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Journal of Arthroscopy and Joint Surgery

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Contents


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A Systematic Review of Noncircular (Rectangle, Oval) Femoral Tunnel Anterior Cruciate Ligament Reconstruction: Does it Improve Outcomes?

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Abstract

Purpose: The purpose of this study is to systematically review the clinical and biomechanical studies regarding noncircular (rectangular and oval) femoral tunnel anterior cruciate ligament reconstruction (ACLR). We hypothesized that noncircular femoral tunnel ACLR has its advantages in unique situations while maintaining comparable clinical and radiographic outcomes when compared to conventional techniques. **Methods:** A systematic review of the literature was performed in PubMed and Scopus databases to identify published articles on the clinical outcomes of noncircular (rectangle and oval) ACLR. The results of the eligible studies were analyzed in terms of instrumented laxity measurements, Lachman test, pivot-shift test, Lysholm and Tegner scores, objective and subjective International Knee Documentation Committee (IKDC) scores, and surgical complications/failures. A meta-analysis was performed on Lysholm scores and KT side-to-side data comparing noncircular ACLR with the conventional round technique. **Results:** A total of 22 papers for the rectangle group (n = 1314) met the inclusion criteria. With an average follow-up of 15.8 months (±10.4 months), the mean reported Lysholm score was 97.8 (±0.80) and the mean reported KT-1000 arthrometer measurement was 1.2 (±1.9). When comparing the rectangle technique to the conventional round, no significant differences were seen regarding the Lysholm score (P = 0.95) or KT-1000 arthrometer measurements (P = 0.14) at the final follow-up. In the oval group, a total of 5 studies (n = 322) met the eligibility criteria. With an average follow-up of 20.2 months (±13.7 months), the mean reported Lysholm score was 94.4 (±2.0), the mean IKDC subjective was 90.4 (±1.2), and the mean KT-1000 arthrometer measurement was 1.6 (±0.4). The scarcity of randomized controlled trials available for this analysis limited the amount of data available for meta-analysis. **Conclusions:** Noncircular femoral tunnel ACLR has shown reasonable and comparable clinical outcomes to the conventional technique, demonstrating no difference between the two techniques and making it a valuable option for primary or revision ACLR.

Keywords: Anterior cruciate ligament reconstruction, anterior cruciate ligament tear, knee, knee arthroscopy

Introduction

The shape of the anterior cruciate ligament (ACL) femoral attachment is broad and flat and consists of two bundles. The anteromedial (AM) bundle is tight in flexion from 45° to 60° and the posterolateral (PL) bundle is tight in extension.[1] Several studies have shown that the conventional single bundle (SB) ACL reconstruction (ACLR) is successful in the restoration of the anterior tibial translation but does not effectively restore rotational stability.[2-4] The rate of return to sports is not favorable after conventional ACLR with studies reporting only 45%–65% of patients returning to preinjury level activity.[5,6]

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Anatomic studies have shown that the shape of the femoral attachment of the ACL is not round, but rather oblong, and a more anatomic reconstruction can be achieved by creating an oval or rectangular shape of the attachment.[7] Shino *et al*. described

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the rectangular ACLR technique, claiming that the rectangular attachment more closely resembles the shape of the native ACL femoral attachment.[8] Noh *et al*. demonstrated another noncircular femoral tunnel ACLR with an oval footprint.[9]

The purpose of this study is to evaluate the clinical and biomechanical studies regarding noncircular (rectangular and oval) femoral tunnel ACLR. In addition to investigating the utility of noncircular femoral tunnel ACR, a meta-analysis was performed to compare the clinical outcomes and survival of these techniques. We hypothesized that noncircular femoral tunnel ACLR has its advantages in unique situations while maintaining comparable clinical and radiographic outcomes when compared to conventional techniques.

Methods

A comprehensive search of PubMed and Scopus databases was performed with the use of the following keywords: "rectangle," "oval," "oblong," "anterior cruciate ligament," and "ACLR." All articles in the English language up to February 1, 2022, were included, including articles published online. The titles and abstracts of the potentially relevant studies were reviewed and articles that included human subjects and were deemed potentially relevant were retrieved for more detailed evaluation.

The study included all papers addressing the clinical outcomes of nonround femoral tunnel ACLRs. The search was limited to the English language and human studies. Articles that were excluded discussed studies that failed to meet the inclusion criteria, specifically those that did not report clinical outcomes on human subjects, review articles, that did not involve the use of noncircular femoral and/or tibial tunnels in ACLR. After removing the duplicates, the full text of the papers was evaluated with the application of predetermined inclusion and exclusion criteria. The references of the included papers were screened to find any paper that was not found in the primary search. Of the papers included in our study, 22 discussed rectangular tunnel reconstruction and 5 discussed oval tunnel reconstruction [Figures 1, 2 and Tables 1, 2].

The number of patients, average follow-up and clinical outcome data were extracted from each paper, and in papers

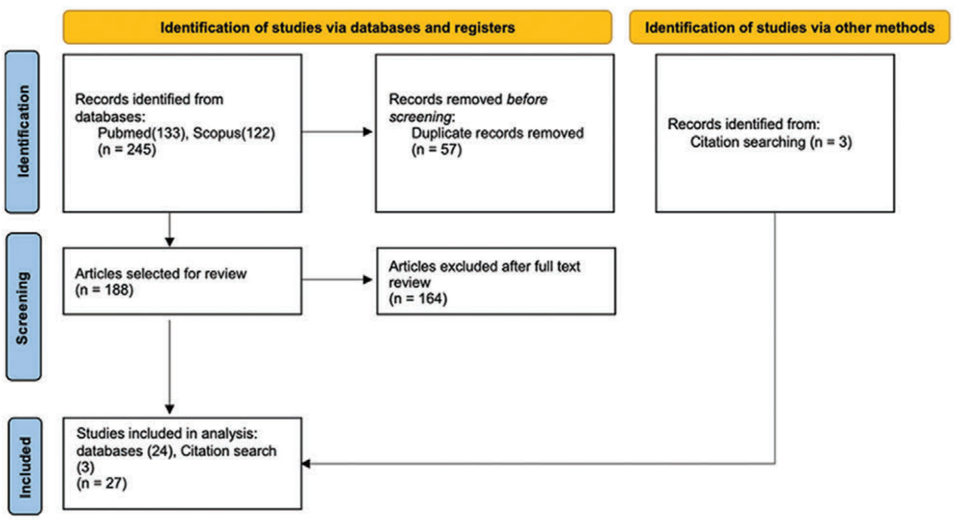

Figure 1: PRISMA Flowchart showing the identification, selection, eligibility, and inclusion of primary studies. PRISMA: Preferred reporting items for systematic reviews and meta-analysis

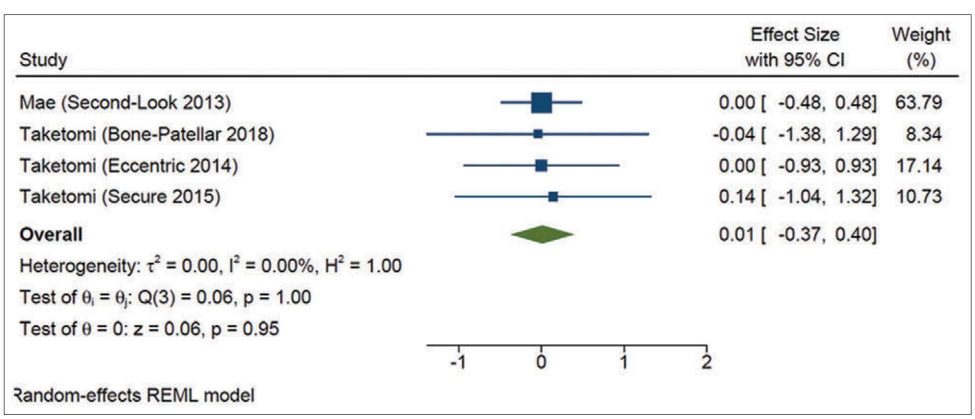

Figure 2: Forest plot showing standard mean differences in Lysholm score between rectangular and round femoral tunnel ACLR. No significant difference was found between the two techniques. ACLR: Anterior cruciate ligament reconstruction, CI: Confidence interval, REML: Restricted Maximum Likelihood

Table 1: Study characteristics

Author	Year	Journal	Country	Design	Period	LOE	Sample Size (*n*)	Surgery	Age (years)	Follow-up (months)
Lui *et al*.	2018	Am J Transl Res	China	PCS	2015-2016	II	40	Oval (*n*=40)	29.7 (18-40)	0.5
Noh *et al*.	2011	JARS	Korea	PCS	2006-2008	II	74	Oval (*n*=34)	24.5 (19-47)	32.4
Zhang *et al*.	2019	Am J Transl Res	China	PCS	2015-2016	II	80	Oval (*n*=40)	29.2 (+/- 8.0)	24
Wen *et al*.	2019	KSSTA	China	PCS	2016-2017	III	108	Oval (*n*=39)	31.4 (+/- 9.9)	24
Petersen *et al*.	2013	AOTS	Germany	RCS	2011	IV	24	Oval (*n*=44)	N/A	N/A
Mae *et al*.	2019	JOS	Japan	PCS	2007-2011	II	467	Rectangle (*n*=233)	22.5 (13-39)	24
Sasaki *et al*.	2016	AJSM	Japan	RCT	2007-2009	I	150	Rectangle (*n*=69)	27.0 (+/- 11.9)	38.9
Inoue *et al*.	2015	Kurume Med J	Japan	RCS	N/A	IV	40	Rectangle (*n*=40)	22 (13-45)	N/A
Amano *et al*.	2019	KSSTA	Japan	RCS	2012-2013	IV	32	Rectangle (*n*=32)	25.1	6
Takata *et al*.	2016	AOTS	Japan	RCS	2010-2014	IV	81	Rectangle (*n*=42)	23.2 (+/- 8.4)	3
Hayashi *et al*.	2019	PLOS	Japan	PCS	2015-2017	III	42	Rectangle (*n*=42)	29.9 (+/- 10.1)	1
Take *et al*.	2015	AP-SMART	Japan	RCS	1996-2009	IV	133	Rectangle (*n*=111)	21.5 (13-44)	N/A
Taketomi *et al*. (Eccentric)	2014	JARS	Japan	RCS	2009-2012	IV	52	Rectangle (*n*=26)	27 (16-50)	12
Taketomi *et al*. (Secure)	2015	Joints	Japan	RCS	2009-2012	IV	34	Rectangle (*n*=34)	25 (16-50)	12
Taketomi *et al*. (Bone)	2018	J Knee Surg	Japan	RCS	2012-2014	IV	48	Rectangle (*n*=25)	32 (15-55)	25
Uchida *et al*. (Excellent)	2019	J ISAKOS	Japan	RCS	2012-2013	IV	20	Rectangle (*n*=20)	25 (+/- 10)	2
Uchida *et al*. (Relationship)	2018	KSSTA	Japan	RCS	2013-2015	IV	30	Rectangle (*n*=30)	20.4 (14-36)	6
Ohori *et al*.	2019	JOS	Japan	RCS	2010-2017	IV	18	Rectangle (*n*=18)	26.6 (16-38)	12
Nakase *et al*. (Clinical)	2021	BMC MSKD	Japan	RCS	2011-2016	IV	116	Rectangle (*n*=40)	24.8 (+/- 11.1)	24
Nakase *et al*. (Technique)	2016	Knee	Japan	RCS	2013-2015	IV	50	Rectangle (*n*=50)	N/A	0.25
Okimura *et al*.	2019	JOS	Japan	RCS	2005-2013	IV	50	Rectangle (*n*=50)	N/A	24
Tachibana *et al*.	2018	KSSTA	Japan	RCS	2009-2014	IV	61	Rectangle (*n*=61)	22.7 (14-48)	24
Kusano *et al*.	2018	JARS	Japan	PCS	2013-2014	IV	50	Rectangle (*n*=50)	24 (14-45)	24
Hiramatsu *et al*.	2018	KSSTA	Japan	RCS	2011-2014	III	149	Rectangle (*n*=149)	22.6 (14-46)	1
Shino *et al*.	2012	CORR	Japan	RCS	2004-2008	IV	18	Rectangle (*n*=18)	23 (15-34)	38
Suzuki *et al*.	2011	KSSTA	Japan	PCS	N/A	IV	20	Rectangle (*n*=20)	21 (16-36)	2
Masuda *et al*.	2018	KSSTA	Japan	PCS	2013-2014	IV	40	Rectangle (*n*=40)	20.5 (16-49)	5

that compared results of nonround femoral tunnels with conventional round tunnels, data from both groups was collected. Based on the comparative clinical outcome data, a meta-analysis was performed.

Data extraction and synthesis

The information extracted from the original studies included

Demographic data, follow-up data, and subjective and objective clinical scores. The mean values for subjective International Knee Documentation Committee (IKDC), Lysholm, and Tegner were extracted. The objective clinical evaluation was performed by extracting the objective IKDC, Lachman test, pivot shift test, and range of motion (ROM). In addition, the mean KT side-to-side difference and standard deviation (SD) measured in millimeters (mm) on anterior translation were extracted. Finally, the complications and failures that occurred during the follow-up period were noted. Data were extracted and tabulated into an Excel database by one author.

Analysis and methodological assessment

Articles were assessed for level of evidence and methodology using a modification of the original Coleman Methodology Score (CMS). Twenty-seven articles met the inclusion criteria and were therefore included in the meta-analysis and analyzed [Table 1]. Of the reviewed studies, there was one randomized controlled trial, nine prospective cohort studies, and 17 retrospective evaluations. The mean modified CMS was 53.9 ranging from 29 to 76 [Table 2]. The items that most affected the overall quality of the studies were: mean follow-up and type of study.

