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The role of sagittal axis in biceps tenodesis for superior capsular reconstruction in massive irreparable rotator cuff tears

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Abstract

Background This study aims to compare histopathological results following a 6-week postoperative follow-up of biceps tenodesis (BT) at 1/3 median, 1/3 posterior, and 1/3 anterior locations to the rotator cuff footprint (RCF) in cases of massive irreparable rotator cuff tears (MIRCT).

Materials and methods Thirty rabbits were assigned to three groups. BT for superior capsular reconstruction (SCR) was performed on rabbits 1–10 at the 1/3 median part of the RCF along the sagittal axis using a transosseous reinforced suture with the modified Mason-Allen technique, maintaining consistent pressure in the groove (Group 1). In rabbits 11–20 (Group 2), tenodesis was performed 1/3 posterior to the RCF, while rabbits 21–30 (Group 3) underwent tenodesis 1/3 anterior to the RCF. Following the 6-week follow-up, the shoulders were excised en bloc, and histopathological evaluation was conducted using a modified Bonar's scale. Results were statistically compared among the groups.

Results The level of cell morphology was significantly lower in Group 2 compared to the other groups ($p < 0.05$). The extracellular matrix level was also significantly lower in Group 2 compared to the others ($p < 0.05$). There were no statistically significant differences in collagen levels across Groups 1, 2, and 3 ($p > 0.05$), nor in cellularity levels among the groups ($p > 0.05$). General score evaluation levels were significantly lower in Group 2 than in the other groups ($p < 0.05$).

Dicsussion BT performed on the 1/3 posterior part of the RCF demonstrated greater success compared to procedures conducted at the 1/3 median and 1/3 anterior locations for MIRCT.

Keywords Superior capsular reconstruction, Biceps tenodesis, Massive irreparable rotator cuff tear, Biceps tendon

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Background

Massive irreparable rotator cuff tears (MIRCT) pose significant challenges for orthopedic surgeons due to factors like muscle fatty infiltration, tissue degeneration, and tendon retraction [1]. Treatment options for MIRCT are influenced by several factors, including patient age, activity level, the severity of joint arthropathy, and the extent of disability [2]. Various surgical approaches have been suggested for managing MIRCT, such as medialized repair, partial repair, patch augmentation, tendon transfer, reverse total shoulder arthroplasty, subacromial resurfacing, bursal acromial reconstruction, and the use of subacromial balloon spacers [3–5]. The high failure rates in partial rotator cuff (RC) repair in MIRCT have led to the consideration of using reconstruction techniques more frequently [6]. Among these techniques, superior capsular reconstruction (SCR), developed by Mihata et al., has demonstrated promising results by preventing the static superior migration of the humeral head [7, 8]. Recent studies indicate that SCR for MIRCT leads to excellent short-term clinical outcomes, effective pain relief, and functional improvements, along with low rates of graft failure and complications [9, 10].

Despite ongoing improvements in the SCR technique using allografts, autografts, and xenografts, it raises concerns among shoulder surgeons due to high costs, complexity, lengthy procedures, technical difficulties, and potential donor-site morbidity. The graft typically used is a tensor fascia lata autograft, attached medially to the superior glenoid and laterally to the greater tuberosity. Recently, the long head of the biceps (LHB) tendon has been suggested as an alternative to the standard SCR graft, potentially addressing issues related to donor site morbidity, grafting feasibility, and the costs associated with allografts [7, 11]. Currently, anatomical superior capsular reconstruction (SCR) utilizing the long head of the biceps (LHB) tendon in situ and tendon transfer represent two of the most widely utilized surgical approaches for managing MIRCT [12]. Several studies have reported on the outcomes of RC repairs using the LHB while maintaining its proximal attachment to the glenoid, followed by tenodesis to the greater tuberosity. This technique is believed to allow the LHB to serve as a restraint against the superior migration of the humeral head while also providing structural support for RC healing [13–15].

