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Journal of Arthroscopy and Joint Surgery

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Journal of Arthroscopy and Joint Surgery, JAJS is an official, peer reviewed, online scientific journal. The first edition of which rolled out in January 2014. The journal's full text is available online at https://journals.lww.com/jajs and issues are published quarterly in March, June, September, December. The Journal is committed to bring forth scientific manuscripts in the form of original research articles, current concept reviews, meta-analyses, case reports with a clear message and letters to the editor.

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Contents

A New Chapter for the Journal of Arthroscopy and Joint Surgery

It gives us immense pleasure to inform you that the Journal of Arthroscopy and Joint Surgery (JAJS) is beginning a fresh chapter with the recent change of publishers from Elsevier to Wolters Kluwer. It has come a long way since its first publication in January 2014 and established itself as a unique journal with publications in arthroscopy and arthroplasty. Articles of high quality have been published. The journal is indexed in Embase and Scopus and is aiming to get PubMed indexing in the near future. There have been 9 volumes and 28 issues of JAJS published until now.

Publication in the JAJS would also give an opportunity (Exponential weightage is given for publications in JAJS) to the authors to enroll into one of the more than 100 partly to fully funded clinical fellowships offered by the parent society, ISKSAA, for a period between 2 weeks and 1 month in India, and abroad with reputed surgeons. This includes fellowships in centers of excellence around the world.

We welcome contributions from researchers from all over the world on topics conforming to the above scope of the journal. The articles will be of high quality and published on merit, and we recommend authors carefully read the guide for authors. The editorial board comprises distinguished surgeons from each specialty from different parts of the world, including centers of excellence. The reviews are blinded, and the reviewers are experienced and provide us with high-quality reviews, and we are thankful for their time in improving the authors' manuscripts. We aim to decide on manuscripts at a reasonable time after submission, aiming to make a final decision before 3 months of submission. Any deviation from the author's guidelines could result in a delay in processing the manuscript. Hence, the authors are advised to conform to the published guidelines to avoid delay and disappointment.

Wishing the readers a very Happy New year!!

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The Outcome of Debridement in Massive and Irreparable Rotator Cuff Tear - A Systematic Review

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Abstract

Introduction: Multiple procedures have been described for massive and irreparable rotator cuff tears (RCTs), which involve either conservative trial or surgical options such as debridement, partial repair, superior capsule reconstruction, and arthroplasty. The choice of surgical procedure depends on various factors such as the age and activity level of the patient, tear configuration, and tissue quality, including both muscle and tendon. No consensus has been reached regarding optimal treatment in massive and irreparable RCTs. **Purpose:** To systematically review the published literature assessing the outcomes after debridement alone for irreparable and massive RCTs. **Study Design:** Systematic review: Level of evidence-3. **Methodology:** A thorough literature search was carried out in July 2021, using PubMed and Science direct electronic databases based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. All studies were analyzed for the procedures performed along with debridement and the outcomes of surgery with scores such as Constant score, University of California Los Angeles score, American Shoulder and Elbow Score, Visual Analog Scale (VAS), and patient satisfaction. **Results:** Out of 1223 search results, a total of 13 studies were included following the PRISMA guidelines, and data extraction and analysis were carried out. The total patient cohort was 360, with male predominance (62%). The mean age of the total studies included was 66.4 years (range, 60–75.6 years) and the mean follow-up duration was 57 months (range, 18 to 145 months). The constant score was used in 7/13 studies, and the range was from 31 (preoperative) to 84 (postoperative during follow-up). The American Shoulder and Elbow Surgeons was used in 4/13 studies and the range was from 24 (preoperative) to 74 (postoperative during follow-up). University of California Los Angeles score was used in 6/13 studies and the range was from 8.4 (preoperative) to 27.7 (postoperative during follow-up). VAS was used in 6/13 studies and the range was from 9 (preoperative) to 0.5 (postoperative during follow-up). **Conclusion:** Debridement, along with any of the concomitant procedures (Acromioplasty, tuberoplasty, tenotomy of long head of biceps), is a simple procedure and has favorable patient-related outcomes in terms of pain relief. However, the range of motion and muscle strength improvement depends on various factors such as transverse couples, coracoacromial ligament release, and preoperative movement, which necessitates further high-quality prospective randomized control studies.

Keywords: Debridement, irreparable tear, massive tear, rotator cuff tear

Introduction

Rotator cuff tears (RCTs) can be broadly classified into partial-thickness and full-thickness tears. Each group has been further classified based on the number of tendons involved, the configuration of the tear, the amount of retraction, fatty infiltration, etc., The terms massive tear and irreparable tear are used with full-thickness RCT. These two terms, though often used interchangeably, are not synonymous. Most irreparable tears can be massive, but not all massive tears are irreparable.[1] The tears are considered massive when two or more tendons are involved or when the diameter is >5 cm.[2] The tears are considered irreparable when the tear in the tendon cannot be repaired to its footprint despite adequate surgical slides/releases/convergence/mobilizations.[3] The irreparable tears are those which are retracted beyond the glenoid articular surface and have fatty infiltration >50%.[4]

The treatment of the said massive and irreparable tears has to be tailored based on the comprehensive assessment of the

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age of the patient, functional demands of the patient, tear pattern, configuration, retraction, fatty infiltration, probability of the treatment success, and surgeon's familiarity with the operative technique.[5] All the patients are initially tried on a nonoperative regimen which includes physiotherapy, steroid injections, analgesics, etc., For a patient with low functional demand, the treatment is directed to pain relief, and the procedures are debridement (Subacromial debridement, acromioplasty, long head of biceps tenotomy, tuberoplasty Rotator cuff debridement), Subacromial spacer application, and physiotherapy. For a patient with high functional demand where the shoulder range of motion is also aimed, the procedures are partial repair (convergence, slides), graft augmentation with patches, superior capsular reconstruction, tendon transfers, and arthroplasty.[5-12]

Unfortunately, there is no consensus as to which treatment modality is superior and optimal.

Rockwood *et al*. described the procedure of arthroscopic debridement for irreparable RCT in 1995. He used this procedure as a treatment for a group of 50 patients, and 83% had satisfactory outcomes.[13] Although the original procedure involved debriding the torn rotator cuff, it can be tailored to include subacromial debridement, acromioplasty, long head of biceps tenotomy, and tuberoplasty to provide pain relief and increased acromiohumeral distance.[14] The purpose of our systematic review study is to critically review the literature reporting clinical outcomes of debridement for irreparable and massive RCT.

Methodology

A systematic review of the literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[15] guidelines to assess the outcome of debridement in irreparable and massive RCTs.

Search strategy

A comprehensive literature search was conducted using PubMed and Science Direct databases. The Mesh words used in the PubMed database were "Massive" or "Irreparable" and "Rotator cuff tears" and the search yielded 1223 results. The keywords used in Science Direct were Massive RCT (n = 4099) and Irreparable RCT (n = 1). All the systematic reviews, meta-analyses, books and documents, editorials, and conference abstracts were excluded, which yielded PubMed (n = 184) and Science direct (n = 2078) results. The final literature search was carried out on July 4, 2021.

Study selection

Studies were considered eligible for inclusion in this review if they matched the following inclusion criteria.

1. Patients with massive or irreparable RCTs
2. Such tears were treated with debridement where in debridement also includes subacromial debridement, acromial debridement or acromioplasty, rotator cuff debridement, long head of biceps tenotomy, and tuberoplasty.

All the procedures where repair (partial or full), and reconstruction (tendon transfers, prosthesis, spacers, patches) are attempted are excluded from our study. All the studies which are not in the English language are excluded, and all the review articles are excluded as well from our study.

By applying all the above-mentioned criteria, the initial screening was done using titles and abstracts in PubMed (n = 184) and Science direct (n = 2078) which yielded 29 studies in PubMed and 22 in Science direct. Two were excluded for non-English language. Then, both the database results were screened for duplicates and two were excluded. Finally, all the remaining 47 studies were thoroughly studied to ascertain whether they fit into described criteria. At the end of the scrutinization of the literature search, a total of 13 studies were considered for this systematic review study.

Analysis

The data from the final 13 included studies were extracted and recorded in a Microsoft Excel spreadsheet. The data included the type of study, level of evidence, sample size, mean patients' age, sex, mean follow-up period, inclusion and exclusion criteria, procedure performed and position, and functional outcomes. The outcomes of all the studies were assessed. The outcomes included the Constant Score, University of California Los Angeles Shoulder Score (UCLA), American Shoulder and Elbow Surgeons (ASES), Oxford Shoulder Score, and Visual Analogue Scale (VAS).

The quality of all the considered studies was assessed with the MINORS [Table 1] (Methodological Index for Non-Randomized Studies) checklist.[28] The final version of the checklist contained 12 items, of which the first eight items are used routinely. Each item in the checklist is assigned a score of 0, 1, or 2. The score was 0 if not reported, 1 if inadequately reported, and 2 when adequately reported. The maximum score for the checklist with 8 items is 16, which indicates that the nonrandomized study has the highest possible score. A minimum of 24 months follow-up was taken as an appropriate mean follow-up period and scored 2. All the studies were thoroughly reviewed by two authors, KS and SK, for MINORS score. Any discrepancy in the score was resolved by discussing it with the senior author VD.

Statistical analysis was used to describe the data and outcomes assessment. Descriptive analysis was carried out in the present study. Results on continuous variables were presented as mean ± standard deviation (min–max) and results on categorical variables were presented as frequencies with percentages. The outcome measures were not pooled because of the variety of scores used in each of the studies and differences in the surgical procedure, and follow-up period. Hence, they are presented in a narrative summary fashion.

Results

Figure 1 shows PRISMA Flow chart.

Table 1: Methodological index for nonrandomized studies

Serial number with references	MINORS	A clearly stated aim (1)	Inclusion of consecutive patients-no exclusion (2)	Prospective collection of data (3)	.Endpoints appropriate to the aim of the study (4)	Unbiased assessment of the study endpoint (5)	Follow-up period appropriate (6)	<5% follow-up (7)	Prospective study size calculation (8)
1[16]	8	2	0	0	2	0	2	2	0
2[17]	11	2	0	2	2	1	1	2	1
3[18]	9	2	0	0	2	1	2	2	0
4[19]	7	2	0	0	2	1	2	0	0
5[20]	10	2	1	0	2	1	2	2	0
6[13]	8	1	2	2	1	2	2	0	0
7[21]	14	2	2	2	2	2	2	2	0
8[22]	14	2	2	2	2	2	2	2	0
9[23]	11	2	2	2	2	2	2	1	0
10[24]	11	2	0	2	2	2	2	1	0
11[25]	10	2	0	2	2	2	2	0	0
12[26]	12	2	2	2	2	2	2	0	0
13[27]	11	2	1	2	2	2	2	0	0

MINORS: Methodological index for nonrandomized studies

Included studies

All the included studies[13,16-27] [Table 2] are nonrandomized cohort studies, composed of five retrospective case series, seven prospective studies, and a prospective cohort study. The average MINORS score was 10.04 out of 16. In none of the studies, the prospective sample size was calculated. The mean follow-up was taken as 24 months and only one study had less than the mean follow-up.

The level of evidence was level 3 in all of the included studies. There was patient overlap in two studies where the 31 patients in Liem *et al*.[20] were followed up by Vogler *et al*.[19] leaving the dropouts (12 patients), the final size of follow-up was 19. The total patient size was 360, with male predominance (62%). The mean age of this review study was 66.4 years (range 60–75.6 years), and the mean follow-up duration was 57 months (range 18 to 145 months).

Inclusion and exclusion criteria of studies considered for the review

The inclusion criteria in all the studies[13,16-27] were that the tears were massive and irreparable and that the patients have tried an initial conservative trial. The exclusion criteria, in general, were that the subjects were excluded if the tears were repairable or if they were undergoing reoperation. In some studies, the exclusion criteria were the presence of osteoarthritis changes, rotator cuff arthropathy, open procedures, and pseudo-paralysis [Table 3]. Most of the procedures were performed in a beach chair, while in three studies, lateral position was used to perform the procedure [Table 3]. Most of the procedures were performed via the arthroscopic method, while in three studies, open procedures were used.

Concomitant procedures

The concomitant procedures used along with debridement were long head of biceps tenodesis, tenotomy, distal clavicle excision, supra-scapular nerve decompression, acromioplasty, tuberoplasty, and coracoacromial ligament release [Table 4].

The long-head biceps tenotomy was a commonly performed concomitant procedure. In our present review of the total 360 patients, tenotomy was done in 136 (37.8%), intact in 164 (45.6%) with or without pathologic changes, absent in 53 (14.7%), and ruptured in 7 (1.9%).

Outcome scores, range of movement, and salient findings

The outcome scores used in the included studies[13,16-27] were Constant score, UCLA, Oxford score, VAS, and ASES [Table 5]. The constant score was used in seven studies; the mean preoperative constant score was 39.95 (range 31–63), which improved to 58.22 (range 59–84) in the postoperative period. ASES was used in four studies with a mean ASES score was 31.3, which has improved to 66.28 (range 24–74). UCLA score was used in six studies and the mean UCLA score was 10.6 during the preoperative period which has improved to 26.6 (range 21–27). VAS was used in six studies and the range was from 9 (preoperative) to 0.5 (postoperative during follow-up). The salient findings of all the papers, along with

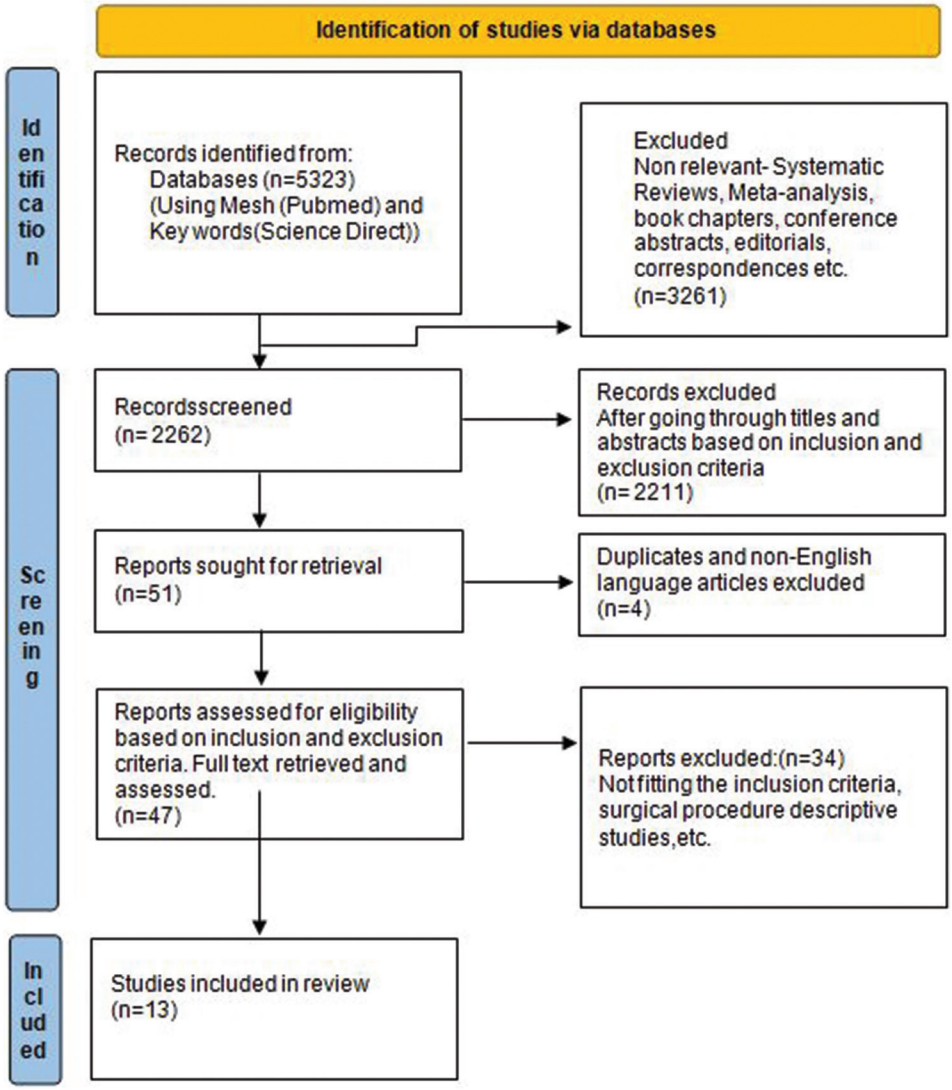

Figure 1: PRISMA chart. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

the range of movement, both preoperative and postoperative have also been presented [Table 6].

Discussion

The key findings of our systematic review are that all the patients in all the studies underwent an initial conservative trial ranging from three to six months. The initial conservative treatment is aimed at strengthening the deltoid and periscapular muscles to achieve a mean preoperative forward flexion and abduction of 90°, which yielded better postoperative clinical outcomes. The debridement was the procedure of choice in irreparable tears, which included bursectomy, and debriding the torn rotator cuff tendons. The long head of the biceps tenotomy was advised in all the studies if the tendon was frayed, subluxated, dislocated, partially torn, or associated with synovitis. There was no difference in the clinical outcomes between the tenotomy and the intact group, as long as there were no pathologic changes in the biceps tendon (subluxation, tears, synovitis).[16-27] The CAL was preserved in almost all the studies to function as a final restraint.[16-27] The other concomitant procedures were acromioplasty and tuberoplasty, which were advised if the acromial humeral distance was <7 mm.[18,25-27] The factors that were associated with poor outcomes when present with each other are, poor preoperative range of motion, subscapularis complete tear, and superior migration of humeral head (Acromial humeral distance <4 mm).[16-27]

Cofield classified tears based on size, with small tears as <1 cm, medium as 1–3 cm and large as 3–5 cm, and massive as more than 5 cm^2. Irreparable tears are those which have retracted beyond the glenoid articular surface and could not be restored or repaired back to their footprint because of excessive tension and poor quality of tissue that cannot be repaired with anchors.[16]

Most of the said irreparable and massive tears occur in elderly patients, and the best surgical option is based on factors such

Table 2: Demography and study quality

Author	Study design	Evidence	Size (patients sample)	Sex	Mean age in years	Mean follow up in months	Minors score
Ho *et al*.[16]	Retrospective	3	26	21 males, 5 females	60	98	8
Mirzaee *et al*.[17]	Prospective	3	12	7 males, 5 females	65	18	11
Pander *et al*.[18]	Retrospective	3	39	17 males, 22 females	75.6	78	9
Vogler *et al*.[19]	Retrospective	3	19	9 males, 10 females	68	145	7
Liem *et al*.[20]	Retrospective	3	31	19 males, 12 females	70.6	47	10
Rockwood *et al*.[13]	Prospective	3	50	40 males, 10 females	60	78	8
Klinger *et al*.[21]	Prospective	3	41	25 males, 16 females	67	33	14
Klinger *et al*.[22]	Prospective	3	33	23 males, 10 females	69	31	14
Veado and Rodrigues[23]	Prospective	3	22	7 males, 15 females	69	27	11
Gartsman[24]	Prospective	3	33	30 males, 3 females	62	24	11
Fenlin *et al*.[25]	Prospective	3	19	15 males, 4 females	63	27	10
Verhelst *et al*.[26]	Prospective	3	38	11 males, 22 females	69.6	38	12
Park *et al*.[27]	Retrospective	3	16	8 males, 8 females	64	98	11

Table 3: Exclusion criteria of the included studies

Author	Exclusion criteria	Position
Ho *et al*.[16]	Repairable, open procedure	Beach chair
Mirzaee *et al*.[17]	Repairable, rotator cuff arthropathy	Beach chair
Pander *et al*.[18]	Reoperation, distal clavicle osteotomy, open procedure	Beach chair
Vogler *et al*.[19]	Reoperation, reparable	Beach chair
Liem *et al*.[20]	Reoperation, frozen shoulder, gleno-humeral osteoarthritis	Beach chair
Rockwood *et al*.[13]	Repairable	Beach chair
Klinger *et al*.[21]	Repairable, reoperation	Lateral
Klinger *et al*.[22]	Repairable, reoperation	Lateral
Veado and Rodrigues[23]	Reoperation, gleno-humeral osteoarthritis	Lateral
Gartsman[24]	Reoperation, repairable	Beach chair
Fenlin *et al*.[25]	Glenohumeral osteoarthritis, functional cable not reestablished	Beach chair
Verhelst *et al*.[26]	Glenohumeral osteoarthritis	Beach chair
Park *et al*.[27]	Open procedure, repair, gleno-humeral osteoarthritis, no pseudo-paralysis	Beach chair

as tissue quality, osteoarthritis changes, and activity level apart from age. The management of such tears still poses a considerable challenge, and there is no consensus regarding the preferred surgical treatment.[17,18] There are a variety of surgical options for massive and irreparable tears such as debridement, tendon transfer, and prosthesis (hemiarthroplasty and reverse shoulder arthroplasty). Novel procedures such as superior capsular reconstruction and subacromial spacer application, have also been described.[19] Tissue transfers have also been described for massive and irreparable tears such as supraspinatus advancement,[29] deltoid flap usage, superior subscapularis advancement, usage of intra-articular biceps tendon,[24] tendon transfers (L. dorsi by Gerber *et al*.[30]) and dermal tissue allograft.[31] The procedures involving slides, and transfers have been described aptly by Fenlin *et al*.[25] as robbing peter to pay paul.

The inclusion criteria in all of the studies were almost the same without much heterogeneity, though there are variations in the follow-up period and concomitant procedures performed. All of the patients are aged more than 60 years. The inclusion criteria in almost all of the studies were that the RCTs should be of an irreparable RC tear and the patients should necessarily undergo an initial conservative trial. The conservative trial includes NSAIDs, stretching, and strengthening exercises, as described by Rockwood as ortho therapy.[13]

Rockwood *et al*.[13] and Gartsman *et al*.[24] performed open debridement for irreparable tears and reported satisfactory patient outcomes. According to Rockwood *et al*.,[13] pain relief is due to subacromial decompression, and it should be performed even in repairable tears for adequate postoperative pain relief and rehabilitation.

Although debridement includes subacromial decompression, the concomitant procedures varied. Rockwood, in his debridement, included acromioplasty and resection of the coracoacromial ligament (CAL) as a concomitant procedure.[13] Apoil *et al*. neither advised acromioplasty nor CAL release but included superior arthrolysis as a part of debridement.[32] Nirsh and Flatow[33] also advised against CAL as there is a risk of superior escape of the humeral head. Even though there is a risk of superior migration of the humeral head post resection of CAL, the results, according to Gartsman *et al*. showed significant pain relief but unsatisfactory outcomes for a range of movement and strength.[24]

Fenlin *et al*.[25] described tuberoplasty and Verhelst *et al*.[26] used the term reverse subacromial decompression to describe the same procedure. The procedure involved debriding the reactive hyperostosis on the greater tuberosity with a high-speed burr for smooth articulation with the acromion. The decompression is on the humeral side rather than on the acromial side, and CAL is spared to avoid humeral head escape. In long term, the radiographs showed femoralization of the humerus and acetabularization of the acromion, creating an articulation between the humerus and acromion.[25,26]

Table 4: Concomitant procedures

Author	Concomitant procedures	Biceps procedure
Ho *et al*.[16]	Arthroscopic, biceps tenodesis or tenotomy, distal clavicle excision, Tuberoplasty, acromioplasty, bursectomy	9 tenotomy, 4 intact, absent-13
Mirzaee *et al*.[17]	Arthroscopic, tenotomy, tuberoplasty, bursectomy (CAL preserved)	12 tenotomy
Pander *et al*.[18]	Arthroscopic, tenotomy, acromioplasty, bursectomy (CAL preserved)	12 intact 17 tenotomy absent-10
Vogler *et al*.[19]	Arthroscopic, tenotomy, bursectomy, no acromioplasty (CAL preserved)	17 tenotomy, 2 rupture
Liem *et al*.[20]	Arthroscopic, tenotomy, bursectomy , no acromioplasty (CAL preserved)	24 tenotomy, 4 rupture, intact-3
Rockwood *et al*.[13]	Open procedure, acromioplasty, distal clavicle excision, tuberoplasty, CAL excised.	Absent in17, frayed-18, hypertrophied-9, not recorded-9
Klinger *et al*.[21]	Arthroscopic, bursectomy, tenotomy (CAL preserved)	Tenotomy-17, intact-24
Klinger *et al*.[22]	Arthroscopic, tenotomy, acromioplasty, distal clavicle excision (limited CAL release)	Tenotomy-6, 9-intact, pathologic-23
Veado and Rodrigues[23]	Arthroscopic, tenotomy, bursectom, no acromioplasty (CAL preserved)	Tenotomy-12, intact-10
Gartsman[24]	Open, acromioplasty	Intact-21 (tenodesis-1), absent-12,
Fenlin *et al*.[25]	Open, bursectomy, tuberoplasty, no acromioplasty (CAL preserved)	Intact-18 (subluxated-1), absent-1
Verhelst *et al*.[26]	Arthroscopic, tuberoplasty, tenotomy, no acromioplasty (CAL preserved)	Tenotomy-39
Park *et al*.[27]	Arthroscopic, bursectomy, tuberoplasty, acromioplasty	Intact-13, ruptured-2, partial rupture (tenodesis)-1

CAL: Coraco acromial ligament

The long head of the biceps has also been described as a source of pain when it is associated with synovitis, or it is subluxated or dislocated.[23] When it is pathological, biceps tenotomy has been performed in all of the included studies. According to Klinger *et al*.,[21,22] the biceps tendon is considered the final restraint in irreparable tear for superior humeral head migration and might be considered a source of pain because of its restraint mechanism, which stresses the pulley system. This leads to synovitis, subluxation, or dislocation and eventually to pre-rupture and finally rupture. However, the study did not show significant superior humeral head migration or cuff tear arthropathy post-tenotomy. Walch *et al*.[34] first described the procedure of arthroscopic biceps tenotomy and compared debridement with and without tenotomy between two groups. Pander *et al*.[18] also compared debridement with and without tenotomy between the two groups. However, the results did not show a significant difference in constant scores between the two groups.[18,21,22] Vogler *et al*.[19] also in their study described that results were satisfactory with debridement with or without tenotomy. Although in his study, there was a negative correlation between the adjusted constant score and acromial-humeral distance post-tenotomy, the relation was not significant.

Burkhart *et al*.[35] described the concept of transverse couples or suspension bridge principle where the teres minor and subscapularis when intact, can act as a couple and maintain a range of motion and prevent superior humeral head migration. Hence, in an irreparable and massive tear involving supra and infraspinatus, he described such shoulders as anatomically deficient but biomechanically intact if transverse couples are maintained.[30] In shoulders without transverse couples, reverse subacromial decompression or tuberoplasty has been advised.[27] According to Ho *et al*.,[16] patients with a less preoperative range of motion (Forward elevation < 90°) had lower constant scores and postoperative movement but have an improvement in pain relief.

Table 5: Outcome scores

Author	Constant score	Oxford score	ASES	VAS	UCLA score
Ho *et al*.[16]			38-74	7-0.5	
Mirzaee *et al*.[17]				9 T0 2.5	9.2-27.5
Pander *et al*.[18]	77	21		2	
Vogler *et al*.[19]	63-79		36-66-66	7.4 to 3.4 to 3	
Liem *et al*.[20]			24-69.8	7.8-2.9	
Rockwood *et al*.[13]					8.4-25.6
Klinger *et al*.[21]	40-68				
Klinger *et al*.[22]	31-67				
Veado and Rodrigues[23]					15-31
Gartsman[24]	31.2-52.4		27.2-55.3	7.9-4.3	11.5-20.8
Fenlin *et al*.[25]					9.3-27.7
Verhelst *et al*.[26]	34.9-84				
Park *et al*.[27]	39.6-59.2			6.9-2.3	10.3-27.2

UCLA: University of California Los Angeles, ASES: American Shoulder and Elbow Surgeons, VAS: Visual analog scale

Table 6: Salient findings with range of movement

Author	Preoperative ROM (mean)	Postoperative ROM (mean)	Salient findings
Ho *et al*.[16]	Forward elevation of 132°	N/A	Poor preoperative FE is a negative predictor
Mirzaee *et al*.[17]	Abduction of 100°	Abduction of 160°	Increased postoperative ROM correlated with improvement in pain. Posttuberoplasty the acromiohumeral distance decreased, but the degenerative changes had no significant correlation with clinical and functional outcomes
Pander *et al*.[18]	N/A	N/A	Two groups with and without tenotomy. No significant difference between them. Debridement with or without tenotomy yields better results. Biceps tenotomy is required when it is pathologic
Vogler *et al*.[19]	Forward elevation and abduction of 90°	N/A	Debridement with tenotomy yields better results at a mean follow-up of 145 months. There is radiographic progression attributed due to natural history of the disease
Liem *et al*.[20]	Forward elevation and abduction of at least 90°	N/A	Debridement with tenotomy yields better functional outcome, No association between radiograph changes and clinical outcomes
Rockwood *et al*.[13]	Forward elevation of 105°	Forward elevation of 140°	Improvement is ROM is accompanied by decrease pain and crepitus. Acromioplasty relieved pain, and postoperative ROM could be regained with strengthening of subscapularis, teres minor, and deltoid and periscapular muscles. Better outcome if better preoperative rom
Klinger *et al*.[21]	N/A	N/A	Two groups with and without tenotomy. No significant difference between them. Tenotomy if tendon is pathologic. No significant migration of humeral head in tenotomy group
Klinger *et al*.[22]	N/A	N/A	Negative prognositic factors – Complete subscapularis tear, poor preoperative ROM, Superior migration of humeral head and osteoarthritis. Two or more negative factors lead to poor outcome. Acromial humeral distance did not change significantly due to intervention
Veado and Rodrigues[23]	N/A	Forward elevation of 160°	No difference in supination and elbow flexion strength between tenotomy and intact group. Tuberoplasty if decreased acromial humeral distance
Gartsman[24]	Forward elevation of 96°	Forward elevation of 118°	Unsatisfactory results were associated with irreparable tears of subscapularis and teres minor
Fenlin *et al*.[25]	Forward elevation of 100°	Forward elevation of 162°	Acromial humeral distance of<7 mm was advised tuberoplasty, CAL to be preserved
Verhelst *et al*.[26]	Forward elevation of 91°	Forward elevation of 154°	Biceps not considered as humeral head depressor. Even less than 90° ROM can yield better results with tuberoplasty if mobility can be improved through conservative trial first
Park *et al*.[27]	Forward elevation of 109°	Forward elevation of 132°	Poor postoperative outcomes if poor preoperative ROM of<90° or acromial humeral distance of<4 mm

ROM: Range of movement, N/A: Not available, CAL: Coraco acromial ligament, FE: Forward elevation

Mirzaee *et al*.[17] also in their study had better postoperative movement and constant scores when the patients had decent forward elevation and abduction before treatment.