Statistical analysis

A random-effects meta-analysis model was used for these analyses; this assumes the observed estimates of treatment

Table 2: Modification of the original Coleman methodology score

Study	Part A							Part B			Total
	Study size	Mean follow-up	Surgical approach	Type of study	Description of diagnosis	Descriptions of surgical technique	Description of postop rehab protocol	Outcome Criteria	Producedure of assessing outcomes	Description of subject selection process	
Lui *et al.*	7	0	7	10	5	10	0	7	9	5	60
Noh *et al.*	7	4	7	10	5	10	5	7	9	5	69
Zhang *et al.*	7	4	7	10	5	10	5	7	9	5	69
Wen *et al.*	10	4	7	10	5	10	5	7	9	5	72
Petersen *et al.*	0	0	10	0	0	10	5	5	0	5	35
Mae *et al.*	10	4	7	10	5	10	5	7	5	5	68
Sasaki *et al.*	10	7	7	15	5	10	5	7	5	5	76
Inoue *et al.*	4	0	10	0	0	10	0	5	0	0	29
Amano *et al.*	4	0	10	0	0	10	5	7	4	5	45
Takata *et al.*	4	0	7	0	0	10	5	7	4	5	42
Hayashi *et al.*	4	0	10	10	0	10	0	7	0	5	46
Take *et al.*	10	0	7	0	5	10	0	5	4	5	46
Taketomi *et al.* (Eccentric)	7	4	7	0	5	10	5	7	4	5	54
Taketomi *et al.* (Secure)	4	4	10	0	5	10	5	7	9	5	59
Taketomi *et al.* (Bone)	4	4	7	0	0	10	5	7	4	5	46
Uchida *et al.* (Excellent)	0	0	10	0	5	10	5	7	4	5	46
Uchida *et al.* (Relationship)	4	0	10	0	5	10	5	7	4	5	50
Ohori *et al.*	0	4	10	0	5	10	5	7	4	5	50
Nakase *et al.* (Clinical)	7	4	7	0	5	10	5	7	4	5	54
Nakase *et al.* (Technique)	4	0	10	0	5	10	0	7	5	5	46
Okimura *et al.*	4	4	10	0	5	10	5	7	4	5	54
Tachibana *et al.*	7	4	10	0	5	10	5	7	4	5	57
Kusano *et al.*	4	4	10	10	5	10	5	7	9	5	69
Hiramatsu *et al.*	10	0	7	0	5	10	0	7	4	5	48
Shino *et al.*	0	7	10	0	5	10	5	7	0	5	49
Suzuki *et al.*	0	0	10	10	5	10	5	7	9	5	61
Masuda *et al.*	4	0	10	10	5	10	0	7	5	5	56
Total	5.0	2.3	8.7	3.9	3.9	10.0	3.7	6.8	4.9	4.8	53.9

effect can vary across studies because of real differences in the treatment effect in each study as well as sampling variability. Thus, even if all studies had an infinitely large sample size, the observed study effects would still vary because of the real differences in treatment effects.

A random-effects meta-analysis was performed on four subgroups of outcome measurement: Oval Subjective, Oval Objective, Rectangle Subjective, and Rectangle Objective. For each individual outcome measure, Hedge's G was used to estimate effect size, the calculation for the estimate and its standard error are below:

For each group (and each outcome available), calculate the mean difference (post – pre) and the SD of the difference:

$$s_{diff} = \sqrt{s_{pre}^2 + s_{post}^2 - 2 \times r \times s_{pre} s_{post}}$$

Using the mean difference, SD of difference, and sample size for each group (1 and 2) calculate the bias-adjusted version of Hedges G as

$$G = \left(1 - \frac{3}{4(n_1 + n_2) - 9}\right) * D \text{ } whrere \text{ } D = \left(\frac{\bar{d}_1 - \bar{d}_2}{s*}\right) \text{and}$$

$$s^* = \sqrt{\frac{(n_1-1)\, s^2_{diff\,1} + n_2 - 1)\, s^2_{diff\,2}}{n_1 + n_2 - 2}}$$

$$\text{The SE for G is } SE(G) = \left(1 - \frac{3}{4(n_1 + n_2) - 9}\right) * \sqrt{\left(\frac{n_1 + n_2}{n_1 n_2} + \frac{D^2}{2(n_1 + n_2)}\right)}$$

The overall effect size of each subgroup was generated and tested against a null hypothesis of Effect Size = 0, the *z*-score, 95% confidence interval, and *P* value are reported in the table. Each subgroup was tested for Heterogeneity, the I^2 value and its *P* value were also reported.

Results

A total of 22 studies for the rectangle group (*n* = 1314) met the inclusion criteria [Figure 1]. With a mean age of 24 (±3.4) and an average follow-up of 15.8 months (±10.4 months), the mean reported Lysholm score was 97.8 (±0.80) and the mean reported KT-1000 arthrometer measurement was 1.2 (±1.9) [Tables 3 and 4]. When comparing the rectangle technique to the conventional round technique, no significant differences were seen regarding the Lysholm score or KT-1000 arthrometer measurements at the final follow-up [Figures 2, 3 and Table 5]. In the oval group, a total of 5 studies (*n* = 322) met the eligibility criteria. With a mean age of 28.5 (±2.9) years and an average follow-up of 20.2 months (±13.7 months), mean reported Lysholm score was 94.4 (±2.0), the mean IKDC subjective was 90.4 (±1.2), and the mean KT-1000 arthrometer measurement was 1.6 (±0.4). When comparing the oval technique to the conventional round technique, no significant differences were seen regarding Lysholm score final follow-up [Figure 4 and Table 5].

Discussion

Through a systematic review and meta-analysis on noncircular femoral tunnel ACLR, this study was able to demonstrate that this technique has reasonable and comparable clinical outcomes compared to the conventional round technique as well as some biomechanical advantages as the noncircular graft more closely resembles the native ACL footprint.

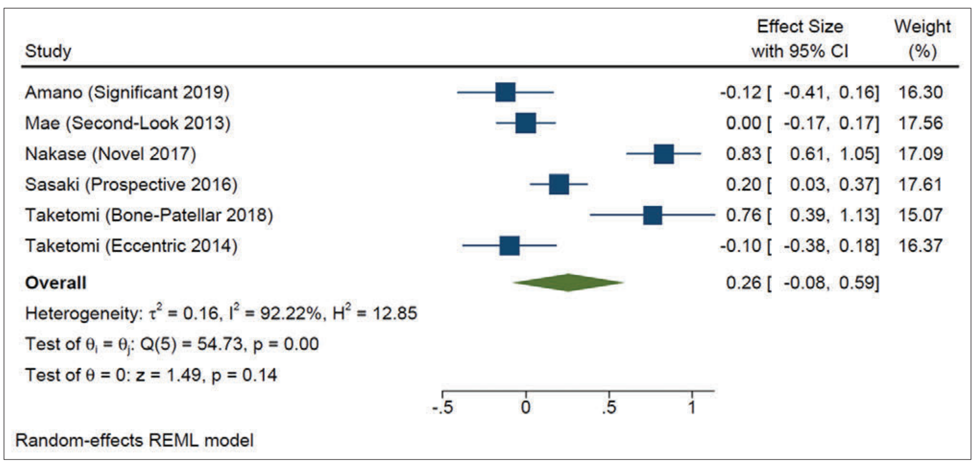

Figure 3: Forest plot showing standard mean differences in KT-1000 arthrometer measurements between rectangular and round femoral tunnel ACLR. When comparing the two techniques, no significant difference was found. ACLR: Anterior cruciate ligament reconstruction, CI: Confidence interval, REML: Restricted Maximum Likelihood

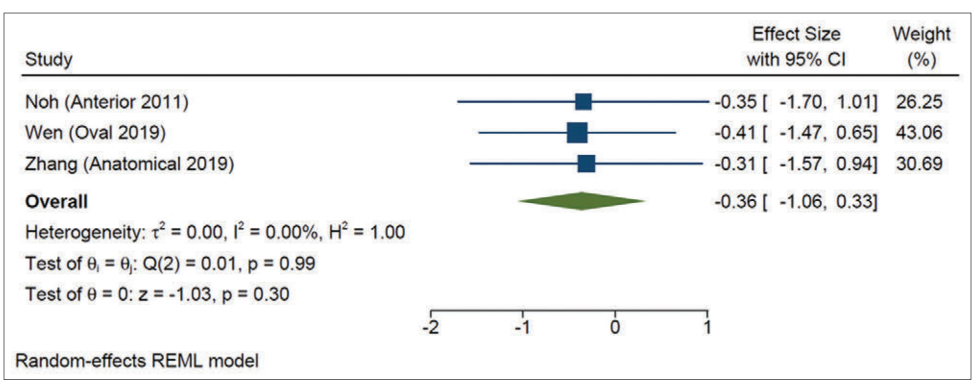

Figure 4: Forest plot showing standard mean differences in Lysholm score between oval and round femoral tunnel ACLR. When comparing both techniques, no significant differences were found. ACLR: Anterior cruciate ligament reconstruction, CI: Confidence interval, REML: Restricted Maximum Likelihood

Multiple studies have described techniques to accomplish anatomic rectangular tunnels and their advantages which have resulted in both minimal complications as well as clinical success. Shino *et al*. described a technique for the creation of rectangular tunnels.[8,10,11] The authors created a 10 mm wide graft made of two continuous 5-mm round tunnels along the long axis in the center of the attachment area that were then dilated using a 5 mm × 10 mm dilator and a rectangular 10 mm graft was then inserted. This rectangular bone-patellar tendon-bone graft was found to better mimic the fiber arrangement inside the native ACL.[12] Hayashi *et al*. described a similar technique but noted that the direction of the dilator should be adjusted under fluoroscopy before insertion, ensuring it is parallel to the line connecting the centers of the AM bundle and the PL bundle and posterior to the resident ridge.[13]

Fink *et al*. proposed a technique utilizing a quadriceps tendon (QT) graft along with rectangular bone tunnels.[14] Their study suggested that rectangular bone tunnels more closely recreate the native ACL attachments along with the QT graft which broad flat structure mimics the "ribbon-like" morphology of the native ACL. Their technique was described as simulating the native ACL rotation during knee ROM and thus improving biomechanics. These authors created the rectangular tunnels through the use of a rectangular rasp matched with the diameter of the graph. Once the tunnel was created and rasped to a depth of 25–30 mm, a dilator matching the graft size was inserted, and rough edges were removed with an arthroscopic shaver.

Noh *et al*. proposed an oval-footprint technique for ACLR, creating elongated femoral and tibial tunnels that are more representative of the native ACL footprint, which has been described as more oval-shaped rather than round.[9,15] To prepare an oval-footprint femoral tunnel, the authors reamed their initial femoral tunnel, which corresponded to the AM bundle, to 30 mm. The PL part of the tunnel, corresponding to the PL bundle, was reamed with the guide pin held steady on the wall. Their modified technique described the creation of the femoral tunnel transtibial, which is thought to result in a more elongated tunnel as the guide pin and reamer are more oblique to the intercondylar surface. Furthermore, an oval-shaped dilatator has been described by a number of authors to create oval-shaped bone tunnels more closely resembling the oblong femoral tunnel attachment.[16]

Table 3: Summary of patient demographic data

	Age (years)	Follow-up (months)
Oval	28.5 (+/- 2.9)	20.2 (+/- 13.7)
Rectangle	24.0 (+/- 3.4)	15.8 (+/- 10.4)

Table 4: Summary of mean clinical outcomes

	Subjective IKDC	Lysholm	KT-1000 SSD (mm)
Mean Oval	90.4 (+/- 1.2)	94.4 (+/- 2.0)	1.6 (+/- 0.4)
Mean Rectangle	N/A	97.8 (+/- 0.8)	1.2 (+/- 1.9)

Herbort *et al*. demonstrated a reconstruction technique in cadavers using a rectangular tunnel with a SB-bone-patellar tendon-bone (BTB) graft that resulted in significantly lower anterior tibial translation compared to the conventional round tunnel technique at 0° and 15° of flexion.[17] Their findings suggest that clinically, rectangular tunnel BTB ACLR may result in better anterior knee stability at low flexion angles. Biomechanically, Mae *et al*. demonstrated that the use of an anatomic rectangular tunnel technique in BTB-ACLR resulted in a force-sharing pattern similar to that of the normal ACL in response to anterior tibial load and during passive knee extension.[18] In addition, Nakase *et al*. noted that creating large oblong femoral tunnel attachments for oval grafts improves rotational and anteroposterior stability.[19]

There are numerous causes for ACLR failure, with femoral tunnel malpositioning being the most common one. The cross-sectional area of tunnels used in the rectangular graft technique was found to be 50 mm^2 as compared to the conventional round tunnel technique (79 mm^2), when a 10-mm wide BTB graft was used.[10] One-stage rectangular bone-patellar tendon-bone (BTB) grafts have been recommended for revision in cases of gross malpositioning of the femoral tunnel due to the previously mentioned cross-sectional area differences of rectangular grafts when compared to conventional round grafts. The smaller area allows for the creation of a new properly positioned tunnel that avoids overlap by allowing for greater space between previous tunnels and new tunnels while also preserving bone. When significant tunnel widening was present, bone grafting is recommended in conjunction with the rectangular graft.[10-12]

The revision of a failed double-bundle (DB) ACLR is further complicated by enhanced bone loss created by two femoral tunnels. Oftentimes, two stages ACLR and bone grafting are required.[20]

Table 5: Significant results after meta-analysis demonstrating no significant differences in Lysholm score or KT side-to-side measurements in noncircular anterior cruciate ligament reconstruction techniques

Significant Results After Meta-Analysis				
Variable	**Pooled OR/SMD**	**95% Confidence Interval**	**Sig/n.s.**	***I^2***
Oval Lysholm	-0.36	[-1.06 to 0.33]	n.s.	0.00%
Rectange Lysholm	0.01	[-0.37 to 0.40]	n.s.	0.00%
Rectangle KT side-to-side	0.26	[-0.08 to 0.59]	n.s.	92.22%

In the revision of the properly placed DB femoral tunnels, dilating the two tunnels with a rectangular dilator was advised.[10,12]

Several studies evaluated the outcome of the ACL anatomic rectangular reconstruction (ART) utilizing radiographic analysis.[21,22] The BTB graft healing improved with this technique because of the close contact and fit of the graft in the tunnel. There are two types of union in graft healing. In indirect union, the granulation tissue fills the gap and after callus formation the bone heals, union occurs. There is no observed granulation tissue and callus formation in a direct union. Suzuki *et al*. showed the BTB graft healed 8 weeks after surgery in the femoral tunnel and the snug fit of the graft in the tunnel resulted in direct union as the primary mechanism for healing.[22] Inoue *et al*. found that this procedure improved graft-tunnel healing around the femoral bone tunnel aperture for the PL bundle, a known weak point of DB ACLR.[23] Masuda *et al*. demonstrated that the healing and integration of BTB graft occurs earlier in the tibial tunnel compared to femoral tunnel.[21]

Femoral tunnel malposition has been shown to be the most common cause of graft failure, making graft placement a key aspect of the procedure, regardless of type of graft, and fixation technique.[1]

In the past, the effort was directed at positioning the center of the femoral tunnel at the isometric point, identified as the anterior-superior border of the ACL footprint, to achieve more native ACL function. Drilling the isometric point has resulted in several problems such as impingement at the posterior cruciate ligament or the intercondylar notch/wall and potentially poor rotational stability due to a more vertical graft orientation. As a result, more anatomically oriented approaches have since been investigated. Take *et al*. have demonstrated that rectangular grafts not only show a mean elongation most similar to that of the native ACL but also significantly superior biomechanical characteristics compared to the isometric round tunnel (IRT) procedure.[24,25] In a study by Forsythe *et al*. utilizing Dynamic three-dimensional, it was shown that the most isometric point is located at the center of the direct fiber insertion of the ACL and the junction of the intercondylar ridge and bifurcate ridge.[26]

While investigating the biomechanical differences between IRT and ART techniques, based on overall graft length changes, Take *et al*. found a significant difference in length change between the IRT and ART groups, 1.0 ± 0.7 mm versus 3.4 ± 0.9 mm, respectively ($P < 0.001$).[24] These findings suggest the ART technique more closely replicates the biomechanical function of the native ACL, which has an intrinsic length change of 3–6 mm.

