providing a safer shoulder immobilization position post-rotator cuff repair.

Saul, et al. conducted a simulation analysis investigating the passive tension and moment-generating capacity of the supraspinatus muscle under varying gap lengths and shoulder positions [31]. They observed that passive force increased significantly from 29N to 518N as the shoulder moved from 60° to 0° of abduction, surpassing the previously reported pull-out strength value of 215N [24,25]. Their findings suggested that the optimal shoulder posture, particularly for minimizing strain on the supraspinatus and infraspinatus tendons, was approximately 30° of abduction with neutral rotation. Jackson, et al. similarly noted this trend, suggesting potential adjustments in elevation depending on the specific rotator cuff tendon involved [30]. Their computational model analyzed the ideal position of the glenohumeral joint and demonstrated that strains at the repair site for isolated supraspinatus tears could be reduced by 76% to 90% by utilizing an abduction pillow compared to having an arm at the side.

## Discussion

Overall, numerous biomechanical studies demonstrate glenohumeral joint abduction to be protective for rotator cuff repairs in a relatively dose-dependent manner, with the majority of studies favoring 30° of abduction as the optimal position. Biomechanical data shows abduction in the coronal and scapular planes to be protective in minimizing strain, as well as gap formation while improving contact area and pressure on the repair [24,26]. The rotational profile of the arm post-operatively appeared to have significant effects on rotator cuff strain as well as contact area and pressure at the repair site as well [29,38]. Increasing internal rotation led to greater tension in the posterior rotator cuff and greater external rotation led to greater tension in the anterior rotator cuff.

A large abduction pillow which clinically translates to glenohumeral abduction of 25° and internal rotation of 11°, showed a reduction in supraspinatus tension by 42% anteriorly and 56% posteriorly, compared with a traditional sling [29]. Biomechanically, studies overall demonstrated that

an abduction pillow which increases the angle of abduction in the scapular plane and decreases internal rotation of the arm is a safer environment for the rotator cuff to heal. Despite the strong evidence seen in biomechanical studies, it did not translate to superiority in clinical outcomes for abduction brace compared with traditional sling.

Overall, our literature search demonstrated a dearth of studies comparing clinical outcomes of various immobilization positions in patients undergoing rotator cuff repair. In the current systematic review, immobilization with an abduction brace did not lead to convincing improvements in ROM, and pain, patients reported outcomes such as ASES, UCLA, SST scores, or re-tear rates over sling immobilization.

A double-blinded randomized controlled trial by Conti et al, which evaluated 40 total patients undergoing repair of isolated superior or posterosuperior rotator cuff tears demonstrated the most favorable results in favor of those immobilized with an abduction brace. In those immobilized with an abduction brace, better active glenohumeral abduction, and external rotation were demonstrated at all time points including their final follow-up at 6 months, while demonstrating lower VAS pain scores at all time points.

However, even in this study, they ultimately found no significant difference in the UCLA, DASH, SST, and Constant-Murley scores between the abduction brace and traditional sling group [32]. Other clinical studies included in this review, including two level-I randomized controlled trials [34,37], as well as two level-II prospective cohort studies [33,36], and a level-III retrospective cohort study [35] essentially failed to find the superiority of abduction brace over traditional sling in all outcomes measured. Interestingly, Pandey et al, found ultrasonographic evidence of increased blood flow in the repair at 6 weeks post-operatively which did not translate to any superior clinical outcomes [37].

There are a variety of factors that may account for the discrepancy between the biomechanical and clinical findings reported in the current review. One such factor is compliance with the method of immobilization. While it is well known from other areas of the orthopedic literature that patient adherence to bracing and immobilization is low [39-43], compliance with the wear time of abduction braces has been identified to be very unreliably reported [33,34,41]. In 2018, Grubhofer studied abduction brace compliance rates in 50 post-operative patients by utilizing a temperature sensor implanted into their braces, they found a statistically significant ( $p < 0.001$ ) discrepancy of 21% between self-reported and objectively measured rates [41]. Decreased compliance to both abduction brace and traditional sling in clinical studies would make it difficult to reliably assess the effects of either treatment in a clinical study. Only two clinical studies in this review evaluated the compliance rate of their immobilization method in a self-reported manner [33,34].

The significant findings seen in biomechanical studies truly do not translate to differences significant enough to meet the minimal threshold to be clinically relevant regarding patient outcomes such as pain, PROM, ROM, and re-tear rates after rotator cuff repair. For instance, Pandey et al found ultrasonographic evidence of increased blood flow in the repair at 6 weeks post-operatively with the utilization of abduction bracing, but it did not translate to any superior clinical outcomes [37]. The glenohumeral joint is an incredibly complex joint with soft tissue interactions between various peri-scapular muscles. Strain levels and differential levels in contact pressure, area, and gap formation seen in biomechanical studies may therefore be less relevant in a complex dynamic model that exactly mimics the clinical shoulder after a rotator cuff repair.

Limitations of this study are as follows: Firstly, there was significant heterogeneity in the tear characteristics, surgical techniques, and abduction braces (including the angle of abduction) used by the included clinical studies. Secondly, McColl, et al., notwithstanding, the eligible clinical studies consisted of small sample sizes. Thirdly, the heterogeneity among outcomes reported by the clinical studies limited our ability to quantitatively pool the results. Another limitation is non-uniform rehabilitation protocols among the studies included. All studies allowed immediate pendulum motion, with active ROM beginning at the latest 6 weeks post-operatively. One study utilized a more accelerated rehabilitation protocol with an active range of motion starting at day 8, progressing to a more conservative rehabilitation protocol as the study progressed [35]. The slight variations in rehabilitation protocols could have affected clinical outcomes especially post-operative pain levels as early ROM. Despite these limitations, the present study provides a comprehensive review of the current state of the literature on the effect of postoperative immobilization position on outcomes following arthroscopic rotator cuff repair. Future prospective studies with a large sample size and uniform rehabilitation protocols are needed to investigate the effect of immobilization position among patients with similar rotator cuff tear sizes, with longer radiographic and clinical evaluations.

## Conclusion

Based on current biomechanical evidence, placement of the arm into an abducted position following rotator cuff repair was found to be favorable. An abduction angle of 30° was associated with lower strain on the repair while maintaining appropriate contact pressure at the footprint. However, the use of an abduction brace did not result in a clinically significant improvement in PROM, ROM, and re-tear rates when compared to a traditional sling in clinical studies. Future studies with a greater sample size are needed to prospectively investigate the effect of immobilization position among patients with similar rotator cuff tear sizes and with longer radiographic and clinical re-evaluations.

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