In all of the studies, there were patients with degenerative changes and decreased acromion-humeral interval postoperatively, but there was no correlation between pain or the preoperative X-ray findings. In all the studies, there was no correlation between pain relief and cuff tear arthropathy. The progression of arthritis postoperatively neither can be prevented nor correlated with scores and pain relief.

Klinger *et al*.[21,22] described the negative prognostic criteria and postulated that the patients who had two of the four criteria might have poor outcomes. The criteria, according to the authors, are loss of transverse couples (tears involving teres minor or subscapularis), poor preoperative range of movement, superior humeral head migration, and arthritis.

All full-thickness tears which are repairable need to be repaired, and repair should be attempted to the original footprint.[27] Codman, in 1911, described operative intervention for full-thickness RCTs, and in his study, he divided patients into two groups. In one group, the repair was attempted, and in another, only debridement was done. The results that Rockwood and Hawkins observed with debridement could not be reproduced by Codman. In his study, the repair group had better postoperative outcomes.[36]

Levy *et al*.,[37] in their study, included patients with full-thickness tears (small, medium, large and massive) and all the tears were treated with debridement. His results in large and massive were satisfactory compared to small and medium. Hence, he concluded that in young and active individuals, the repairable tears should be repaired.

Ellman *et al*.[38] also performed debridement on all of their patients with full-thickness tears. He divided his patients into three groups based on age and tear size. The debridement alone produced satisfactory results in massive and large tears and some patients with small tears. He concluded that debridement produces satisfactory results in carefully selected patients at both ends of the tear spectrum. He proposed four factors related to poor prognosis for surgical repair and where debridement can be attempted. The factors are poor and weak preoperative

abduction and external rotation, long duration of symptoms, and less acromion-humeral distance (<7mm).

This systematic review and all the studies included revealed that massive and irreparable tears are common in the elderly population. In patients with low functional demand, the initial treatment should be a conservative trial to strengthen the muscles and improve the range of movement. As proposed by Ellman *et al*.,[33] all repairable tears should be repaired with debridement for better postoperative rehab and pain relief. In irreparable tears, the first line of surgical treatment in elderly low-demand patients is debridement with concomitant procedures. All the studies had better pain scale ratings postoperatively. Although there is a progression of arthritis postoperatively, there is no correlation with satisfaction. To get better strength and range of movement, the transverse couples have to be maintained, and patients should have a better preoperative range of movement. Coraco acromial ligament (CAL), should not be debrided, whenever the transverse couples are not maintained, and tuberoplasty or reverse subacromial decompression should be attempted. Although the results and scores in all the studies are satisfactory postdebridement, the results depend on careful patient selection, and further investigations are needed to fully elucidate the mechanism of transverse couples, preoperative range of movement, and superior restraints on postoperative muscle strength and movement.

Conclusion

This systematic review of existing literature suggests that arthroscopic debridement of an irreparable and massive cuff tear is a technically simple procedure and can be done with or without concomitant procedures and involves short operative time, low complications, and easy rehabilitation with favorable scores and patient outcomes. This age-old procedure with its variations (concomitant procedures) may be most appropriately indicated in the low-demand elderly population as a first-line surgical option. The patient population had significant improvement in pain relief. The range of motion and the muscle strength improvement depends on various factors such as transverse couples, CAL, and preoperative movement, which necessitates further prospective studies (Randomized or comparative) to ascertain its efficacy in the long term with other salvage procedures (tendon transfers, advancements, allograft, prosthesis).

Limitations

Level of evidence-all the studies are non-randomized, with almost all of the studies having level 4 evidence and no control groups. There was no uniform consensus regarding the concomitant procedures in the included studies. The outcome measures were heterogeneous in the included studies, with only one-third of the studies at a time having a uniform scoring scale; hence, meta-analysis was not done. The sample size was also limited.

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Conflicts of interest

There are no conflicts of interest.

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Review Article

Current Status of Preventive and Therapeutic Strategies Against Biofilm Formation in Arthroplasty

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Abstract

Total joint replacements have increased significantly, resulting in a corresponding increase in infections. Consequently, patients may undergo additional surgical procedures and be prescribed antibiotics for a prolonged period due to these infections. Periprosthetic joint infections are associated with the development of bacterial biofilms. The biofilm is a microbial community attached to a surface containing one or more bacterial species. In orthopedics, biofilm-forming bacteria are the most severe infection that can lead to multiple operations, prolonged antibiotic therapy, morbidity, and increased health-care expenditures. These biofilm communities pose several clinical challenges relating to infection prevention, detection, and treatment. Over the past few years, biofilm formation mechanisms have been extensively studied, as have the mechanisms by which bacteria communicate within biofilms to perform specialized functions, such as persister cells. Currently, the orthopedic literature is very scarce, and understanding the cause and eradicating the disease requires a deep understanding. Several studies have demonstrated that the delivery of antibiotics locally through absorbable carriers and novel coatings for prostheses can deliver high concentrations of antibiotics. This literature review aims to identify mechanisms and structures of biofilm, especially in the context of arthroplasty, and to provide strategic guidance on current diagnosis, prevention, and target-specific treatment. In addition, the review discusses future diagnostic and therapeutic advancements.

Keywords: Antibiotic Resistance, arthroplasty, biofilm, exopolysaccharides, coating, infections, prosthesis

Introduction

A significant morbidity and mortality risk is associated with a periprosthetic joint infection (PJI). According to the report, 1%–2% of those with PJI have significant impairments.[1] Furthermore, health-care costs can be extremely high, reaching $60,000.[2] Despite several therapeutic measures, surgeons remain concerned about the recurrence of infections. In primary THRs and primary TKRs, PJI occurs with an average annual incidence of 0.25%–1.0% and 0.4%–2%, respectively.[3-6] There is a higher incidence of infection following revision re-surgery, with estimated rates of 3.2%–5.6% for both hips and knees.[7] As per the National Joint Registry, infection is responsible for up to 12% of the indications for revision hip arthroplasty and 22% of the indications for revision knee arthroplasty.[8] Infection rates for primary and revision hip and knee arthroplasties are expected to increase by 4% between 2005 and 2030.[9,10] There is an intrinsic link between the pathogenesis of PJI and the formation of biofilms. This review investigates the impact of biofilms on prosthetic joint infections (PJIs), explores current diagnostic challenges, and evaluates eradication measures.

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The Significance of Biofilms in Arthroplasty

Our understanding of the pathogenesis of biofilm will facilitate identifying and treating these devastating infections. Initially, bacteria adhere to foreign materials such as implants and cause infection, and these bacteria may passively reside and interact with the implant surface, growing into minor colonies. As a result of the pathogen's phenotype, biofilms are formed

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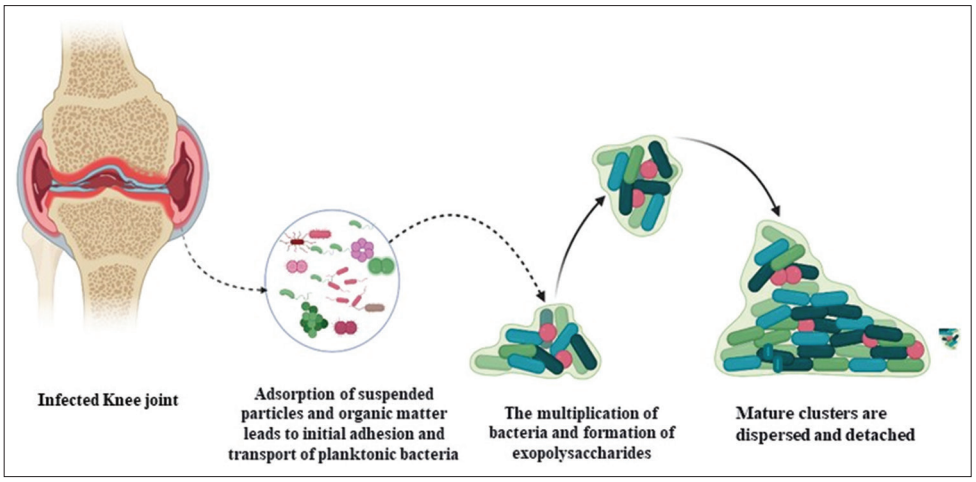

Figure 1: Stages of bacterial colonisation and biofilm formation in knee implant

more frequently, which results in persistent infections and the development of antibiotic resistance. As shown in Figure 1,[11] bacteria adhere to each other during this accumulative phase and form biofilms. An implant is more likely to become contaminated intraoperatively if foreign material is in direct contact with the surgical wound or the skin or if airborne contaminants are present. Extracellular matrix proteins and host cells (fibroblasts, osteoblasts, and endothelial cells) compete for the surfaces of implanted biomaterials. The homogeneous transmission of bacteria is also possible and can occur in the case of pneumonia, urinary tract infections, and skin infections. As a result of the formation of *de novo* biofilms at nearby sites, such as diabetic ulcers or infected wounds, osteomyelitis can spread.

The Biofilm Life Cycle

The term biofilm refers to a community of microbes enclosed within polymeric matrixes, which exhibit altered growth characteristics, gene expression, and protein synthesis.[12] In 1978, Geesey *et al*.[13] used recovery methods to quantify naturally occurring biofilm bacteria in pristine mountain streams. Even though biofilms are composed of nonuniform polymers, when observed macroscopically, they appear as thin, homogeneous layers. According to the National Institutes of Health, in late 2002, biofilms were responsible for more than 80% of bacterial infections and 56% of chronic illnesses.[14] Bacteria can be divided into two types: planktonic and biofilm formation. In the case of bacteria that can colonize on surfaces within the patient in the form of planktonic bacteria, they can be catalysts for forming biofilms. Compared to stationary bacteria, bacteria that form biofilms have reduced metabolic activity. During the dispersal and metabolism of microorganisms, multilayer biofilms are formed. An encapsulated biofilm protects bacteria from both the host's environment and antibiotics.

The formation of biofilms assists bacteria in adapting to hostile environments. Below is an illustration of the biofilm formation process.

a. A matrix of polysaccharides, DNA, and proteins is produced by bacteria to adhere to surfaces. As a result, well-defined and highly structured bacterial colonization can be formed by attracting microbes to the matrix and allowing them to adhere to it
b. As a biofilm matures, bacteria become more resistant to antibiotics and host defenses.[15] Exopolysaccharides (EPSs) bind the surfaces of mature cells together. In addition, EPS contributes to resistance by preventing chemicals from diffusing into and out of the biofilm [Figure 2]
c. A unique phenomenon called quorum sensing (QS) enables communication between cells within a biofilm. Bacteria can also be detached from mature biofilms by the QS system.[15] A biofilm's unique property ensures its persistence in hostile environments.

Bacterial Pathogenesis in Periprosthetic Joint Infection

Bacteria are capable of invading, surviving, and multiplying within host tissues. Generally, it occurs in epithelial and osteoblast cells. The extracellular space of these bacteria is not affected by antibiotics. Pathogenic bacteria communicate with one another in a biofilm when they exhibit different phenotypes. The infection may reappear if debridement, antibiotics, and washing fail to eradicate the bacteria from the overlying fluid, foreign body, and subsurface tissues. One of the most notable classifications proposed in the literature is Trampuz and Zimmerli.[16,17] Infections are classified according to the onset of symptoms after implantation as follows:

i. Acute infection (<3 months postoperatively), usually caused by *Staphylococcus aureus* or Gram-negative bacteria (such as *Escherichia coli*)
ii. Coagulase-negative staphylococci or *Propionibacterium acnes* usually cause postoperative infection (3–24 months postoperatively)
iii. Streptococci, Gram-negative bacteria, and *S. aureus* are the most common causes of long-term infections.

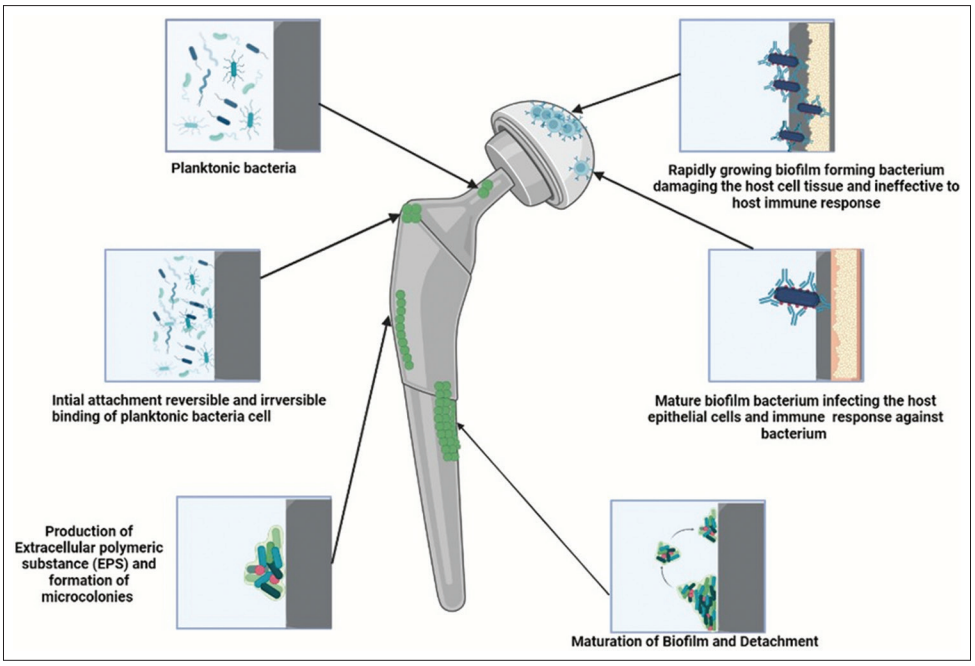

Figure 2: Stages of biofilm formation on a hip arthroplasty implant and host immune response against infection

Perioperative contamination is the most common cause of biomaterial-related infections.[18-20] There is usually a combination of local and systemic symptoms associated with these infections, as well as elevated levels of C-reactive protein (CRP), erythrocyte sedimentation rate (ESR), and white blood cell count in the blood. The detection of an infection can also occur through blood and tissue cultures during the early stages of the infection. A number of late infections occur after a relatively asymptomatic postoperative period and are most commonly caused by hematogenous seeding, most commonly from the skin and soft-tissue infections.[21,22] An infection of the urinary tract, the respiratory tract, or the gastrointestinal tract may also result in seeding. There may be an alteration in the immune response of the host.

Challenges In Management of Biofilms in Periprosthetic Joint Infection

Biofilms are inherently resilient despite therapeutic measures. In biofilms, outermost bacteria mount protective defenses despite being more susceptible to the host's defenses and antibiotics. A biofilm's matrix and layers of cells resist antibiotic diffusion during the physical process of diffusion. Antibiotic degradation can be enhanced by intrinsic biofilm metabolism and anoxic or acidic environments—EPSs from "antibiotic sinks" in biofilms. Without nutrients, biofilms can undergo dormancy, resulting in persistent, resistant cells. Antibiotic concentration gradients may occur by binding to matrix components, diffusion-limited transport, and bacterial uptake. Antibiotics are, therefore, only exposed to sublethal levels in the biofilm. As a result of this sublethal exposure, antibiotic resistance is increasing.[23]

Various novel tolerance mechanisms and conventional resistance mechanisms exist in biofilm bacteria. Beta-lactamases degrade antimicrobials such as penicillin and cephalosporin in biofilms.[24] Furthermore, biofilm bacteria can express efflux pumps, allowing them to eliminate antibiotics once they have penetrated the bacterial wall and reached the intracellular space.[24] In *P. aeruginosa* and methicillin resistant *S. aureus* (MRSA), the formation of biofilms increases the minimum inhibitory concentration of antibiotics by a factor of 1000.[25,26] Furthermore, biofilm structure inhibits the host's innate and adaptive immune responses.[27] As the foreign body has no blood supply, the immune system has difficulty recognizing it. Immune cells and antibodies cannot reach a foreign surface. EPS matrix prevents polymorphonuclear leukocytes from phagocytosing bacteria in biofilms formed on and around implants. Consequently, granulocytes produce less superoxide when interacting with implant components.[28] Granulocytes unable to function correctly can be referred to as frustrating granulocytes. The presence of inflammation may allow biofilm bacteria to acquire nutrients, leading to further deterioration of the condition.

Diagnostic Challenges of Periprosthetic Joint Infection

Bacteria within a biofilm are metabolically sluggish as a result of nutrient deficiencies. In most cases, biofilms are patchy and cannot detect by fluid swabs or tissue biopsies. Identifying whether microbes are growing planktonically or in biofilms within a patient is even more challenging. *In vitro* growth states of bacteria isolated from patients may vary from those observed *in vivo*. The culture of bacteria from biofilms can, however, be challenging. A nucleic acid mixture

isolated from a clinical sample of a patient is amplified and sequenced using primers specific to the microbe. Polymerase chain reaction (PCR) can use to detect resident bacteria from a biopsy or joint fluid culture. Other studies have reported detection rates ranging from 70% to 80%.[29] Since PCR can detect slow-growing microbes, it has helped diagnose other infections, such as bloodstream infections. Because of the high sensitivity of PCR, contamination and false positives remain a concern. Performing a preoperative diagnosis, identifying the organism, and identifying the growth patterns can be accomplished using this imaging technique before removing a potentially infected implant.

There are many instances where it is only possible to identify pathogens after removing implants. Aside from joint fluid samples, surgeons should also obtain periprosthetic tissue samples. It is possible to examine the surface of the prosthesis microscopically after it has been removed to detect adhered bacteria.

Nevertheless, it is essential to keep in mind that removing an implant may cause the biofilm to dissociate mechanically. There is evidence that pathogens isolated from drainage sinuses associated with knee and hip replacements do not match those found in the PJI, leading to inaccurate treatment recommendations.[30] The results of laboratory and clinical tests indicate an acute infection, including an elevated ESR, a high CRP level, and a high synovial leukocyte count or neutrophil percentage. Pathogens can detect them more effectively by sonicating prosthetics rather than simply vortexing (mixing in a circular motion). Multiple bacterial and fungal pathogens can detect using sonication and multiplex PCR.[31] Microcalorimetry can also use in addition to sonication.[32] It is also possible to detect pathogens directly by examining the explanted prosthesis, cement, or periprosthetic tissue under a microscope. As bacteria adhere to surfaces over time, microscopy is the only method of confirming the presence of biofilms on a site, rather than being casually attacked by surgeons or specimen collectors.

Microscopy has additional benefits, such as detecting pathogens inside and outside cells. Confocal microscopy allows the detection of pathogens adhered to periprosthetic tissues at a depth of approximately 100-200μm (micrometre).[33] To determine the presence and viability of bacteria, a Fluorescence *in Situ* hybridization (FISH) probe specific to the 16S rRNA. Similar approaches to identify pathogens in periprosthetic orthopedic infections and implanted suture material in the abdominal wall.[34,35] FISH can remove biofilms, but vigorous washing steps may dislodge them. This problem can be overcome by embedding samples in paraffin, thinly sectioning them, and mounting them on slides.

A recent study by Southern *et al*. and MacVane *et al*. demonstrated that biofire could rapidly detect biofilms and antimicrobial resistance in implanted tissue. A comprehensive, pathogen-specific result is provided by BioFire within 1 h using multiplex PCR technology. The BioFire System also contains three panels that target genes associated with antimicrobial resistance. A BioFire System provides actionable results within hours rather than days, facilitating better antimicrobial stewardship and reducing the need for unnecessary antibiotics.[36,37]

A polymer sensor array has been recently reported by Ngernpimai *et al*. that uses selective interactions between polymer sensor elements and the biofilm matrix to identify bacterial species. As a result of the appropriate choice of the fluorophore, six output channels were generated from three polymers, resulting from excimer formation and inter-polymer FRET. As a result of selective multivalent interactions of these polymers with the biofilm matrix, the fluorescent pattern of the biofilm was altered, providing a species-based signature of the biofilm. In addition, the platform was validated by identifying mixed-species bacterial biofilms and the differentiation of biofilms in a mammalian cell-biofilm co-culture wound model.[38]

As reported by Dastgheyb *et al*., methicillin-resistant *S. aureus* forms extremely strong biofilm-like aggregates in human synovial fluid (SF), significantly higher than those observed in growth medium or serum, one of the most common causes of joint infections. Fibronectin- and fibrinogen-binding proteins were critical for forming macrophage aggregates in SF. The pretreatment of SF with plasmin resulted in a marked reduction in the formation of aggregates and increased antibiotic susceptibility. According to Dastgheyb *et al*., staphylococcal joint infections are associated with the pronounced aggregate formation and biofilm formation. Considering these findings, it becomes clear why joint infections are resistant to therapeutic intervention and clearing by the host defenses and suggest possible new therapeutic strategies that rely on the enzymatic digestion of biofilms in joint infections to treat them.[39]

PJI may be treatable if the appropriate, timely diagnosis and identification of organisms, according to the musculoskeletal infection society and the American Academy of Orthopaedic Surgeons. Since biofilms are difficult to culture, these diagnostic criteria provide indirect evidence [Table 1].[40]

According to the Musculoskeletal Society 2011, PJI is defined as follows:[41]

1. In the case of a prosthesis, there may be a sinus tract communicating with it; or
2. The pathogen is isolated by culture from two or more samples of tissue or fluid obtained from the affected prosthetic joint; or
3. If four out of six of the following criteria are met:

a. CRP and ESR elevations
b. A high number of synovial white blood cells
c. An elevated percentage of polymorphonuclear cells (PMNs) in the synovial
d. An affected joint that exhibits purulence
e. Microorganisms isolated from one culture of periprosthetic tissue, fluid, or both.

Table 1: Diagnostic criteria for periprosthetic joint infection[41]

Major diagnostic criteria	
Follow one of the criteria	a) Two positive cultures of the same organism. b) Sinus tract with communication to joint space or visualisation of the prosthesis.
Minor diagnostic criteria	
Follow one of the criteria	a) 0 to 1 - not infected b) 2 to 5 - inconclusive c) ≥6 - infected
Serum ESR	1
Serum CRP or D-Dimer	2
Synovial WBC or leukocyte esterase	3
Synovial alpha-defensin (+ result)	3
Elevated synovial PMN %	2
Elevated synovial CRP	1
Intraoperative diagnosis	
Inconclusive preoperative score (2 to 5) or dry tap	a) ≥6 - infected b) 4–5 - inconclusive c) ≤3 - not infected
Preoperative score	Inconclusive
Positive histology	3
Positive purulence	3
Single positive culture	2

CRP: C-reactive protein, ESR: Erythrocyte sedimentation rate, PMN: Polymorphonuclear, WBC: White blood cell

f. An analysis of histological images of periprosthetic tissue at ×400 revealed more than five neutrophils in each high-power field in 5 high-power fields.

Prevention Of Periprosthetic Joint Infection

Modification of the implant surface

Two implant coatings can prevent biofilm-based infections: passive coatings, which inhibit bacterial adhesion and kill bacteria upon contact, and functional coatings, which release preincorporated antimicrobials to inhibit the growth of bacteria.[42]

As a passive coating

Titanium-based implants are the most widely used orthopedic devices, but they enhance protein layer formation, facilitating bacterial adhesion. A polymer chain consisting of polyethene glycol or polyethene oxide can hinder protein absorption and bacterial adhesion to biomaterial surfaces.[43] A chemical modification of titanium surfaces with zinc can also inhibit bacterial colonization.[44]

Functional coating

Antibiotics can also serve as coatings for orthopedic implants.[45] In one study by Bitschnau *et al*., rabbit tibias were injected with *S. aureus*, followed by either gentamicin-hydroxyapatite-coated steel K-wires or gentamicin-RGD (arginine-glycine-aspartate)-HA coated steel K-wires. Both types of gentamicin-coated K-wires did not induce infection in the rabbits after 28 days, whereas seven of the eight animals implanted with the standard HA coating did. In addition, the HA implants with the supplementary coatings showed good biocompatibility and bony integration, similar to the standard HA implants.[46] Similarly, Darouiche *et al*. reported that minocycline-rifampicin-coated titanium-alloy pins implanted into rabbit femurs and left *in situ* for 1 week were colonized less frequently than uncoated implants.[47]

Bio-surfactants

To reduce microbes' attachment to prosthetic surfaces, several compounds with hydrophilic and hydrophobic moiety were examined.[48] Bacteria adhere to coated surfaces initially and then modify the surface to enhance their binding ability.[49] In addition, many coatings are not capable of treating all bacteria, similar to antibiotics, which are only able to treat specific bacteria. Micromolecules (heparin and polypeptides) prevent bacteria from adhering to surfaces, thereby reducing colonization and biofilm formation.[50]

Metallic and metal oxide nanoparticles

Several medical devices are coated with silver, which has antibacterial properties.[51] Silver binds to thiol groups and produces reactive oxygen species, which interfere with DNA, RNA, and phosphoproteins.[52,53] A silver nanoparticle coating is effective against Gram-positive and Gram-negative bacteria.[54] In a rabbit model, silver nanoparticle coatings inhibited the formation of biofilms on titanium implants. In addition, copper, titanium, zinc, and iron are studied. Zinc oxide on the cell wall increases membrane permeability and causes cell damage. In hospitals and on public surfaces, copper is a beneficial antibiofilm agent. Indwelling devices may be unable to use nanoparticles due to their potential toxicity.[55] An orthopedic infection model in rabbits found that copper-chromium inhibited bacteria growth more effectively than titanium. Titanium surfaces with rough surfaces colonized more bacteria than those with smooth surfaces.[56] Antimicrobial peptides (AMPs)[53] and silicate nanoparticles were used in a formulation for titanium implant coatings. *In vitro* tests demonstrated that AMP loaded into a hydrogel had potent antimicrobial activity against *E. coli, Staphylococcus epidermidis, S. aureus, and P.aeruginosa.*

Antibiotic-coated metals

Antibiotics can be applied directly to metal orthopedic implants to kill bacteria at the point of contact and prevent the formation of biofilms. When applied to stainless steel 316 L-grade, the self-assembled monolayers of vancomycin and gentamycin proved to be resistant to *S. aureus* for up to 48 h.[55] A titanium implant covalently attached with vancomycin reduced bacterial colonization in a bovine implant infection model.[57] An additional layer of protection provided by a coating may be beneficial for protecting a component. Several concerns have emerged regarding longevity and possible reactions to the underlying materials.

Local Antibiotic delivery using Biocomposites

Gentamicin or vancomycin coatings are often applied to hydroxyapatite/calcium sulfate bone graft substitutes to control bacteria. Several studies have shown that nanolayered implants coated with Gentamicin and BMP-2 effectively eliminate *S. aureus* biofilms and accelerate bone regeneration.[58] Vancomycin and ciprofloxacin were more effective against Gram-negative *P. aeruginosa*. A combination of vancomycin and silver-containing hydroxyapatite is effective against methicillin-resistant *S. aureus*. A combination of silver-containing hydroxyapatite and vancomycin has been shown to reduce MRSA biofilms in periprosthetic joints[59] [Figure 3].

Therapeutic Strategies

An infected arthroplasty requires antibiotics, debridement, irrigation, and removal of the component. Treatment options are determined based on the infection's severity, chronicity, virulence, wound condition, and soft-tissue condition. If sensitive antibiotics are available, there is no systemic sepsis, and there are no severe comorbidities, a patient may be eligible for an exchange procedure.[60] During revision procedures, the original prosthesis was removed and debrided, and a combination of polymethyl methacrylate (PMMA) cement spacer and antibiotics was applied to maintain soft-tissue tension and deliver antibiotics locally. Generally, intravenous antibiotics are administered for 6 weeks before reimplantation. The procedure's success rate varies according to the type of organism, the host's immunity, and the timing of the procedure. Occasionally, this procedure may be recommended for virulent or uncultured organisms, resistance to medications, sinus infections, or insufficient coverage of soft tissues. During implantation and two-stage revision, it is imperative to ensure that the wounds are debrided, the infecting organism identified, and antibiotics administered. One of its disadvantages is that it requires a longer recovery and rehabilitation periods and higher costs.