Sasaki *et al*. demonstrated that the ACL-ART technique provides more coverage of the ACL attachment compared to the conventional round tunnel.[7] In addition, Hayashi *et al*. showed with this technique, 92.9% of the femoral tunnels were located behind the resident ridge and 7.1% had some overlap on the resident ridge. They concluded that the high rate of anatomic femoral tunnel placement occurred because the rectangular shape of the tunnel allowed for better fitting and placement of the ACL footprint.[13]

Femoral tunnel widening can be considered a complication of ACLR as this enlargement may interfere with the creation of a new bone tunnel when anatomical revision reconstruction is performed. The cause of this enlargement can be attributed to a number of mechanical and biological factors.[27,28] In addition, greater tunnel widening has been reported in ACLR using hamstring grafts than with the use of BTB grafts.[29-31] Tunnel enlargement is a significant consideration in ACLR not only due to the difficulties faced when creating a new tunnel for revision ACLR and the need for bone grafting but also its effect on graft healing and maturation within the tunnel.[32-34]

A number of studies have investigated how femoral tunnel widening is affected by the use of a noncircular ACLR technique as compared to a standard round one.[27,35-37] The rounded rectangular bone tunnel and the oval tunnel both showed better compression of cancellous bone that led to increased bone density and osteosclerosis. Both techniques also helped in minimizing heat-related bone damage. Matching the bone graft to the bone tunnel wall and a well-fitted graft to the wall in the rectangular technique prevents micromotion and invasion of the synovial fluid into the tunnel.[27]

Uchida *et al*. found a correlation between femoral tunnel enlargement and the position of the distal portion of the femoral bone plug, suggesting the position of the deep plug in the tunnel is a risk factor for femoral tunnel enlargement.[38] They also suggested minimizing this risk by deviating the harvest site in the patellar tendon to match the shape of the tunnel aperture. Taketomi *et al*. demonstrated that the use of an anatomical rectangular ACLR using Bone-patellar tendon-bone (BPTB) graft resulted in a lower incidence of bone plug migration and a shorter mean distance of bone plug migration when compared to DB-ACLR with a hamstring tendon (HT) graft.[39] They theorized that this decrease in incidence of bone plug migration could be due to the higher friction between the bone plug and the bone socket making it less movable than compared to the soft tissue and the bone socket.

Meta-analysis

The concept of rectangular tunnels in the setting of both primary and revision ACLR has a number of biomechanical advantages as the noncircular graft more closely resembles the native ACL footprint compared to the conventional technique. The meta-analysis of the clinical outcomes of the ART showed that there were no differences between ART utilizing BTB grafts and the conventional round femoral tunnel technique.

When comparing rectangular tunnel ACLR with conventional round tunnel, a number of studies reported no significant difference in clinical outcomes between the two groups.[15,32,33,40] Nakase *et al*. compared the area of the femoral tunnel and clinical results between conventional single bundle

ACLR (ASBR) and rounded rectangular femoral tunnel ACL reconstruction (RFTR).[41] These authors found that compared to ASBR group, RFTR showed better anteroposterior stability (0.8 ± 1.1 mm vs. 1.8 ± 1.2 mm; $P < 0.01$), improved rotational laxity (negative pivot shift, 93.3% vs. 82.5%; $P < 0.01$), created a larger femoral tunnel area (52.7 ± 4.8 mm^2 vs. 47.0 ± 7.3 mm^2; $P < 0.01$), had better Lysholm scores (98.9 ± 2.4 vs. 97.6 ± 3.3; $P < 0.01$).

Inui *et al*. compared the clinical outcomes DB-ACLR using a HT autograft and rectangular femoral tunnel ACLR with BTB autografts. These authors found the rectangular tunnel BTB group showed improved anterior knee stability compared to the DB-HT group. Furthermore, this study found significant differences in other objective or subjective evaluations between the two techniques.[42]

Hayashi *et al*. demonstrated that the use of the rectangular femoral tunnel resulted in an average return to sport time of 10.4 ± 2.5 months and 78.8% return to the same competitive level before injury.[13] In addition, 66.7% of cases returned to sports without recurrence, which is comparable to reported 65% return rate in conventional ACLR.[6]

Several studies demonstrated the clinical efficacy of an oval femoral tunnel technique compared to that of the conventional round technique. Noh *et al*. found improved the clinical outcome scores, specifically Lysholm, with modified oval tunnel ACLR as compared to the conventional technique (median score of 94, range 75–98) versus a median score of 96 (range 76–98) in the oval-footprint group at the last follow-up ($P < 0.048$). Other clinical outcome variables investigated were not found to be significantly different between the two groups.[9]

Wen *et al*. compared the efficacy between ACLR using the oval femoral tunnel technique[9] and the conventional round tunnel technique using hamstring autograft.[35] These authors found that the oval femoral tunnel technique resulted in higher Lysholm scores (97.1 ± 3.9 vs. 94.8 ± 5.6, $P = 0.031$), higher IKDC subjective scores (92.0 ± 2.6 vs. 89.0 ± 3, $P < 0.001$), improved postoperative pivot shift test (1/37 vs. 10/65, $P = 0.048$), and improved graft maturity as demonstrated by a lower mean signal/noise quotient in the postoperative magnetic resonance imaging (MRI) (2.7 ± 0.9 vs. 3.6 ± 1.1, $P < 0.001$) at 2-year follow-up. This study found no statistically significant differences in Visual analog scale (VAS) score, Lachman's, knee ROM, and graft status or synovium coverage determined by second-look arthroscopic evaluation between the two groups at the final follow-up. The authors concluded that the patients in the oval femoral tunnel group had better knee stability and function, which was consistent with the findings of Noh *et al*.[9]

Zhang *et al*. have supported similar findings demonstrating improved Tegner scores, rotational stability via pivot-shift tests, and earlier graft maturation as seen on MRI in the oval group when compared to conventional techniques at 2-year follow-up.[16]

A significant finding in a number of studies investigating the rectangular tunnel technique when performing primary ACLR was that no significant increase in intraoperative or postoperative complications was observed.[21-23,27,32,39] Sasaki *et al*. demonstrated that the re-injury injury rate was 7.8% in the DB-ACLR hamstring graft DB-HT group and 4.1% in the rectangular SB patella tendon graft rectangular-tunnel SB (RTSB)-PT group.[40] Notably, they reported no graft failure without a traumatic episode. In Hayashi *et al*.'s study, a partial fracture of the BTB bone fragment was observed in two patients in ACL-ART patients, but no serious complications including neurovascular injury were observed.[13] Furthermore, they stated that 4 incidences of recurrence (3 within 1 year of surgery) had also occurred; however, all were due to poor compliance. Taketomi *et al*. demonstrated loss of flexion of >5° compared with the contralateral knee in one patient (4%) from each group in a study comparing the DB-HT and RTSB-PT groups.[33] Uchida *et al*. observed three cases of bone plug extrusion from the extra-articular tibial tunnel aperture. For these cases, the bone plugs were shortened or partially removed.[38] A partial posterior tunnel wall blowout was observed in the Nakase *et al*.'s study, however, the damage was noted to be minimal and was corrected using normal techniques.[19] In their investigation, using the rectangular tunnel technique in revision ACLR, Shino *et al*. demonstrated one of the 18 patients re-ruptured the graft at 28 months postoperatively.[12]

Of the studies investigating the oval femoral tunnel technique, three experienced no intraoperative or postoperative complications in either group.[16,36,43] In the study performed by Noh *et al*., one patient in the oval technique group lost 5° of extension, and all others regained normal full extension. An additional one subject in the oval technique group sustained an injury playing basketball requiring revision surgery.[9]

In a comparison between the oval femoral tunnel and rectangular femoral tunnel techniques, Nakase *et al*. demonstrated that the rectangular technique provides a more flat graft-bone junction than the oval one. Hence, there is more room to increase the size of the femoral tunnel without roof impingement in rectangular technique particularly in patients with small intercondylar area.[19]

Limitations

Several limitations of this study warrant mention. First, the number of articles that were used in the meta-analysis was relatively small, and they were mostly nonrandomized retrospective cohort studies. Due to the novel nature of this technique, there are limited randomized controlled trials investigating the use of noncircular ACLR that were available for inclusion in our analysis. Because of the paucity of large prospective comparative studies between rectangular tunnels and conventional round, there were significant limitations in the data that was able to be analyzed for meta-analysis. In addition, within those studies that were analyzed, not unlike many other meta-analyses on various ACLR techniques, the results of which should be considered in light of the variable methodologies among the included studies and lack of standardization that could potentially confound the findings as described. In addition, follow-up time varied between studies and may have influenced our results. Larger, randomized prospective studies are needed to further our understanding of the clinical efficacy of these novel techniques in ACLR.

Conclusions

Noncircular femoral tunnel ACLR has been shown to have some biomechanical advantages, including early graft healing and less tunnel widening, as well as reasonable and comparable clinical outcomes. Studies have demonstrated improved rotational stability due to the flatter shape of the graft and improved Lysholm scores in comparison to the conventional round femoral tunnel ACLR. The smaller surface area of the graft makes this operation desirable particularly in patients with a small intercondylar area and in some revision, cases allowing the creation of the tunnel in a more anatomic position.

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Conflicts of interest

There are no conflicts of interest.

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Osteochondritis Dissecans of the Shoulder: A Narrative Review of the Current Literature

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Abstract

Osteochondritis dissecans (OCD) primarily affect the ankle and knee joints, but its occurrence in the shoulder is rare. This condition can lead to long-term complications and early osteoarthritis, especially in young athletes, potentially jeopardizing their professional careers. To aid in early diagnosis, advanced imaging techniques like magnetic resonance imaging (MRI) are used. However, due to the rarity of this condition, there is no consensus on the optimal treatment approach. In an effort to provide a concise and up-to-date review of this rare condition, we conducted a detailed search on OCD of the shoulder using PubMed, Scopus, and Google Scholar. We utilized keywords such as "osteochondritis dissecans," "shoulder," and "humeral head." Despite our search, we found limited literature available on this condition. The etiology of osteochondritis dissecans of the shoulder is multifactorial, and its diagnosis relies on a combination of clinical history, physical examination, and imaging studies, particularly MRI. The MRI provides detailed information about the lesion, articular cartilage, and subchondral bone, aiding in accurate diagnosis. Treatment options for OCD of the shoulder encompass conservative management, biological interventions, and surgical approaches to alleviate symptoms and improve outcomes.

Keywords: Chondral lesions, humeral head, loose body, osteochondritis, regenerative treatment, shoulder

Introduction

Osteochondritis dissecans (OCD) is characterized by the separation of a segment of cartilage from the underlying subchondral bone, which may lead to instability and separation over time.[1] The Research in Osteochondritis of the Knee study has redefined OCD as a focal, idiopathic, subchondral lesion that can cause long-term complications, such as osteoarthritis (OA).[1] Although the condition is relatively rare, it can affect various joints, including the ankle, knee, hip, and shoulder.[2] However, the shoulder joint is less commonly affected compared to the ankle, knee, and hip. The OCD has a mysterious etiopathogenesis and natural history.

Ancient "doctors" first noted the condition when they found loose bodies in joints, which prompted them to look into its causes.[3] Ambroise Paré, first documented the case of loose bodies in the knee in 1558.[4] Over time, other people such as Alexander Monro, John Hunter, Paul Broca, Thomas Teale, and Baron Albrecht von Haller contributed to the understanding of the condition, with many theories proposed to explain its underlying causes.[5-9] Paget, for instance, suggested that vascular factors could contribute to the development of loose bodies in the joint.[10] Franz König, a German pathologist, named the condition "osteochondral bodies" in 1887.[11] Still, not much is known about the OCD of the shoulder joint.

In this review article, we aim to provide an up-to-date overview of the current literature on osteochondritis dissecans (OCD) of the shoulder joint. The objective of this review is to enable better diagnosis and management of this rare condition by summarizing the existing knowledge on its epidemiology, etiopathogenesis, clinical presentation, and treatment options. By doing so, we hope to contribute

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to the understanding of OCD of the shoulder joint and facilitate its effective management.[2,12]

Epidemiology

Regarding the incidence and prevalence specifically for OCD of the shoulder, there is limited data available. The incidence and prevalence of OCD of the shoulder are not well-established.[13] However, it is known that OCD is more commonly seen in adolescents and young adults.[3] This age group is particularly vulnerable due to the ongoing development of the shoulder joint and the participation in sports activities that involve repetitive overhead motions.[14] The repetitive stress placed on the shoulder joint during certain sports activities, such as baseball, tennis, and swimming, can contribute to the development and progression of OCD lesions in the shoulder.[3] In fact, a study by Takahara *et al*. found a high prevalence of OCD of the humeral head in high school baseball players, indicating the potential association between sports participation and the development of the condition.[15]

The overall understanding of OCD has evolved over time, as highlighted by Edmonds and Polousky in their review of knowledge spanning 123 years.[16] It is important to note that the prevalence of OCD may vary depending on the population studied and the diagnostic criteria used. Further research is needed to provide a better understanding of the epidemiology of this condition.

Etiopathogenesis

OCD of the shoulder is believed to have a multifactorial etiology, with genetic, biomechanical, vascular, and traumatic factors potentially contributing to the development of the condition.[14] However, the exact role and significance of each factor remain unclear.

The onset of OCD in the shoulder is commonly seen in adolescents and young adults.[3] Certain sports activities that involve repetitive overhead motions, such as baseball, tennis, and swimming, have been identified as potential risk factors for developing OCD lesions in the shoulder.[1] While not all individuals engaged in these activities will develop OCD, the repetitive stress placed on the shoulder joint may increase the risk.[3]

In addition to age and sports activities, there may also be genetic and anatomical factors contributing to the development of OCD. A genome-wide association study revealed candidate loci associated with juvenile OCD, suggesting a genetic predisposition to the condition.[17] Furthermore, mechanical axis deviation, which refers to abnormal alignment of the joint, has been found to be highly concordant with the location of OCD lesions.[18] This suggests that anatomical factors may play a role in the etiology of OCD.