Currently, there are no studies addressing the optimal placement of the biceps tenodesis (BT) in the rotator cuff footprint (RCF) during SCR for MIRCT treatment.

The hypothesis of our study was positioning the BT to the 1/3 posterior part of the RCF for MIRCT treatment will yield better histopathological healing outcomes.

The objective of this study is to compare histopathological results following a 6-week postoperative follow-up of BT performed at 1/3 median, 1/3 posterior, and 1/3 anterior positions along the sagittal axis of the RCF for SCR, all conducted in a single session in rabbits with MIRCT.

Materials and methods

This prospective randomized controlled in vivo animal experiment has been approved by Acibadem University Experimental Animals Local Ethics Committee numbered ACU-HAYDEK 2022/24. Clinical trial number: not applicable. The inclusion criteria were that the animals were of the same breed, had not been used in another experiment before, and had no disease.

Similar studies on this subject were examined, and a sample size of $n = 30$ and a 90% confidence interval were used. The effect size of the study is sufficient with a value of 0.43. The study was carried out with 60 shoulders (both sides) of 30 normally active New Zealand White male rabbits (12–14 weeks old, weighing 2.5–3.0 kg) were obtained from the Acibadem University Animals Laboratory Farm. Animals were housed in individual cages under controlled environmental conditions (temperature 22 ± 2°, 12-hour light/dark cycle) with ad libitum access to water and standard rabbit chow. Animal care and handling procedures were approved by IRB. Informed content was obtained from the laboratory farm management. After a 7-day acclimatization period, procedures commenced.

The assignment of animals to groups was performed by an independent researcher using a computer-aided random number to ensure the impartiality of the study, and this process was designed in accordance with the randomization protocols [16].

Surgical technique

As a preparation, he was placed under general anesthesia by intramuscular injection with 10 mg/kg Xylazine Hydrochloride (Rompun®; Bayer, Istanbul-Turkey) and 40 mg/kg Ketamine Hydrochloride (Ketalar®; EWL Eczacıbaşı Warner Lambert Istanbul-Turkey). After shaving both shoulder areas in a way that does not interfere with the surgical incision, the surgical area is antisepsis with 10% Povidoneiodine (Batticon, Adeka İlaç, Turkey).

During the surgical procedures, the bicipital groove was palpated in both shoulder regions under sterile conditions. With a skin incision the LHB in the bicipital groove was found by blunt dissection.

The pressure between the LHB and the groove in the biceps groove was measured and recorded in the neutral position with the Flexiforce ELF system and B201 sensors (tekscan.com) [17].

A MIRCT model was performed to all rabbits in the study in terms of the literature [18].

1/3 posterior, 1/3 median and 1/3 anterior parts of the RCF were marked according to the sagittal axis (Fig. 1).

Fig. 1 Rotator cuff footprint was dived 3 parts and biceps tendon exploration

Fig. 2 Tenodesis performed median to the footprint of the rotator cuff

Rabbits were divided 3 groups in terms of BT location on RCF.

Group 1: BT for SCR applied to rabbits 1–10 to the 1/3 median to the RCF with a transosseous reinforced suture using the modified Mason-Allen technique, with the same pressure value measured in the groove (Fig. 2).

Fig. 3 Tenodesis performed posterior to the footprint of the rotator cuff

Fig. 4 Tenodesis performed anterior to the footprint of the rotator cuff

Group 2: BT for SCR was performed 1/3 posterior to the RCF with the same value we measured in the biceps groove of 11–20 rabbits (Fig. 3).

Group 3: In rabbits 21–30, BT was performed 1/3 anterior to the RCF at the same value measured before tenotomy (Fig. 4).

After the intervention, rabbits were administered 0.01–0.05 mg/kg twice a day subcutaneous until sacrifice and 30 mg/kg Cefazolin Na (Cefozin ®, Bilim Pharmaceuticals-Turkey) twice a day for 3 days. Mobilization of rabbits is not restricted. They were kept in single cages until sacrifice. After six weeks of follow-up, chemical euthanasia with potassium chloride was made, and the surgical area was removed en bloc, including the scapula and humerus, through the same incision.