Role Of Localized Antibiotic Delivery In Biofilm Elimination

PMMA is an acrylic-based polymer cement that can incorporate antibiotics, as can calcium sulfate and phosphate, which are biodegradable substances administered locally at the surgical site at sufficient concentrations to destroy any biofilm. In addition, these materials provide transient mechanical stability, eliminate dead space, and stimulate osteoconductivity. Due to its mechanical strength and better release characteristics, PMMA can maintain therapeutic levels much longer. A change in the microstructure of the cement caused by the addition of antibiotics will ultimately affect its mechanical properties and ability to elute—antibiotic beads and cement help to deliver drugs and manage dead spaces. Drug release by diffusion, however, has the disadvantage that it is difficult to control in most cases. Over a few hours to days, a rapid burst of antibiotics is released with nonabsorbable materials. As a result, bacteria in the burst zone may be exposed to subinhibitory levels if not all eliminated, potentially leading to the development of antibiotic resistance. The elution of cement may reduce the risk of chronic infection after surgery since it kills planktonic cells before they infect with biofilms caused by antibiotics with a longer half-life and higher concentrations.[61] Infections can be prevented and treated by

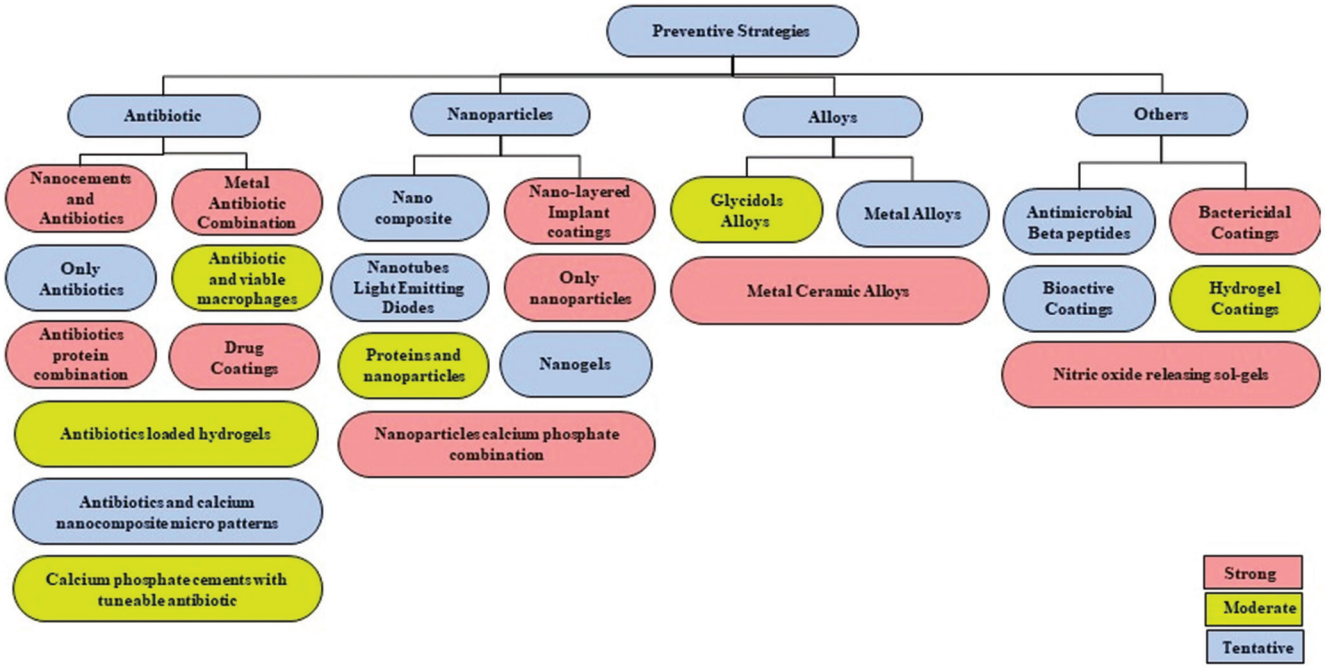

Figure 3: Different preventive strategies used against biofilm

using bioabsorbable materials such as calcium sulfate and phosphate. Although both absorbable and nonabsorbable carriers are relatively effective in treating osteomyelitis, absorbable carriers offer the advantage of not providing a permanent surface for infection and requiring no additional surgical procedures to remove. Hydrogels are networks of polymer chains containing an enzyme called lysostaphin and a bone-growth protein called BMP-2. Antibiotic hydrogels containing Gentamycin, Cefazoline, and Vancomycin have effectively prevented biofilm growth during hip replacement surgery.[62] Implanting hydrogels into the body is easy and firmly secure. Gelatin-alginate-antibacterial hydrogels can be used to deliver antibiotics to titanium implants before biofilm formation and MRSA colonization.[63]

Moreover, Bacteriophages kill antibiotic-resistant bacteria by replicating them inside them. By infecting bacteria with bacteriophage genomes, bacteriophages prevent further viral replication. Gram-positive and Gram-negative bacteria are treated with triclosan by inhibiting the production of fatty acids. A nano injection of triclosan reduced its minimum biofilm-eradicating concentration against *S. aureus* and *S. epidermidis* by three orders of magnitude. Antimicrobial efficacy can be significantly enhanced when physical destruction is in combination with active nano injection. Triclosan increases therapeutic efficacy by reducing the minimal bactericidal concentration hundreds of times [Table 2].

Recent Advances

Vaccines

Patients' immune systems can recognize antibiotic-resistant bacteria with biofilm-specific vaccines. Despite this, there are still challenges to overcome. Vaccines developed against epitopes on the surfaces of planktonic bacteria might not be effective against biofilm bacteria since they change their gene expression when they aggregate from a planktonic form.[64] The effectiveness of several vaccines has been limited. As a result

Table 2: A summary of the study type for various strategies for surface modifications imparting antimicrobial activity to orthopedic implants with the implant type and the biofilm

Authors	Year	Preventive strategies	Implant type	Bacteria
Yang	2021	Copper-bearing titanium alloy	Titanium implants	*S. aureus*
Chung-Kai Sun	2021	gelatin/alginate/gentamicin or vancomycin hydrogel with transglutaminase	Titanium pin	MRSA
Hashimoto	2020	Silver-containing hydroxyapatite-vancomycin	Pure titanium discs	MRSA
Bidossi	2020	Titamium-niobium nitride cereamic	Orthopedic implants	*S. aureus* and others
Bidossi	2020	Gentamicin or vancomycin	Orthopedic implants	*S. aureus and others*
De Meo,	2020	Cefazoline, gentamycin, vancomycin+hydrogels	Hip implant	MRSA and MSSA
Jahanmarda	2020	Nanofiber-filled lattices	Rod-shape titanium implants	*S. aureus*
Qayoom1	2020	Calcium sulfate hemihydrate Nanohydroxyapatite Rifampicin and Isoniazid	Orthopedic implants	TB
Guangyue Zu	2020	Triclosan	Orthopedic implants	*S. aureus* and others
Chi h-Chien Hu	2020	On-Ag coated titanium	Titanium rods	*S. aureus* and others
Dong	2020	TiO2 with gallium nitrate	Titanium plate	*S. aureus and others*
Rahmati	2020	Enamel matrix derivate and strontium	Titanium–zirconium implant	*S. aureus*
Leonetti	2020	Silver nanoparticles	Titanium and cobalt chrome alloys	Others
Mokabber	2020	Silver containing calcium phosphate	Titanium implant	*S. aureus*
Honda	2020	Protamine-loaded hydroxyapatite with AMPs and proteins	Bone Tissue Implant	Others
Douthit	2019	Rifampin and vancomycin	Stainless steel	*S. aureus*
Aldrich1	2019	Rifampin and daptomycin	Bone scaffold	*S. aureus*
Gilbertie	2019	Vancomycin and amikacin	Orthopedic implants	*S. aureus* and others
Min	2019	Gentamicin and osteoinductive growth factor (BMP-2)	Orthopedic implants	S. aureus
Lockharta	2018	Poly (glycidol) and poly (glycidol allyl glycidyl ether) (PG-Allyl)	hip-and-knee implants	*S. aureus*
Zhang	2018	Capsule-integrated polypeptide multilayer films and nanoparticles	Osteoblast cells	*S. aureus*
Cheng	2017	Antimicrobial peptide and synthetic silicate nanoparticles	Titanium implant	*S. aureus* and others
Gosh	2016	vancomycin or ciprofloxacin with nanoparticulate hydroxyapatite	Bone Graft	*S. aureus and others*
Lópeza,	2015	chitosan and hyaluronic acid	Titanium Implant	*S. aureus*
Yexin Gu	2012	Rifampicin and poly (D, L-lactic-co-glycolic) acid) biphasic calcium phosphate nanoparticles	Orthopaedic implants	Others
Nablo,	2005	N-aminohexyl-aminopropyltrimethoxysilane and isobutyltrimethoxysilane	Stainless steel	*S. aureus* and others
Lucke	2003	Gentamicin	Orthopedic implants	*S. aureus*
Price	1996	Gentamicin-loaded poly (D, L-lactide) coating	Metallic implants	*S. aureus*

TB: Tuberculosis, *S. aureus*: *Staphylococcus aureus*, MRSA: Methicillin resistant *S. aureus*, MSSA: Methicillin sensitive *S. aureus*, AMPs: Antimicrobial peptides, BMP-2: Bone morphogenetic protein-2

Table 3: Current strategies against biofilm-forming pathogens on orthopedic implants

Type	Preventive strategies
Metal-antibiotic combination	Silver-containing hydroxyapatite-vancomycin
Antibiotics-proteins combination	Protamine-loaded hydroxyapatite with AMPs and proteins
NC and antibiotics	Calcium sulfate hemihydrate nanohydroxyapatite rifampicin and Isoniazid
Nano-layered implant coatings	Gentamicin and osteoinductive growth factor (BMP-2)
Nanotubes with light-emitting diode	TiO_2 with gallium nitrate
Nanoparticles	Silver and copper chromium nanoparticles
Nanoparticles-calcium phosphate combination	Silver containing calcium phosphate
Metal-ceramic alloys	Titanium-niobium nitride ceramic
Nitric oxide-releasing sol-gels	N-aminohexyl-aminopropyltrimethoxysilane and isobutyltrimethoxysilane
Bactericidal coating	Nanofiber-filled lattices, the combinatorial release of rifampicin and vancomycin

NC: Nano cement, AMPs: Antimicrobial peptides

of masking biofilm-specific epitopes from vaccine surveillance, the EPS may not be able to detect them.

Quorum sensing inhibitors

Numerous studies have attempted to disrupt QS communication within biofilms. A quorum-sensing signaling system forms biofilms in Gram-negative bacteria. The LasR transcription regulatory protein binds to acetylated homoserine lactones, which are secreted by bacteria. A variety of virulence factors can form biofilms. A quorum-sensing inhibitor of *P. aeruginosa* accelerated bacterial clearance and reduced pathology in a mouse lung infection model.[65,66] The agents have been successfully tested in the laboratory, but no clinical trials have been conducted.

Irrigant solution

In addition to betadine, hydrogen peroxide, and Chlorhexidine, a new irrigation solution for total joint arthroplasty was recently approved by the US Food and Drug Administration after being tested *in vitro* on several bacterial strains by Bashyal *et al*.[67] been approved. Before neutralizing the broth, organisms were given either XExperience or phosphate buffer solutions for 5 min. Biofilms were then quantified based on their log10 density. A 5-min *in vitro* test showed that the irrigant reduced planktonic bacteria by six logs and biofilms by four to eight. Despite causing minimal cytotoxicity to host cells, this solution provided a barrier against biofilms for up to 5 h without irrigation. This treatment's effectiveness in preventing primary and recurrent surgical site infections needs to be determined by further *in vivo* testing [Table 3].

Conclusion

Biofilms can pose significant risks when they form, so prevention is essential during all clinical steps, primarily when prostheses use. Antibiotics are overused to the point that resistant strains of bacteria have developed. Orthopedic surgeons cannot use specific tools or protocols to manage biofilm infections. Although many challenges are associated with biofilm prevention and treatment paradigms, knowledge is valuable, and these paradigms give surgeons a better understanding of infection management. Orthopedic surgeons may have a role to play in reducing the burden of biofilm-related infections as biofilm-specific therapies become available from the bench to the clinic. This review aims to provide readers with information regarding pertinent issues regarding prosthetic joint infections, including the role of biofilms in the infection of orthopedic implants.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Is Posterior Tibial Slope and Mechanism of Failure Crucial for an Anatomically Reconstructed Primary Hamstring Graft Anterior Cruciate Ligament?

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Abstract

Purpose: Native anterior cruciate ligament (ACL) failure is multifactorial with tibial slope identified as a crucial risk factor. The aim was to examine relation between lateral posterior tibial slope (LTPS) and failed ACL primary reconstruction by negating the associated risk factors such as tunnel position, gender, and graft types based on the mechanism of failure. **Materials and Methods:** Our retrospective study included 102 patients, diagnosed as failed primary anterior cruciate ligament reconstruction (ACLR). The LPTS was measured on lateral radiographs and the tunnel position assessed by magnetic resonance imaging on both femoral, tibial side by two musculoskeletal radiologists. We compared the slopes in patients based on their mechanism of failure. **Results:** The mean LPTS in patients with anatomically placed tunnel (9.28° ± 3.5°; range, 4°–18°) was significantly higher than the rest (7.7° ± 2.9°; range, 3°–15°; $P = 0.01$). There was a significant association of higher tibial slope in graft rupture due to contact mechanism of failure ($P = 0.02$). LPTS was not significantly associated with noncontact mechanism of failure. **Conclusion:** LTPS is a significant risk factor for failure in hamstring graft reconstructed ACL patients with optimally placed tunnels. LPTS ≥10° increases the risk of hamstring graft failure due to contact mechanism.

Keywords: Contact failure, noncontact failure, posterior tibial slope, primary anterior cruciate ligament reconstruction, tunnel

Introduction

Anterior cruciate ligament reconstruction (ACLR) is a very common orthopedic surgical procedure of lower limb.[1] So, is ACLR failure which is consequentially increasing at an exponential rate accounting for 10% of the total ACLR surgeries performed, with an estimated 5.4% revision rate at 5-years and 11% at over 10 years.[2-4] Despite the recent advances in the anatomical, biomechanical knowledge, and surgical techniques, the graft failure rate has remained unchanged.[5] With the associated morbidity and cost of increasing frequency of ACL injuries, identification of risk factors, particularly the modifiable ones to prevent failure, is important.[6]

ACL injury either native or graft is multifactorial, classified as environmental, anatomical, hormonal, neuromuscular, comprising individual risk factors such as gender, graft type, tunnel position, posterior tibial slope (PTS), mechanism of failure, and skeletal malalignment which are well recognized.[2,4,6,7]

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The studies on the morphology of tibial bone elaborate an association between ACL injury and tibial slope.[8] Increased slope during a compressive axial force directly affects the loading of ACL and thus increases risk of rupture.[6] Graft failure is multifactorial, and presently, evidence is unclear regarding the relative contribution of each factor. Thus, PTS despite the multiple studies proving the risk posed for ACL rupture still remains unclear in a failed primary ACLR setting where the normal anatomy is altered.[6,9]

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Nonanatomical tunnels are the most common contributor of ACLR failure in primary, with femoral tunnel malposition most common (80%), followed by tibial tunnel malposition (37%).[10,11] Higher PTS increases risk of native ACL failure, but uncertainty still persists in relation to the tunnel position in failed primary graft.[6,12] Anatomical grafts have not only better biomechanical stability against failure but also better biological graft healing.[13,14]

Graft type and sex are known to have significant role in knee stability and thus graft failure.[13] The choice of graft for primary ACLR is debatable, with studies corroborating a higher incidence of failure in hamstring compared to bone patella tendon bone (BPTB) grafts and females noted to have two-fold to eight-fold increased risk of ACL tear compared to male.[2]

The study purpose was to analyze association of LPTS in hamstring graft ACLR failure with respect to tunnel position and mechanism of injury. Firstly, our hypothesis was failure in nonanatomical tunnel would be at lower LPTS compared to failure in anatomic tunnels. Secondly, we hypothesized that noncontact mechanism failure predisposed at higher PTS compared to contact mechanism of failure.

Materials and Methods

A review of all the failed primary ACLRs who underwent revision ACLR at our hospital between 2015 and 2018 was performed retrospectively, after prior approval from the Institute Review Board. The patients were identified from the record system. The medical records and operative notes were reviewed to identify the primary ACLR failures. Confirmation of ACLR failure was based on examination clinically and assessment radiologically with magnetic resonance imaging (MRI). Records further reviewed to identify the mechanism of failure, whether contact or noncontact, choice of primary graft, and the presence of associated injuries.

Based on the Hunt Valley II meeting mechanism of failure was classified as contact and noncontact.[15] Contact failure was defined as failure after the patient's knee or body came in contact with an external force (e.g., another person or object).

Noncontact failure was defined as failure due to twist, sprain, jump/land, but without direct physical contact with other people or stationary objects. If the cause and mechanism of failure was unavailable in detail, patient was interviewed for necessary information on follow-up.

Patients with coexisting multiligament injuries, lower limb malalignment same or contralateral side, those who underwent concomitant multiligamentous reconstruction or alignment correction surgery were excluded. Failure due to infection requiring revision surgery and failed implants were not included. Patients who underwent meniscal repair, more than one revision surgery, previous lower limb surgeries, and incomplete medical records were all excluded.

Imaging

The knee was scanned using a 1.5-T scanner (Siemens) MRI machine. Multiplanar images were obtained after 3 plane localizers, using sequences of proton density-weighted fat suppressed turbo spin echo in transverse, sagittal, and coronal planes; T1 turbo spin echo in the coronal plane; and turbo inversion recovery magnitude in the sagittal plane. All the studies were done with the knee in or near full extension.

Lateral radiographs of patients with overlap of femoral condyles adequately, to assess the tibial slope were only included in the study. The initial MRI study and lateral radiograph performed after the diagnosis of primary ACLR failure were analyzed by two blinded, independent, experienced musculoskeletal radiologists. Interexaminer reliability of the MRI based tunnel position and the lateral tibial slope was assessed with intraclass correlation (ICC). The blinded observers reviewed each MRI and radiograph using the digital image InteleViewer software (Intelerad Medical Systems).

Measurements and criteria

The tunnel position was assessed on MRI according to the technique defined by Tomczak *et al*.[16] The femoral and tibial tunnel positions were identified based on

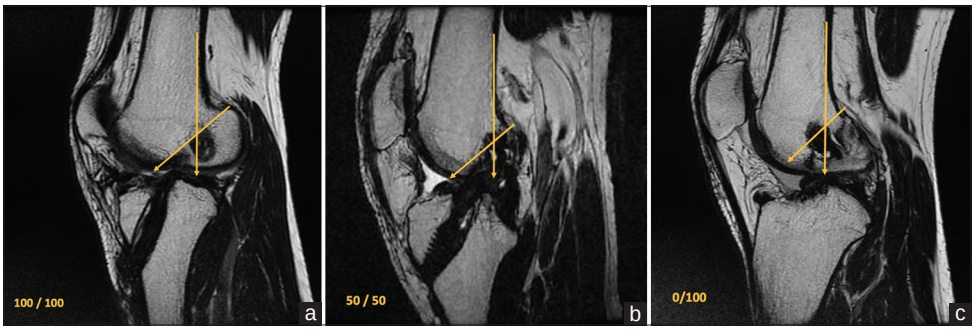

Figure 1: (a) T2-weighted, sagittal image of the knee with superimposed tangent to the posterior cortical femoral borderline and tangent to the intercondylar roof (notch). The optimal femoral tunnel placement (100%), as defined by the fact that the tunnel entrance is visible in the right upper quadrant of this cross. The tibial tunnel is visible in the second quarter of the tibial plateau, indicating optimal (100%) placement. (b) Saggital image of the knee with the femoral tunnel and tibial tunnel 50% correct placement. (c) Sagittal image of the knee with 0% desired femoral tunnel placement and 100% desired tibial tunnel placement

degree of ideal attachment as 100%, 50%, and 0%, respectively [Figure 1].[16]

The lateral tibial slope was the angle between a line drawn tangentially to the lateral tibial plateau and the proximal anatomic axis of the tibia on lateral radiographs. The longitudinal axis of tibia was a line connecting the two midpoints of the anteroposterior diameters of tibia, one just inferior to tibial tubercle and second at a point, 5 centimeters distal to the proximal point, which have shown acceptable inter- and ICC in the literature.[17,18] All the LPTS were measured in reference to the tibial axis from the operative records and tabulated using Microsoft Excel 2010 software [Figure 2].

The study population was segregated into two groups based on their mechanism of failure. Only patients operated with hamstring primary graft, i.e., semitendinosus–gracilis (STG) included in the study.

Statistical analysis

Analysis was performed with SPSS version 22 (SPSS Inc, Chicago, Illinois, USA). Means and standard deviations (SDs) were calculated for demographic characteristics and PTS of the study group as descriptive statistics.

The individual patient's mean value of slope was calculated from the two examiners for statistical analysis. The reliability of the measurements was analyzed, using a single rater ICC study of 15 randomly selected MRI and lateral radiographs, which were measured separately by each in a blinded manner. The ICC was 0.90 for tunnel position and 0.85 for lateral slope, suggesting a strong correlation between both the examiner's measurements and indicating a very small chance of systemic error.

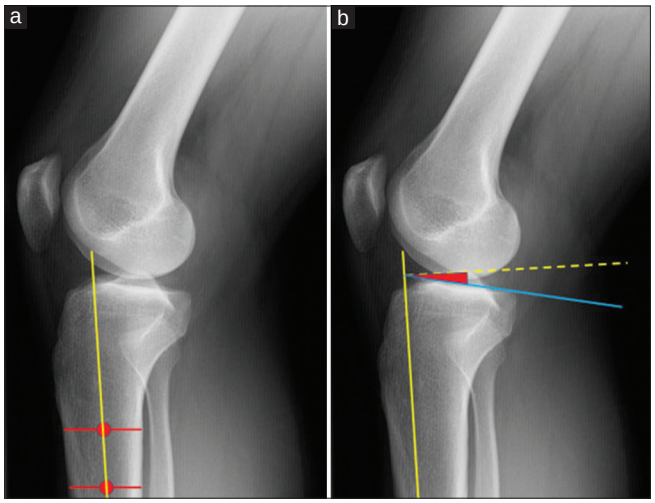

Figure 2: LTPS measured on the lateral radiograph relative to the longitudinal axis of the tibia. (a) The longitudinal axis of tibia was a line connecting the two midpoints of the anteroposterior diameters of tibia, one just inferior to tibial tubercle and second at a point just 5 centimeters distal to the proximal point. (b) The surface of the lateral tibial plateau identified and a tangential line (Blue) drawn. The angle between the tangential line and the central axis of the tibia measured. LTPS: Lateral posterior tibial slope

Descriptive statistics were calculated for continuous variables including means. The LPTS between the anatomical and nonanatomical tunnel groups was compared using an independent *t*-test. Similarly, the slopes between groups based on mechanism of failure was compared with a $P < 0.05$ was considered significant statistically. A receiver operating characteristic curve was calculated to determine the cut-off point.

Results

Seventy-five subjects made it to the final study of the one hundred and two enrolled. Twenty-seven patients were excluded of which nine had BPTB as primary graft, eight had more than one surgery for ACLR failure, eight had incomplete medical records, and one each for biological failure cause of infection and technical failure cause of endobutton pull-out.

The participant's characteristics are shown in Table 1; the mean age was 28 years (range: 24–44 years). The most affected side was the right side (50) and rest left side (25). The femoral tunnel position was identified to be at anatomical attachment of 100% in 58.66% (44), 50% ideal in 34.66% (26) and 0% in 6.66% (5) respectively. The tunnel position in femur was found nonanatomical the most (41.32%) and the tibial tunnel was most anatomical (72%). Similarly, the tibial tunnel position was recognized to be 100% anatomical attachment in 72% (54), 50% ideal in 24% (18) and 0% in 4% (3) respectively [Table 2].

The mean PTS was significantly higher in anatomically placed graft failure group compared to nonanatomically placed graft failure (9.2° and 7.7°, respectively; $P = 0.01$). The mean PTS in the contact mechanism of failure subgroup was significantly higher in anatomically placed tunnel compared to the nonanatomically placed tunnel (9.7° and 7.8°, respectively; $P = 0.02$). However, the difference of mean was insignificant between anatomically and nonanatomically placed tunnel patients of the noncontact mechanism of failure subgroup (8.2° and 7.4°, respectively; $P > 0.05$) [Table 3].

The mean LPTS of right side was 8.32° ± 3.28° (SD) with a range of 4°–18° and on the left side was 8.48° ± 3.36° (SD) with a range of 3°–15° distribution shown respectively in Figure 3. However, no significant difference existed between mean PTS of right and left knees ($P > 0.05$). Our hypothesis

Table 1: Demographic distribution of the study population

Age	28 year (24-44)
M/F	75/0
R/L	50/25
Contralateral ACLR	8
Primary Graft STG	75
Lateral posterior tibial slope[a]	8.370±3.390 (30-180)
Failure mechanism of Primary ACLR	
Contact/Non-contact	52/23

[a]Values are expressed as mean±standard deviation. *M, Male; F, Female; R, Right; L, Left; ACLR, Anterior cruciate ligament reconstruction, STG, Semitendinosus -gracilis.

of a higher lateral posterior tibial slope (LTPS) in patients with failure due to noncontact mechanism is invalid.

We determined an optimal cut-off point using the receiver operating characteristic curves. We found with a $P = 0.039$ with the LPTS ≥10°, the likelihood of graft failure was higher with a specificity (0.814) and sensitivity (0.406), respectively.

Discussion

We believe to be the first to examine the relation between the PTS and ACLR hamstring graft failure in association with the position of the tunnel. Malposition of tunnel is identified as one of the major contributing factors for primary ACLR failure (37%–39%).[8,15] Tunnel positions influence the stability of the graft, their subsequent elongation and deterioration.[19] Hence, an anatomically placed graft is reported to not only to have a better biomechanical rotatory stability but also a better stability against the antero-posterior tibial translation compared to nonanatomical graft.[14,20] In this study, the mean LPTS of anatomical tunnel failure group was significantly higher compared to nonanatomical tunnel failures, thus reiterating the previous literature.[14,20,21] The finding of this study also highlights the influence of tibial slope as a risk factor for failure in an anatomically reconstructed ACL.[13,21,22]

Table 2: The distribution of the tunnels after primary anterior cruciate ligament reconstruction

Tunnel position Femoral/Tibial	Contact	Non-Contact	Total
100/100 (I)	23	9	32
50/100	10	8	18
0/100	3	1	4
50/50	5	1	6
100/50	8	3	11
0/50	1	0	1
100/0	1	0	1
50/0	1	1	2
0/0	0	0	0
	52	23	75

*I, Ideal placement

Table 3: Comparison of lateral posterior tibial slope in patients with anatomic and nonanatomic tunnel position and within the mechanism of failure subgroups

Independent student '*t*'- test	Number of patients	*P*
Ideal tunnel/Non-ideal tunnel	32/43	0.01
Contact/Non-contact	52/23	0.13
Contact failure Ideal tunnel/ non-ideal tunnel	23/29	0.02
Non-contact failure Ideal tunnel/Non-ideal tunnel	9/14	0.28
Ideal tunnel Contact/ Non-contact	23/9	0.14
Right/Left side	50/25	0.42

*P<0.05: significant

The association of increased PTS with the failure due to noncontact mechanism is well established.[6] Previous studies have compared the noncontact reconstruction failure with native ACL failure. Ours is one of the first to analyze correlation of tibial slope based on mechanism of failure i.e., contact and noncontact, irrespective of tunnel position to the best of our knowledge.[6,12] We found no association of the slope based on the mechanism of failure irrespective of tunnel position, our hypothesis was rejected [Figure 4].

However, we believe the tibial slope to play a very crucial role in failure of graft due to contact mechanism of trauma with respect to the tunnel when ideally placed. In our study, we noted, the tibial slope to be significantly higher with the

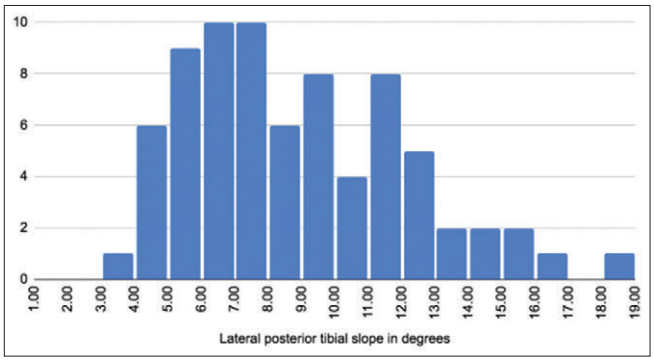

Figure 3: Distribution of LTPS. LTPS: Lateral posterior tibial slope

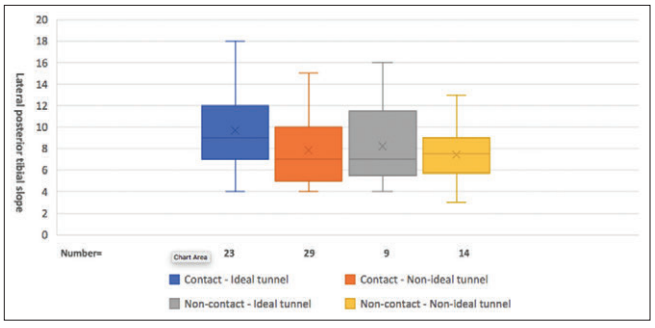

Figure 4: Grouped LTPS distribution. LTPS: Lateral posterior tibial slope

mean of 9.7°±3.3° in patients with failure due to contact mechanism having ideally placed tunnel than the rest of failure due to contact mechanism. The PTS of ≥9° has an incidence of 65% in the group and the optimal cut-off point PTS ≥10° has a specificity of 81.4%. The failure risk due to noncontact mechanism is higher in PTS >12°, but in failures due to contact mechanism occurs at lower PTS.[12] Our results showed that at patients with steeper slopes within the spectrum of normal range were at increased risk of reconstructed ACL graft rupture due to contact mechanism.