The underlying mechanism of OCD involves a disruption in the blood supply to the subchondral bone, leading to necrosis and subsequent separation of the bone and cartilage fragment. The exact cause of the vascular compromise is not fully understood, but it is believed to involve a combination of factors such as trauma, repetitive microtrauma, and ischemia.[19,20] Trauma, either acute or repetitive, can lead to the initial insult, while repetitive microtrauma from overhead activities can contribute to the progression of the condition.[13] Ischemia, resulting from compromised blood flow, further impairs the healing capacity of the affected area.

However, not all individuals who experience trauma to the shoulder joint develop OCD, suggesting that additional factors may be involved. Overall, while each of these factors may contribute to the development of OCD of the shoulder, the relative significance of each factor and the interplay between them remains unclear and requires further investigation.

Pathology

The development of OCD passes through several stages [Figure 1] [Table 1], as below:

I. The first stage of OCD involves a disruption of the blood supply to the subchondral bone, which is the layer of bone just beneath the articular cartilage. This disruption can be caused by a variety of factors, including trauma, repetitive microtrauma, and genetic predisposition. The disruption of blood supply can lead to necrosis of bone cells[21]
II. In the second stage, the necrotic bone tissue is gradually reabsorbed, leading to the formation of a lesion. The lesion can vary in size and shape and may involve both bone and cartilage. As the lesion grows, it may eventually reach the surface of the joint and become visible in imaging studies[20]
III. In the third stage, the lesion may progress to a full-thickness defect in the articular cartilage. This can occur as a result of the continued loss of bone tissue, as well as the mechanical stress placed on the remaining cartilage. The defect in the cartilage can lead to joint pain, stiffness, and loss of function[22]
IV. In the fourth stage, the body attempts to repair the defect in the cartilage by producing fibrocartilage. Fibrocartilage is a type of cartilage that is less resilient than normal articular cartilage and may not provide the same level of cushioning and shock absorption. This can lead to further joint damage and a worsening of symptoms over time.[23]

Classification

Several classification systems are available to classify OCD. Magnetic resonance imaging (MRI)-based classification by Anderson [Table 2][24] and arthroscopic classification by Cheng [Table 3][25] are the most popular ones.

Clinical Features

Osteochondritis dissecans (OCD) of the shoulder is characterized by a range of clinical features that can vary based on the severity and location of the lesion.

Patients with OCD of the shoulder commonly experience shoulder pain, stiffness, and limited range of motion (ROM).[1,3] The pain is typically localized in the anterior or anterolateral aspect of the joint and can be exacerbated by overhead activities or throwing.[1,3] In some cases, patients may also report a catching or locking sensation in the joint during movement.[2] The pain associated with OCD in the shoulder tends to worsen at night and can interfere with sleep.[1] The duration of symptoms can vary, with a gradual onset of mild and intermittent symptoms that progressively worsen over time.[1] The duration of symptoms may range from weeks to months.[3]

Physical examination of the shoulder in individuals with OCD may reveal tenderness over the affected area, and there may be a palpable defect or crepitus.[2] The ROM of the shoulder, particularly in the abduction and external rotation, may be limited.[1] Weakness of the rotator cuff muscles can also be present.[1] It is worth noting that the age is an important factor in the clinical presentation, as OCD of the shoulder is more commonly seen in adolescents and young adults.[3]

Certain sports activities that involve repetitive overhead motions, such as baseball, tennis, and swimming, have been associated with the development and progression of OCD lesions in the shoulder.[1] While not all individuals engaged in these activities will develop OCD, the repetitive stress placed on the shoulder joint increases the risk.[3] Therefore, a thorough history including the patient's engagement in such activities is essential in the evaluation of OCD of the shoulder.

Diagnosis

The diagnosis of osteochondritis dissecans (OCD) of the shoulder is achieved through a combination of clinical history, physical examination, and imaging studies.[13] While the clinical presentation of OCD of the shoulder can be nonspecific and resemble other shoulder conditions, imaging studies play a crucial role in confirming the diagnosis and evaluating the extent of the lesion.[13]

Various imaging modalities are used for diagnosing OCD of the shoulder, including X-rays, MRI, and computed tomography (CT) scans.[26] MRI is considered the gold standard imaging modality for diagnosing OCD, as it provides detailed information about the articular cartilage, subchondral bone, and surrounding soft tissues.[26] It is highly sensitive and specific in detecting OCD lesions, with reported sensitivities ranging from 87% to 100% and specificities ranging from 75% to 95%.[13] MRI can also differentiate OCD from other shoulder conditions such as rotator cuff tears or labral tears.[13]

In cases where the diagnosis is uncertain or further evaluation is needed, arthroscopy may be performed to confirm the diagnosis and assess the extent of the lesion.[13] Arthroscopy also serves as a treatment option for OCD of the shoulder by removing loose fragments, debriding damaged cartilage, and performing procedures such as drilling or microfracturing the subchondral bone.[13]

Treatment

The treatment of OCD of the shoulder depends on various factors, including the severity and location of the lesion, patient age, and activity level. The goals of treatment include reducing pain, improving shoulder function, and preventing further damage to the joint. It involves a combination of conservative management and surgical intervention, depending on the severity and location of the lesion.

Conservative

It is an initial treatment option and considered when symptoms are mild and the lesion is stable. Activity modification, nonsteroidal anti-inflammatory drugs, physical therapy, and rest are often tried first. The success rate of conservative treatment for OCD of the shoulder varies depending on the severity of the lesion and individual response to treatment. However, in cases where conservative treatment fails to alleviate symptoms or the lesion progresses, surgical intervention may be necessary.[13,27]

Biological

In recent years, there has been increasing interest in the use of biological agents, such as platelet-rich plasma (PRP), to promote the healing of the lesion.

Platelet-rich plasma

PRP is derived from autologous blood and contains a concentrated amount of platelets and growth factors. When administered via injection into the affected area, PRP aims to stimulate tissue healing and regeneration. The growth factors present in PRP have the potential to enhance cell proliferation, collagen synthesis, and tissue remodeling, thereby facilitating repair of the OCD lesion.[28,29]

Sodium hyaluronate

Sodium hyaluronate, known as visco-supplementation, involves injecting a gel-like substance that mimics natural joint fluid. This approach aims to provide lubrication and cushioning to the affected joint, thereby reducing friction and relieving pain. Sodium hyaluronate injections have been utilized in various joint conditions, including OCD of the shoulder, with the goal of improving joint function and alleviating symptoms.[30,31]

While there is ample evidence supporting the utilization of PRP and sodium hyaluronate in treating OCD of the knee and talus, there is a lack of specific evidence to substantiate its effectiveness in addressing OCD of the shoulder. It is crucial to recognize that the effectiveness of biological agents may vary among individuals, and further research is warranted to establish their optimal utilization, long-term outcomes, and success rates in managing OCD of the shoulder.

Surgical

The treatment approach for osteochondritis dissecans depends on the patient's age and the stability of the chondral fragment.

In cases where the lesion is stable and the growth plate (physis) is open, conservative treatment is typically pursued. However, if the lesion remains stable and the growth plate is closed, multiple drilling is often preferred. In instances where the lesion is deemed unstable and nonsalvageable, options such as osteochondral autograft transplantation (OAT), autologous chondrocyte implantation (ACI), or osteochondral allografting may be considered, taking into account the size of the lesion and the patient's needs. Alternatively, if the lesion is unstable yet salvageable, arthroscopic or open reduction, and fixation procedures can be performed.[28]

Determining the optimal treatment for chondral and osteochondral lesions in the glenohumeral joint of young and active patients remains a complex task for surgeons, and surgical techniques in this regard are continuously advancing.

Arthroscopic loose body removal/debridement

Arthroscopic treatment is indicated for the removal of loose bodies and unstable cartilage fragments in the shoulder joint. It is also considered when conservative treatment has failed, and there is persistent pain and functional impairment. Studies have shown that arthroscopic techniques can effectively remove loose bodies and unstable cartilage fragments and promote healing of the affected area.[32]

Subchondral drilling

Subchondral drilling is a well-established technique used for the treatment of stable osteochondritis dissecans (OCD) lesions. It aims to stimulate the influx of mesenchymal cells and growth factors into the subchondral bone, promoting healing, and repair processes.[33,34] Two common drilling techniques employed for stable lesions are trans-articular drilling and retroarticular (transepiphyseal) drilling.[33,34]

Trans-articular drilling involves the arthroscopic perforation of the articular cartilage directly above the OCD lesion.[35] On the other hand, retroarticular drilling is performed through the affected condyle, avoiding direct penetration of the articular cartilage. This technique requires intraoperative fluoroscopy to guide the placement of the drilling instrument.[36] A systematic review has concluded that both trans-articular and retroarticular drilling techniques yield comparable patient-oriented and radiographic outcomes.[37]

In some cases, adjunctive bone grafting may also be employed along with subchondral drilling.[38] While subchondral drilling is considered a viable treatment option for OCD of the knee, there is currently no established evidence supporting its effectiveness for OCD of the shoulder.

Surgical fixation

Surgical fixation is widely regarded as the optimal treatment method for addressing unstable osteochondritis dissecans (OCD) lesions or displaced osteochondral fragments, particularly among younger patients. Extensive literature supports the effectiveness of this approach in achieving positive mid- and long-term outcomes.[39]

When dealing with stable OCD lesions that have intact cartilage following unsuccessful nonoperative management or unstable lesions with sufficient bone support, surgical fixation becomes a viable option. The primary goals of surgical fixation for OCD lesions are to restore the articular cartilage surfaces, promote adequate vascular perfusion to the defect, and apply compression to facilitate optimal healing. Surgeons can choose between an open or arthroscopic approach for fixation.[40]

Arthroscopic techniques offer several potential advantages, including reduced operative morbidity and a faster recovery period. A diagnostic arthroscopy can be performed to assess the size and characteristics of the lesion. Following exposure of the lesion's base and debridement, microfracture is carried out to create a bleeding base.[40] The fragment is then carefully repositioned anatomically and temporarily secured using a K-wire.

Various fixation devices have been.[41] It is crucial to ensure that the fixation device is placed beneath the articular surface to prevent any potential damage to the cartilage. Metallic or non-absorbable devices are typically removed after 8–12 weeks.[40]

The effectiveness of surgical fixation for OCD of the shoulder is currently unsupported by established evidence, despite its acceptance as a viable treatment for knee OCD.

Osteochondral autograft transplantation (OAT)

Osteochondral autograft transplantation (OAT) involves transferring healthy osteochondral plugs from a non-weight-bearing area of the knee joint to the chondral defect site in the shoulder. It is indicated for small- to-medium-sized (approximately 2.5 cm–3.5 cm) areas of isolated chondral and osteochondral damage.

This surgical technique aims to replace damaged cartilage and bone in the affected joint with healthy tissue. In the case of OCD in the shoulder, the procedure involves harvesting one to three osteochondral autograft plugs from the outer edge of the lateral femoral condyle in the knee joint. These plugs are then transferred to the chondral defect site in the shoulder using a press-fit technique. The resulting repair is native hyaline cartilage, promoting better long-term outcomes.

Limited published evidence exists regarding the use of OAT specifically for the treatment of osteochondral defects in the shoulder. The case series by Scheibel *et al*. demonstrated significant improvement in shoulder function after osteochondral autograft transplantation (OAT) for osteochondral defects, with excellent graft integration and viability.[42] Long-term follow-up by Kircher *et al*. showed sustained positive outcomes, with minimal need for revision surgery and continued improvement in the Constant score.[43] These findings suggest that OAT is a promising treatment option for OCD shoulder defects, providing long-term functional benefits and graft durability.

Based on the available evidence, osteochondral autograft transplantation appears to be a viable treatment option for focal chondral defects in the glenohumeral joint. The procedure has shown significant improvements in shoulder function, with excellent graft viability and congruence of the chondral surfaces. Long-term follow-up studies have indicated the durability of the outcomes and low revision rates.

It is important to note that further research, including randomized controlled trials and larger studies, is needed to validate these findings and establish the optimal indications and long-term outcomes of OAT for OCD shoulder.[44] In addition, individual patient factors, defect characteristics, and the expertise of the surgical team should be considered when determining the most suitable treatment approach for each case.

Fresh osteochondral allograft transplantation (OCA)

Osteochondral allograft transplantation (OCA) is an emerging treatment option for osteochondral defects (OCD) of the shoulder that have failed conservative and arthroscopic treatments. It is primarily indicated for large, uncontained lesions associated with significant pain and functional limitations. The procedure involves the use of donor tissue to replace damaged cartilage and bone in the shoulder joint. However, the use of allografts carries risks such as disease transmission and rejection, necessitating further research to determine long-term effectiveness and safety, including success rates.[45,46]

Structural allograft reconstruction is a technique employed for large lesions involving the anterior and posterior aspects of the humeral head, comprising a significant portion of the articular surface. Precise preoperative planning is crucial to obtain an appropriately sized humeral head allograft with a matched radius of curvature. In lesions of the anterior aspect, a standard deltopectoral approach is used, and a uniform defect is created for graft placement. The allograft is then inserted and secured using screws.[46]

Alternatively, for defects up to 35 mm in diameter, large allograft plugs or multiple plugs can be used. A cannulated allograft osteochondral autograft transplant system (OATS) sizer is chosen, and a drill tip guide pin is drilled through the sizer into the bone. The appropriate allograft is harvested, measured, marked, and inserted into the defect. Similar techniques can be applied to lesions of the posterior aspect, typically utilizing an anterior, deltopectoral surgical approach.[46]

Clinical studies have reported positive outcomes following osteochondral allograft transplantation for OCD of the shoulder. In a series by Miniaci *et al.*, osteoarticular allograft reconstruction of the humeral head resulted in no recurrent instability episodes at a 2-year follow-up. Some case reports have also shown good results with no recurrent instability and improved shoulder function at 1-year follow-up.[47]

Riff *et al*. conducted a study involving 20 patients who underwent osteochondral allograft transplantation for humeral head osteochondral defects. At a mean follow-up of 67 months, significant improvements were observed in various outcome scores, including pain levels, shoulder function, and quality of life.[48]

Another study by Diklic *et al*. focused on 13 patients with a chronic posterior shoulder dislocation and associated humeral head osteochondral defects. At a mean follow-up of 54 months, the majority of patients reported no pain or restriction of activities, although one patient developed osteonecrosis of the humeral head.[49]