Histopathological evaluation

Bilateral shoulders of sacrificed rabbits were extracted en bloc and tissue fixation was performed in 10% Formaldehyde solution for 24 h. Then, tissue tracking was started by passing it through Alcohol, Formaldehyde and Xylene solutions for 14 h on a Sacura brand tissue tracking device. Subsequently, the tissues were embedded in paraffin blocks in the Thermo Scientific tissue embedding device and were taken onto slides in 0.5 mm sections using the same brand microtome device. These preparations were stained with Hematoxylin Eosin staining and Masson Trichrome staining, which histochemically shows muscle and collagen fibers, in the same brand tissue staining device and were prepared to be evaluated in a Nikon brand light microscope. Cell morphology, extracellular matrix, collagen, vascularity, and cellularity in the tissue were evaluated with the help of a light microscope at (x 100) and (x 200) magnifications (Fig. 5). The modified Bonars scale was used for evaluation [19]. After the scoring, the values were summed, and the tendinopathy score was determined for each rabbit shoulder. Statistical evaluation was performed between the groups with these scores.

Statistical evaluation

Descriptive statistics were shown as mean ± standard deviation and median-min-max values for continuous variables. The suitability of the data for normal distribution was evaluated with the Kolmogorov-Smirnov test. Kruskall Wallis test was used for comparisons between groups. In groups determined to be significant, the group that made the difference was determined using the Mann Whitney U test. In the study, $p < 0.05$ was accepted as the critical decision-making value. The data were analyzed on the computer using the Statistical Packages of Social Sciences 25.0 (SPSS) program. Intraclass Correlation Coefficent (ICC) was used for continuous data for assessment between observers and the consistency of repeated measurements by the same observer.

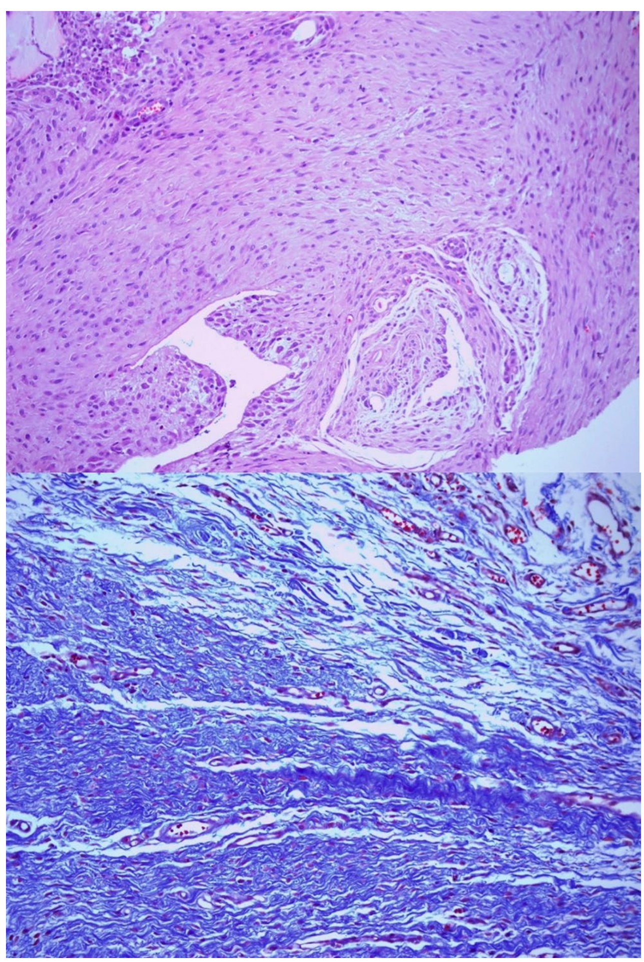

Fig. 5 Extracellular matrix and cellularity analysis by H&E x100 in group 2. Collagen analysis by Masson Trichrom x200 in group 2