Every type of graft has a unique individual biomechanical property. Hamstring autograft is most commonly used for primary ACLR and also accounts for highest failure rate of 22% due to biological cause than 4% as seen in the BPTB graft.[19] A soft tissue graft like hamstring is associated with slightly higher objective laxity, hence an increase in potential failures.[24] Thus, we believe the effect of tibial slope on failure would also be subjective to the type of the autograft used as the mean PTS in patients with graft tears was 5.4°±3.1° in those with BPTB graft and the mean PTS in our patients with STG was 9.2°±3.5°.[25] Anatomical factor, especially sex, is known to significantly influence the failure of the graft with higher rate reported in female and Sauer *et al*. reported LPTS to play a significant role in failure in female patients only.[2,7,21,26,27] We evaluated a homogenous population of male patients with hamstring graft ideally placed showing a significant association of LPTS to failure contrary to Cooper *et al*. who suggested no association in patients matched by sex, graft type and age.[28]

The results of this study can be summated as follows: Primarily higher LPTS significantly increases risk of graft failure in ACLR patients with an anatomically placed tunnel position. Secondly higher LPTS is also an independent risk factor for graft rupture due to contact mechanism of failure in males. Finally, our results indicate a LPTS >10° has higher risk of failure in hamstring graft.[21]

There are certain limitations to our study. Ours is a retrospectively designed study with a smaller number of patients since the number of revisions ACLRs are small compared to primary ACLR. ACL graft failure is multifactorial, other potential risk factors for failure like age, BMI, level of activity was not subjected to analysis. In addition, computer tomography-based 3D reconstruction would have been better suited to identify the graft tunnel position than MRI. The LPTS was measured using a short lateral radiograph, which is reported to be 3° more than MRI measurement.[29] Another limitation is the quantification of forces experienced during failure of the graft, which is beyond the scope of the study.

Conclusion

LTPS is a significant risk factor for primary ACLR failure with hamstring graft failure in patients with optimally placed tunnels. Higher risk of hamstring graft rupture was associated with PTS ≥10° due to contact mechanism in primary ACLR failure.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Original Article

Differences in Hospital Length of Stay and Cost of Hospitalization Between Income Levels in Patients Hospitalized for Shoulder Arthroplasty

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Abstract

Introduction: There has been an increase in volume and cost of total shoulder arthroplasty (TSA). Performing procedures in high-volume inpatient centers and outpatient centers can help limit costs while preserving quality. This study aims to identify whether a difference in length of stay (LOS) and cost exists between income levels in patients hospitalized for TSA and reverse TSA (R-TSA) to identify potential disparities. **Methodology:** NIS data defined by ICD-10 codes for patients diagnosed with primary shoulder osteoarthritis undergoing TSA or R-TSA between 2016 and 2019 were collected. Demographic, social, and comorbidity data were collected and stratified by income quartile. **Results:** Patients had R-TSA (n = 173,695) more frequently than TSA (n = 149,075). The mean age was greater for R-TSA (71.8) than TSA (67.0) and increased by income quartile (P < 0.0001). Among TSA, LOS (days) decreased Q1 (1.50) to Q2 (1.40) and then remained consistent Q2–Q4. Among R-TSA, LOS decreased Q1 (1.67) to Q2 (1.64) to Q3 (1.62) and then increased in Q4 (1.65) (P = 0.03). The lowest income quartile had the highest cost in R-TSA and the second highest in TSA (P < 0.0001). By location, the percentage of urban teaching hospitals increased by income quartile, while the percentage of rural hospitals decreased by quartile (P < 0.0001). **Conclusion:** Low-income shoulder arthroplasty patients had the longest LOS, high costs, and account for vast majority of rural cases. R-TSA had higher costs and LOS across income quartiles than TSA. Continued attention needs to be placed on the disparities in resource utilization for upper extremity arthroplasty among patients of different socioeconomic status.

Keywords: Arthroplasty, cost, income, length of stay, shoulder, socioeconomic

Introduction

The United States spends considerably more on health care per capita than any other country in the world.[1] National health-care spending has continued to increase from an estimated $1.4 trillion (13.3% Gross Domestic Product (GDP)) in 1996 to an estimated $3.1 trillion (17.9% GDP) in 2016.[2] Furthermore, among 154 conditions, musculoskeletal disorders had the highest spending together accounting for an estimated $265 billion in 2016.[2] Despite annual record-breaking health-care expenditure, health inequality remains prevalent in the United States.[3] Differences in socioeconomic status (SES) whether measured by income, education, or occupation have significant associations with disparities in health outcomes.[3] Patients with lower SES reported more preoperative pain and lower function after total shoulder arthroplasty (TSA) for glenohumeral osteoarthritis (OA).[4] Several metrics have been used to evaluate surgeon and hospital ability to provide cost-effective care, including hospital length of stay (LOS).[5]

TSA is an effective treatment for patients with end-stage degenerative changes to the glenohumeral joint. There has been an increase in volume, rate, and charges of TSA over the past two decades, and this trend is expected to continue

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as the population ages.[6,7] There is a great incentive to limit costs while preserving quality in upper extremity arthroplasty procedures. Prior studies have shown that this is best accomplished by performing these procedures in high-volume inpatient centers and outpatient centers.[8] A consequence of the transition from low-volume inpatient centers to high-volume inpatient centers or outpatient centers is less availability of quality upper extremity arthroplasty services to underserved rural areas. A study on TSA in the state of Texas showed that despite overall increase in TSA, the majority (85%) of TSA utilizers lived within 50 miles of a TSA center. Despite the increase in volume of TSA across the entire Texas population, there seems to be a concentration of these services to high-volume inpatient and outpatient centers in urban metropolitan areas.[6] This is also supported in the realm of lower extremity arthroplasty, with prior studies highlighting geographic distance as an important factor in patient utilization of total hip and total knee arthroplasty.[9] A review by Somerson *et al*. showed that high-volume surgeons were more likely to practice within major metropolitan areas with a population of >1 million.[10] Unsurprisingly, TSA utilization rates have followed this trend with significantly higher utilization rates in metropolitan areas than rural areas ($P < 0.001$). Additionally, TSAs performed in metropolitan areas received significantly higher reimbursements per case than TSAs performed in rural areas ($1108.05 and $1066.40, respectively; $P = 0.002$), and there was a significant negative association between utilization rates for primary TSA and poverty rate.[11]

Along with increased costs, LOS has been a key performance indicator for hospitals as increased LOS has been associated with higher morbidity, mortality, and likelihood of revision procedure. The relative risk of requiring a revision TJA increased with prolonged LOS (>5 days) and even more so with extremely prolonged LOS (>10 days).[12] Therefore, it is in the interest of both hospitals and patients to decrease costs and LOS while maintaining access to high-quality equitable orthopedic care. The purpose of this study is to identify whether a difference in LOS and cost exists between income levels in patients hospitalized for TSA and R-TSA in order to identify a potential disparity within a subset of orthopedic surgery patients.

Methodology

Discharge data from the National Inpatient Sample (NIS) database between 2016 and 2019 were used for this study. The NIS is the largest inpatient health-care database available to the public. It utilizes inpatient and disposition data from hospitals across 47 states as well as the District of Columbia. The database represents approximately 20% of United States hospitals and is estimated to represent 97% of the U. S. population. Information available on the database includes patient demographics, baseline comorbidities, hospital location, hospital LOS, diagnoses, mortality, discharge disposition, among others.[13] The study was approved as nonhuman subject research by the institutional review board.

The primary outcomes for this study were LOS and total charges for patients who underwent either TSA or R-TSA for primary shoulder OA. These data were then stratified by income quartile. We included NIS data for all patients diagnosed with primary shoulder OA defined by ICD-10 codes M19.011, M19.012, and M19.019. In all patients with primary shoulder OA, those undergoing TSA were identified using ICD-10 codes 0RRK0JZ, 0RRK0KZ, 0RRJ00Z, 0RRJ07Z, 0RRJ0JZ, and 0RRJ0KZ while those undergoing R-TSA were identified using ICD-10 codes 0RRK00Z and 0RRK07Z. The full list of ICD-10 codes utilized for this study is found in Supplemental Table 1.

Statistical analysis was used to identify differences in hospital LOS and total charges between income quartiles of patients undergoing TSA or R-TSA for primary shoulder OA. Income quartile was determined based on the median income of the patient's home residence zip code. Demographic, social, and comorbidity data were collected and are listed in Supplemental Table 1. All collected data were stratified by income quartiles. The data in Tables 1 and 2 were analyzed with descriptive statistics using SAS Proc SurveyFreq. Statistical significance was determined as $P < 0.05$. All analyses were performed on SAS version 9.4 (SAS Institute Inc., SAS Campus Drive, Cary, North Carolina, USA).

Results

The total number of patients with primary glenohumeral OA who underwent either TSA or R-TSA between 2016 and 2019 was 322,770. More patients had R-TSA (n = 173,695) than TSA (n = 149,075). Results are summarized in Table 1 (TSA) and Table 2 (R-TSA).

Among TSA, the lowest income quartile (Q1) had the fewest patients, while the other quartiles (Q2, Q3, and Q4) were relatively equal. The mean patient age increased by quartile ($P < 0.0001$). The patient distribution by sex was approximately even across all income quartiles. The majority of patients were non-Hispanic White (86%). The percentage of non-Hispanic White and Asian/Pacific Islander patients increased by income quartile. Conversely, the percentage of non-Hispanic Black and Native American patients decreased by income quartile.

The lowest income quartile had the longest LOS. The LOS decreased from Q1 to Q2 but then remained similar from Q2 to Q4. The total hospital charges increased by income quartile with the exception of Q1 which had the second highest charges. The highest charges were among the wealthiest income quartile.

Most TSA procedures occurred in urban teaching centers. Across all income quartiles, TSA was most commonly performed in urban teaching centers (43%), followed by rural (30%) and urban nonteaching (25%). The percentage of patients undergoing TSA in urban teaching centers increased by income quartile. The highest two income quartiles (Q3

Table 1: Baseline demographic information and clinical and cost outcomes for patients hospitalized with total shoulder arthroplasty from 2016 to 2018 divided by patient income quartile

TSA for primary glenohumeral OA										
Variable	**Total**	**Quartile 1**		**Quartile 2**		**Quartile 3**		**Quartile 4**		***P***
		n	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	
Total number of patients	149,075	28,325	100.00	39,585	100.00	42,275	100.0	38,890	100.0	<0.0001
LOS, mean (SEM)	N/A	1.50 (0.15)	100.00	1.40 (0.01)	100.00	1.40 (0.01)	100.00	1.40 (0.01)	100.00	0.00
Total charges, mean (SEM) ($)	N/A	65,771 (634)	100.00	63,039 (401)	100.00	64,039 (382)	100.00	67,723 (441)	100.00	<0.0001
Age, mean (SEM)	N/A	66.27 (0.12)	100.00	67.09 (0.10)	N/A	67.22 (0.09)	N/A	67.53 (0.10)	N/A	<0.0001
Gender (female)	73,680	14,660	51.76	19,535	49.35	20,915	49.47	18,570	47.75	0.00
Age group										
<65	53,610	11,045	38.99	14,465	36.54	14,935	35.33	13,165	33.85	<0.0001
65-79	84,460	15,400	54.37	22,130	55.91	24,210	57.27	22,720	58.42	
80 and over	11,005	1,880	6.64	2990	7.55	3130	7.40	3005	7.73	
Race										
Non-Hispanic White	128,890	22,815	80.55	34,265	86.56	37,135	87.84	34,675	89.16	<0.0001
Non- Hispanic Black	6195	2675	9.44	1625	4.11	1140	2.70	755	1.94	
Hispanic	4225	1150	4.06	1075	2.72	1060	2.51	940	2.42	
Asian/PI	615	65	0.23	115	0.29	155	0.37	280	0.72	
Native American	510	200	0.71	120	0.30	125	0.30	65	0.17	
Others	1927	435	1.54	430	1.09	292	0.69	770	1.98	
Hospital type										
Urban teaching	64,161	3457	12.20	2479	6.26	28,745	68.00	29,480	75.80	<0.0001
Urban nonteaching	37,765	7175	25.33	10,285	25.98	11,370	26.90	8935	22.98	
Rural teaching	44,710	17,285	61.02	24,790	62.62	2160	5.11	475	1.22	
Comorbidities										
Obesity (BMI>30)	32,340	6380	22.52	8960	22.63	9445	22.34	7555	19.43	<0.0001
DM	26,775	6035	21.31	7555	19.09	7430	17.58	5755	14.80	<0.0001
Heart disease	36,935	7105	25.08	10,140	25.62	10,335	24.45	9355	24.06	0.11
Lung disease	27,500	6025	21.27	7695	19.44	7410	17.53	6370	16.38	<0.0001
Kidney disease	10,965	2255	7.96	2975	7.52	3090	7.31	2645	6.80	0.08
Liver disease	3010	730	2.58	900	2.27	780	1.85	600	1.54	<0.0001
PVD	2725	470	1.66	690	1.74	795	1.88	770	1.98	0.50
HLD	65,785	11,610	40.99	17,260	43.60	18,590	43.97	18,325	47.12	<0.0001
HTN	85,030	16,835	59.44	23,400	59.11	24,180	57.20	20,615	53.01	<0.0001
Hypothyroidism	23,045	4075	14.39	6195	15.65	6720	15.90	6055	15.57	0.09
Cancer	1470	255	0.90	295	0.75	490	1.16	430	1.11	0.03
Dementia	995	145	0.51	325	0.82	280	0.66	245	0.63	0.17
Cerebrovascular disease	1265	300	1.06	360	0.91	285	0.67	320	0.82	0.09
Alcohol abuse	700	115	0.41	225	0.57	195	0.46	165	0.42	0.48
Tobacco use	920	285	1.01	265	0.67	185	0.44	185	0.48	0.08
Payer										
Medicare	92,665	17,910	63.23	24,820	62.70	26,450	62.57	23,485	60.39	N/A
Medicaid	5280	1880	6.64	1570	3.97	1150	2.72	680	1.75	
Private, including HMO	44,685	7120	25.14	11,350	28.67	12,870	30.44	13,345	34.31	
Self-pay	720	150	0.53	235	0.59	195	0.46	140	0.36	
Others	5495	1200	4.24	1515	3.83	1560	3.69	1220	3.14	
Discharge disposition										

Contd...

Table 1: Contd...

TSA for primary glenohumeral OA										
Variable	**Total**	**Quartile 1**		**Quartile 2**		**Quartile 3**		**Quartile 4**		***P***
		n	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	
Routine	116,820	21,855	77.16	31,160	78.72	33,155	78.43	30,650	78.81	N/A
Transfer, short-term hospital	135	50	0.18	45	0.11	25	0.06	15	0.04	
Other transfers	7345	1440	5.08	1895	4.79	2055	4.86	1955	5.03	
Home health care	24,595	4925	17.39	6435	16.26	6995	16.55	6240	16.05	

Income quartiles for 2018 are defined as follows: Quartile one: $1-$45,999 per year, Quartile two: $46,000-$58,999 per year, Quartile three: $59,000-$78,999 per year, and Quartile four: $79,000+per year. The discharge disposition "other transfers" includes transfer to skilled nursing facility, intermediate care facility, inpatient rehabilitation facility, or hospice facility. BMI: Body mass index, HMO: Health Maintenance Organization, LOS: Length of stay, OA: Osteoarthritis, TSA: Total shoulder arthroplasty, SEM: Standard error of mean, DM: Diabetes mellitus, PVD: Peripheral vascular disease, HLD: Hyperlipidemia, HTN: Hypertension, N/A: Not available, PI: Pacific Islander

and Q4) accounted for 91% of all urban teaching cases. The percentage TSAs in rural centers decreased by quartile. The two lowest income quartiles (Q1 and Q2) accounted for 94% of all rural cases.

The most common payer for TSA was Medicare, followed by Private and Medicaid. The percentage of patients having Medicare and Medicaid payers decreased by income quartile, while the percentage of Private payers increased by quartile. The percentage of patients with routine discharge increased by income quartile. The percentage of patients discharged to short-term facilities or with home health care decreased by quartile [Table 1].

Among R-TSA, the highest income quartile (Q4) had the fewest patients. This was opposite of TSA where the lowest income quartile (Q1) had the fewest patients. Patients undergoing R-TSA were, on average, older across all income quartiles as compared to TSA. The mean patient age increased by income quartile ($P < 0.0001$). The patient distribution by sex was stable across income quartiles with females more prevalent than males in all quartiles. The percentage of females was approximately 58% across quartiles, with Q3 as a relative outlier (62.26%), $P = 0.84$. The distribution by sex in R-TSA was more heavily skewed in favor of females than for TSA where an approximately even split among sexes was observed. Most patients undergoing R-TSA were non-Hispanic White (85%). Similar to TSA, the percentage of 39 non-Hispanic White and Asian/Pacific Islander patients increased by income quartile. Conversely, the percentage of non-Hispanic Black and Native American patients decreased by income quartile.

For patients with R-TSA, the lowest income quartile had the longest LOS. LOS decreased Q1 to Q2 to Q3, and then increased in Q4. The total hospital charges increased by income quartile with the exception of Q1 which had the highest charges. The highest charges were in the lowest income quartile, which contrasts with TSA where the highest charges were among the highest income quartile. In both TSA and R-TSA, however, the charges were highest at the income extremes of Q1 and Q4, followed by Q2 and Q3. The lowest income quartile had the highest charges among R-TSA, and the second highest charges among TSA.

Most R-TSA procedures occurred in urban teaching centers. Across all income quartiles, R-TSA was most commonly performed in urban teaching centers (55%), followed by urban nonteaching (26%) and rural (19%). The percentage of patients undergoing R-TSA in urban teaching hospitals increased by income quartile. The lowest income quartile accounted for only 7% of all urban teaching cases. The percentage of R-TSAs in rural centers decreased by income quartile. The lowest income quartile accounted for 72% of all rural cases while the highest income quartile accounted only for 1% of all rural cases.

The most common payer for R-TSA was Medicare, followed by Private and Medicaid. The percentage of patients with Medicare and Private payers increased by income quartile. The percentage of patients with Medicaid payer decreased by quartile. There were no differences observed across income quartile with regard to discharge disposition.

Univariate and multivariate analyses were conducted to analyze which variables maintained statistically significant effects on LOS and total charges. Female sex, non-Hispanic Black/Hispanic race, Medicaid insurance, time to surgery, and disposition to skilled nursing facility (SNF)/home health care were associated with increased LOS in both TSA and R-TSA groups [Tables 3 and 4]. Hispanic race, time to surgery, urban nonteaching hospital, and disposition to SNF/home health showed increased total charges in both TSA and R-TSA groups. Age, female sex, and self-pay insurance decreased total charges in both groups. Comorbidities were much more likely to maintain a significant effect on LOS as compared to total charges [Tables 5 and 6].

Discussion

Shoulder arthroplasty is a common orthopedic procedure requiring hospitalization and is a major contributor to morbidity and mortality. The literature suggests that there

Table 2: Baseline demographic information and clinical and cost outcomes for patients hospitalized with reverse total shoulder arthroplasty from 2016-2018 divided by patient income quartile

R-TSA for primary glenohumeral OA										
Variable	**Total**	**Quartile 1**		**Quartile 2**		**Quartile 3**		**Quartile 4**		***P***
		n	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	
Total number of patients	173,695	39,725	100.00	49,145	100.00	47,665	100.0	37,160	100.0	<0.0001
LOS, mean (SEM)	N/A	1.67 (0.02)	100.00	1.64 (0.01)	100.00	1.62 (0.01)	100.00	1.65 (0.01)	100.00	0.0337
Total charges, mean (SEM) ($)	N/A	77,113 (493)	100.00	73,541 (397)	100.00	74,508 (417)	100.00	76,893 (520)	100.00	<0.0001
Age, mean (SEM)	N/A	70.90 (0.090)	100.00	71.61 (0.08)	N/A	72.09 (0.08)	N/A	72.44 (0.09)	N/A	<0.0001
Gender (female)	102,885	23,410	58.93	28,070	57.12	29,675	62.26	21,730	58.48	0.84
Age group										
<65	30,755	8435	21.23	9115	18.55	7670	16.09	5535	14.90	<0.0001
65-79	113,010	25,260	63.59	31,635	64.37	31,320	65.71	24,795	66.72	
80 and over	29,930	6030	15.18	8395	17.08	8675	18.20	6830	18.38	
Race										
Non-Hispanic White	148,111	31,715	79.84	42,236	85.94	41,235	86.51	32,925	88.60	<0.0001
Non-Hispanic Black	7890	3785	9.53	1835	3.73	1435	3.01	835	2.25	
Hispanic	7210	2325	5.85	1895	3.86	1825	3.83	1165	3.14	
Asian/PI	795	75	0.19	200	0.41	230	0.48	290	0.78	
Native American	555	220	0.55	165	0.34	100	0.21	70	0.19	
Others	2465	535	1.35	655	1.33	600	1.26	675	1.82	
Hospital type										
Urban teaching	95,935	6410	16.14	28,975	58.96	32,375	67.92	28,175	75.82	<0.0001
Urban non-teaching	45,370	10,100	25.42	13,665	27.81	12,990	27.25	8615	23.18	
Rural teaching	32,480	23,305	58.67	6505	13.24	300	4.83	370	1.00	
Comorbidities										
Obesity (BMI >30)	34,850	8120	20.44	10,160	20.67	9710	20.37	6860	18.46	0.02
DM	39,340	10,505	26.44	11,625	23.65	10,430	21.88	6780	18.25	<0.0001
Heart disease	58,205	13,270	33.40	16,350	33.27	16,050	33.67	12,535	33.73	0.90
Lung disease	39,135	9455	23.80	11,395	23.19	10,590	22.22	7695	20.71	<0.0001
Kidney disease	19,225	4335	10.91	5540	11.27	5520	11.58	3830	10.31	0.06
Liver disease	3505	855	2.15	970	1.97	970	2.04	710	1.91	0.47
PVD	4870	895	2.25	1280	2.60	1415	2.97	1280	3.44	<0.0001
HLD	85,660	18,690	47.05	24,340	49.53	23,555	49.42	19,075	51.33	<0.0001
HTN	104,745	24,625	61.99	29,820	60.68	28,060	58.87	22,240	59.85	0.00
Hypothyroidism	31,710	6765	17.03	9105	18.53	8725	18.30	7115	19.15	0.01
Cancer	2110	375	0.94	610	1.24	615	1.29	510	1.37	0.75
Dementia	2585	605	1.52	645	1.31	795	1.67	540	1.45	0.23
Sepsis	125	45	0.11	30	0.06	25	0.05	25	0.07	0.46
Cerebrovascular disease	2435	600	1.51	670	1.36	675	1.42	490	1.32	0.76
Alcohol abuse	935	235	0.59	285	0.58	235	0.49	180	0.48	0.68
Tobacco use	945	270	0.68	295	0.60	230	0.48	150	0.40	0.08
Payer										
Medicare	136,180	30,710	77.31	38,475	78.29	37,475	78.62	29,520	79.44	N/A
Medicaid	4090	1550	3.90	1260	2.56	855	1.79	425	1.14	
Private, including HMO	26,105	5515	13.88	7110	14.47	7420	15.57	6060	16.31	
Self-pay	570	140	0.35	180	0.37	150	0.31	100	0.27	
Others	6520	1770	4.46	2005	4.08	1735	3.64	1010	2.72	
Discharge disposition										

Contd...

Table 2: Contd...

R-TSA for primary glenohumeral OA										
Variable	**Total**	**Quartile 1**		**Quartile 2**		**Quartile 3**		**Quartile 4**		***P***
		n	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	***n***	**Percent of quartile**	
Routine	117,900	26,580	66.91	33,395	67.95	32,825	68.87	25,100	67.55	N/A
Transfer, short-term hospital	270	75	0.19	85	0.17	55	0.12	55	0.15	
Other transfers	18,315	4105	10.33	5020	10.21	5015	10.52	4175	11.24	
Home health care	37,025	8915	22.44	10,595	21.56	9720	20.39	7795	20.98	
Against medical advice	75	25	0.06	15	0.03	20	0.04	15	0.04	
Discharged alive, unknown	0	0	0.00	0	0.00	0	0.00	0	0.00	

Income quartiles for 2018 are defined as follows: Quartile one: $1-$45,999 per year, Quartile two: $46,000-$58,999 per year, Quartile three: $59,000-$78,999 per year, and Quartile four: $79,000+per year. The discharge disposition "other transfers" includes transfer to skilled nursing facility, intermediate care facility, inpatient rehabilitation facility, or hospice facility. SEM: Standard error of mean, BMI: Body mass index, HMO: Health Maintenance Organization, TSA: Total shoulder arthroplasty, R-TSA: Reverse TSA, LOS: Length of stay, OA: Osteoarthritis, DM: Diabetes mellitus, PVD: Peripheral vascular disease, HLD: Hyperlipidemia, HTN: Hypertension, N/A: Not available, PI: Pacific Islander

will be a significant increase in volume and cost of these procedures as the population ages. Furthermore, as providers attempt to rectify these strains by concentrating practice in high-volume inpatient centers and outpatient centers, underserved populations may be left struggling through barriers of geographical distance in order to access quality care. This study indicates that low-income shoulder arthroplasty patients had the longest LOS, high costs, and account for the vast majority of rural hospital cases in both TSA and R-TSA for primary shoulder OA [Figures 1-3]. The lowest income patients had the fewest TSA, while the highest income patients had the fewest R-TSA. Furthermore, R-TSA patients are older, and have higher costs and longer LOS across income quartiles than TSA. Longer LOS has been associated with increased mortality in hospitalized patients, as well as increased hospital cost.[12]

R-TSA patients were older and had higher charges across income quartiles as compared to TSA. This is consistent with existing literature. Fang *et al*. showed that patients undergoing R-TSA were significantly older, had a larger American Society of Anesthesiologists classification, and a longer LOS.[14] The difference in charges was attributed to implant cost, as there was no significant difference between R-TSA and TSA overall hospital charges when omitting implant costs.[14] Similarly, Chalmers *et al*. compared costs associated for shoulder arthroplasty and identified R-TSA as a factor associated with increased operative cost ($P = 0.04$)[15] Although prior studies have attributed procedural cost differences to implants, older patient age and longer hospital LOS may also contribute to the higher costs in R-TSA. Rohrer *et al*. demonstrated that older age increased the total hospital cost, partly due to higher nursing costs and longer LOS.[16] Gholson *et al*. showed that age increases LOS by 0.02 days per year in total joint arthroplasty patients.[5] Implant costs, older age, and longer LOS may help explain why R-TSA is the costlier procedure.

Another possible explanation for higher charges in R-TSA is that these patients are sicker and more likely to have preexisting medical comorbidities. In this study, R-TSA patients had higher proportions of diabetes mellitus (DM), heart disease, lung disease, kidney disease, peripheral vascular disease (PVD), hyperlipidemia (HLD), hypertension (HTN), hypothyroidism, cancer, dementia, sepsis, cerebrovascular disease, and alcohol abuse across all income quartiles [Tables 1 and 2] compared to TSA patients. Implant costs, age, and medical comorbidities should be extensively evaluated during patient selection for R-TSA to help mitigate the differences in LOS and total charges between TSA and R-TSA. Wright *et al*. showed that in patients aged > 70 years with an intact rotator cuff, there were no differences in complication rate, revision rate, or patient-reported outcomes between TSA and R-TSA.[17] Given the similar patient outcomes between the two procedures, providers may instead look to the differences in total charges and LOS between TSA and R-TSA to help guide procedure selection.

In both TSA and R-TSA, total charges increased as income quartile increased [Figure 1]. Patient age also increased by income quartile, with wealthier patients receiving TSA and R-TSA at older ages than patients in lower income quartiles. Several studies have highlighted older age as a factor increasing LOS,[5,18] which could in turn lead to increased charges. This would support the longer LOS and higher charges observed in wealthier income quartiles, as these patients were older at the time they received shoulder arthroplasty. It was interesting, however, that following multivariate analysis, higher income quartile increased total charges in TSA ($P = 0.02$) but decreased charges in R-TSA ($P = 0.04$). It is possible that the magnitude of the highest R-TSA charges within Q1 is skewing the data to show an overall negative effect [Tables 5 and 6].