In addition, the use of different allografts, such as femoral head and iliac crest bone allografts, has been explored for osteochondral allograft transplantation in the shoulder joint, showing promising outcomes in terms of pain relief and functional improvement.[48,49]

Overall, while osteochondral allograft transplantation holds promise as a treatment option for OCD of the shoulder, further research is necessary to establish its long-term effectiveness and safety. Individualized treatment decisions should be made based on a thorough evaluation, considering the patient's symptoms, lesion characteristics, and response to conservative measures.[46]

Table 1: Stages of osteochondritis dissecans

Stage	Description
1	Disruption of blood supply to subchondral bone, leading to bone cell death (necrosis)
2	Reabsorption of necrotic bone tissue, forming a lesion that can involve both bone and cartilage
3	Progression to a full-thickness defect in the articular cartilage, resulting in joint problems
4	Attempted repair of the defect with fibrocartilage, which is less effective and worsens symptoms over time

Table 2: Magnetic resonance imaging staging of osteochondritis dissecans

Stage	Evaluation	Findings
I	Early	Subchondral bone flattening in the epiphyseal plate before growth plate closure
IIA	Stable	Subchondral cyst formation
IIB	Unstable	Incomplete separation of the osteochondral fragment
III	Unstable	Undetached, nondisplaced osteochondral fragment
IV	Terminal	Complete separation of the osteochondral fragment

Table 3: Arthroscopic staging of osteochondritis dissecans

Grade	Findings
A	Articular cartilage is smooth and intact but may be soft or ballotable
B	Articular cartilage has a rough surface
C	Articular cartilage has fibrillations or fissures
D	Articular cartilage with a flap or exposed bone
E	Loose, nondisplaced osteochondral fragment
F	Displaced osteochondral fragment

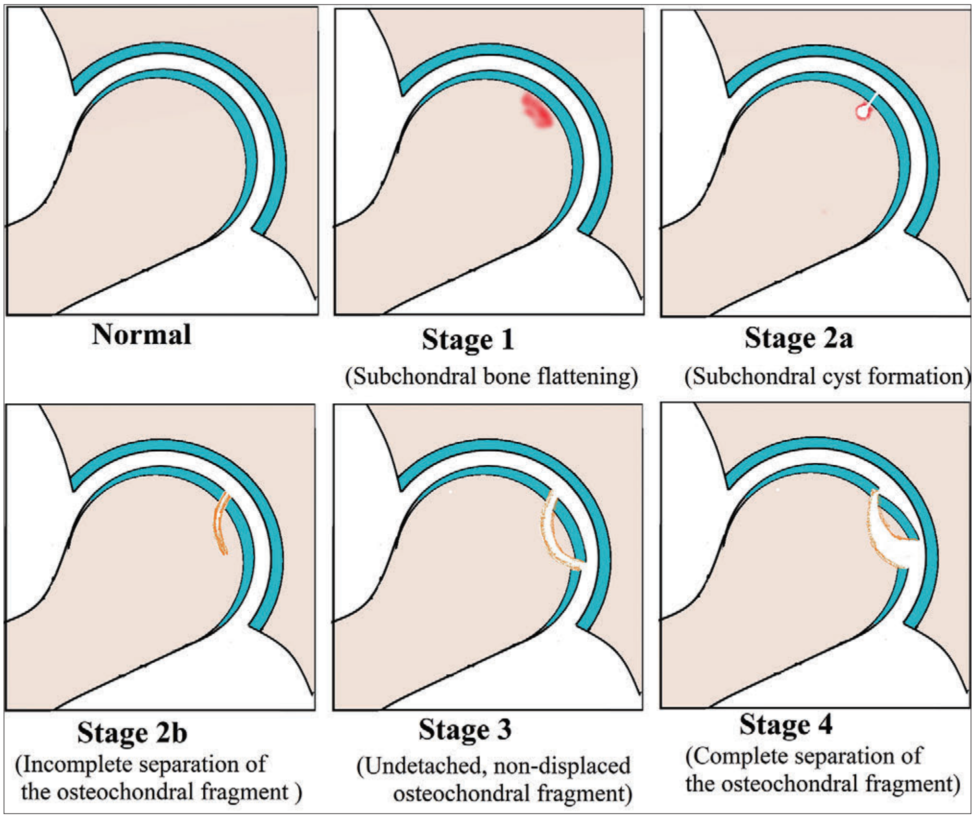

Figure 1: Stages of osteochondritis dissecans

Combination therapy

Combination therapy for OCD of the shoulder involves the strategic utilization of multiple treatment modalities to enhance therapeutic outcomes. One commonly employed combination approach includes PRP in addition to the surgical fixation or allograft. The studies demonstrated significant outcomes.[28,50] However, further research and well-designed studies are required to establish standardized protocols, optimize treatment combinations, and elucidate the underlying rationale behind the selection of specific treatment modalities in combination therapy. The combination therapies are currently under evaluation for the treatment of OCD knee and the same can be expanded to OCD shoulder in future.

Prognosis and Complications

The prognosis of OCD of the shoulder varies depending on various factors, including the stage and location of the lesion, the age of the patient, and the chosen treatment approach. Early-stage lesions that are stable and well-managed with conservative treatment or arthroscopic interventions tend to have a better prognosis compared to advanced or unstable lesions.

If left untreated or inadequately managed, OCD of the shoulder can lead to long-term complications include, OA, joint instability, functional limitations, secondary injuries, such as rotator cuff tears, labral tears, or other shoulder pathologies.[51]

It is essential to diagnose and manage OCD of the shoulder promptly to minimize the risk of complications and optimize long-term outcomes. Regular follow-up, adherence to treatment plans, and appropriate rehabilitation are crucial for achieving the best possible prognosis.

Conclusion

Osteochondritis dissecans of the shoulder are a rare condition. Its etiology is multifactorial, involving genetic, biomechanical, vascular, and traumatic factors. The diagnosis of OCD of the shoulder relies on a combination of clinical history, physical examination, and imaging studies. MRI is the gold standard imaging modality, providing detailed information about the lesion, articular cartilage, and subchondral bone. Treatment options for OCD of the shoulder include conservative management, biological, and surgical interventions.

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Conflicts of interest

There are no conflicts of interest.

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Comparison of Single Dose with Continuous Infusion of 0.2% Ropivacaine in Interscalene Brachial Plexus Nerve Block for Pain Relief in Rotator Cuff Repair Surgery

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Abstract

Background: Severe postoperative pain is the most common complication after arthroscopic rotator cuff surgery. Peripheral nerve blocks, whether single-shot interscalene block (SSISB) or continuous interscalene nerve block, have consistently demonstrated superior analgesia after upper extremity surgery compared to general anesthesia alone. **Aims:** The aim of this study was to evaluate the difference in pain relief provided by single shot versus catheterized interscalene block. **Materials and Methods:** A prospective observational study was conducted in the Department of Orthopedics of Justice K.S.Hegde Charitable Hospital, Mangalore, from January 2020 to June 2021. Thirty patients who were diagnosed of complete rotator cuff tear were included in the study. All of them underwent arthroscopy-assisted single-row rotator cuff repair by the same surgeon under general anesthesia. They were randomly allocated into Groups I and B of 15 each. Patients in Group A received a SSISB and Group II received continuous infusion after the insertion of catheter. The catheter was removed after 24 h of surgery. Both groups followed the same postoperative management protocol. The pain perception assessment was measured using the Visual Analog Scale (VAS) at 6, 24, 48 h after surgery, and at 2nd week postoperative during suture removal. Power was assessed for the wrist (wrist flexion and extension) and for the fingers (finger flexion and abduction) at 6 h, 24 h, 48 h, and after 2 weeks on day 14 when suture removal was done. The results were calculated and tabulated using an independent "*t*-test" and "Chi-square test." **Results:** The patients in Group A had a higher VAS score with a mean of 0.26 ± 0.06 as compared to Group B which showed a mean VAS score of 0 (P = 0.01). Six patients needed analgesia of postoperative day 2. Eight patients of Group B required rescue analgesia on postoperative day 2. **Conclusion:** Continuous infusion scalene block was noted to be superior to SSISB in the management of postoperative pain postarthroscopy assisted single-row rotator cuff repair.

Keywords: Arthroscopy, catheter, interscalene block, rotator cuff, single shot

Introduction

Arthroscopic surgery has taken bone and joint surgeries to the next level. It reduced scarring, faster recovery, and reduced pain and infection rates as compared to open surgery. This also reduces hospital stays.[1-3] However, there are incidences of some pain which can hamper and reduce shoulder function. Use of interscalene blocks of the brachial plexus is noted to effectively reduce pain even 8–10 h after surgery and reduce dependence on opiates and analgesics. It is noted to have high success and low complication rates.[4-8]

Opioids are noted to have adverse effects such as nausea, sedation, and vomiting also in some cases failure to control pain. Addition of regional never blocks can improve the management of postoperative pain.[9]

All the motor and sensory functions of the shoulder are provided by the brachial plexus. The majority of the brachial plexus which supply the shoulder are suprascapular and axillary nerves. C5-C6 and possibly C4 arise from the superior trunk of the brachial plexus. It descends posteriorly through the scapular notch innervating supraspinatus and infraspinatus muscles. Posterior cord of the brachial plexus from C5-C6

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occasionally C4 gives birth to the axillary nerve. It crosses the anteroinferior aspect of the subscapularis muscle, where posteriorly it forms the anterior and posterior trunk through the quadrilateral space.[10]

Aims and objectives

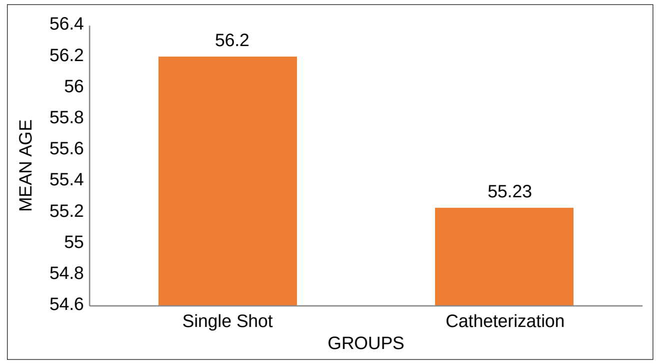
This study aims to compare single shot versus catheterized interscalene block for the management of postoperative pain for patients who have undergone arthroscopic single-row rotator cuff repair under general anesthesia at 6 h, 24 h, 48 h, and on day 14 postsurgery.

Materials and Methods

A prospective study was conducted in the Department of Orthopedic Surgery of Justice K.S.Hegde Charitable Hospital, Mangalore, from January 2020 to June 2021. A total of 30 patients with complete rotator cuff tears were included in the study after taking appropriate consent and clearance from the Institution Ethics Committee. Patients between the ages of 20 and 50 years were included in the study. The exclusion criteria included patients with systemic conditions such as diabetes mellitus, hypertension, glenohumeral arthritis, patient refusal, history of shoulder intra-articular injections, and pregnancy. After fitness for surgery was obtained, the patients were randomly divided into Groups I and II of 15 patients each. All the surgeries were performed under general anesthesia by the same surgeon. Single-row rotator cuff repair was done for all the patients using titanium suture anchors in beach chair position. Single-shot interscalene block (SSISB) (Group I) with 0.2% ropivacaine or catheter insertion (Group II) was done just before extubation from anesthesia. The patients were kept in the postoperative ward for a period of 6–12 h. Continuous drug infusion was delivered through the catheter for patients in Group II over 24 h with 0.2% ropivacaine and the catheter was removed after 24 h. Patients were started on a standard rehabilitation protocol from postoperative day 3. Some patients in each group required rescue analgesia during which 50 mg oral diclofenac tablets were used for the management of pain. They were discharged on postoperative days 4–6. Suture removal was done on postoperative day 14. Scoring for perception of pain was done using Visual Analog Scale (VAS) scoring criteria[11] at 6, 24, 48 h, and 14 days postoperative. Power was assessed for the wrist (wrist flexion and extension) and for the fingers (finger flexion and abduction), at 6 h, 24 h, 48 h, and after 2 weeks on day 14 when the patient comes for suture removal. The results were calculated and tabulated using an independent "*t*-test" and "Chi-square test."

Results

The study showed an age distribution of a mean age of 56.2 ± 7.85 years in Group I and 55.2 ± 7.76 years [Graph 1]. Group 1 included 5 females and 10 males and Group II included 7 females and 8 males. Six of the 15 patients in Group I needed rescue analgesia of one dose of oral tablet diclofenac on postoperative day 2. Eight patients of the 15 in Group II required the same rescue analgesia on postoperative day 2. Motor and sensory recovery was complete by postoperative day 2 in all cases of both groups. At a time interval of 6 h, Group 1 showed a higher mean VAS score of 8.47 ± 1.77 as compared to Group 2 which showed a mean VAS score of 6.69 ± 1.60 (P = 0.01). At a time interval of 24 h, Group 1 showed a higher mean VAS score of 6.27 ± 2.12 as compared to Group 2 showed a mean VAS score of 5.08 ± 1.89 (P = 0.13). At a time interval of 48 h, Group 1 showed a higher mean VAS score of 4.27 ± 1.44 and Group 2 showed a mean VAS score of 2.77 ± 1.69. At a time interval of 2 weeks, Group 1 showed a higher mean VAS score of 0.26 ± 0.06 as compared to Group 2 which showed a mean VAS score of 0 [P = 0.01, Graph 2].



Graph 1: Bar graph showing age distribution in Groups I (single shot - 56.2 years) and II (catheterization - 55.23 years)

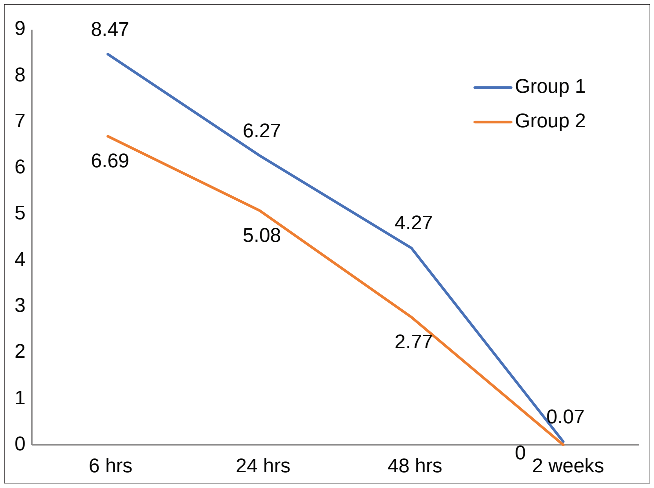
Discussion

Peripheral nerve blocks, whether SSISB or continuous interscalene nerve block (CISB), have consistently demonstrated superior analgesia after upper extremity surgery compared to general anesthesia alone.[10] Several studies exist in the literature that state CISB most effective method in postoperative pain relief following rotator cuff repair surgery.[12,13] However, there were very limited comparative studies that compared single shot versus continuous infusion of 0.2% ropivacaine following shoulder surgery.[5]

The study showed an age distribution of a mean age of 56.2 ± 7.85 years in Group I and 55.2 ± 7.76 years. Gumina *et al*. reported that in their cohort of 586 patients undergoing rotator cuff surgery, the range of mean age was found to be 57–59.[14]

Yamamoto *et al*. performed shoulder surgery in 683 patients which included 229 males (33.5%) and 454 females (66.5%).[15] On the contrary, in our study, there were 12 females (40%) and 18 males (60%). However, this variation could be attributed to a lower sample size.