Table 1 Comparison between groups

	Groups			*p*
	Group 1 Median	Group 2 Posterior	Group 3 Anterior	
	X ± s.s.	X ± s.s.	X ± s.s.	
Cell Morphology	1.55 ± 1	0.6 ± 0.75	1.45 ± 0.76	0.01*
Extracellular Matrix	14 ± 0.68	1 ± 046	1.70 ± 0.73	0.03*
Collagen	1.5 ± 0.61	1.55 ± 0.6	1.6 ± 0.6	0.22
Vascularization	0.65 ± 0.75	1.05 ± 0.89	1.4 ± 0.75	0.02*
Cellularity	1.65 ± 0.67	1.7 ± 0.57	1.8 ± 0.41	0.16

Results

Cell Morphology levels were significantly lower in group 2 compared to other groups ($p < 0.05$) (Table 1).

Extracellular matrix levels were significantly lower in group 2 compared to other groups ($p < 0.05$) (Table 1).

There was no statistical difference was found for collagen levels in group 1, group 2 and group 3 ($p > 0.05$) (Table 1).

It was found that vascularity levels were lower in group 1 only compared to group 3 ($p < 0.05$) (Table 1).

There was no statistical difference was found for cellularity levels in group 1, group 2 and group 3 ($p > 0.05$) (Table 1).

In the study, it was found that the general score evaluation levels were significantly lower in Group 2 compared to the other groups ($p < 0.05$) (Table 1).

Comparison of the modified Bonar score parameters of the groups were listed in Fig. 6.

The correlation between the three different observers (inter-rater reliability) was 0.829, 95% confidence interval (CI) 0.732– 0.897. The ICC of repeated measurements of one observer (intra-rater reliability) was 0.963, 95% CI 0.855–0.988.

Discussion

Consistent with our hypothesis, we found that BT performed 1/3 posterior part of the RCF for SCR, with a same pressure value measured in the biceps groove, was more successful than BT performed at the 1/3 medial and 1/3 anterior aspects. This evaluation was conducted using the modified Bonar's scale, a histopathological scoring system [19].

Several studies have advocated for tenotomy or tenodesis of the LHB tendon to alleviate anterior shoulder pain. These techniques involve surgically detaching the LHB tendon from its origin, thereby enabling surgeons to utilize its intra-articular portion [20, 21] Some studies reported that contact surface area of LHB and pressure at the LHB tendon/bone interface; thus improving the local biomechanics for tenodesis healing [22, 23].

MIRCT become more common with advancing age, and delayed treatment can lead to severe muscle retraction and fatty degeneration. To address these challenges, various techniques have been developed, with varying outcomes. Among them, SCR has shown promising results by preventing static superior migration of the humeral head [24, 25].

In our study involving rabbits with MIRCT, we investigated the optimal location on the sagittal axis of the RCF for BT, while preserving the LHB anchor superior to the glenoid for SCR. LHB creates a downward force to the humeral head; thus, show down-migration of the humeral head after our procedure. We believe this study will contribute significantly to the literature, as it explores for the first time whether tenodesing the LHB to different parts of the RCF relative to the sagittal axis impacts healing. Our findings are expected to provide valuable insights for future research on this topic.

It has been shown that the biceps augmentation procedure applied in addition to RC repair in chronic RC tears has successful results [26]. Another study found that patients who underwent biceps augmentation surgery