The lowest income quartile (Q1) is an outlier in both TSA and R-TSA, as patients in this quartile are the youngest, and

Table 3: Multivariate analysis of factors affecting hospital length of stay in patients admitted for total shoulder arthroplasty in the US from 2016-2018

Parameter	Estimate	SE	*T*	*P*	Lower CL	Upper CL
Income quartile	0.0012655	0.00467109	0.27	0.7865	−0.0078901	0.0104210
Age	0.0026484	0.00079774	3.32	0.0009	0.0010848	0.0042120
Gender	0.1183981	0.01042094	11.36	<0.0001	0.0979726	0.1388237
Race (relative to non-Hispanic White)						
Non-Hispanic Black	0.1674812	0.02968897	5.64	<0.0001	0.1092894	0.2256731
Hispanic	0.0934553	0.03099743	3.01	0.0026	0.0326988	0.1542118
Asian/PI	0.2417548	0.08151799	2.97	0.0030	0.0819755	0.4015340
Native American	−0.0125327	0.06090984	−0.21	0.8370	−0.1319189	0.1068536
Others	0.0194060	0.03429700	0.57	0.5715	−0.0478178	0.0866298
Hospital type (relative to rural)						
Rural versus urban nonteaching	−0.0423596	0.01981764	−2.14	0.0326	−0.0812031	−0.0035160
Rural versus urban teaching	−0.0104665	0.01854572	−0.56	0.5725	−0.0468170	0.0258840
Payer (relative to Medicare)						
Medicare versus Medicaid	0.1584442	0.03587599	4.42	<0.0001	0.0881255	0.2287629
Medicare versus Private (HMO)	0.0190308	0.01401224	1.36	0.1744	−0.0084339	0.0464955
Medicare versus self-pay	0.0262450	0.05356410	0.49	0.6242	−0.0787433	0.1312332
Medicare versus no charge	0.5678054	0.17392828	3.26	0.0011	0.2268975	0.9087133
Medicare versus others	0.0712588	0.02401900	2.97	0.0030	0.0241804	0.1183372
Time to surgery	0.9668829	0.00914013	105.78	<0.0001	0.9489678	0.9847980
Discharge disposition (relative to routine)						
Routine versus short-term hospital	0.1643809	0.26061940	0.63	0.5282	−0.3464459	0.6752076
Routine versus SNF	1.8922349	0.05378095	35.18	<0.0001	1.7868216	1.9976482
Routine versus Home health care	0.2563594	0.01409708	18.19	<0.0001	0.2287284	0.2839904
Routine versus another facility type	0.3656856	0.43488554	0.84	0.4004	−0.4867113	1.2180824
Routine versus unknown	−1.1564251	0.02555378	−45.25	<.0001	−1.2065117	−1.1063384
Comorbidities						
DM	0.0366750	0.01584167	2.32	0.0206	0.0056245	0.0677254
Heart disease	0.0870770	0.01423587	6.12	<0.0001	0.0591740	0.1149800
Lung disease	0.1636891	0.01700389	9.63	<0.0001	0.1303606	0.1970176
Kidney disease	0.1989812	0.03394724	5.86	<0.0001	0.1324429	0.2655194
Liver disease	0.1329254	0.04784431	2.78	0.0055	0.0391482	0.2267026
PVD	0.0262094	0.05544979	0.47	0.6365	−0.0824749	0.1348937
HLD	−0.0199740	0.01053891	−1.90	0.0581	−0.0406308	0.0006828
HTN	0.0254629	0.01074147	2.37	0.0178	0.0044091	0.0465167
Cancer	0.0605028	0.04579743	1.32	0.1865	−0.0292624	0.1502680
Dementia	0.5334275	0.22089713	2.41	0.0157	0.1004583	0.9663966
Cerebrovascular disease	0.2712020	0.09065684	2.99	0.0028	0.0935102	0.4488939
Alcohol abuse	0.1468656	0.09890231	1.48	0.1376	−0.0469877	0.3407190
Tobacco use	0.0804819	0.08392646	0.96	0.3376	−0.0840181	0.2449818
Obesity	0.0331588	0.01328491	2.50	0.0126	0.0071197	0.0591979

R^2: 0.5007. SE: Standard error, CL: Confidence limit, HMO: Health Maintenance Organization, SNF: Skilled nursing facility, PI: Pacific Islander, DM: Diabetes mellitus, PVD: Peripheral vascular disease, HLD: Hyperlipidemia, HTN: Hypertension

yet still have the longest LOS, the highest charges among R-TSA, and the second highest charges among TSA. We sought to examine whether Q1 had significantly more medical comorbidities despite their young age as compared to the wealthiest income quartile (Q4) to help explain the high charges and longest LOS. Among TSA, our study showed that Q1 had the highest likelihood of DM, lung disease, HTN, kidney disease, liver disease, cerebrovascular disease, and tobacco use among the four income quartiles ($P < 0.05$). This supports the theory that Q1 had more medical comorbidities than Q4. The data among R-TSA, however, were more conflicting as Q1 had the highest likelihood of DM and lung disease but also had the lowest likelihood of PVD, HLD, and hypothyroidism ($P < 0.01$). Conversely, the wealthiest quartile had the highest likelihood of PVD, HLD, and hypothyroidism but the lowest likelihood of obesity, DM, and lung disease ($P < 0.02$). This suggests that the higher charges and LOS among R-TSA in the lowest income quartile cannot be solely explained by older age (these patients are the youngest in both TSA and R-TSA), or higher likelihood of medical comorbidities. Sheth *et al*. evaluated the effects of lower SES in patients with primary glenohumeral OA and

Table 4: Multivariate analysis of factors affecting hospital length of stay in patients admitted for reverse total shoulder arthroplasty in the US from 2016-2018

Parameter	Estimate	SE	*T*	*P*	Lower CL	Upper CL
Income quartile	0.0002564	0.00587172	0.04	0.9652	−0.0112523	0.0117652
Age	0.0001886	0.00099314	0.19	0.8494	−0.0017580	0.0021352
Gender	0.0857371	0.01204899	7.12	<0.0001	0.0621207	0.1093536
Race (relative to to non-Hispanic White)						
Non-Hispanic Black	0.1320888	0.03105196	4.25	<0.0001	0.0712258	0.1929518
Hispanic	0.1325116	0.03738691	3.54	0.0004	0.0592319	0.2057913
Asian/PI	0.0878579	0.07163937	1.23	0.2201	−0.0525579	0.2282737
Native American	−0.0442524	0.07062217	−0.63	0.5309	−0.1826744	0.0941697
Others	0.0118704	0.04748912	0.25	0.8026	−0.0812101	0.1049508
Hospital type (relative to rural)						
Rural versus urban nonteaching	−0.0280945	0.02037125	−1.38	0.1679	−0.0680229	0.0118339
Rural versus urban teaching	0.0295856	0.01906546	1.55	0.1207	−0.0077834	0.0669546
Payer (relative to Medicare)						
Medicare versus Medicaid	0.1672158	0.05470587	3.06	0.0022	0.0599903	0.2744413
Medicare versus Private (HMO)	0.0338026	0.01999379	1.69	0.0909	−0.0053859	0.0729912
Medicare versus self-pay	0.1181768	0.10884638	1.09	0.2776	−0.0951660	0.3315197
Medicare versus no charge	0.8682055	0.47875229	1.81	0.0698	−0.0701665	1.8065775
Medicare versus others	0.0834676	0.03097431	2.69	0.0070	0.0227569	0.1441784
Time to surgery	0.9666136	0.01765138	54.76	<0.0001	0.9320162	1.0012109
Discharge disposition (relative to routine)						
Routine versus short-term hospital	1.0434953	0.32047998	3.26	0.0011	0.4153428	1.6716478
Routine versus SNF	1.9245188	0.03471085	55.44	<0.0001	1.8564843	1.9925534
Routine versus home health care	0.3647127	0.01434734	25.42	<0.0001	0.3365914	0.3928340
Routine versus another facility type	−0.1185856	0.21320180	−0.56	0.5781	−0.5364690	0.2992977
Comorbidities						
DM	0.0181257	0.01570850	1.15	0.2486	−0.0126635	0.0489150
Heart disease	0.1103943	0.01390796	7.94	<0.0001	0.0831342	0.1376544
Lung disease	0.2128008	0.01719116	12.38	<0.0001	0.1791055	0.2464961
Kidney disease	0.3168671	0.03261903	9.71	<0.0001	0.2529326	0.3808016
Liver disease	0.2720772	0.08812511	3.09	0.0020	0.0993488	0.4448057
PVD	0.0556574	0.04486745	1.24	0.2148	−0.0322845	0.1435992
HLD	−0.0510381	0.01222877	−4.17	<0.0001	−0.0750070	−0.0270693
HTN	0.0362901	0.01273044	2.85	0.0044	0.0113379	0.0612422
Cancer	0.0382704	0.04933894	0.78	0.4380	−0.0584358	0.1349765
Dementia	0.2863494	0.08365685	3.42	0.0006	0.1223789	0.4503199
Cerebrovascular disease	0.2224819	0.07106644	3.13	0.0017	0.0831891	0.3617748
Alcohol abuse	−0.0612381	0.06439977	−0.95	0.3417	−0.1874640	0.0649878
Tobacco use	0.2185689	0.16622258	1.31	0.1885	−0.1072335	0.5443712
Obesity	0.0086796	0.01601332	0.54	0.5878	−0.0227071	0.0400663

R^2=0.4174. SE: Standard error, CL: Confidence limit, HMO: Health Maintenance Organization, SNF: Skilled nursing facility, PI: Pacific Islander, DM: Diabetes mellitus, PVD: Peripheral vascular disease, HLD: Hyperlipidemia, HTN: Hypertension

demonstrated that lower SES was directly correlated with poorer preoperative function scores. This is important given several studies in the hip and knee arthroplasty literature that have shown that preoperative function is strong, and in some studies, the strongest predictor of postoperative function.[19-21] They postulate that patients with lower SES have less access to care, and consequently present at more advanced stages of glenohumeral OA.[4] This may help explain the higher charges and longer LOS among R-TSA in the lowest income quartile as patients with more advanced diseases would be expected to have more complicated treatment courses and recovery.

Several studies have highlighted the improved outcomes following shoulder arthroplasty performed at high-volume inpatient centers. Ramkumar *et al*. showed that primary shoulder arthroplasty by high-volume surgeons at high-volume hospitals had shorter LOS and decreased costs.[22] Compared to low-volume hospitals, patients receiving TSA at high-volume hospitals had a significantly lower likelihood of being discharged to an inpatient medical facility, had hospital stay greater than the median, and had lower rates of postoperative complications and revisions.[8] Similarly, Farley *et al*. demonstrated that hospitals which

Table 5: Multivariate analysis of factors affecting total hospital charges in patients admitted for total shoulder arthroplasty in the US from 2016-2018

Parameter	Estimate	SE	*T*	*P*	Lower CL	Upper CL
Income quartile	517.579	224.8870	2.30	0.0214	76.789	958.3689
Age	−70.790	34.0443	−2.08	0.0376	−137.519	−4.0616
Gender	−2081.961	471.8021	−4.41	<0.0001	−3006.717	−1157.2059
Race (relative to non-Hispanic White)						
Non-Hispanic Black	2288.777	1184.1693	1.93	0.0533	−32.253	4609.8073
Hispanic	13,116.938	1456.2563	9.01	<0.0001	10,262.604	15,971.2723
Asian/PI	7089.350	3842.9365	1.84	0.0651	−442.995	14,621.6950
Native American	−1237.744	3359.1873	−0.37	0.7125	−7821.917	5346.4288
Others	7280.470	2224.4836	3.27	0.0011	2920.372	11,640.5673
Hospital type (relative to rural)						
Rural versus urban nonteaching	15,857.516	1389.7952	11.41	<0.0001	13,133.449	18,581.5832
Rural versus urban teaching	12,330.574	1323.2135	9.32	<0.0001	9737.010	14,924.1372
Payer (relative to Medicare)						
Medicare versus Medicaid	−2259.904	1267.8609	−1.78	0.0747	−4744.974	225.1657
Medicare versus Private (HMO)	−1894.671	633.2208	−2.99	0.0028	−3135.815	−653.5268
Medicare versus self-pay	−12,372.350	2864.9101	−4.32	<0.0001	−17,987.715	−6756.9846
Medicare versus no charge	−15,375.214	4628.7151	−3.32	0.0009	−24,447.724	−6302.7038
Medicare versus others	2860.371	1310.6115	2.18	0.0291	291.508	5429.2341
Time to surgery	734.224	268.4500	2.74	0.0062	208.049	1260.3991
Discharge disposition (relative to routine)						
Routine versus short term hospital	−3936.789	7537.5605	−0.52	0.6015	−18,710.779	10,837.2015
Routine versus SNF	11,273.997	1204.5719	9.36	<0.0001	8912.976	13,635.0170
Routine versus home health care	8743.403	652.3650	13.40	<0.0001	7464.736	10,022.0710
Routine versus another facility type	7942.866	6690.7907	1.19	0.2352	−5171.414	21,057.1462
Comorbidities						
DM	−252.955	602.2721	−0.42	0.6745	−1433.438	927.5285
Heart disease	295.204	587.2150	0.50	0.6152	−855.767	1446.1741
Lung disease	3145.358	746.8213	4.21	<0.0001	1681.552	4609.1649
Kidney disease	1900.564	1014.8678	1.87	0.0611	−88.627	3889.7552
Liver disease	3435.913	1647.8906	2.09	0.0371	205.966	6665.8598
PVD	511.355	1787.7791	0.29	0.7749	−2992.780	4015.4904
HLD	−535.312	492.0346	−1.09	0.2766	−1499.724	429.1002
HTN	−103.705	509.3292	−0.20	0.8387	−1102.015	894.6054
Cancer	−971.832	2141.3992	−0.45	0.6500	−5169.081	3225.4156
Dementia	973.413	2980.0828	0.33	0.7439	−4867.696	6814.5221
Cerebrovascular disease	5053.516	2594.7775	1.95	0.0515	−32.375	10,139.4085
Alcohol abuse	782.133	3661.9598	0.21	0.8309	−6395.489	7959.7548
Tobacco use	6059.441	4023.2558	1.51	0.1321	−1826.339	13,945.2204
Obesity	−1159.557	556.9894	−2.08	0.0374	−2251.283	−67.8301

R^2: 0.0284. SE: Standard error, CL: Confidence limit, HMO: Health Maintenance Organization, SNF: Skilled nursing facility, PI: Pacific Islander, DM: Diabetes mellitus, PVD: Peripheral vascular disease, HLD: Hyperlipidemia, HTN: Hypertension

perform more than 100 R-TSAs per year have lower readmission rates, fewer revisions, fewer complications, and shorter LOS.[23] It is clear that surgeon and hospital volume play an important role in achieving successful patient outcomes following shoulder arthroplasty.[24] A population-level analysis in Texas revealed that there is a concentration of these high-volume inpatient centers in urban metropolitan areas.[6] Out of 774 identified high-volume TSA surgeons, 45% of them practiced within major metropolitan areas with a population >1 million.[10] This trend has also been demonstrated on a national level, as from 2011 to 2015, urban teaching hospitals increased the number of R-TSA procedures performed (42.6%-61.7%), whereas there was a decrease in the proportion of R-TSA performed at rural hospitals (14.0%-8.5%).[25]

Wealthier patients were more likely to undergo TSA and R-TSA in urban teaching centers, while lower-income patients were more likely to undergo their procedures at rural centers. These data are summarized in Figure 3. The data presented in this study reinforce the dominance of urban hospital centers with most TSAs (43%) and the majority of R-TSAs (55%) between 2016 and 2019 occurring in urban teaching centers. Secondly, this study shows that the lowest

Table 6: Multivariate analysis of factors affecting total hospital charges in patients admitted for reverse total shoulder arthroplasty in the US from 2016-2018

Parameter	Estimate	SE	*T*	*P*	Lower CL	Upper CL
Income quartile	−466.3962	232.0173	−2.01	0.0444	−921.159	−11.634
Age	−145.2532	33.7561	−4.30	<0.0001	−211.416	−79.090
Gender	−1896.4533	487.9727	−3.89	0.0001	−2852.898	−940.009
Race (relative to non-Hispanic White)						
Race - Non-Hispanic Black	2156.5920	1147.2485	1.88	0.0601	−92.058	4405.242
Race - White versus Hispanic	20,406.8341	1408.7898	14.49	<0.0001	17,645.554	23,168.114
Race - White versus Asian/PI	11,284.9966	3391.4014	3.33	0.0009	4637.724	17,932.269
Race - White versus Native American	−3636.5160	3380.7158	−1.08	0.2821	−10,262.844	2989.812
Race - White versus others	10,891.1690	2417.9125	4.50	<0.0001	6151.971	15,630.367
Hospital type (relative to rural)						
Rural versus urban nonteaching	17,715.9576	764.4938	23.17	<0.0001	16,217.521	19,214.394
Rural versus urban teaching	14,759.8853	679.7522	21.71	<0.0001	13,427.546	16,092.225
Payer (relative to Medicare)						
Medicare versus Medicaid	2500.2840	2045.3652	1.22	0.2216	−1508.708	6509.276
Medicare versus Private (HMO)	162.8161	708.4739	0.23	0.8182	−1225.819	1551.451
Medicare versus self-pay	−8378.2679	3279.2040	−2.55	0.0106	−14,805.629	−1950.906
Medicare versus no charge	41,357.3136	29,930.0782	1.38	0.1670	−17,306.749	100,021.376
Medicare versus others	2508.5893	1361.1577	1.84	0.0653	−159.330	5176.509
Time to surgery	2724.9962	528.0188	5.16	<0.0001	1690.060	3759.933
Discharge disposition (relative to routine)						
Routine versus short-term hospital	841.3705	5547.5109	0.15	0.8795	−10,031.956	11,714.697
Routine versus SNF	14,291.8394	1026.1128	13.93	<0.0001	12,280.620	16,303.058
Routine versus home health care	9216.3783	577.1632	15.97	<0.0001	8085.117	10,347.640
Routine versus another facility type	12,513.1492	14,639.1400	0.85	0.3927	−16,180.108	41,206.406
Comorbidities						
DM	−276.2981	586.4724	−0.47	0.6376	−1425.806	873.209
Heart disease	−86.0363	554.5580	−0.16	0.8767	−1172.991	1000.918
Lung disease	1665.6700	573.5346	2.90	0.0037	541.521	2789.819
Kidney disease	4639.0639	1026.0044	4.52	<0.0001	2628.057	6650.071
Liver disease	1305.1294	2169.8768	0.60	0.5475	−2947.909	5558.168
PVD	−770.9741	1445.8914	−0.53	0.5939	−3604.975	2063.027
HLD	−475.0601	480.7403	−0.99	0.3231	−1417.329	467.209
HTN	−714.7315	515.8972	−1.39	0.1659	−1725.909	296.446
Cancer	1426.3475	2019.5253	0.71	0.4800	−2531.997	5384.692
Dementia	4865.3159	2357.0264	2.06	0.0390	245.457	9485.175
Cerebrovascular disease	−277.4095	1926.5667	−0.14	0.8855	−4053.552	3498.733
Alcohol abuse	−512.0799	3054.8105	−0.17	0.8669	−6499.622	5475.462
Tobacco use	−3229.8848	2637.4909	−1.22	0.2207	−8399.465	1939.695
Obesity	−1993.5798	574.6340	−3.47	0.0005	−3119.884	−867.276

R^2=0.0464. SE: Standard error, CL: Confidence limit, HMO: Health Maintenance Organization, SNF: Skilled nursing facility, PI: Pacific Islander, DM: Diabetes mellitus, PVD: Peripheral vascular disease, HLD: Hyperlipidemia, HTN: Hypertension

income patients were more likely to undergo TSA and R-TSA at rural centers, which may preclude them from access to high-volume shoulder arthroplasty surgeons. This is of interest as the lowest income quartile had the longest LOS in both TSA and R-TSA. The discrepancy in LOS, despite this quartile possessing the youngest patients on average, could be partly explained by the lack of access to high-volume surgeons. Consequently, the longer LOS may be due to worse outcomes following shoulder arthroplasty performed by low-volume surgeons at rural centers. Multivariate analysis revealed that TSA performed at rural centers had longer LOS than those performed at urban nonteaching centers [Table 3]. Practices in rural areas may lack supportive medical specialties to assist with complex cases, face tighter finances, and experience delays in technology compared with urban practices. In addition, they may not have comprehensive inventories of surgical instruments and devices compared to their urban counterparts, all of which can contribute to worse patient outcomes and longer LOS.[26]

Among TSA and R-TSA, the wealthiest patients were more likely to utilize private insurance, while lower-income patients were more likely to use Medicare or Medicaid to fund their shoulder arthroplasties. Matsen *et al*. showed that Medicaid

Figure 1: Total Charges for Total Shoulder Arthroplasty (TSA) and Reverse Total Shoulder Arthroplasty (R-TSA) by Income Quartile in 2016-2018

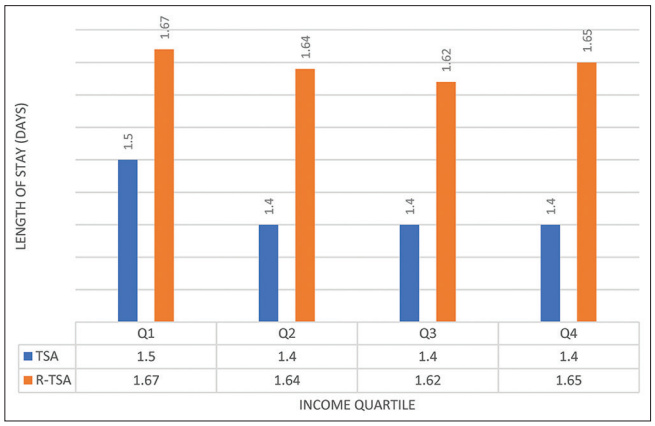

Figure 2: Length of Stay for Total Shoulder Arthroplasty (TSA) and Reverse Total Shoulder Arthroplasty (R-TSA) by Income Quartile in 2016-2018

insurance is associated with longer hospital stays and revision rates after shoulder arthroplasty.[27] This study shows that the lowest income patients had the longest LOS. It is possible that the increased likelihood of utilizing Medicaid for primary shoulder arthroplasty contributes to their increased LOS, despite being the youngest income quartile. Li *et al*. demonstrated that Medicare or Medicaid/uninsured patients were more likely to have medical and surgical perioperative complications after shoulder arthroplasty than age- and sex-matched patients with private insurance.[28] This study reveals a discrepancy in insurance providers for primary shoulder arthroplasty between low-income and high-income patients. With literature supporting differences in LOS, revision rates, and perioperative complications based on insurance providers, attention needs to be placed on the discrepancies in insurance between income levels to help account for the high charges and longest LOS observed in low-income shoulder arthroplasty patients.

In both TSA and R-TSA, the proportion of non-Hispanic White/Asian patients increased by income quartile while the proportion of non-Hispanic Black/Native American patients decreased by income quartile ($P < 0.0001$). This study shows that non-Hispanic Black and Native American patients are disproportionately represented in the lowest income quartile in both TSA and R-TSA as compared to the highest income quartile. This is relevant as the lowest income quartile had the longest LOS, the highest charges in R-TSA, and the second highest charges in TSA. Farley *et al*. demonstrated similarly growing racial disparities in shoulder arthroplasty between 2011 and 2017. Non-Hispanic Black patients had a higher rate of nonhome discharge, longer LOS, and higher overall costs, while Hispanics had a longer LOS and higher cost than non-Hispanic Whites.[29] This study reveals a racial disparity between income quartiles of patients undergoing TSA and R-TSA. Given the existing literature describing differences in disposition, charges, and LOS in patients of different races who receive primary shoulder arthroplasty, further studies need to characterize the causes of these disparities and address possible solutions to reduce them.

The strengths of this study include a large patient sample size that is nationally representative. The NIS is a fairly comprehensive and representative database, but it does not include veteran and military hospitals, both of which could account for a large number of patients undergoing shoulder arthroplasty.[13] Data were collected by ICD-10 codes, and as such may introduce some reporting error that is inherent to any database. Furthermore, patients' median income was determined by zip code. This generalization may misrepresent the accurate SES of each patient. However, given individual economic data do not exist, zip code has been used as an acceptable income quartile surrogate and the effect of this is likely minimal when

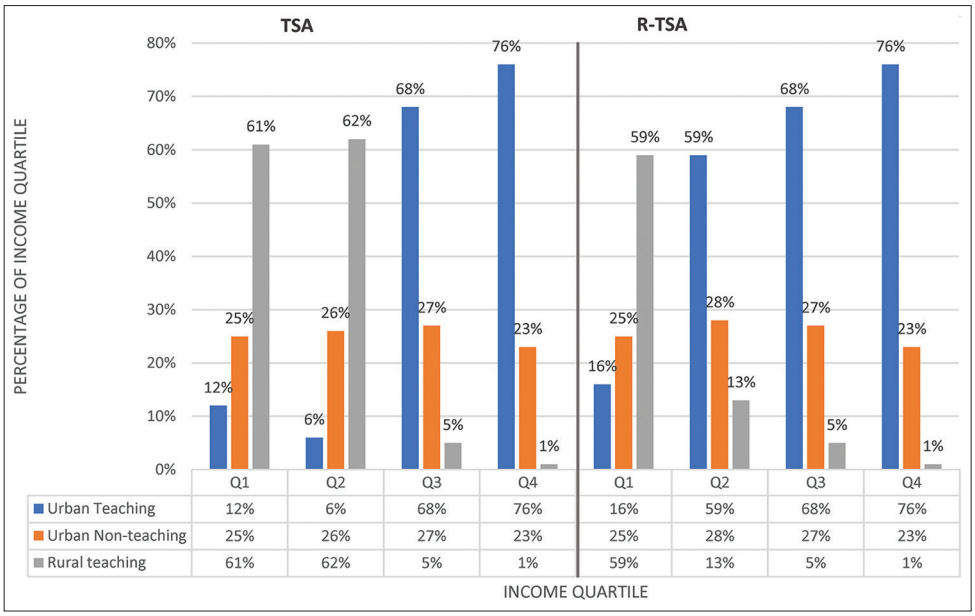

Figure 3: Procedure Location of Total Shoulder Arthroplasty (TSA) and Reverse Total Shoulder Arthroplasty (R-TSA) by Income Quartile in 2016-2018

extrapolated over a large national patient population. Finally, a meta-analysis on the effect of hospital and surgeon volume on outcomes of primary shoulder arthroplasty by Kooistra *et al*. revealed that despite consistent associations of high-volume surgeons and hospitals with shorter LOS and decreased costs, there was insufficient evidence to support significant differences in patient outcomes such as mortality, complication rate, or revision rate.[30] This suggests that LOS and total charges are imperfect measures of patient-related outcomes, and although differences are observed in these metrics, this does not concretely infer poorer patient function, outcomes, complications, or revisions in shoulder arthroplasty patients.

Conclusion

This study indicates that, despite being the youngest, the lowest income shoulder arthroplasty patients had the longest LOS, high charges, and account for the vast majority of rural cases in both TSA and R-TSA. These disparities might be explained by differences in baseline comorbidities, delayed presentation with advanced disease, performing procedures in low-volume rural hospitals, or utilization of public insurance of Medicare or Medicaid. R-TSAs have higher costs and longer LOS across all income quartiles than TSA. Continued attention needs to be placed on the disparities in resource utilization for upper extremity arthroplasty among patients of different SES.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Value-Based Care in Arthroscopic Rotator Cuff Repair: A Lean Six Sigma Approach for Optimizing the Surgical Recovery Period

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Abstract

Background: There is an overall need to optimize the surgical recovery period after rotator cuff repair, and there is no lean six sigma (LSS) protocol on how to effectively manage follow-up without increasing burden on patients or providers. **Materials and Methods:** The Kanban board outcome assessment tool was managed by athletic trainers and was used to organize the recovery period. Using ICD-10 codes, we benchmarked our outcomes from May 2017 to February 2019-4633 rotator cuff repairs recorded in a global registry (Surgical Outcomes System). Statistical analysis was done by two-tailed, two-sample *t*-test, and multiple linear regression. **Results:** Fifty-seven patients with a survey compliance rate of 82.4% and a minimum follow-up of 2 years were compared to 4633 patients in a global registry with 58% compliance at 2 years. Pretreatment baseline scores were also significantly worse in our LSS cohort. Despite this, our analysis identified a statistically significant improvement in Visual Analog scales, American Society of Shoulder and Elbow Surgeons, and Veterans-Rand 12 physical and mental scores in our LSS cohort compared to the global registry ($P < 0.01$). Subgroup analysis of partial, complete, and massive rotator cuff tears in our cohort also compared favorably to the global registry. Our LSS protocol resulted in 12 scheduled patient-provider interactions with two physician follow-up appointments postoperatively. **Conclusions:** Our LSS approach yielded clinically significant 38% less pain and 20% improved shoulder function at 2 years postoperation compared to a global registry. Quality of life measures also improved by nearly 20% for both physical and mental health. Our LSS model improved patient outcomes following arthroscopic rotator cuff repair.

Keywords: Kanban board, lean six sigma, rotator cuff repair, value-based care

Introduction

Health-care costs in the United States are rapidly increasing, with the OR serving as a hospital's largest source of revenue and costly medical errors.[1,2] Risk mitigation has passed on from insurers to health-care delivery systems, emphasizing value-based care and bundled payment models. This makes it essential to continuously refine system operations to improve patient outcomes and enhance overall value, defined as outcomes divided by costs.

Lean is a data-driven quality improvement philosophy aimed at cutting waste and increasing value.[3] Lean was first implemented in Japan, gaining popularity after two Toyota executives developed their own lean six sigma (LSS) production system in the 1970s, which resulted in a 23% net income increase during a time when the rest of the car industry was struggling.[4] Six sigma was developed by Motorola and uses an approach known as Define, Measure, Analyze, Improve, Control to uncover the root causes of system inefficiencies. Both have been introduced into health care, and the National Health System in the UK has even developed a combined approach known as LSS. Since then, LSS has been used to develop health-care protocols that maximize accuracy

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and efficiency, including decreased operating room times and infection rates.[1,5]

LSS has previously been implemented in orthopedic care and has now expanded to a number of specialties to coordinate different steps in the patient's care, including preoperative clinic, hospital admission, and postoperative infection control.[1,2,6,7] However, there is no protocol on how to effectively manage postoperative follow-up through LSS protocols without increasing burden on patients or providers. Particular attention should be paid to team communication, both within the team and to the patient, given its link to a majority of medical errors.[4,5,8]

Kanban boards are low-cost outcome assessment tools that quantify processes into smaller, measurable steps with built-in inspection protocols. These protocols can then be managed primarily by nonphysician members of the health-care team, such as athletic trainers, who can serve as valuable liaisons between the patient and care team for important questions that arise throughout the postoperative period. This tool increasingly allows our care team to inquire about various aspects of postoperative care, such as healing and adherence to home exercise and physical therapy regimens. While these aspects are important components of the recovery process, they often do not warrant additional burden on physicians, who primarily deliver value in orthopedic care. Therefore, the goal of this LSS management tool is to combine easy implementation to the health-care team with no additional burden to the patient or provider, resulting in improved patient outcomes, or increased value.

Thus, the primary objective of our study was to prospectively evaluate if the application of an LSS approach to the surgical recovery period following rotator cuff repair will yield statistically and clinically significant improved pain control, shoulder function, and quality of life outcomes compared to global benchmarks at a minimum 2-year follow-up. Our secondary objective was to conduct a subgroup analysis to evaluate if this approach would result in similar improvement in patients with partial, complete, or massive rotator cuff tears. Our tertiary objective was to identify any variables that are independent predictors of success.

Materials and Methods

Ethical approval

Our study was approved by the Institutional Review Board at Brockton Hospital. We retrospectively reviewed our single-center experience of 57 patients who underwent shoulder arthroscopy and a rotator cuff repair from July 2017 to February 2019.

Study design

A level III retrospective comparison of prospectively collected outcome data of 57 consecutive patients at a minimum follow-up of 2 years and 82.4% survey compliance rate. The inclusion criteria was undergoing an arthroscopic rotator cuff repair. Exclusion criteria included being under 18 years old, Non-English speaking, having no E-mail address, or being unwilling to participate in surgical outcomes system (SOS). Non-English speakers and patients who lacked an E-mail address were not included due to the limitations of our team to administer outcome surveys. All patients underwent shoulder arthroscopy requiring a rotator cuff repair from July 2017 to February 2019. Our study had two participating orthopedic surgeons, and our results were compared to a SOS global registry with 4633 rotator cuff repairs at 59% survey compliance at 2-year follow-up. ICD-10 codes were used to filter the SOS shoulder arthroscopy data according to rotator cuff repair, as well as partial or complete rotator cuff tears.