Severe postoperative pain is the most common complication of arthroscopic rotator cuff surgery. Continuous infusion has proven to be superior in terms of providing pain relief with less side effects.[16] In our study, 6 of the 15 patients in Group I needed rescue analgesia of one dose of oral tablet diclofenac



Graph 2: Line graph showing comparison of the Visual Analog Scale score improvement in Groups I (single shot 0.26 ± 0.06) and II (catheterization - 0). VAS: Visual Analog Scale

on postoperative day 2. Eight patients of the 15 in Group II required the same rescue analgesia on postoperative day 2.

Kim *et al*. evaluated factors affecting pain in the first 12 months after rotator cuff repair.[17] They found that high initial VAS scores, the acute onset of pain, and internal rotation stiffness resulted in higher-than average pain scores. Our study also showed that both Group 1 and Group 2 showed a decline in VAS score at a time interval of 6 h, 24 h, 48 h, and 2 weeks ($P = 0.01$).

Conclusion

Continuous infusion scalene block was noted to be superior to SSISB in the management of postoperative pain postarthroscopy assisted rotator cuff repair. There were no motor or sensory deficits noted in either of the groups.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Does Arthroscopic Knotless Double-row Rotator Cuff Repair Yield Better Patient-reported Outcome Measures than Knotted Double-row Repair? A Prospective Comparative Interventional Study

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Abstract

Objective: The objective of the study was to find out whether a significant difference exists in patient reported outcome measures (PROM) after arthroscopic knotless (KTL) versus knotted (KTT) double-row rotator cuff repair (RCR). **Materials and Methods:** A study was done on forty patients from June 2021 to December 2022 as per inclusion criteria. All patients underwent arthroscopic KTL/KTT double-row RCR with or without soft-tissue Bankart repair and/or superior labrum anterior to posterior repair by a single surgeon. Patients were followed up with University of California Los Angeles (UCLA) score and Visual Analog Scale (VAS) score for a period of 12 months. Average time of surgery and complications if any were noted. **Results:** Patients in both KTL and KTT groups had mean values of 0.7 and 0.55 for VAS score and 31.25 and 30.4 for UCLA score, respectively, at the end of 12-month follow-up. Excellent UCLA score was seen in four patients (value of 34). The average time of surgery for the KTL and KTT groups was 93.25 and 113.50 min, respectively. One patient had an intraoperative complication in the form of offloading of lateral row anchor which was revised during surgery itself. **Conclusion:** No significant difference exists in PROM, in terms of UCLA score and VAS score for those treated with KTL versus KTT double-row arthroscopic RCR in a short-term follow-up of 12 months. A KTL RCR might have the advantage of ease of procedure and reduced time of surgery though.

Keywords: Arthroscopic rotator cuff repair, double-row rotator cuff repair, knotless versus knotted repair, suture bridge

Introduction

Rotator cuff repair (RCR) has emerged as one of the most common procedures performed due to increase in the prevalence of rotator cuff (RC) injuries owing to the aging trend of the population and seems to increase further by the next 3–4 decades.[1-3] Healing of the repaired RC tissue has always been a concern for treating surgeons with more than one factor implicated from time to time.[4-6] After the repair of RC tears (RCTs), a fibrovascular scar consisting of type III collagen is formed and not type I collagen, which otherwise is biomechanically superior.[7] Furthermore, the absence of typical calcified cartilage in repaired RC tendons makes the repair more prone to failure. Since double-row repair of RCTs showed better healing and less re-tear rates in literature, it has become a widely used technique at present.[8,9] However, further modification of the same in terms of using knotted (KTT) medial row anchor or knotless (KTL) has opened an area of discussion. Few studies show promising results for RCR with KTT medial row anchors, i.e., more coverage of RC footprint and less gap formation, whereas others do not provide any significant differences.[10,11] One of the recently published meta-analyses of KTT versus KTL repair showed no significant differences in clinical outcomes among the two groups and further stress was laid on to perform the direct comparisons

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in future studies.[12] Studies also argue the fact that high strain and decreased vascularity of the repaired RC tendons at the site of knot tying increase the chances of medial row failure.[13,14] In this debate, KTL double-row repair for RCTs has picked momentum over KTT repair, despite the fact that superiority of one over the other in terms of patient-related clinical outcomes is still cloudy.[15,16] The purpose of our study was to compare the patient-reported outcome measures (PROMs) in subjects undergoing KTL versus KTT double-row RCR, using University of California Los Angeles (UCLA) score[17] and Visual Analog Scale (VAS)[18] score.

Materials and Methods

We did a prospective interventional comparative study at the Department of Orthopaedics, Military Hospital Kirkee, Pune, from June 2021 to December 2022. A total of forty patients were enrolled, who underwent arthroscopic KTT/KTL double-row RCR along with repair of other injuries (superior labrum anterior to posterior [SLAP]/Bankart, etc.) at our center and were followed up for a period of 12 months.

Study population

Subjects for the purpose of the study were enrolled from the outpatient department (OPD) of the hospital. Patients with RCTs with or without labral tears and/or SLAP injuries, patients who consented to participate in the study, and those who were willing to follow the postoperative rehabilitation protocol were included in the study, whereas skeletally immature patients (<15 years), patients with massive RCTs,[19] those with RCT of size >5 cm or <1 cm on magnetic resonance imaging (MRI), patients with concomitant subscapularis tear and/or biceps tendon injuries requiring surgery, those with neurovascular deficit of the involved limb, and patients who needed revision surgery were excluded from the study. Patients with American Society of Anesthesiologists III and above as per anesthesiologist and those having advanced osteoarthritis of shoulder joint rendering the patient to be a candidate for reverse shoulder arthroplasty (RSA) were also excluded from the study. Patients were subjected to a detailed preoperative clinical and radiological examination (radiographs and MRI) to establish the diagnosis and formulate the plan of treatment. Various parameters such as age, sex, dominant hand involvement, osteoarthritis, history of smoking, and Goutallier grade for fatty infiltration,[20] along with associated comorbidities, were documented. Patients underwent diagnostic arthroscopy and proceed under the effect of general anesthesia, by a single surgeon (first author). Patients also received regional anesthesia of the involved shoulder in addition, to make the postoperative period pain free as per the hospital protocol. The choice of technique for RCR (KTT/KTL) was decided on an alternate basis prehand in OPD while being enrolled in the study.

Statistics and ethical aspects

Clearance from the Institutional Ethical Committee through Ethical Committee No. 62/21/June/Ortho-2021 dated June 17, 2021, was obtained for the study. The results of the study were analyzed using IBM SPSS software (Version SPSS Statistics 29.0.0.0 [241], Armonk, New York, USA). Independent samples *t*-tests were conducted for VAS score, UCLA score, size of RCTs, Goutallier grade, period of hospital stay, and average time of surgery, with a confidence limit of 95% and $P < 1.005$ as significant. Besides, other statistical measures such as mean, standard deviation, and standard error of mean were also calculated.

Surgical technique

Patients were positioned in lateral decubitus position [Figure 1a]. Standard posterior viewing portal was made, and diagnostic round of the glenohumeral joint was done. Working portals were made through rotator interval in standard fashion and any pathology in the labrum/glenohumeral ligaments was addressed. A detailed examination of the RC footprint from the articular side was done and debridement if required carried out. Subacromial space was accessed through the same posterior portal by passing the arthroscope under acromion process. Lateral entry portal (in 50-yard line from the lateral acromial border) was made to carry out the debridement and various measurements of the RCTs. The bursal side of the RC was examined, and the tear was measured in both anteroposterior direction and medial retraction [Figure 1b]. Subacromial decompression was done in all patients. Acromioplasty using a high-speed bur was done in those with type III acromion anatomy (two patients). The anterior extent of debridement and bursectomy was limited to coracoacromial ligament. We found using suture retriever for grasping RC tendons to be less traumatic than a grasper, hence preventing further damage to the already compromised cuff tissue. We made two more portals (one portal: just brushing the lateral border of acromion for the placement of medial row anchor and shuttling the sutures later and second portal, i.e., posterolateral portal: 3 cm posterior to first lateral portal for passing sutures in posterior most part of the cuff). Bone bed was prepared using shaver blade and burr to achieve bleeding surface at RC footprint. We did not preserve any leftover footprint of the torn RC. Two double-loaded medial row anchors (each with 4 sutures) of size 5 mm made of titanium (BIOTEK) were placed just lateral to articular margin taking care not to damage the cartilage [Figure 1c]. A suture passing device (Scorpion; Smith and Nephew/BIOTEK) was used to pass the sutures, and the sequence of sutures was kept as anterior first in all cases to maintain the uniformity. For KTT technique, a horizontal knot was placed between adjacent sutures of each anchor before making the cross bridge (W) configuration [Figure 1d] in order to achieve a uniform tension on both anchors, whereas the same procedure without knot tying was done for KTL repair [Figure 1e]. After sufficient tension of the sutures (removing any slack), lateral row fixation was done in standard fashion using two 5.5 mm (PEEK, BIOTEK, SwiveLock) anchors placed approximately 2 cm lateral to greater tuberosity in the cortical bone [Figure 1f].

After suture cutting, the tension of the repair site was checked with arthroscopic probe for any left gap and/or loose suture.

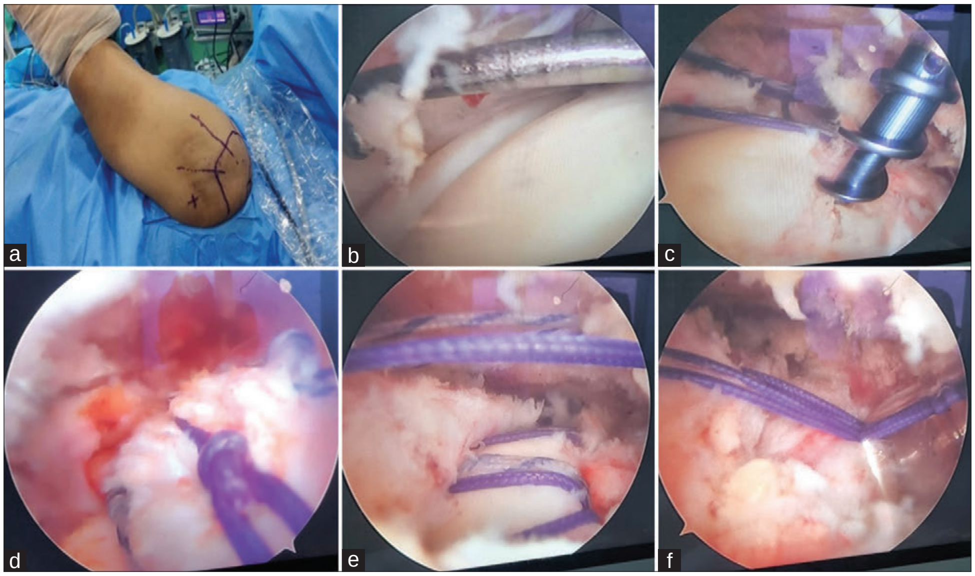

Figure 1: (Right to left): (a) Patient positioning, (b) measuring rotator cuff tear, (c) medial row anchor, (d) knotted repair, (e) knotless repair, (f) lateral row anchor

Complete coverage of the RC footprint was checked by rotating the humeral head (external rotation to internal rotation). Bankart lesion in four patients was repaired as single row repair using four all inside suture anchors of size 1.5 mm in each patient, and the same implant was also used for repairing type III SLAP tear in two patients. One patient had type I SLAP tear which was managed by debridement only.

Postoperative protocol

All patients were subjected to the same standard rehabilitation protocol irrespective of the type of repair. Wound examination was done on the 4th postoperative day followed by suture removal on the 14th postoperative day as per hospital protocol. All patients were recommended shoulder immobilizer sling along with an abduction pillow in immediate postoperative period in order to provide around 20° abduction and 20°–30° internal rotations. Pendulum exercises were started on the 2nd postoperative day (as per pain tolerance), followed by passive forward flexion after the 2nd postoperative week. Abduction brace and shoulder immobilizer were discontinued after the 6th postoperative week, and active range of motion was started. Resistance-based muscle strengthening was allowed after 12 weeks only. Activities requiring heavy weight lifting were restricted till 9 months postoperatively. However, observed sports training was allowed from 6 months onward. Regular documentation of the results for UCLA and VAS was done at postoperative 6-week, 3-month, 6-month, and 12-month interval.

Results

Baseline characteristics for patients in the two groups, i.e., KTL and KTT, were compared and subjected to analysis [Tables 1 and 2].

The mean age of the patients was 48 years with 29 males and 11 females. Dominant side was involved in 68% of cases (27 out of 40 patients), whereas 13 patients had injury over nondominant shoulder. Early degenerative changes in the glenohumeral joint were seen in nine patients (22%). Goutallier grade 4 was present in two patients (5%), grade 3 in four patients (10%), grade 2 in nine patients, grade 1 in four patients, and the rest of the patients had no fatty infiltration of RC tendons. A total of 33 patients (83%) had RCTs in isolation, four patients (10%) had an associated soft-tissue Bankart lesion, and three patients (7%) were diagnosed with SLAP tear (types I, III, and III, respectively). The mean size of RCTs was 2.9 cm for the KTL group and 2.8 cm for the KTT group as measured intraoperatively. Only four patients (10%) had 4 cm size RCTs. VAS score for both KTL and KTT groups showed a progressive decrease by the end of 12-month follow-up with mean values of 0.7 and 0.55, respectively [Figure 2a and Table 3]. UCLA score also had good results with mean values of 31.25 and 30.4 for the KTL and KTT groups, respectively, at the end of 12-month follow-up [Figure 2b and Table 4].