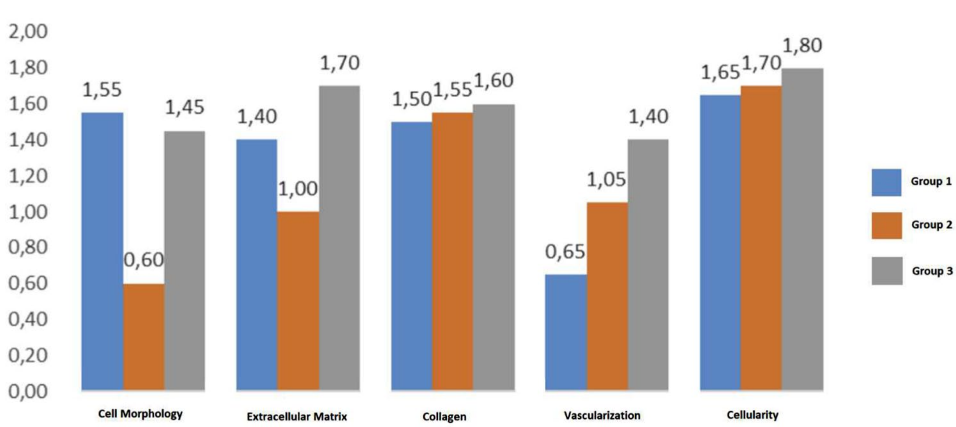

Fig. 6 Comparison of the modified Bonar score parameters between groups

experienced higher functional outcomes and a more rapid reduction in pain compared to the control group that only received repair [27]. Similarly, a study where the LHB was tenotomized and used as a free graft to reduce tension during repair showed that patients regained muscle strength faster and achieved significant improvements in clinical scores during postoperative follow-up [28]. A study analysed the graft status after LHB tenodesis for SCR on postoperative MRI. Only 2 patients had revison of LHB graft among 45 patients [29].

Some of the main reasons the LHB tendon has been frequently chosen as an autograft in past studies include the absence of the need for additional incisions, low cost, and no donor site morbidity [11]. Given its numerous advantages over other graft types, we believe it will continue to be widely used for SCR in the future. To address this critical usage, we undertook a focused investigation utilizing the LHB tendon, aiming to reveal insights that could not only guide future research but also pave the way for optimized BT location. This is why we conducted our study using the LHB to provide insights that could inform future research. Our study focuses on improving healing after MIRCT surgery by analyzing how the location of LHB tenodesis application affects tissue recovery at a histopathological level.

Although an improvement in the acromiohumeral distance was observed with the use of the LHB, no difference was detected in the incidence of postoperative retear [15]. Another study recommended using the LHB for SCR rather than fascia lata graft due to better functional outcomes [24]. The LHB is often favored over fascia lata graft because it is more minimally invasive and does not involve donor site morbidity. It has shown advantages over fascia lata graft in various clinical and radiological parameters during postoperative follow-up [9, 24].

A cadaveric study showed that SCR using the LHB with augmentation in irreparable supraspinatus tears increased glenohumeral stability and reduced subacromial peak contact pressure [30]. In another study, researchers demonstrated that RC repair could be enhanced with biceps augmentation by creating a new biceps groove for SCR in MIRCT. This new technique involves proceeding within the newly created groove without fixing the LHB [31]. A study tried to answer the question of in vivo transposition arises. Indeed, one legitimate question is the clinical tolerance of such a transplant as well as the biological fate of the transplant [32] In order to answer some questions regarding the use of LHB for SCR, we designed a study to investigate the importance of teodesis localization of on RCF tenodesis and evaluated its effect on tendon-bone healing histopathologically.

A study reported in cadaveric shoulders that SCR using the LHB is biomechanically effective in reducing posterosuperior translation of the humeral head in the setting of a MIRCT. Graft tensioning and fixation at 30° of glenohumeral abduction combined with either a middle or posterior tenodesis location on the greater tuberosity most effectively restores near normal time-zero humeral head kinematics [33]. During our study, we found that in the surgical technique we applied, BT to the 1/3 posterior RCF, so that the LHB is farther from the biceps groove, which is not natural localization, had better healing results histopathologically than BT performed to the 1/3 median or 1/3 anterior. We think that this is because BT posteriorly on the sagittal axis of the RCF provides some advantages. Since the blood supply to the posterior shoulder joint is better than to the anterior, posterior BT is likely to result in fewer complications. Additionally, posterior BT will experience less load because the force arm of the autograft is shorter, leading to a reduction in the distance the LHB travels above the joint compared to anterior BT. This shorter distance means that the LHB acts more as a passive stabilizer, further minimizing the load and potential complications [34, 35].