Kanban board operations

The Kanban board outcome assessment tool was utilized to break down the rotator cuff repair recovery period into smaller, time-specific checkpoints [Figure 1]. The electronic Kanban board separates patients according to their next care team action and allows for easy monitoring of the recovery process by alerting the care team when the next action is due [Figure 2]. For example, when the athletic trainer would sign into the program, their status board would show all patients who had a task to be completed that day according to their stage of recovery. The athletic trainer would double-click on the patient's care team action, pull up the patient's medical record and SOS profile, and then complete the associated action and remove it from their task list. Three athletic trainers were trained to maintain the Kanban board system, in addition to other duties at our accountable care organization (ACO). This system creates a streamlined, easy-to-monitor protocol for our athletic trainers to manage over 12 scheduled patient-care team interactions while only requiring two physician follow-up appointments in a 2 year period after the surgery.

Surgical outcomes system global registry

Our ACO utilizes the SOS outcome repository to track the recovery of our patients. The SOS was developed by Arthrex (Naples, Florida) in 2017 and is a comprehensive database that collects patient demographics, diagnostic data, detailed surgical data, and validated Patient-reported outcome measures. SOS integrates into our electronic medical record systems and allows us to send electronic surveys to assess patient outcomes such as visual analog scales (VAS), American Society of Shoulder and Elbow Surgeons (ASES) shoulder function and index scores, and Veterans-Rand 12 (VR-12) physical and mental scores at certain time-points in their recovery period. It has been used as a benchmark in a number of previous studies.[9,10] Our rotator cuff repair outcomes were then compared to the 4633 rotator cuff repairs in the SOS global registry.

Data collection and statistical analysis

Patient demographics were examined, and outcomes were collected via E-mailed SOS surveys completed by the patient at 2 weeks, 6 weeks, 3 months, 6 months, 1 and 2 years postoperative. Reminders would be sent by athletic trainers via the SOS software, which would forward on automated E-mail

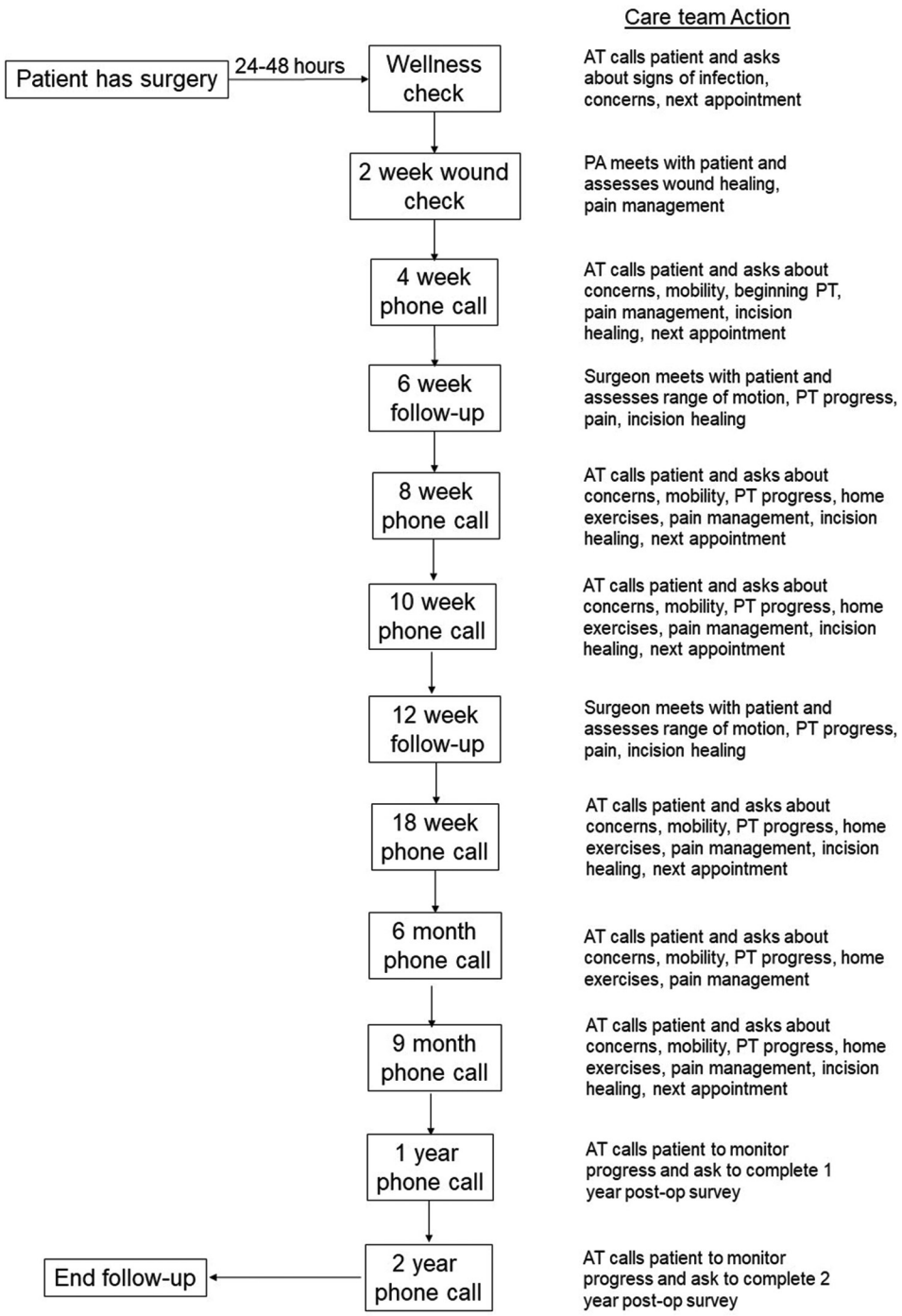

Figure 1: Value-stream map of the surgical recovery period utilizing the Kanban board assessment tool at our LSS ACO. AT: athletic trainer, PA: physician assistant, PT: physical therapy, LSS: Lean six sigma, ACO: Accountable care organization

reminders to patients. Due to baseline differences between cohorts, we compared differences of means to examine whether our Kanban board approach resulted in greater improvements in each variable.

Statistical analysis was descriptive, and a two-tailed, two-sample *t*-test was performed to assess two-group surgical interventions. Clinical significance was determined utilizing previously reported measures.[8,11,12] An *a priori* power analysis was conducted using G× Power3 to test the difference between two independent group means using a two-tailed test, a large effect size (d = 1.5), and an alpha of 0.05.[13] Results showed that a total sample of 22 participants with two equal-sized groups of n = 11 was required to achieve a power of 0.80. A large effect size was estimated using the prematched shoulder arthroscopy data generated by SOS for our organization. *Post-hoc* power analysis yielded a power of 1.0.

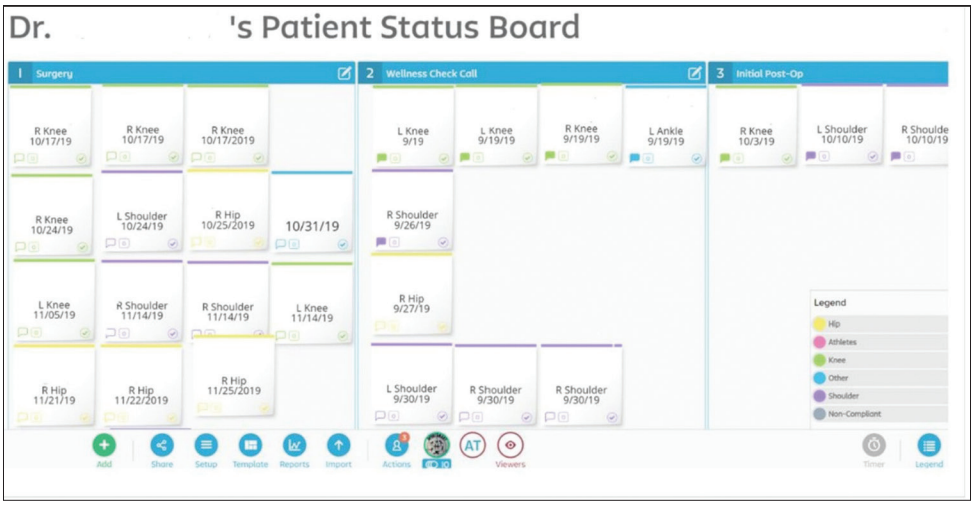

Figure 2: Kanban board interface illustrating various care team actions to be completed. Patient and provider information were removed for publication

Subgroup analysis of partial, complete, and massive rotator cuff tears in our case cohort was completed. Partial and complete tears in our cohort were compared to 1445 partial and 3188 complete tears in the SOS global registry, respectively; logged ICD-10 codes were used to filter partial or complete tears in the SOS global registry. Multiple linear regression was also conducted to investigate the association between patient demographics and surgical data with reported outcomes.

Patient demographics

47 of 57 (82.4%) patients with a minimum of 2-year follow-up were prospectively case-controlled and matched to 4633 patients in the SOS global registry with 58% compliance at 2-year follow-up. Patients lost to follow-up were due to failure of survey completion after multiple reminders but not failure to attend follow-up appointments; these patients were not included in the analyses. The payor mix included 40.4% with ACO coverage, 36.8% with Medicaid/Medicare, 19.3% with commercial, and 3.5% who were self-pay. Demographic and surgical data in our case cohort are outlined in Table 1. Shapiro–Wilk test using our cohort's dependent criteria confirmed a normal distribution (P = 0.34). The mean age was 56.5 ± 11.5 years and 40.5% of patients were female in the SOS global registry.

The size and type of rotator cuff tears, along with concurrent injuries and procedures in our case cohort, were also described. 48 (84.2%) patients had supraspinatus tears, 18 (31.6%) had infraspinatus tears, and 14 (24.6%) had subscapularis tears. 12 (21%) patients had partial rotator cuff tears (1 patient had grade IIIA tear, 9 had grade IIIB tear, and 2 had grade IIIC tear), and 45 patients (79%) had complete rotator cuff tears. 13 (22.8%) of these complete tears were small, 10 (17.5%) were medium, 5 were large (8.8%), and 17 (29.8%) were massive sized according to the Cofield classification. In addition, 4 (7%) patients had frozen shoulder, 8 (14%) had calcific tendonitis, and 35 (61.4%) had superior labral anterior to posterior tears, with 3 having type I, 26 having type II, and 4 having type III tears according to the Snyder classification. Within the SOS global registry cohort, 1445 had partial tears (31.2%) and 3188 patients had complete rotator cuff tears (68.8%), according to the logged ICD-10 codes.

Table 1: Demographic and surgical data in our case cohort

Surgical procedure	Case cohort (n=57)
Age, mean (SD)	52.2 (10.6)
Female, *n* (%)	32 (56.1)
ASA level, mean (SD)	2.2 (0.5)
Rotator cuff repair, *n* (%)	57 (100)
Single-row	24 (42.1)
Double-row	16 (28.1)
TOE	13 (22.8)
Isolated subscapularis repair	4 (7.0)
Rotator cuff anchors used, mean (SD)	2.6 (1.6)
Biceps tenodesis, *n* (%)	48 (84.2)
Subpectoral	44 (77.2)
Arthroscopic	4 (7.0)
Biceps tenotomy, *n* (%)	8 (14.0)
Subacromial decompression, *n* (%)	57 (100)
Capsular release, *n* (%)	16 (28.1)
Capsulorrhaphy, *n* (%)	2 (3.5)
Labral repair, *n* (%)	3 (5.3)
Distal clavicle excision, *n* (%)	3 (5.3)

Isolated subscapularis tendon tears were repaired using Arthrex Bio-Swivelock anchors. SD: Standard deviation, TOE: Transosseous-equivalent, ASA: American Society of Anesthesiologists

Results

90-day reoperation rate for our cohort was 1.8%, similar or lower compared to other studies.[12,14] Table 2 compares VAS, ASES, and VR-12 scores in our LSS case cohort versus the SOS global registry cohort.

Our case cohort's baseline pretreatment VAS pain, ASES shoulder function and index, and VR-12 quality of life measures were significantly worse from the SOS global registry cohort (P < 0.001). Both cohorts showed statistically

Table 2: Visual analog scale, American Society of Shoulder and Elbow Surgeons shoulder function and index, and Veterans-Rand-12 physical and mental scores for case cohort versus global registry control patients

Variable	Case cohort (n=57)	Global registry (n=4633)
VAS, mean (SE)		
Pretreatment VAS	6.51 (0.28)*	5.20 (0.04)*
1 year ΔVAS from pretreatment	5.11 (0.05)*	3.63 (0.001)*
2 years ΔVAS from pretreatment	5.40 (0.04)*	3.92 (0.002)*
ASES shoulder function score, mean (SE)		
Pretreatment ASES shoulder function score	10.29 (0.59)*	13.87 (0.09)*
1 year ΔASES function from pretreatment	14.98 (0.12)*	11.22 (0.003)*
2 years ΔASES function from pretreatment	15 (0.12)*	12.48 (0.004)*
ASES shoulder index score, mean (SE)		
Pretreatment ASES shoulder index score	34.92 (2.38)*	47.10 (0.28)*
1 year ΔASES index from pretreatment	50.21 (0.42)*	36.75 (0.009)*
2 years ΔASES index from pretreatment	51.16 (0.40)*	40.26 (0.002)*
VR-12 physical, mean (SE)		
Pretreatment VR-12 physical score	33.67 (0.86)*	36.95 (0.12)*
1 year ΔVR-12 physical from pretreatment	14.78 (0.17)*	10.07 (0.004)*
2 years ΔVR-12 physical from pretreatment	14.79 (0.18)*	12.55 (0.006)*
VR-12 mental, mean (SE)		
Pretreatment VR-12 mental score	45.81 (1.28)*	50.36 (0.17)*
1 year ΔVR-12 mental from pretreatment	3.15 (0.24)*	3.84 (0.005)*
2 years ΔVR-12 mental from pretreatment	4.53 (0.25)*	3.75 (0.007)*

*P<0.01 at respective time-points compared to the SOS global registry. ASES: American Society of Shoulder and Elbow Surgeons, SE: Standard error, VAS: Visual analog scale, VR-12: Veterans-Rand 12-Item health survey, Δ: Change, SOS: Surgical outcomes system

significant (P < 0.001) improvement from pretreatment VAS pain, ASES shoulder function, and VR-12 physical and mental scores at both 1 and 2 years postoperation. Our LSS cohort was also statistically significant from the SOS global registry cohort with 38% improvement in VAS pain (P < 0.001), 20% improvement in ASES shoulder function (P = 0.006), 18% improvement in VR-12 physical, and 21% improvement in VR-12 mental scores (P < 0.001) at 2 years postoperation.

Both cohorts showed clinically significant improvement from pretreatment VAS pain (ΔVAS >1.4)[15] and VR-12 physical (ΔVR-12 physical >4.94)[16] scores at both 1 and 2 years postoperation. Only our case cohort yielded a clinically significant improvement from pretreatment ASES shoulder function scores at 1 and 2 years postoperation (ΔASES >11.4 points).[8] Neither cohort showed clinically significant improvement from pretreatment VR-12 mental (ΔVR-12 mental >5.99) scores at both 1 and 2 years postoperation.[16] Our LSS cohort also showed clinically significant improvement in VAS pain but not ASES shoulder or VR-12 scores compared to the SOS global registry.

Table 3 illustrates a subgroup analysis of various demographic, surgical, and patient-reported outcome data of 12 patients with partial rotator cuff tears, 45 with complete tears, and 17 with massive tears in our case cohort compared to the SOS global registry. There was no statistically significant difference in outcomes between the two surgeons in any subgroup analyses (P > 0.4). Subgroup analysis of partial tears resulted in a statistically significant 34% improvement in VAS pain at 2 years postoperation (P = 0.011) but nonsignificant 23% improvement in ASES shoulder function (P = 0.221), 15% improvement in VR-12 physical (P = 0.251) and 19% improvement in VR-12 mental scores (P = 0.245) compared to partial tears in the SOS global registry. Subgroup analysis of complete tears resulted in statistically and clinically significant 39% improvement in VAS pain at 2 years postoperation (P < 0.001), and statistically significant 18% improvement in ASES shoulder function (P = 0.024), 20% improvement in VR-12 physical, and 22% improvement in VR-12 mental scores (P < 0.001) compared to complete tears in the SOS global registry. Patients with massive rotator cuff tears in our cohort also yielded statistically and clinically significant (P = 0.001) 44% improvement in VAS pain, and statistically significant 23% improvement in ASES shoulder function (P = 0.011), 19% improvement in VR-12 physical, and 29% improvement in VR-12 mental scores (P < 0.001) at 2 years postoperation compared to all rotator cuff tears in the SOS global registry.

Independent predictors of success

Multiple linear regression was performed to identify any independent predictors of 2-year VAS, ASES shoulder function, or VR-12 score improvement in our entire 57 patients case cohort. Neither age, sex, the orthopedic surgeon, ASA score, payor mix, type of rotator cuff repair, number of anchors used, or Cofield classification of tear size were independent predictors for 2 years ΔVAS, ΔASES shoulder function, or ΔVR-12 scores. However, respective pretreatment baseline scores were found to be independent predictors [P = 0.026; Table 3].

Discussion

LSS practices have been previously implemented in a number of medical settings to effectively cut waste and improve overall value, including in orthopedics. However, they have not yet been implemented to optimize the postoperative recovery period following arthroscopic rotator cuff repair, and thus, there is no LSS protocol on how to effectively manage follow-up on an outpatient basis without increasing burden on patients or providers. In this study, the LSS approach implemented at our ACO resulted in 38% less pain and 20% improved shoulder

Table 3: Subgroup analysis of partial, complete, and massive rotator cuff tears in our case cohort

Variable	Partial tears ($n=12$)	Complete tears ($n=45$)	Massive tears ($n=17$)
Age, mean (SD)	47.3 (9.5)	53.6 (10.4)	53.5 (10.7)
Female, *n* (%)	6 (50)	26 (57.8)	9 (52.9)
ASA level, mean (SD)	2.4 (0.55)	2.1 (0.45)	9 (52.9)
Double-row, *n* (%)	3 (25)	13 (28.9)	6 (35.3)
TOE, *n* (%)	0	13 (28.9)	11 (64.7)
Rotator cuff anchors used, mean (SD)	1 (0)	3.0 (1.45)	4.5 (0.79)
VAS, mean (SE)			
Pretreatment VAS	6.45 (0.58)	6.50 (0.39)	6.78 (0.23)
2 years ΔVAS from pretreatment	5.23 (0.54)*	5.49 (0.37)*	5.64 (0.47)*
ASES shoulder function score, mean (SE)			
Pretreatment ASES function score	9.91 (1.63)	10.51 (0.75)	9.78 (0.49)
2 years ΔASES function from pretreatment	15.89 (2.50)	14.64 (1.01)*	15.41 (0.48)*
VR-12 physical and mental scores, mean (SE)			
Pretreatment VR-12 physical	36.53 (2.57)	32.87 (1.05)	31.10 (0.73)
Pretreatment VR-12 mental	49 (1.48)	45.13 (1.81)	44.08 (1.41)
2 years ΔVR-12 physical from pretreatment	13.72 (2.72)	15.10 (1.77)*	14.88 (1.84)*
2 years ΔVR-12 mental from pretreatment	4.30 (0.62)	4.61 (2.02)*	4.82 (0.59)*

*$P<0.05$ at respective time-points compared to the SOS global registry. Partial and complete tears in our cohort were compared to 1445 partial and 3188 complete tears in the SOS global registry respectively; massive rotator cuff tears in our cohort were compared to all rotator cuff tears in the SOS global registry which did not stratify according to tear size. VAS: Visual analog scale, SD: Standard deviation, SE: Standard error, ASES: American Society of Shoulder and Elbow Surgeons, VR-12: Veterans-Rand 12-item, TOE: Transosseous-equivalent, ASA: American Society of Anesthesiologists

function at 2 years postoperatively compared to a global registry. Quality of life measures also improved by nearly 20% for both physical and mental health. Our LSS model improved patient outcomes in orthopedics through increasing patient-provider interactions while simultaneously reducing physician workload.

Both cohorts showed clinically significant improvement from pretreatment VAS pain and VR-12 physical scores at both 1 and 2 years postoperation,[15,16] but only our case cohort yielded a clinically significant improvement from pretreatment ASES shoulder function scores at 1 and 2 years postoperation.[8] When compared to the control global benchmark, our LSS cohort yielded statistically and clinically significant improvement in pain, and a statistically significant improvement in shoulder function and quality of life scores. These findings suggest that our LSS Kanban board tool can subjectively improve pain and shoulder function for patients.

Our secondary objective was to conduct a subgroup analysis to evaluate if this LSS tool would result in similar improvement in patients with partial, complete, or massive rotator cuff tears compared to the SOS global registry. Our case cohort compared favorably to the SOS global registry when stratifying for each of these tear types. Partial tears in our cohort resulted in statistically significant improvement in pain but not ASES or VR-12 scores compared to partial tears in the SOS global registry, likely a result of the smaller sample and effect size in our cohort. Complete tears in our cohort resulted in statistically and clinically significant improvement in pain, and statistically significant improvement in shoulder function and quality of life scores compared to complete tears in the SOS global registry. A majority of complete tears underwent either double-row or transosseous-equivalent (TOE) rotator cuff repair, compared to partial repairs that primarily underwent single-row repair.

Nearly 30% of the rotator cuff tears in our case cohort were massive tears according to the Cofield classification, substantially higher than the prevalence found in other studies.[17] Pretreatment pain was higher, while shoulder function and quality of life measures were lower than the remainder of our case cohort and the global registry [Table 3]. A majority of these patients received TOE rotator cuff repair due to surgeon preference and the theoretical biomechanical advantage in these repairs, although historically, there has been minimally reported differences in most outcomes.[18-20]

Optimal treatment of massive rotator cuff tears is controversial; however, it is possible to repair these severe tears in certain patients, especially in younger populations like our cohort that require higher activity levels or work manual labor, making reverse shoulder arthroplasty not as desirable.[21] Because of the difficulty in repairing massive rotator cuff tears, it becomes critical to optimize the surgical recovery period to improve patient outcomes. Our LSS approach to the surgical recovery period in massive tears resulted in the greatest improvement in pain control compared to the rest of the case or control cohorts, as well as a statistically significant improvement in shoulder function and quality of life measures compared to the global registry.

Our tertiary objective was to identify any variables that are independent predictors of success. A multiple linear regression was conducted to identify any predictors of improved patient outcomes utilizing our LSS approach. Higher pretreatment baseline pain scores and lower baseline ASES shoulder

function and VR-12 physical scores were associated with greater improvement at 2 years in our case cohort. The case cohort had statistically significant higher preoperative pain scores and lower functional baselines at the time of surgery, indicating a potentially at-risk patient population undergoing shoulder arthroscopy at our ACO. Furthermore, our 57 patient cohort consisted of 12 (21%) partial tears, 45 (79%) complete tears, and 17 (29.8%) massive tears compared to 31.2% partial tears and 68.8% complete tears in the SOS global registry, suggesting more severe injuries in our case cohort. This information suggests that our LSS tool may be potentially more effective with worsening injury severity and more at-risk patient populations. In addition, 37% of our patients were also on Medicaid/Medicare, substantially higher than the average across the nation, according to various government sources.[22]

Considering these at-risk populations, it has been estimated that low health literacy accounts for about $100 billion in health-care costs annually,[23,24] while being associated with increased hospitalizations and postoperative length of stay, greater use of emergency care services, and decreased likelihood that medications are taken correctly.[25,26] Recognizing the communication barriers that prevent maximal patient recovery,[4,5,8] our Kanban board system broke down the recovery period into smaller, procedural-based time checkpoints that allotted more patient-provider interactions to ask important questions while reducing the burden on physicians, who historically create the most value for patients and health systems. This was emphasized in the 2018 American Medical Association's National Economic Impact of Physicians Report.[27]

Previous studies have demonstrated how increased communication in the surgical recovery process can enhance recovery time and patient compliance.[11] Our LSS approach enabled athletic trainers to ask about wound healing, pain management, adherence to home exercise and physical therapy regimens, and reminded patients of their next appointment. Patients could ask questions multiple times throughout the recovery process, with only questions pertaining to the surgery or their medication regimen relayed to the physician, minimizing the additional time burden. Medication lists, especially after operations, are a common source of confusion for both providers and patients,[28] and could now be extensively reviewed for patients by our athletic trainers. Athletic trainers completed a full medicine reconciliation at the patient's preoperative visit or via phone, saving our physicians time and providing them with an up-to-date list to reference when prescribing pre and postoperative medications. Athletic trainers could view the patient's prescribed postoperative regimen, allowing them to verify that the patient's received the correct prescriptions and were taking their medications as prescribed. We believe that all of this can be reviewed thoroughly while increasing efficiency for our surgeons.

Untreated postoperative pain, especially outside of the immediate postop period, has also been shown to be a significant negative predictor of outcomes.[28] This often prevents patients from engaging in their physical therapy and home exercise regimen, which is important for functional improvement. Our framework allows us to monitor patient's pain throughout the perioperative period, ensuring they are adequately treated with minimally narcotic pain regimens and able to maximize their functional recovery. We believe this has likely contributed significantly to the improved pain and functional outcomes in our cohort, and is particularly important in our patients with massive rotator cuff tears. The findings of this study suggest that LSS approaches that effectively improve communication between patients and providers can improve patient recovery following arthroscopic rotator cuff repair.

Our study has several limitations. First, it is a single-center retrospective study in a limited population that may introduce selection bias and not be generalizable to other institutions. Our cohort size is significantly smaller than the global registry; however, our power analysis demonstrated that our study was well-powered given the large effect size in our cohort. Our results are also subject to nonresponse bias, given that not all participants in our case cohort completed their surveys. However, our survey compliance rate of 82% is sufficient and greater than the survey compliance rate of the SOS global registry (58%), with nonresponse bias in the global registry potentially minimizing the true difference between our case cohort. Our improved communication framework could explain why patient survey compliance was significantly higher in our cohort during the study period, which we believe is actually encouraging to help maintain follow-up when treating at-risk patient populations. Given that patients know they were enrolled into SOS for potential research purposes, observation bias may have also played a role in our study. In addition, our findings are subject to confounding, with our cohort being significantly smaller than the global registry. Although we were able to classify the tear size, type of rotator cuff repair (single vs. double row vs. TOE), and concurrent injuries/procedures in our cohort, as well as stratifying our subgroup analysis, these clinical characteristics and subsequent postoperative protocols could not be determined from the SOS global registry.

Despite this, a large number of complete and massive rotator cuff tears and the worse pretreatment scores in our cohort make it likely that we were dealing with a more at-risk population than the global registry. There is no known LSS surgical recovery protocol reported in the literature, and our postoperative protocols at our ACO are unique from what's common throughout shoulder arthroscopy. The SOS global registry has also been used as a benchmark in a number of previous studies,[9,10] so there is precedent for using it for research purposes. Given that our study was well-powered and the intention of this study was to simply illustrate how LSS practices can be utilized to improve orthopedic patient outcomes in the postoperative period and reduce burden on physicians, further analysis of the global registry was not warranted at this time.

Overall, the employment of athletic trainers to operate the Kanban board at a low cost, while minimally impacting physician workload, helped improve the surgical recovery period for rotator cuff repair patients at our ACO. These LSS tools could be tailored to individual practices and procedure-specific timelines could be further delineated to increase overall value at health-care institutions.

Conclusions

Overall, the employment of athletic trainers to operate the Kanban board at a low cost, while minimally impacting physician workload, helped improve the surgical recovery period for rotator cuff repair patients at our ACO. Our LSS approach yielded clinically significant 38% less pain and 20% improved shoulder function at 2 years post-operation compared to a global registry. Quality of life measures also improved by nearly 20% for both physical and mental health. Our LSS model improved patient outcomes following arthroscopic rotator cuff repair.

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Conflicts of interest

There are no conflicts of interest.

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Technical Note

Modified All-Arthroscopic Metal-Free Latarjet with Cerclage Tape for Recurrent Shoulder Dislocation with Critical Glenoid Bone Loss: Technical Note

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Abstract

Latarjet procedure involving coracoid bone transfer has been the preferred method of treatment for anterior shoulder instability with critical glenoid bone loss, failed Bankart repair, severe soft tissue insufficiency, bipolar bone lesions, and young patients involved in contact sports. Screw-related complications were the most common reason for revision surgery following the Latarjet procedure. We describe an all-arthroscopic method of Latarjet procedure with cerclage fiber tape (Arthrex) and a modified technique for performing the procedure in this technical note.

Keywords: Coracoid graft, fiber tape, Latarjet

Introduction

Latarjet procedure has been widely performed shoulder stabilization procedure for recurrent shoulder instability with significant glenoid bone loss more than 15%, previous failed Bankart repair, severe soft tissue insufficiency, bipolar bone lesions, and in young contact athletes.[1-4]

The arthroscopic Latarjet procedure was described by Laurent Lafosse in 2007 with two metal screws.[5] Less postoperative pain, quicker recovery, and improved cosmetics were some of the benefits of the arthroscopic approach.[6] Similar results to the open Latarjet with arthroscopic Latarjet treatment were reported by many surgeons.[7,8]

Latarjet procedure has its share of disadvantages, the majority of drawbacks are related to metal screws used for stabilizing the bone block.[9] Drawbacks related to metal screws were screw pullout, loosening, breakage, intra-articular hardware, graft fracture, and osteolysis around screws. Recently, the Latarjet procedure using cerclage fiber tapes (Arthrex) was developed to avoid metal-related complications.[10] We describe an all-arthroscopic Latarjet procedure with cerclage fiber tape (Arthrex) and a modified technique using the instrumentation (Depuy-Mitek) used for arthroscopic screw Latarjet as described by Lafosse in this technical note. Video illustration of the technique is shown in Video 1.