Excellent values for UCLA score were seen in four patients (value of 34). We encountered an intraoperative complication in one patient in the form of off-loading of a lateral row anchor, for which another suture anchor was replaced by making an adjacent entry point. We also included variables such as history of tobacco consumption (14 patients [35%]) and diabetes (7 patients [17%]) in our study in order to see their effect on RCR in long follow-up. However, in a short follow-up of 1 year, neither of the two variables had any significant effect on PROM measures.

Discussion

History of RCTs dates back to 1788 in the works of Monro, titled “A description of All the Bursal Mucosae of the Human body.”[21] Much later in the year 1985, Andrews from the

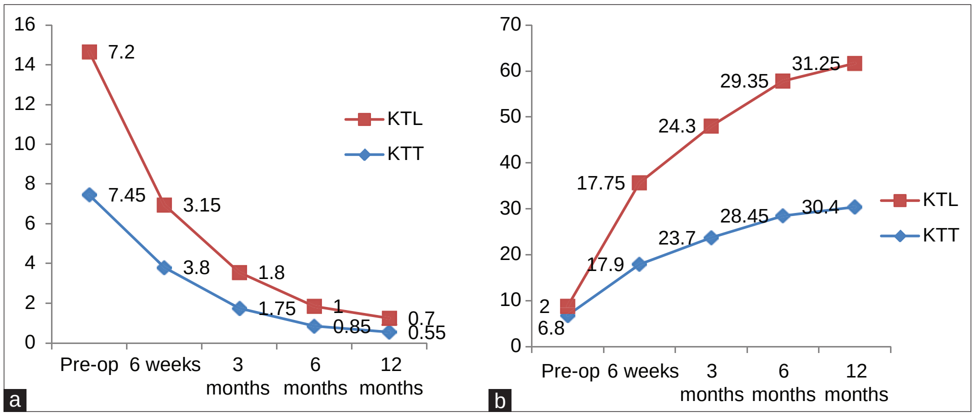

Figure 2: Visual Analog Scale (VAS) score and University of California Los Angeles (UCLA) score, (a) VAS score (knotless/knotted [KTL/KTT]), (b) UCLA score (KTL/KTT). KTL: Knotless, KTT: Knotted

Table 1: Patient characteristics

	Type of cuff repair	*n*	Mean	SD	SEM	Two-sided *P*
Age	KTL	20	47.20	10.501	2.348	0.292
	KTT	20	50.60	9.588	2.144	0.292
RCT size (anterior to posterior) intraoperative measurement (cm)	KTL	20	2.900	0.5525	0.1235	0.901
	KTT	20	2.875	0.7048	0.1576	0.901
Goutallier grading	KTL	20	0.95	1.191	0.266	0.540
	KTT	20	1.20	1.361	0.304	0.540
Hospital stay (days)	KTL	20	4.30	0.733	0.164	0.515
	KTT	20	4.50	1.147	0.256	0.516
Average time of surgery (min)	KTL	20	93.25	15.241	3.408	<0.001
	KTT	20	113.50	18.144	4.057	<0.001

KTT: Knotted, KTL: Knotless, RCT: Rotator cuff tears, SD: Standard deviation, SEM: Standard error of mean

Table 2: Baseline data

Characteristics	Type of cuff repair	*n*	Number of patients (out of 20 in each group) (%)
Dominant hand involvement	KTL	20	15 (75)
	KTT	20	12 (60)
Glenohumeral arthritis	KTL	20	4 (20)
	KTT	20	5 (25)
Diabetes	KTL	20	3 (15)
	KTT	20	4 (20)
Smoking history	KTL	20	8 (40)
	KTT	20	6 (30)
History of trauma to the index joint	KTL	20	13 (65)
	KTT	20	12 (60)

KTT: Knotted, KTL: Knotless

United States reported the use of shoulder arthroscopy in RCT management for the first time.[22] However, Snyder gave this world the first-ever technique of arthroscopic RCR.[23] Since then, the technique has undergone further advances from single row to conventional double row (transosseous equivalent), medial knot tying, and KTL with pros and cons of each. Advances have also been made in the type of sutures (fiber wire or tape) to be used as well as optics for better visualization. Despite these advances, haze still surrounds the use of best technique to provide an ideal RCR.

An ideal RCR should restore the maximum footprint area, achieve adequate compression, and minimize the motion at tendon–bone interface of the repair site until healing is completed.[24,25] Lately, there has been a lot of debate over the use of KTT or KTL to achieve the ideal RCR. Theoretically, few studies suggest compromised vascularity of repaired RC tendon in KTT repair as compared to KTL but with superior biomechanical stability, whereas others suggest no significant difference between the two groups.[26] In our study, no significant difference was found in UCLA score and VAS score at the end of 12-month follow-up. We specifically chose UCLA score to follow our cases as literature shows this score to be a better predictor of treatment success in shoulder patients in <24-month follow-up.[27] Similar outcomes have been reported in studies using scores such as American Shoulder and Elbow Surgeons scores.[28] Studies done by Kim *et al*. and Kunze *et al*. about medial row KTL and knot tying RCR showed no significant differences in rates of re-tears as well as biomechanical integrity of the construct.[29,30] Although we did not find any significant differences in the VAS and UCLA scores of the two groups, there were few differences worth mentioning here. First is the ease of doing KTL repair as compared to knot tying and second is less operative time irrespective of associated lesions (Bankart and or SLAP lesion) as depicted in study results [Table 5].

Table 3: Visual Analog Scale score (knotless/knotted)

	Type of cuff repair	*n*	Mean	SD	SEM	Two-sided *P*
Preoperative	KTL	20	7.20	1.399	0.313	0.553
	KTT	20	7.45	1.234	0.276	0.553
6 weeks	KTL	20	3.15	1.565	0.350	0.273
	KTT	20	3.80	2.093	0.468	0.274
3 months	KTL	20	1.80	1.322	0.296	0.898
	KTT	20	1.75	1.118	0.250	0.898
6 months	KTL	20	1.00	1.214	0.271	0.677
	KTT	20	0.85	1.040	0.233	0.677
12 months	KTL	20	0.70	1.081	0.242	0.625
	KTT	20	0.55	0.826	0.185	0.625

KTT: Knotted, KTL: Knotless, SD: Standard deviation, SEM: Standard error of mean

Table 4: University of California Los Angeles score (knotless/knotted)

	Type of cuff repair	*n*	Mean	SD	SEM	Two-sided *P*
Preoperative	KTL	20	06.15	1.309	0.293	0.143
	KTT	20	06.80	1.436	0.321	0.143
6 weeks	KTL	20	17.75	1.618	0.362	0.841
	KTT	20	17.90	2.900	0.648	0.841
3 months	KTL	20	24.30	1.750	0.391	0.402
	KTT	20	23.70	2.638	0.590	0.403
6 months	KTL	20	29.35	2.183	0.488	0.226
	KTT	20	28.45	2.438	0.545	0.226
12 months	KTL	20	31.25	1.916	0.428	0.237
	KTT	20	30.40	2.521	0.564	0.238

KTT: Knotted, KTL: Knotless, SD: Standard deviation, SEM: Standard error of mean

Table 5: Average time of surgery (knotless/knotted)

Type of cuff repair	Mean time (min)	*n*	SD	SEM	Two-sided *P*
KTL	93.25	20	15.241	3.408	<0.001
KTT	113.50	20	18.144	4.057	<0.001
Total	103.38	40	19.460	3.077	

KTT: Knotted, KTL: Knotless, SD: Standard deviation, SEM: Standard error of mean

Another finding of our study was that the improvement in VAS as well as UCLA score was much more in the first 3 months as compared to the rest of the 9-month follow-up in both the groups. Although literature mentions about the advantage of KTL repair in terms of ease of revision surgery in case of type 2 failure due to relatively preserved tendon tissue,[31] advances have also been made in KTT technique as published by Takeuchi *et al*. recently, where in the medial row knots are tied after lateral row fixation and creation of suture bridge.[32] The authors suggest that this technique lowers the tension on medial row anchors and hence reduces the chances of type 2 failure of repair. Our study included a significant number of degenerative RCTs (15 out of 40 patients; 37%), whereas the rest of 73% were posttraumatic RCTs. They were treated with either of the techniques regardless of the different variables and the results did not show any significant difference in clinical outcomes. After analyzing the results of our study, we feel that patient-related outcome measures (PROM) are not hampered despite the use of either technique for RCR, provided that it achieves the characteristics of an ideal RCR.

Limitations

Our study had some limitations as well. Follow-up data were calculated by the authors mentioned above, and none was blinded to the study. We did not take into consideration patient satisfaction with level of functional outcome achieved which might differ from patient to patient and give different results in long run and influence the study outcome. Another limitation is the influence of Bankart/SLAP repair on the functional outcome. Since majority of our patients were cases of posttraumatic RCTs, we feel that a large sample of degenerative RCTs could have given us more insight into the study results. Incidence of re-tear rates and hence the ease of revision surgery in the two techniques could not be assessed due to short follow-up of 12 months only.

Conclusion

There is no significant difference in patient-related outcome measures in terms of UCLA score and VAS score for those treated with KTL versus KTT double-row arthroscopic RCR in a short-term follow-up of 12 months. A KTL RCR might have the advantage of ease of procedure and reduced time of surgery; however, a long follow-up with a larger number of patients is required to substantiate the results of the trial.

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Conflict of interest

There are no conflicts of interest.

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Anatomy and Isometry of Coracoclavicular Ligaments: A Cadaveric Study

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Abstract

Purpose of the Study: Anatomical reconstruction of acromioclavicular joint require understanding the morphology of coracoclavicular ligament attachments. There are very few studies on morphology of coracoclavicular ligaments in the literature. There are no Indian studies looking at the morphology of these ligaments and racial differences have been identified in absolute measurements. We set out to study the morphology of coracoclavicular ligaments in Indian cadavers and define isometric points for tunnel placements during AC joint reconstructions. **Methods:** The current study was a cross sectional observation study on 30 cadaveric shoulders. The lateral half of clavicle was dissected from the cadaver and the footprints of the coracoclavicular attachment marked with marker and various anatomical parameters like morphology, distribution, and clavicular attachment sites of the trapezoid and conoid ligaments were measured once using a vernier caliper and a measuring scale. **Results:** The isometric point for trapezoid ligament is 16.3mm from lateral end of clavicle on anterior half of the clavicle whereas the isometric point for conoid ligament is 33.6 mm from lateral end of clavicle on the posterior half of the clavicle. Average distance between the two isometric points is 17.3 mm. **Conclusion:** The measurements in the Indian population corroborate with the measurements presented in the literature for the trapezoid and conoid components of the coracoclavicular ligaments. Our recommendations of isometric points for trapezoid and conoid tunnel preparation may help the Indian subcontinent surgeons perform anatomic reconstructions of the acromioclavicular joints in acute and chronic injuries.

Keywords: Cadaveric study, conoid, coracoclavicular ligaments, isometry, trapezoid

Introduction

Acromioclavicular joint (ACJ) injuries are common, accounting for 12% of all shoulder girdle injuries seen in clinical practice.[1] Stabilization of the ACJ requires reconstruction of the coracoclavicular ligaments. Recent evidence favors anatomic reconstruction of the Conoid ligament (CL) and Trapezoid ligament (TL) over nonanatomical reconstruction methods. Understanding the morphology of these ligaments is crucial in the reconstruction of the ACJ.[2] However, there are very few studies on the morphology of coracoclavicular ligaments in the literature.[3-5] Racial differences have been identified in absolute measurements by previous studies.[6] There are no Indian studies looking at the morphology of these ligaments. Therefore, we set out to study the morphology of coracoclavicular ligaments in Indian cadavers and compare our values with those published in the literature. These values should help plan for tunnel placements during ACJ reconstructions in the Indian population.

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Materials and Methods

The current study was conducted at the Advanced Learning Center of a Tertiary Primary Teaching Hospital in India. It was a cross-sectional observational study on 30 cadaveric shoulders. All the cadavers used in the study were Indian and preserved by embalming. The study was conducted between September 1, 2018, and March 31, 2019. The sample size was calculated based on a previous study conducted by Keener JD *et al*.[5] by taking the standard deviation of the length of the CL as 2.7 and the absolute error as 0.9 at a 0.05 level of significance and 80% power which amounted to 34 rounded to 30. The age group of the cadavers ranged from 50 to 84. All cadavers with previous shoulder surgery or dissection

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were excluded. Clearance for this study was obtained from the ethics committee of the institute.

The lateral half of the clavicle was dissected from the cadaver and the footprints of the coracoclavicular attachment were marked with a marker. Various anatomical parameters such as morphology, distribution, and clavicular attachment sites of the trapezoid and CLs were measured once using a vernier caliper and a measuring scale [Figures 1 and 2]. Measurements were taken by an orthopedic consultant with 12 years of orthopedic experience. The ligament and tendon attachment perimeters and center points on the coracoid and clavicle were identified and subsequently dissected off the bone for measurement [Figure 3]. The attachment sites of the coracoclavicular ligaments on the undersurface of the clavicle were studied.

Results

In the present study, 30 cadavers were examined for the morphology of coracoclavicular ligaments (*n* = 30). Among these, 87% of the cadavers were over 60 years of age, with 40% of them aged between 71 and 80 years. The majority of the cadavers were male (56.7% vs. 43.3% females), as shown in Tables 1 and 2.