As mentioned by Keough et al. in their review of many studies, osteonecrosis, one of the important complications that may occur after RC repairs, has been proven to increase significantly, especially with injury to the anterolateral branch of the anterior circumflex humeral artery of the shoulder. Based on this study, we think that the healing success rate is low in BT performed anteriorly on the sagittal axis of the RCF, due to the high probability of injury to the anterolateral branch of the anterior circumflex humeral artery [36].

There is no consensus on the optimal application technique and graft configuration for BT applied to the RCF for SCR. Specifically, no studies have addressed which part of the RCF is most advantageous for tenodesing the graft during the procedure. In our study, we aimed to determine which location on the sagittal axis of the RCF was histopathologically more beneficial by BT the distal part of the LHB to different areas after tenotomizing with our technique. One of the significant advantages of this approach is that the LHB is naturally anchored superior to the glenoid.

In our daily practice, a specific technique that has proven its superiority over other techniques for the SCR procedure has still not been introduced. In our study, we preferred the Chinese method, which MIRCT describes the fixation of the RC with a suture anchor to the footprint after biceps tenotomy, because it is easily applicable and does not require an additional incision [11]. In acute MIRCT that we created in the rabbit model; with our histopathological evaluation, we demonstrated that in the treatment of BT, which we applied for SCR with the device called Flexiforce, which we used for pressure measurement, applying the BT to the 1/3 posterior region of the RCF on the sagittal axis with same pressure with normal significantly increased the success rate compared to BT performed in the 1/3 median and 1/3 anterior regions.

After SCR with fascia lata graft, blood flow values were measured at 3 different points with MRI study. In this study, RCF was considered as a whole and compared with the graft midpoint and glenoid insertion [37]. Our study is the first in the literature to examine tendon-bone healing histopathologically by considering 3 different localizations of RCF. Histopathological recovery scores were found to be significantly lower for BT performed on the median and anterior parts of the sagittal axis of the RCF, compared to BT performed posteriorly. We found that BT performed on the posterior part of the sagittal axis of the RCF, which has more blood supply and is more biomechanically advantageous, have more histopathological recovery advantages than BT performed in other locations.

We believe that the placement of the tendon graft to the RCF during BT is crucial for the successful completion of the SCR procedure. Selecting the appropriate location for BT is essential for ensuring proper graft healing and preventing complications.

One of the primary limitations of this study is the challenge of directly translating findings from the rabbit model to human applications. While rabbits provide a useful preclinical model due to similarities in certain physiological and anatomical aspects, differences in biomechanics, tissue healing, and immunological responses may affect the applicability of the results to human subjects. Further comparative studies, including human cadaveric or clinical investigations, would be necessary to validate these findings and ensure their clinical relevance. These differences could potentially impact our histopathological evaluation. Additionally, our study used an acute injury model, which may not fully reflect the repair outcomes seen in human RC tears resulting from chronic degenerative conditions. However, our study's strengths include working with the same genus and species, ensuring homogeneous group distribution, and being a prospective study.

Conclusion

BT for SCR in MIRCT is an effective treatment method. Our study found that BT performed on the 1/3 posterior to the RCF was more successful than those performed at the median and anterior locations. This rabbit study provides valuable insights that could guide future clinical studies to evaluate the outcomes of BT, enhancing our approach to treating MIRCT.

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Author contributions
BEK: Data acquisition, investigation, visualization, writing– original draft review & editing, data analysis, methodology, project administration.EB, OE: Writing-review & editing, data analysis, project administrationYO: Methodology, data analysisBY: Data acquisition, project administration.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The present study has been approved by the Acibadem University Experimental Animals Local Ethics Committee with the number: 2022/44. Informed consent was obtained for the study from the Acibadem University Animal Laboratory.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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