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Surgical Technique (with Video Illustration)

Preoperative assessment

The patients with recurrent anterior shoulder dislocation are assessed with three-dimensional computed tomography and magnetic resonance imaging. The amount of glenoid bone loss and glenoid track is measured using best fit circle method from "en face" view of glenoid with humeral head suppression. The Hill–Sachs interval is measured from axial computed tomography scan and compared with previous measured glenoid track to assess if Hill–Sachs lesion was engaging or nonengaging lesion. When the estimated glenoid bone loss is more than 15%, arthroscopic Latarjet procedure is preferred.

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Patient positioning and portal placement

The patient is positioned in a beach chair position under general anesthesia with an interscalene block. The arm is prepped and draped held by traction cable with the shoulder in 60° anterior elevation, 10° shoulder abduction and neutral rotation [Figure 1].

Portal placement

A portal

Standard posterior portal known as soft spot, 2 cm medial and inferior from the posterolateral corner of the acromion. Used for visualization and passing switching stick for subscapularis split.

E portal

In the rotator interval, made with the outside-in technique just above the lateral half of subscapularis.

D portal

Lateral Portal made anterior to the long head of the biceps-used for instruments during coracoid preparation and coracoid osteotomy. Also used for visualization during the shoulder's anterior access, exposure, subscapularis split, and fixation of the graft.

H portal

Anterosuperior portal above coracoid. Used for coracoid drilling and coracoid osteotomy.

J portal

Anteroinferior portal above subscapularis. Used for visualization during the preparation, osteotomy, and transfer of the coracoid graft.

I portal

Ancillary Portal. Used to make the subscapularis split, also used for visualization during the preparation of the coracoid holes.

M portal

Anterior Portal made medial to the conjoint tendon. Used for the double-barrel coracoid positioning cannula. Portal placements used for arthroscopic Latarjet is shown in Figure 2.

Steps in arthroscopic cerclage tape Latarjet using instrumentation for screw Latarjet (Depuy-Mitek):

1. Diagnostic arthroscopy and rotator interval exposure
2. Coracoid exposure and preparation
3. Coracoid holes drilling
4. Coracoid osteotomy, mobilization and capture using coracoid positioning cannula
5. Subscapularis split
6. Glenoid preparation and coracoid transport through subscapularis split
7. Glenoid tunnel drilling, passing cerclage tapes and coracoid fixation.

Diagnostic Arthroscopy and Rotator Interval Exposure

Diagnostic arthroscopy is performed through the posterior A portal and associated intra-articular pathologies are assessed. Any intra-articular pathologies like SLAP lesions are addressed. Anterior E portal is made with outside-in technique and the probe passed through rotator interval tissue. Glenoid and humeral defects (Hill–Sachs lesion) are assessed and remplissage of the Hill–Sachs lesion is done in all patients. Final tightening of the remplissage sutures is done after fixation of coracoid graft as the final step. The capsulolabral tissue is reflected and detached from the glenoid surface from 3 to 6 o'clock position using Radiofrequency ablator (Arthrocare) exposing the undersurface of the subscapularis. The elevated capsulolabral tissue is stitched with cinch sutures and kept in place for later fixation of capsulolabral complex to glenoid. Exposure of rotator interval is made till proper visualization of the coracoid.

Coracoid Exposure and Preparation

With portal A as visualizing portal and portal E as the working portal, the coracoacromial ligament is traced and detached from the coracoid. The undersurface of the

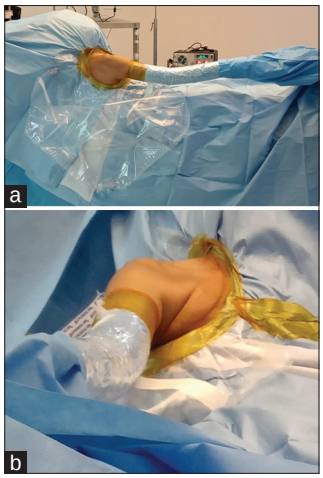

Figure 1: Right shoulder, Beach-chair position. (a and b) Patient positioning for arthroscopic Latarjet procedure

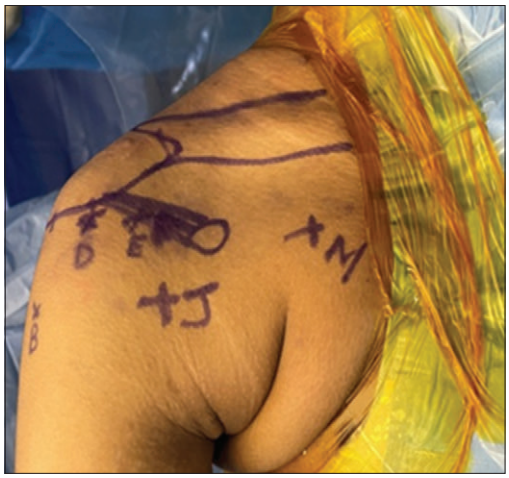

Figure 2: Portal placements while performing arthroscopic Latarjet procedure

coracoid is skeletonized of attached tissue. The visualization portal is shifted to portal D and working from portal E, the superior aspect of the coracoid is freed of all soft tissue attachments. The conjoined tendon is visualized and the lateral part of the conjoint tendon is released from the overlying deltoid fascia. The undersurface of the coracoid is prepared with the arthroscopic burr.

Portals I, J, M are determined using long spinal needles under visualization from Portal D. The switching stick is used to elevate the deltoid from Portal D to expose the coracoid visualizing from Portal J. The Pectoralis minor attachment to the medial part of the coracoid is released taking care of the brachial plexus branches beneath the bursa working from Portal M [Figure 3].

Coracoid Holes Drilling

The H portal is defined with a long spinal needle and the coracoid was drilled through the H portal visualizing from Portal J. We use the Depuy-Mitek coracoid drill guide, introduced through Portal H, which has two drill slots for the alpha and beta holes which are used for arthroscopic screw Latarjet. The guide is placed parallel to the coracoid between the junction of lateral two thirds and medial one-third of the coracoid. The two k wires are drilled through the alpha and beta holes making sure to visualize the undersurface of the coracoid to avoid over drilling. The over drilling of alpha and beta holes is done through the previously placed k wires. We tap the drill holes for helping in further capture of coracoid with positioning cannula.

Coracoid Osteotomy, Mobilization, and Capture using Coracoid Positioning Cannula

Visualizing from Portal J, the coracoid is osteotomized using the DePuy coracoid curved osteotome through the H portal. The osteotome is used and controlled osteotomy is carried out. The H portal is plugged to prevent outflow with gauze pack. The harvested graft is captured with a coracoid positioning cannula using two 3.5 mm coracoid screws through the two cannulas in the positioning cannula. The positioning cannula is introduced through Portal M and always stays in the same portal. The screws are fully tightened until they penetrate the alpha and beta holes with final tightening done with a 4 mm screwdriver. Visualizing from Portal J, the medial spike of the osteotomized coracoid is trimmed using bone nibblers and burr introduced through Portal D. The graft is held stationary with a positioning cannula in the Portal M. The undersurface of the coracoid is also prepared to match the glenoid bed so that good bone contact can be obtained [Figure 4].

Subscapularis Split and Glenoid Bed Preparation

Visualizing from Portal J, a walking stick is passed from posterior A portal at the level of 6 o clock position and advanced through subscapularis to establish the level of the split. The Subscapularis is intended at the level of superior 2/3rd and inferior 1/3rd of the muscle. Subscapularis is split from the anterior aspect at the level of the walking stick till the exposure of the underlying glenoid through Portal I. An assistant holds the walking stick in place to retract the conjoint tendon along with the brachial plexus until the subscapularis split is established. The glenoid neck is visualized and the

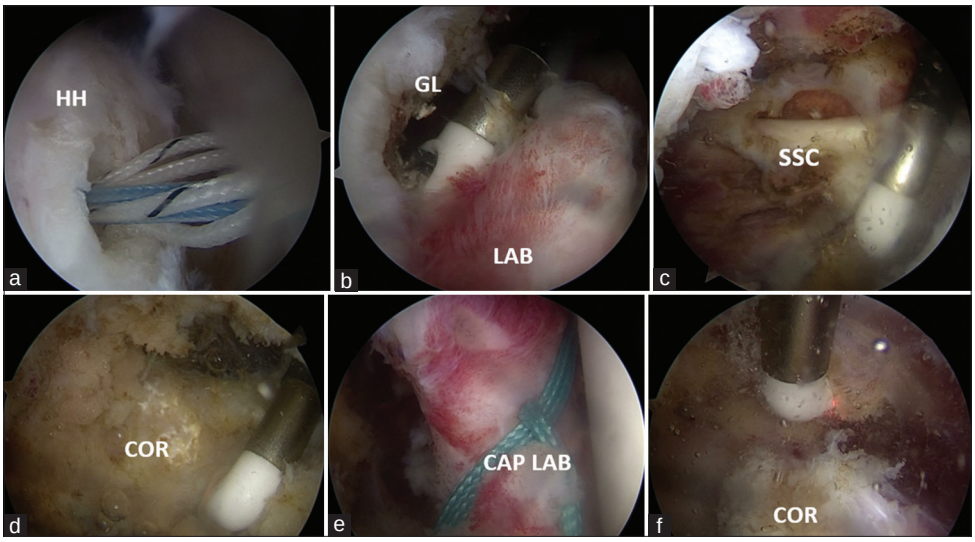

Figure 3: (a) The Hill–Sachs lesion was addressed with remplissage with a triple loaded suture anchor through posterior portal, working from accessory posterior portal. (b) The capsulolabral complex was detached from glenoid neck visualizing from posterior portal and working from anterior portal. (c) The superior capsule and presubscapularis tendon space was released with an ablator visualizing from posterior portal and working through the anterior portal. (d) The rotator interval was exposed and coracoid was freed of all soft tissue attachment with ablator working from anterior portal and visualizing from posterior portal. (e) The capsulolabral complex was held with a cinch suture working through the anterior portal. (f) The pectoralis minor tendon was visualized from J portal and detached with radiofrequency probe working from M portal. HH: Humeral Head, GL: Glenoid, COR: Coracoid, CAP LAB: Capsulolabral complex, SSC: Subscapularis

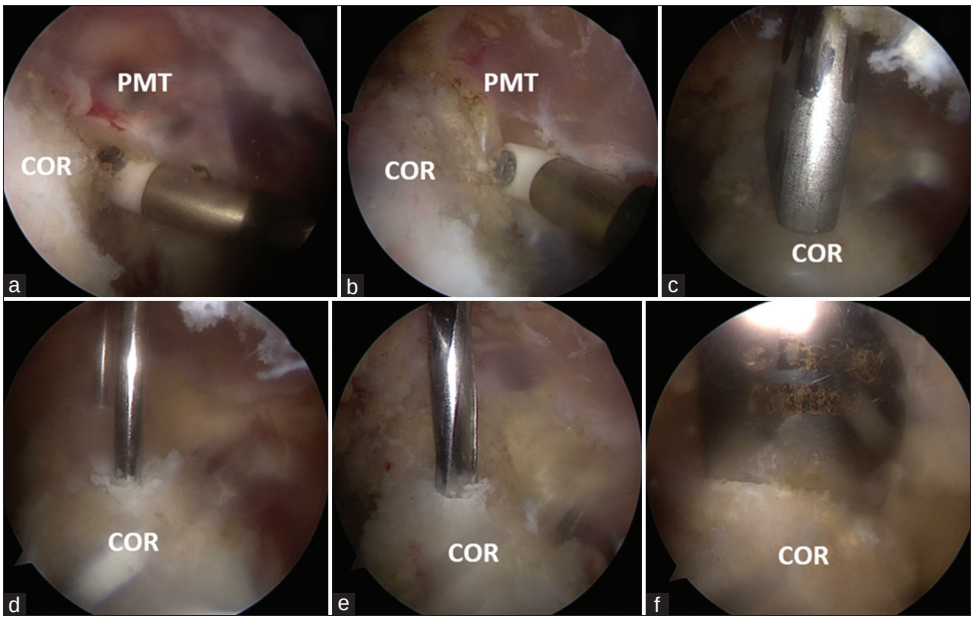

Figure 4: Right shoulder, Beach-chair position, Arthroscopic view, 30° scope. (a and b) The pectoralis minor tendon was detached from the medial part of coracoid working from M portal visualizing from J portal. (c) Coracoid drilling done with specific jig through H portal. (d) K wires drilled through both alpha and beta holes. (e) Over drilling done over the k wires. (f) Coracoid osteotomy done with osteotome (Depuy Mitek). PMT: Pectoralis minor tendon, COR: Coracoid

glenoid bed is prepared with the burr at the intended site of coracoid fixation.

Glenoid Tunnel Drilling, Passing Cerclage Tapes, and Coracoid Fixation

The coracoid graft controlled with positioning cannula is transferred through the subscapularis split after ensuring the conjoint tendon was fully released from the Pectoralis minor and placed over the desired position on the glenoid. The graft is secured with two beath pins with suture eye drilling from anterior to posterior direction through the positioning cannula, superior beta hole, and inferior alpha hole, exiting the posterior aspect of the shoulder. The Nitinol wire loop is passed through a beath pin in the beta hole from the anterior to posterior direction exiting the posterior aspect of the shoulder. One end of the cerclage tape (Arthrex, Naples FL, USA) is transferred from the posterior to anterior direction exiting the anterior surface of the shoulder through the nitinol wire loop. Another Nitinol wire loop is passed through the beath pin in the alpha hole from the anterior to posterior direction exiting the posterior aspect of the shoulder. The already transferred end of the cerclage tape is passed through the nitinol wire loop from the anterior surface of the shoulder and taken out through the posterior aspect of the shoulder. Soft tissue dissection is performed up to glenoid neck to avoid soft tissue interposition while tying the cerclage tape. Both the ends of the cerclage tape are secured from the posterior aspect of the shoulder and the looping of the cerclage tape is done as per the protocol.

Final Fixation, Capsulolabral Fixation, and Tightening of the Remplissage

The cerclage tape is interconnected and tensioning is done with the tensioning device to achieve a maximum tension of 80N, over-tensioning may result in graft fractures. The final construct is visualized ensuring proper bony contact between the coracoid and glenoid neck and also there is no slack in the cerclage tape construct. The entire process of tightening of cerclage tape is visualized from the portal J. The capsulolabral tissue is anchored to the glenoid face with a 2.7 mm Arthrex push-lock leaving the coracoid in an extra articular position. The tightening of the remplissage suture anchors is done as the final step. The modifications done are glenoid drill holes were made using the positioning cannula with free hand technique instead of the glenoid drill jig. The final construct is visualized ensuring proper bony contact between the coracoid and glenoid neck and also there is no slack in the fiber tape construct. Remplissage sutures are tightened as blind procedure in final step [Figure 5]. Preop and 3 months post op CT scans demonstrating good union of coracoid graft is shown in Figure 6. Tips and pitfalls of the technique is given in Table 1.

Discussion

Arthroscopic Latarjet using metal screw was popularized by Lafosse providing good clinical outcomes with less postoperative morbidity. Dumont *et al*. demonstrated lower rates of recurrent instability in follow-up with arthroscopic Latarjet when compared to open Latarjet procedure.[11]

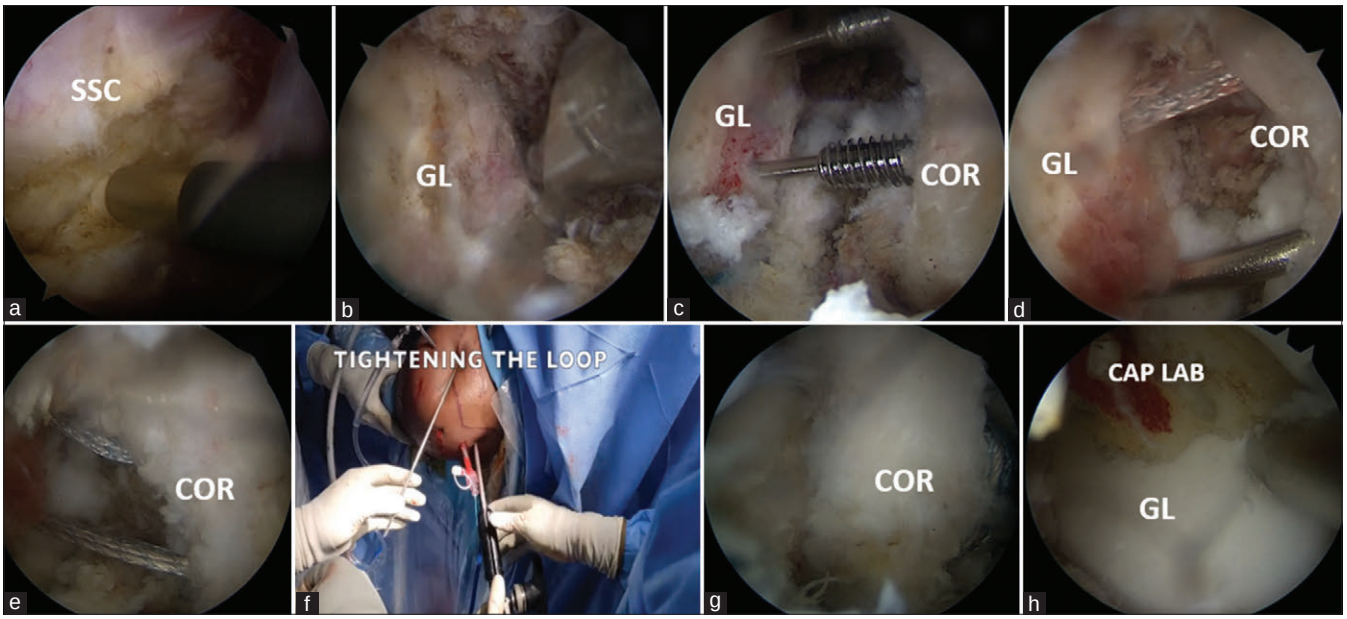

Figure 5: Right shoulder, Beach-chair position, Arthroscopic view, 30° scope. (a) Subscapularis split done working from M portal and visualizing from J portal. (b) Glenoid bed prepared with burr to receive the coracoid graft working from M portal and visualizing from J portal. (c) Drill holes made in glenoid bed and coracoid graft kept in place through M portal, visualizing from J portal, K wires drilled in glenoid bed and over reaming done working from M portal, visualizing from J portal. (d) Cerclage tape passed from posterior to anterior direction through beta hole working from M portal and visualizing from J portal. (e) Cerclage tape also passed from anterior to posterior direction through alpha hole working from M portal and visualization from J portal. (f) Tightening of cerclage tape using tensioning device from posterior portal. (g) Well reduced coracoid graft visualized from J portal. (h) Capsulolabral complex reattached with 2.7 mm push lock (Arthrex, Naples FL, USA). COR: Coracoid, CAP LAB: Capsulolabral complex, GL: Glenoid, SSC: Subscapularis

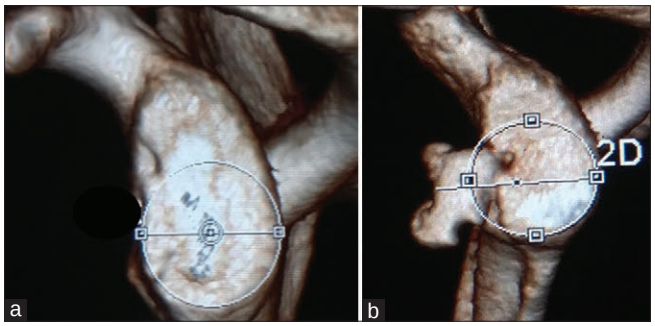

Figure 6: (a) preoperative CT scan with glenoid bone loss. (b) 3 months follow-up CT after surgery demonstrating well positioned and united coracoid graft. CT: Computed tomography

Complications following the Latarjet procedure were studied and incidence rates were similar in both open and arthroscopic methods.[9,12] Complications reported were screw related, graft related, neurological injuries, infection, and early arthritis of the joint. Pereira *et al*. reported a higher percentage of screw-related complications which included screw breakage and loosening, screw bending, impingement related to longer screw length, intra-articular screw placement, and hardware removal surgeries in future.[13] Considering higher rates of screw-related complications, alternative methods of graft fixation were described. Buttress plates, bioabsorbable screws, cortical buttons, and cerclage fiber tape were various other fixation devices used instead of metal screws.[14-16]

Arthrex miniplate fixation ensured good union rates in young patients with failed Bankart repair, but needed extensive dissection, difficulty while using the arthroscopic approach, and also soft tissue irritation. The risk of glenohumeral arthritis persisted with this fixation device.[16]

Fixation using bioabsorbable interference screws was tried but the increased risks of redislocation were reported by Weppe *et al*. They also reported less fixation strength when compared to cortical screws.[15] Cortical endobuttons provided good initial outcomes but the chances of redislocation were higher when compared to screw fixation.[14] To avoid all these complications and to ensure metal free fixation when providing the triple effect of the Latarjet procedure, cerclage tape fixation (Arthrex) was developed.[10] However, long-term follow-up studies of cerclage tape fixation are still pending.

We described all-arthroscopic cerclage tape fixation using the specific instrumentation (Depuy-Mitek) which has the following advantages. The surgeons using this instrumentation for arthroscopic screw Latarjet in their practice can have an easy transition to cerclage tape fixation with our technique. The graft can be easily positioned at the desired level with the positioning cannula ensuring correct tunnel placement in the glenoid as we drill the tunnel through the already made coracoid drill holes. We improvised the screw Latarjet procedure by avoiding larger diameter drills in the glenoid tunnels, avoiding top hat insertion as we do not aim for graft

Table 1: Tips and pitfalls of the technique

Tips
Good preparation of under surface of coracoid and trimming of the medial spike of coracoid graft done to ensure good bony contact and also prevent coracoid graft fracture while tensioning
Capsulolabral tissue is held with cinch sutures before subscapularis split, this helps as traction suture avoiding improper visualization of glenoid surface
Using the Depuy-Mitek drill guide for coracoid drilling ensures proper placement of drill holes and also an adequate distance between two holes
Use of coracoid positioning cannula helps in rigid control of the graft and also in its transfer and correct positioning over the glenoid
Drilling through the positioning cannula helps in obtaining optimal parallel tunnel position
Assistant holding the switching stick while subscapularis split provides proper retraction of the subscapularis
The capsulolabral tissue can be anchored to the native glenoid with a 2.7 mm Arthrex push lock
Pitfalls
Good knowledge of surgical anatomy and the long learning curve of the arthroscopic technique is needed for excellent outcomes
Proper placement of the coracoid drilling jig is necessary to get a good hole position in the coracoid
Capture of coracoid without chia wires needs good surgical expertise
Proper visualization of graft positioning is needed to ensure optimal tunnel position in the glenoid
Exchange of fiber tape with help of bead pin needs proper visualization to prevent suture slack and unnecessary knots of the tape
Risk of injury to brachial plexus while using M portal for coracoid transport and also suprascapular nerve when glenoid drilling is done
Risks and limitations of this technique
Steep learning curve is needed for performing the arthroscopic Latarjet procedure
Surgeon should be well versed in the surgical steps of arthroscopic screw Latarjet
Need for specific jigs and cannula and adequate knowledge of its usage
Slightly larger tunnel diameter, when compared to conventional glenoid jig assisted cerclage tape fixation

compression as in screw Latarjet and capturing the coracoid with positioning cannula using freehand instead of CHIA wires. The incidences of coracoid graft fractures are less with cerclage tape as tensioning is done up to 80N with the tensioner. We also used the same arthroscopic portals as described by Lafosse.

The proximity of the suprascapular nerve and posterior exit site of the glenoid tunnel poses a threat to the injury of the nerve. The distance between the nerve and the posterior exit site was measured only 4 mm.[17] The potential suprascapular nerve injury can be avoided by placing the tunnels within 10° of the glenoid face in the axial plane.[18] In our technique, we drilled through the prepared coracoid drill holes ensuring parallel glenoid drill placement avoiding tunnel malpositioning. The coracoid transfer through subscapularis split was relatively easy when using the positioning cannula. Solid fixation of graft to the positioning cannula made coracoid under surface decortication and contouring to match the glenoid bed easy.

Conclusion

All-arthroscopic Latarjet procedure with cerclage tape (Arthrex) using arthroscopic screw Latarjet (Depuy-Mitek) instrumentation is easy and reproducible while providing sturdy fixation with tensioning up to 80N. The advantages of the arthroscopic approach with less surgical dissection, small scars, less postoperative pain, and early rehabilitation combined with stable fixation and rotational control of the graft are obtained in our technique.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Case Report

Regeneration of a Discoid Meniscus after Saucerization, Reinsertion of the Anterior Segment, and Platelet-Rich Plasma Injection in a 17-Year-Old Girl

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Abstract

Discoid lateral meniscus is relatively common in children. Surgical intervention is indicated for symptomatic discoid menisci. We present the case of a symptomatic complete, anteriorly disinserted, discoid lateral meniscus of the left knee in a 17-year-old girl to whom arthroscopic saucerization to reshape the meniscus, plus reinsertion of the anterior segment and platelet-rich plasma injection on the residual rim, was performed. Articular rigidity and swelling marked the initial rehabilitation for an abnormally slow initial recovery. Six months after surgery, a new magnetic resonance imaging was done, which indicated regeneration of the discoid meniscus. Therefore, a new arthroscopy was proposed. We observed a complete regrowth of the remnant reshaped meniscus, which restored the preoperative state. To our knowledge, this is the third report about the regrowth of a discoid meniscus after surgery. Nonetheless, complete discoid meniscus regrowth at such a late age had not been previously reported. This case report demonstrates discoid meniscus regrowth in a young adult.

Keywords: Arthroscopy, discoid meniscus, platelet-rich plasma, regeneration

Introduction

Discoid meniscus is the most frequent congenital malformation of the menisci and primarily affects the lateral meniscus. Surgical treatment for discoid meniscus is recommended in cases with persistent symptoms, such as pain, blockage, edema, or limitation of sports activities. Currently, the main goal of treatment is to preserve a stable meniscus with anatomy as close as possible to that of a normal meniscus. Aiming to maintain its function of absorbing and distributing loads.[1]

We present a case of a symptomatic discoid lateral meniscus of the left knee in a 17-year-old girl to whom arthroscopic saucerization was performed and later presented with complete meniscus regrowth of the remnant. The literature reported spontaneous regeneration of a partially resected lateral discoid meniscus on two other occasions.[2,3]

This is the first report of discoid meniscus regrowth on a 17 year old associated with platelet-rich plasma (PRP) injection.

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Case Report

A 17-year-old girl presented to our clinic with a 1-month history of recurrent pain and instability in her left knee. No prior trauma was reported, and the patient had no relevant medical history. She also complained about recurrent painful "clunks" when squatting. Despite being active, she was forced to stop dancing because of her knee pain. The patient did not report any complaints on the right side.

A physical examination of her left knee showed a limited and painful range of motion (0°/120°). At exploration, a visible

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and palpable tibial snapping was detected when changing from extension to flexion. McMurray's, Thessaly's, and Apley's tests were positive and reproduced the pain. No apparent quadriceps atrophy was seen.

An initial magnetic resonance imaging (MRI) was done, and an abnormally thickened bow-tie appearance of the lateral meniscus was observed, which suggested a complete anterolateral disinserted discoid meniscus variant. The MRI also informed of a complex tear, a posteromedial shift of the meniscus, and a closed physis. Altogether classified as a Type C (posterocentral shift) by Ahn *et al*.[4] [Figure 1].

The senior author performed an arthroscopic partial meniscectomy (saucerization) of the lateral discoid meniscus and reinsertion of the anterior segment of the left knee to relieve pain and restore function. A functional residual rim of 8 mm [Figure 2] was left. Using an out-in technique with three points of anchorage to the capsule using a FiberWire® (Arthrex) to reattach the anterior horn to the anterior capsule. PRP (Endoret® PRGF® Biotechnology Institute) was injected on the resected margin under arthroscopic vision and intra-articularly.

Orthosis was applied during the 1st month. Physical therapy began after orthosis removal with isometric exercises. Progressively, partial to total weight-bearing was allowed after orthosis removal.

Surprisingly, the postoperative course was marked by swelling and articular rigidity. The pain was elicited at the lateral compartment with passive and active movement. Possible causes included an allergic reaction to suture material or cutaneous nerve entrapment during menisci capsular repair. Furthermore, bleeding could have been due to a capsular breach during repair out-in-repair.

Seven months after surgery, in the fifth scheduled follow-up visit, symptoms that now resembled the ones found before the operation were observed with the addition of rigidity. The onset of the recurring symptoms was subtle as the range of movement and swelling improved. The patient did not report any trauma. The patient had not yet returned to physical activities, and we opted for a new MRI. Imaging of the left knee showed a complete discoid lateral meniscus, with a different signal intensity than the original one [Figure 3], and no associated tears, disinsertion, or displacements.

The second arthroscopy of her knee confirmed the regrowth of the remnant lateral meniscus. No tear, displacement, nor disinsertion was detected. Arthroscopic examination revealed what appeared to be a grossly healthy meniscal tissue regenerated in the area of the previous saucerization, recreating a discoid meniscus [Figure 4]; the anterior horn was correctly reinserted with no tears. Further probing showed that the regenerated tissue was characteristic of normal meniscal

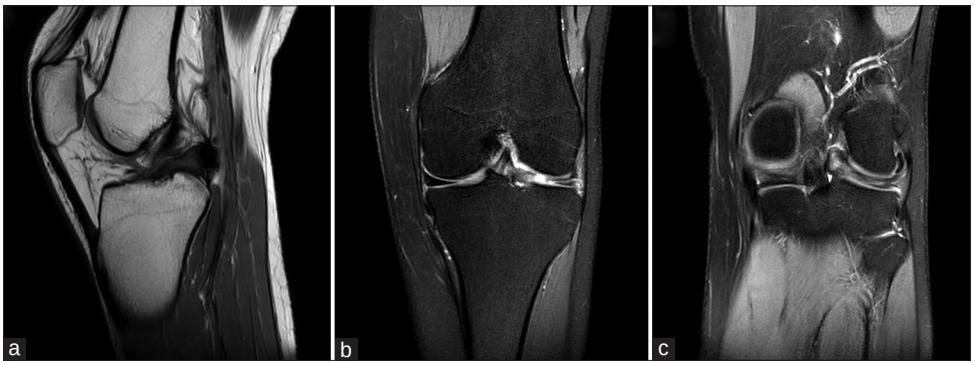

Figure 1: Preoperative MRI imaging of the left knee showing a lateral discoid meniscus with a complex tear with posterocentral shift (Ahn C)[4] (a) Sagittal T1-weighted showing posterior displacement of the lateral discoid meniscus. (b) Coronal T2-weighted MRI imaging showing a complex tear. (c) Coronal T2-weighted MRI imaging showing medial displacement. MRI: Magnetic resonance imaging

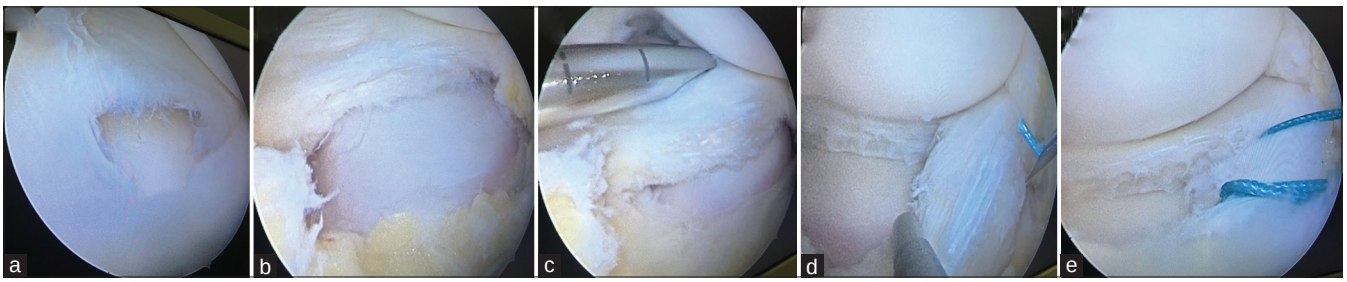

Figure 2: Arthroscopic images from the first procedure showing the lateral discoid meniscus. (a) Complete DM's and an anterior gap indicating anterior disinsertion. (b) The anterior gap after the cruentation of the meniscus using a shaver and an associated degenerative horizontal tear. (c) Regularization of the anterior segment with a shaver and visualization of intended reduction before fixation. Anterior disinsertion and gap. Saucerization of the central aspect of the meniscus. (d) Reduction of the anterior segment before reinsertion with FiberWire® (Arthrex) with 3 out-in points. (e) Final fixation and functional residual rim (7–8 mm). DM: Discoid meniscus

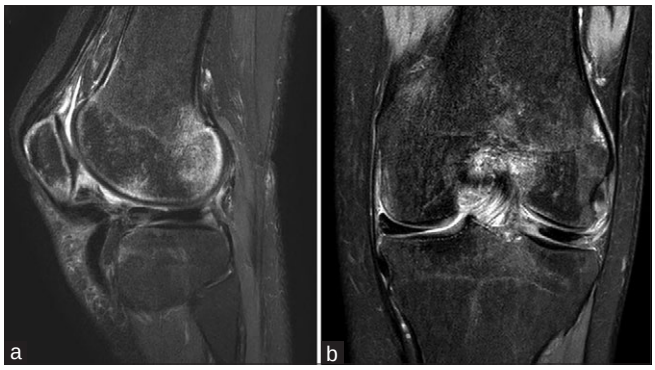

Figure 3: MRI imaging of the left knee after the first lateral discoid meniscus resection. (a) Sagittal T2-weighted MRI shows no displacement of the regenerated lateral discoid meniscus. (b) Coronal T2-weighted MRI imaging showing a centered round meniscus with no displacement nor disinsertion. MRI: Magnetic resonance imaging

tissue. A new saucerization was performed, leaving a functional residual rim of 6–8 mm. PRP was not injected this time.

This time, the postoperative course was uneventful, rehabilitation followed protocol, and the patient reported complete relief of symptoms. Follow-up MRI showed no signs of discoid meniscus (DM's) regrowth. The patient returned to physical activities without any restriction after 3 months. We are still following up on the patient.

When this manuscript was submitted, she was 20 years old, and over 24 months had elapsed since the second operation.

Discussion

As far as we know, only two other scientific articles have reported spontaneous regeneration of a partially resected lateral discoid meniscus. One report was on a 5 years old and the other on an 11 years old; both cases were treated during developmental ages, and a growth spurt was proposed to have impacted meniscal regeneration.[2,3] In this case, regeneration occurred in a female young adult patient at 17 years old who had reached skeletal maturity. Hardly, physical growth might have had little to do with meniscus regrowth.

Surgeons treating meniscal lesions in children are concerned about removing too much tissue since this could promote degenerative osteoarthritis. Indeed, postmeniscectomy joint growth in children is fraught with the premature appearance of radiological signs of degeneration,[3] particularly in cases of lateral meniscectomy.[5,6] On the other hand, surgery aims to restore its crescent shape.[7-9] In our patient, the resection performed during the first operation was judged adequate [Figure 2].

These two questions are worth considering: Why did the lateral meniscus remnant regrow, returning to its discoid shape, after surgery? Did it have any relationship to the symptomatic postoperative course and PRP injection?

Descriptions from Clark and Ogden have provided an overview of the development of menisci in children; they

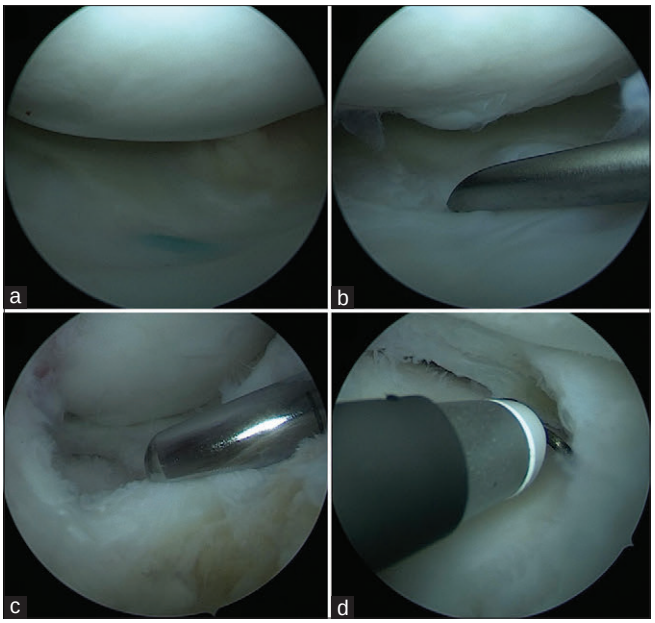

Figure 4: Arthroscopic images from the second procedure show lateral discoid meniscus. (a) Complete regeneration of the discoid meniscus, suture of reinsertion visible, without disinsertion. (b) Palpation of the central aspect with no visible tears. (c) Saucerization, recreating the anatomical meniscus. (d) Final regularization

described increased vascularity and cellularity that can be found throughout the inner parts of the menisci in patients aged 10–11 years, and it is progressively lost with aging.[10] This phenomenon has been proposed to explain why meniscus lesions in patients younger than 10 remain disproportionately low.[8] Petersen and Tillmann. reported on the development of meniscus blood vessels to explain that at the time of birth, nearly the whole meniscus was vascularized to progress as late as the second decennium when blood vessels occurred only in the lateral third.[11,12] Moreover, Inoue *et al*. reported a high concentration of blood vessels in the intercondylar region in cases of the complete discoid lateral meniscus in a group of six patients (aged 8–17 years).[13] More recently, Bisicchia *et al*. presented results contrary to those described above. In a sample of six patients (aged 9–18), they could not find any blood vessels in samples, but only from the 18-year-old patient.[14] These results propose vascular variability and question how, solely from a vascular perspective, the regrowth was possible. In retrospect, it would have been especially instructive to have the tissue resected and examined histologically, which has not yet been done in regenerated DM cases.

Despite an uneventful intervention, the patient presented an abnormal postoperative course with swelling and articular rigidity. This inflammatory response, which marked the 1st month, might have been what fostered or the consequence of the regeneration of the remnant meniscus. PRP injection might have also augmented and propitiated meniscus regrowth. The scientific rationale behind PRPs is the delivery of growth factors, cytokines, and adhesive proteins present in platelets and plasma, as well as other biologically active proteins

conveyed by the plasma, such as fibrinogen, prothrombin, and fibronectin.[15] Recent studies that have looked at PRP injected into the meniscus have proposed it to positively affect fibrochondrocyte migration, extracellular matrix production, cell viability/proliferation, and up-regulate gene expression of Aggrecan, Collagen type I, and Elastin.[16,17] Despite this, other authors have reported against its use and effectiveness.[18,19] Lately, it has been proposed that there is an extreme variability of PRP products used,[15,20] such lack of consistency might cause a disparity in reported results. With such controversial results, we cannot attribute regeneration to PRP, but we imagine it could have had an augmentation effect.

This case has significant relevance and implications for studying meniscal repair and regeneration after meniscal injury, particularly in the young population. The regrowth of the discoid lateral meniscus in our patient could favor the hypothesis of variant morphogenesis, where a regenerative process took place in a specific morphological scenario due to the patient's vascular variability fostered by a strong inflammatory response augmented by PRP injection.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given her consent for her images and other clinical information to be reported in the journal. The patient understands that name and initials will not be published and due efforts will be made to conceal identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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Case Report

A Rare Cause of Knee Pain and Swelling: Venous Malformation Masquerading as Diffuse Pigmented Villonodular Synovitis

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Abstract

This case report recounts the history of a 21-year-old patient who presented with a 19-year history of recurrent unilateral knee pain, swelling, and restricted movement. At age 10, the patient had a diagnostic knee arthroscopy which resulted in a provisional diagnosis of pigmented villonodular synovitis. The patient was treated for this condition for several years through medical and surgical means. Despite treatment, symptoms did not resolve. Only after the case was discussed by the multidisciplinary team was further imaging through ultrasound (US) suggested. A new diagnosis of venous malformation (VM) was made after US, and the patient was treated accordingly. This case report adds to the literature examining intra-articular VMs, the use of multimodal imaging in the diagnosis of intra-articular lesions of the knee, and the importance of multidisciplinary discussion in the diagnosis of complex knee pathology.

Keywords: Complex knee pathology, magnetic resonance imaging, multidisciplinary team, pigmented villonodular synovitis, venous malformation

Introduction

Pigmented villonodular synovitis (PVNS) is a benign tumor which affects the synovium in joints, bursae, or tendon sheaths, often causing inflammation.[1,2] It is characterized as either localized or diffuse. It is commonly seen from the third to fourth decade in males and females alike. The knee is a common site of occurrence in diffuse PVNS. It can present with symptoms of knee pain, swelling, and a restricted range of motion.[3]

Venous malformations (VMs) are benign vascular malformations that develop as a result of the dilatation of venous vascular compartments.[4] They are congenital lesions that rarely involve the knee joint. VMs present with vague clinical symptoms such as knee pain, swelling, and limited range of motion.[4] Intra-articular VM can cause recurrent hemarthrosis resulting in synovial pathology mimicking PVNS both clinically and histologically.

In this case report, we recount the history of a 21-year-old patient who was initially diagnosed and treated for diffuse PVNS of the right knee but later was found to have an intra-articular VM.

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Case Report

A 3-year-old girl presented to her General Practitioner (GP) with intermittent symptoms of right knee pain, swelling, and restricted movement. Symptoms were exacerbated by sporting activities and minor trauma. This patient had neither previous medical history nor took any regular medications. As a result of this, she had a diagnostic right knee arthroscopy at age 10, the biopsy results of which reported *"a pigmented haemosiderin laden synovium,"* the patient was given a provisional diagnosis of PVNS.

During the next couple of years, she was treated conservatively, referred to rheumatology, and given two courses of intra-articular steroid injections. At age 14, her symptoms still persisted, so serial magnetic resonance imaging (MRI)

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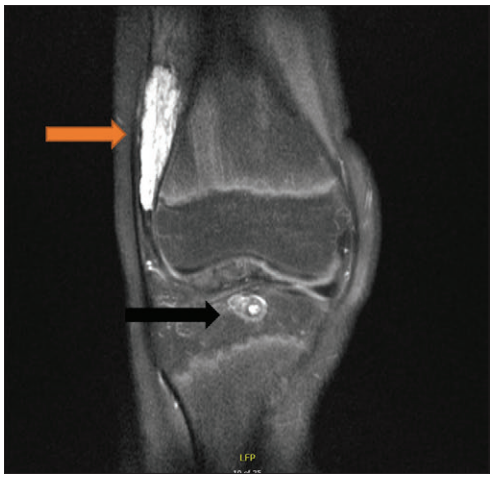

Figure 1: MRI coronal image showing articular degeneration (especially of the lateral compartment of the knee), right suprapatellar recess PVNS (orange arrow), and intraosseous ganglion (black arrow). MRI: Magnetic resonance imaging, PVNS: Pigmented villonodular synovitis

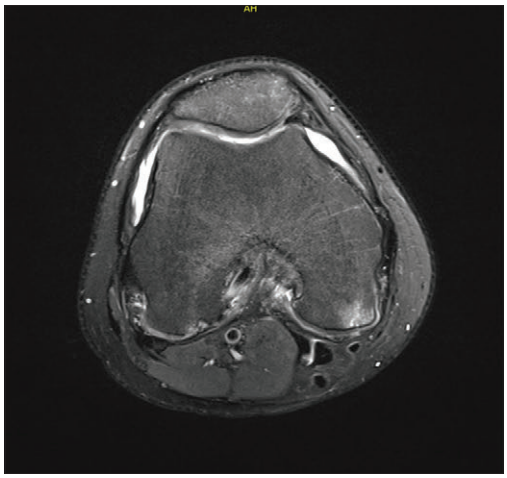

Figure 2: Transverse MRI showing advanced articular cartilage damage in the patellofemoral compartment. MRI: Magnetic resonance imaging

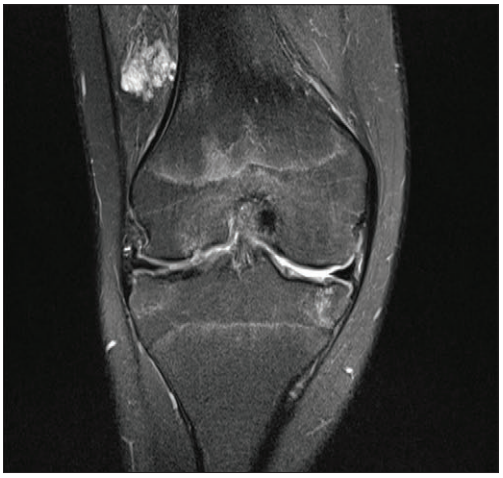

Figure 3: Coronal MRI showing advanced osteoarthritis in the tibiofemoral compartment. MRI: Magnetic resonance imaging

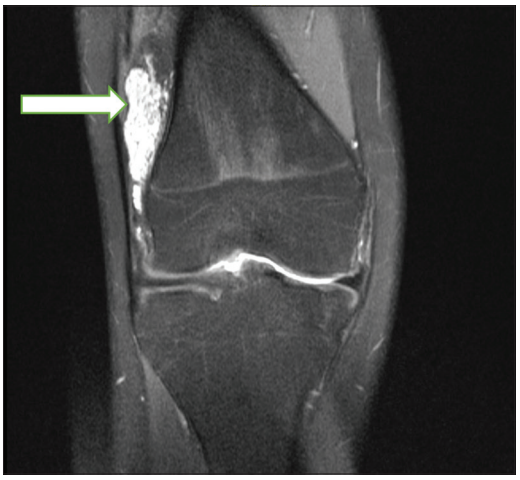

Figure 4: MRI coronal image showing the diffuse synovial changes observed related to recurrent/chronic hemorrhage from a synovial vascular malformation into the joint rather than primary PVNS (white arrow). This image also shows cartilage loss present in the medial compartment. MRI: Magnetic resonance imaging, PVNS: Pigmented villonodular synovitis

scans were performed. They showed "*progressive articular degeneration (especially of the lateral compartment of the knee), right suprapatellar recess PVNS with an intra-osseous ganglion in the tibial plateau suggesting interosseous PVNS* [Figure 1]*.*"

After an initial multidisciplinary team (MDT) discussion, the patient underwent an arthroscopic synovectomy. The biopsy reports from the synovectomy demonstrated "*villous hyperplasia of the synovium with extensive haemosiderin pigmentation and patchy chronic inflammation with aggregates of lymphocytes and haemosiderin laden macrophages suggesting PVNS*."

At age 16, the patient began to display symptoms of progressive degeneration in the right knee with posterior cruciate ligament laxity. A repeat MRI was performed and showed "*advanced osteoarthritis of all knee compartments with moderate joint effusion and residual synovial thickening keeping with PVNS* [Figures 2 and 3]*.*" The following year, she began having right knee pain, symptoms of instability, and swelling at the posterolateral aspect of the knee.

An additional MRI scan suggested an alternate etiology for the recurring symptoms: "*There was possibility that the diffuse synovial changes observed related to* recurrent/chronic *haemarthrosis from a synovial vascular malformation into the joint rather than primary PVNS* [Figures 4 and 5]."

Subsequently, the case was discussed with the vascular radiology team, who suggested an ultrasound (US) scan and an US Doppler of the knee. The US Doppler confirmed the following: "*localised venous malformation in the distal right vastus lateralis extending to the synovium* [Figure 6]." The histology report from the previous synovectomy was then repeated, and it is stated: "*The features present are as previously noted with synovial villous hyperplasia and extensive haemosiderin deposition in the surface synovial*

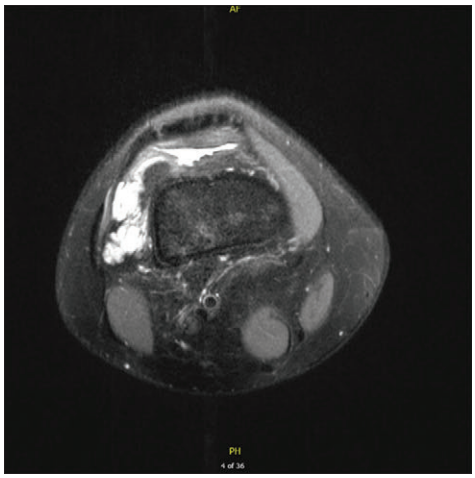

Figure 5: MRI transverse image showing vascular malformation in the lateral suprapatellar pouch involving the synovial lining of the knee joint. The vascular malformation has the typical serpiginous appearance of a cavernous low-flow VM. MRI: Magnetic resonance imaging, VM: Venous malformation

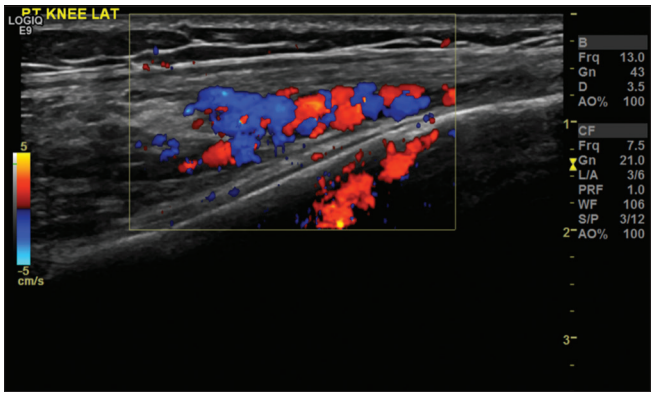

Figure 6: Right leg US Doppler showing localized VM in the distal right vastus lateralis extending to the synovium. VM: Venous malformation, US: Ultrasound

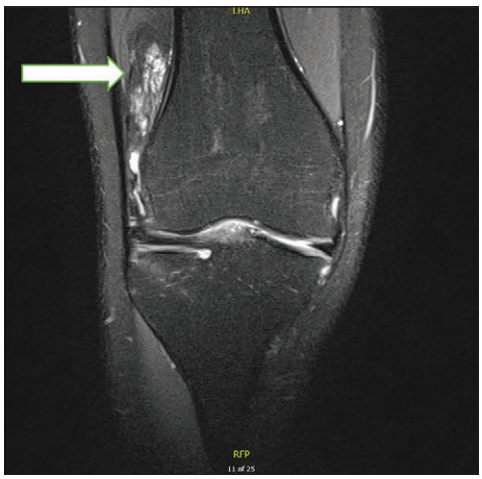

Figure 7: MRI coronal image showing a decrease in size of venous malformation (white arrow). MRI: Magnetic resonance imaging

cells and in the stroma. There is no nodule formation and osteoclast-like giant cells are not seen. The features present could certainly be due to chronic bleeding into the joint and would fit with haemosiderotic synovitis, although the villous pattern and synovial hyperplasia is more prominent than expected in this condition…Therefore the features are not solely diagnostic of PVNS… Taking the clinical, radiological and pathological features into account haemosiderotic synovitis may be the more plausible diagnosis."

The vascular radiology team further advised that the malformation would benefit from percutaneous sclerotherapy, of which the patient agreed to. The orthopedic plan was to allow the current situation to settle and to do an interval MRI scan to assess whether further sclerotherapy was needed. Since sclerotherapy, episodes of knee swelling had reduced, after which a further MRI scan showed the "*venous malformation had decreased markedly in size along with evidence of tricompartmental progression with subcortical cysts, oedema and osteophytes* [Figure 7]."

The final orthopedic plan was to treat symptomatically and review again in 6 months. It was understood that the patient would ultimately need surgical replacement of her right knee, however; for now, she was to be managed conservatively. She continued her care with another hospital from the age of 19.

After following her up in her new place of residence at the age of 22, her symptoms are consistent with the progression of knee degeneration. She is of the opinion that her condition has gotten worse, although she is managing her pain conservatively. She struggles to take part in sports and has to take time off work owing to occasional knee pain and swelling. Despite this, she is otherwise able to carry out her day-to-day activities. She has not had any further medical or surgical treatment since she moved to the new trust.

Discussion

Despite repeated soft-tissue imaging and pathological analysis, it took 8 years to gain a definitive diagnosis of VM of the right knee in this patient. There are lessons we can learn from such cases. First, it is important to distinguish the synovial reaction caused by hemarthrosis from PVNS. Intra-articular bleeding will result in hemosiderin-laden synovium. Hemarthrosis can be caused by bleeding diathesis or an intra-articular lesion such as nodular PVNS or a VM. The biopsy, in this case, demonstrated the findings of synovial proliferation resulting from recurrent hemarthrosis, not PVNS. When synovial pathology such as this is encountered, other causes of recurrent hemarthrosis should be considered and excluded. To some extent, VM has radiological and clinical manifestations that can mimic PVNS.[2,4]

PVNS and VMs present similarly, which can make distinguish between the two challenging.[3,4] MRI, however, is an invaluable tool in characterizing them. Diffuse PVNS displays low signal intensity in both T1-weighted and T2-weighted MRI imaging due to hemosiderin deposition.[2] A characteristic sign that further distinguishes PVNS from other localized swellings is

the heterogeneous pattern of synovial thickening and blooming artifact on gradient-echo imaging.[3] In contrast to PVNS, VMs cause intermediate-to-low intensity signal on T1-weighted and high signal intensity on T2-weighted imaging.[4] VMs are further distinguished by the presence of phleboliths on radiological examination.[4] In addition, VMs have a typical serpiginous appearance on MRI as demonstrated earlier. There are, however, radiological similarities, for example, both VMs and PVNS demonstrate hemosiderin deposition and enhancement on gadolinium administration during MRI.[3,4] Upon discussing the imaging in MDT, previous scans were shown to exhibit signs of VMs.

VM and PVNS in the knee can both present with arthralgia, swelling, and reduced range of motion and are often mistaken for juvenile idiopathic arthritis or other intra-articular tumors.[4] VMs (once they involve the synovium) have the capability of causing hemorrhage within a joint and consequent cartilage damage.[4] In the above report, this was only fully appreciated when histology was re-examined. Even though VMs have a low prevalence due to their progressive nature, they must be considered as a differential diagnosis for persistent unilateral knee pain.[4]

Conclusion

This case report adds to the literature examining VMs of the knee joint. The attainment of a diagnosis, however, did go through several phases, which can be reflected when encountering similar diagnostic conundrums. First, the use of MDT meetings was pivotal in finding a diagnosis, as different specialties were able to employ their expertise together to elucidate pathology. Alongside this, the use of multimodal imaging (USS and MRI) also helped to characterize the lesion in the knee. Finally, the sooner we employ the multipronged approach in the diagnosis of rare articular pathology, the better outcomes will be for patients as we can limit the articular damage caused by hemorrhage (in the context of VMs).

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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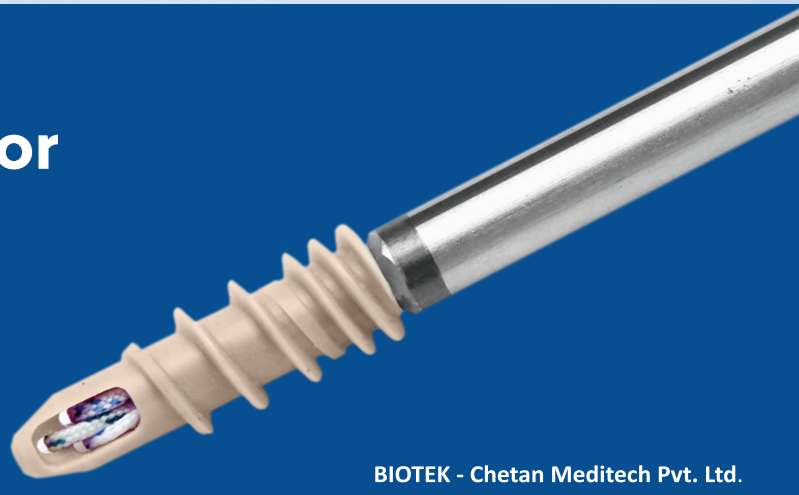

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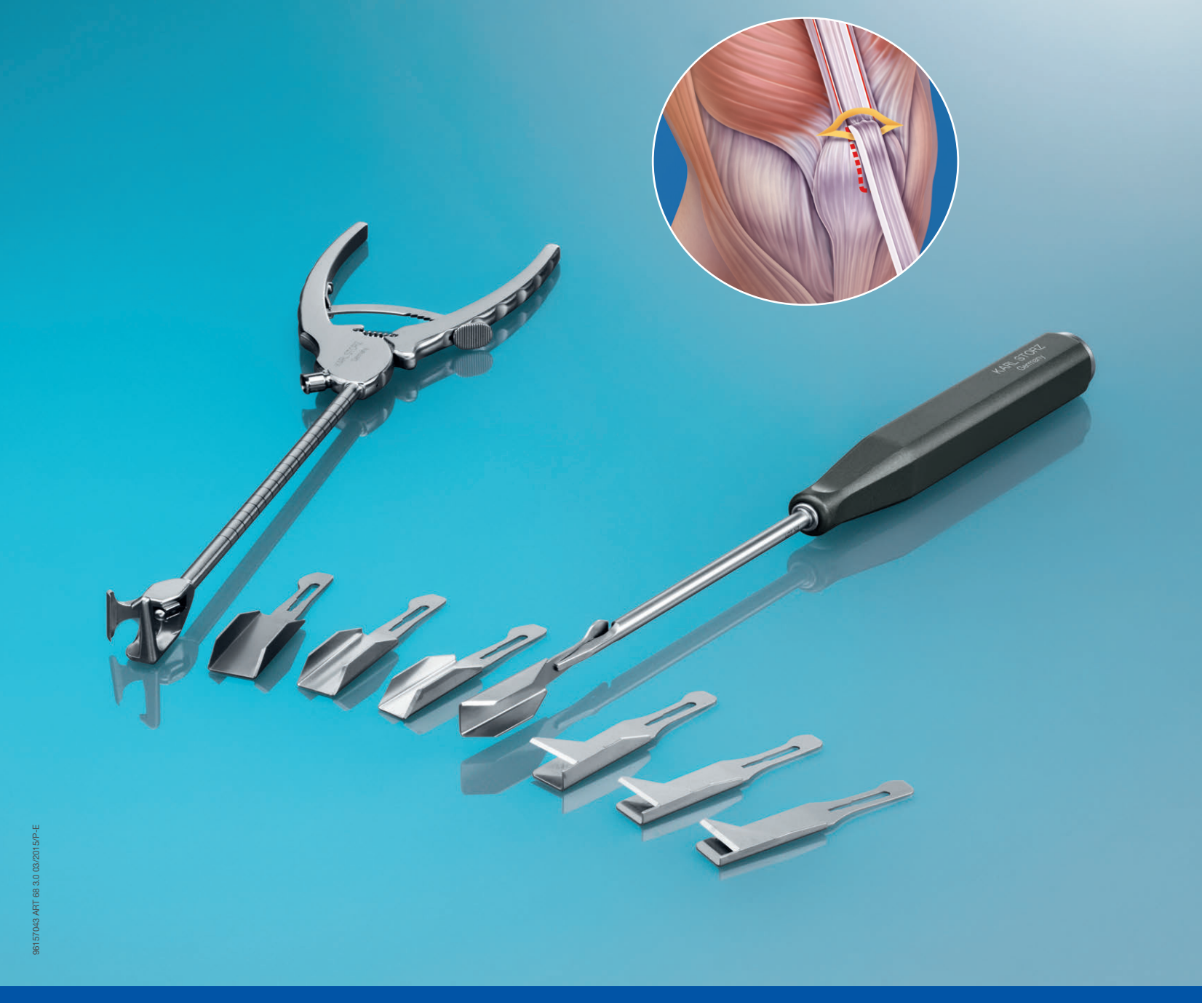

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