The distance of the center of trapezoid (CCg) and center of the conoid (CCi) from the lateral edge of the clavicle were 16.3 mm and 33.6 mm respectively [Figure 4]. The center of TL attachment from the anterior margin of the clavicle was 2.73 (CCe), whereas the center of CL from the anterior

Figure 1: Undersurface of lateral end of clavicle with marked trapezoid and CL attachment. CL: Conoid ligament

Figure 3: Measurement of coracoid parameters with calipers

Table 1: Demographics of the cadavers

Variable	Frequency (%)
Age	
51–60	4 (13.3)
61–70	8 (26.7)
71–80	12 (40.0)
>80	6 (20.0)
Sex	
Female	13 (43.3)
Male	17 (56.7)
Side of shoulder	
Left	15 (50)
Right	15 (50)

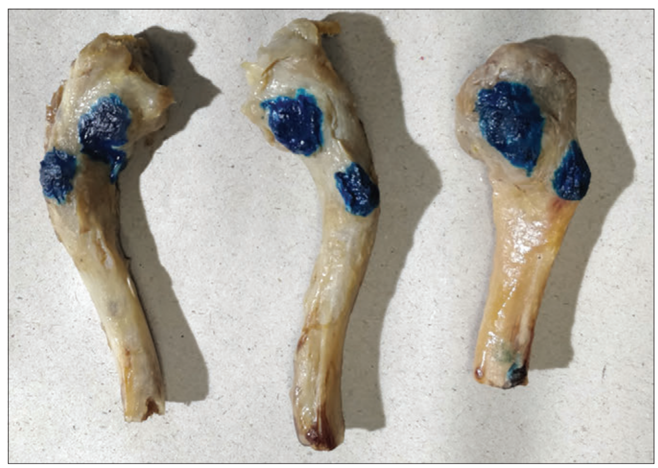

Figure 2: Dissected undersurfaces of clavicles

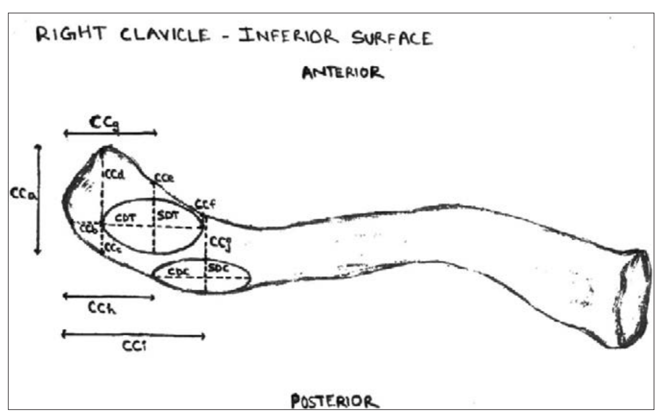

Figure 4: Parameters of Coracoclavicular ligament attachment

Table 2: The parameter measurements of coracoclavicular ligament attachment sites on the undersurface of the clavicle

Parameter	Abbreviation	Mean±SD (mm)	Range (mm) (minimum–maximum)
Coronal dimension of the lateral edge of the clavicle	CCa	24.33±3.09	18–31
Distance between the lateral edge of the clavicle and the lateral end of TLs attachments	CCb	8.4±1.67	6–13
Distance of the lateral end of TLs attachments from the posterior margin of the clavicle	CCc	9.67±2.66	5–16
Distance of the lateral end of TLs attachments from the anterior margin of the clavicle	CCd	5.43±1.83	3–10
Distance of the center of TLs attachments from the anterior margin of the clavicle	CCe	2.73±1.05	2–3
Distance of the medial end of the TLs attachments from the anterior margin of the clavicle	CCf	6.87±2.58	3–13
Distance of the center of the TLs attachments from the lateral edge of the clavicle	CCg	16.3±3.27	11–22
Distance between the lateral edge of the clavicle and the lateral end of conoid ligaments attachments	CCh	24.57±4.9	15–36
Distance of the center of the conoid ligaments attachments (conoid tubercle) from the lateral edge of the clavicle	CCi	33.57±4.15	25–41
Distance from the center of the conoid ligament to the anterior edge of the clavicle	CCj	4.8±1.0	3–5
Sagittal dimension of the TLs attachments	SDT	19.43±3.78	12–26
Coronal dimension of the TLs attachments	CDT	15.63±2.62	12–20
Sagittal dimension of the conoid ligaments attachments	SDC	19.33±5.16	10–30
Coronal dimension of the conoid ligaments	CDC	7.07±2.39	3–11

SD: Standard deviation, TLs: Trapezoid ligaments

Table 3: Correlation of age with all the parameters of coracoclavicular ligament attachment sites on the coracoid process

Parameters	Age	
	Correlation coefficient	*P*
CPA	0.013	0.947
CPB	0.063	0.742
CBC	0.279	0.136
CPD	0.202	0.284
CPE	0.194	0.304

margin of the clavicle was 4.8 mm (CCj). The average distance between the center of the trapezoid and conoid footprint is 17.3 mm [Figure 5].

Age did not show any significant correlation with most of the parameters [Table 3]. However, it was negatively correlated with the distance of the TL from the posterior and anterior margins of the clavicle. The correlation coefficients of the posterior and anterior margin distance of the TL (CCc and CCd) were −0.41 and −0.48, respectively. As age increases, these distances decrease, and the correlation is significant.

From Table 4, it is evident that there was no significant difference in any of the parameter means between males and females.

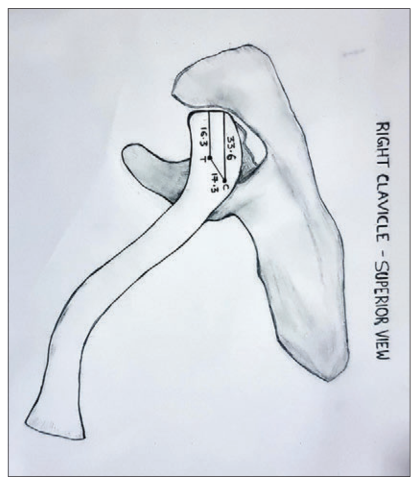

Figure 5: Isometric points of lateral end of the clavicle

Discussion

The surgical management of ACJ disruptions continues to evolve, and there is no gold standard treatment.[7-9] Controversies and debates still persist regarding the timing of surgery, type of graft, and open versus arthroscopic procedures. However, there is a consensus that anatomical coracoclavicular ligament reconstruction provides better results than conservative management in higher-grade ACJ disruptions.[10]

The stability of the ACJ is maintained by both extrinsic and intrinsic ligaments. The coracoclavicular ligament forms an important part of that support structure preventing superior or vertical translocation of the joint.[11] Most of the ACJ injuries occur as sports injuries, and the ligaments are invariably involved in injuries of Type III and higher. Knowledge of the precise anatomical footprints of the coracoclavicular ligament is crucial to make isometric tunnels as a part of joint reconstruction surgeries.[12-16] Very few studies have explored the detailed anatomy of these ligaments. Hence, in this study, we have attempted to shed more light on the subject.

The morphology of the coracoclavicular ligament in our study showed that it consists of two stout ligaments: The trapezoid and the CLs. They extend from the base of the coracoid process to the undersurface of the clavicle [Figure 2]. The TL is oriented in an anterolateral direction as it extends from its coracoid attachment to the clavicular undersurface, which is the trapezoid line. It is wide in its attachment on the undersurface of the clavicle. The CL is more medial in its attachment than the TL. It extends from the base of the coracoid process in a superior and medial fashion to its attachment to the conoid tubercle on the undersurface of the clavicle. The trapezoid is more anteriorly placed than the CL in its clavicular attachment.

Harris *et al*.[17] studied the anatomic variations in the morphology of these ligaments. The width of the attachment of the CL on the undersurface of the clavicle was twice the size of the attachment on the coracoid, making it conoid in shape. The narrowing of attachment of the TL from the clavicle to the coracoid was not much compared to the CL. Furthermore, in six cases, we noticed the confluence of lower fibers of the CL with the superior transverse scapular ligament.

From Table 2 and Figure 4, the distance of the center of the trapezoid (CCg) and the CLs (CCi) from the lateral edge of the clavicle were 16.3 mm and 33.6 mm, respectively. The center of the TL attachment from the anterior margin of the clavicle was 2.73 mm (CCe), whereas the center of the CL from the anterior margin of the clavicle was 4.8 mm (CCj).

The center of the TL attachment was measured from the lateral edge of the clavicle from the anterior half, whereas the center of the CL was measured from the lateral edge of the clavicle from the posterior half**.** Based on these parameters, we would like to recommend isometric points for tunnel making for anatomic coracoclavicular ligament reconstruction. The isometric point [Figure 5] for the TL is 16.3 mm from the lateral end of the clavicle on the anterior half of the clavicle, whereas the isometric point of the CL is 33.6 mm from the lateral end of the clavicle on the posterior half of the clavicle. The average distance between the two isometric points is 17.3 mm.

The sagittal dimension of both trapezoid and conoid ligaments was the same (19 mm), while the coronal dimension of CL was 7 mm, whereas the coronal dimension of TL was 15 mm. This implies that the conoid is less stout than the trapezoid at the clavicular attachment sites. The important parameters of our study, compared with the index article by Takase *et al*. are tabulated in Table 5.[3]

There is approximately a 20 cm difference in the average height of the male and female population in the Netherlands which tops the chart of heights among races, and India (data from 2020).[18] In a list of 122 countries, India ranks twelfth and fifteenth from the bottom for the average heights of men

Table 4: Comparison of means of the coracoclavicular ligament attachment sites on the clavicle between males and females

Parameters	Mean±SD		*P*
	Male	Female	
CCa	24.12±3.20	24.62±3.04	0.67
CCb	8.35±1.93	8.46±1.33	0.86
CCc	9.47±2.96	9.92±2.29	0.65
CCd	5.82±2.04	4.92±1.44	0.19
CCe	2.71±1.16	2.77±0.93	0.87
CCf	6.12±2.20	7.85±2.79	0.07
CCg	16.71±3.37	15.77±3.19	0.45
CCh	24.35±4.08	24.85±5.98	0.79
CCi	34.06±4.13	32.92±4.25	0.47
SDT	19.65±3.87	19.15±3.87	0.73
CDT	15.82±2.70	15.38±2.70	0.66
SDC	19.71±5.42	18.85±5.42	0.66
CDC	6.76±2.33	7.46±2.33	0.44

SD: Standard deviation, SDT: Sagittal dimension of trapezoid, CDT: Coronal dimension of trapezoid, SDC: Sagittal dimension of conoid, CDC: Coronal dimension of conoid

Table 5: Comparison of important parameters with Takase *et al*.'s[3] study

Parameter	Our study (mm)	Takase study (mm)
SDT	19.43±3.78	18.5
CDT	15.63±2.62	15.4
SDC	19.33±5.16	17.4
CDC	7.07±2.39	5.4
CCa	24.33±3.09	24.4
CCg	16.3±3.27	17.4
CCi	33.57±4.15	38.0
CCe	2.73±1.05	-
CCj	4.8±1.0	-

SDT: Sagittal dimension of trapezoid, CDT: Coronal dimension of trapezoid, SDC: Sagittal dimension of conoid, CDC: Coronal dimension of conoid

and women, respectively. With so much variation in the height and skeletal structure measurements, it is possible that the absolute values in the attachments of the ligaments on the bones vary between countries and races. Published values on the attachment of coracoclavicular ligaments, among other countries, are from China and Japan. The heights of Japanese men and women appear to be closer to the Indian values and hence could be expected to have similar values for Coracoclavicular ligaments (CCL) attachments too.

Limitations

The footprint of attachments is regarded as an oval rather than an irregular site. This has been accepted as a limitation by previous studies.[5] We used it so that we could compare our findings with previous studies and to make measurements easier. Another limitation is that 60% of cadavers are aged over 70 years, which is not the common age of ACJ injuries. We feel this may not be a major drawback as anatomy does not change significantly. It is difficult to get cadavers in the same age group as ACJ injuries.

Conclusions

The measurements in the Indian population corroborate with the measurements presented in the literature for the trapezoid and conoid components of the coracoclavicular ligaments. Our recommendations of isometric points for trapezoid and conoid tunnel preparation may help the Indian subcontinent surgeons perform anatomic reconstructions of the ACJs in acute and chronic injuries. Surgeons need not factor in racial changes in measurements while following techniques published on international populations.

Informed consent (Patient/Guardian), mandatory only for case reports/clinical images

Yes, informed consent was taken.

Institutional ethical committee approval

Obtained (EC/PG-54/2018).

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Conflicts of interest

There are no conflicts of interest.

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CT Guided Evaluation of Dedicated Aimer Versus Free Hand Drilling Technique in the Placement of Femoral and Tibial Tunnels in Double Bundle ACL Reconstruction

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Abstract

Aim: The use of a dedicated aimer versus freehand, in double-bundle anterior cruciate ligament reconstruction by co-ordinate axis method on three-dimensional computed tomography (3D-CT) reconstructions models were performed to compare the locations of the femoral and tibial tunnels. **Patients and Methods:** Use of aimer vs free hand technique through the trans portal approach. A 3-Dimensional CT on 40 operated knees and evaluated the position of femoral and tibial tunnels on 3D-CT scan was prepared. **Results:** For femoral tunnel locations, the average posterior-anterior distance for anteromedial (AM) and posterolateral (PL) tunnel positions in the aimer group and freehand group were 46.8% ± 7.4% (B/C) and 34.5% ± 5.0% (A/C) and 56.4% ± 3.1% (B/C) and 40.5% ± 9.0% (A/C), respectively. For, tibial tunnel locations, mean anterior-to-posterior distances for the AM and PL tunnel in the aimer group and freehand group were 29.7% ± 2.5% (A/C) and 46.9% ± 3.8% (B/C) and 28.8% ± 4.3% (A/C) and 47.2% ± 3.6% (B/C), respectively. B/C AND A/C are the measurements posterior to the anterior tunnels for the AM and the PL tunnels, respectively. a/c and b/c are the proximal-distal measurements. **Conclusion:** In the present study, on comparison position of the AM and PL tunnels of the femur and tibia were fairly similar in both techniques.

Keywords: Anterior cruciate ligament reconstruction, computed tomography, femur, tibia

Introduction

The detailed understanding of native anterior cruciate ligament (ACL) insertion sites and their function has greatly evolved over the past 20–30 years. Several studies on biomechanical analysis have shown that placement of anatomic tunnels in ACL reconstruction can reinstate near normal anterior translational as well as rotational stability of the knee joint and also demonstrated superior clinical outcomes when compared to conventional nonanatomic or isometric tunnel positioning.[1-11] Mal-positioned tunnels are another common cause of the recurrence of instability in the ACL.[12]

ACL reconstruction has evolved from conventional nonanatomic or isometric position to anatomic position of femoral as well as tibial tunnels in double-bundle ACL reconstructions by the leading arthroscopic surgeons.[13] Surgeons have concentrated on creating a dependable and reproducible method to assess the accuracy of anatomically placed tunnels and recent research has shown that employing three-dimensional computed tomography (3D-CT) to examine the placement of ACL tunnels retrospectively enhances precision.[14] wherefore 3D-CT has now become a modality of choice over conventional radiographs.[12,15-17]

Effects of various methods on where the femoral and tibial tunnels are located anatomically during ACL reconstruction, including single or double bundles, transtibial versus transportal use, and drilling method.

Different surgeons have employed either the anatomic footprint (freehand) approach or a dedicated aimer and

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their evaluations suggest that the latter has been the more efficient technique. For the purpose of double-bundle ACL reconstruction using multistranded autologous hamstring grafts, the current study adopted a working model utilizing either an aimer or a Freehand (arthroscopic visualization of anatomic footprints) technique for drilling anteromedial (AM) and postero-lateral (PL) tunnels in the femur and tibia using a dedicated aimer. In order to reconstruct the double-bundle ACL with multistranded autologous hamstring grafts. The current research has established a working model to provide drilling AM and PL tunnels using an aimer or a freehand in the femur and tibia (arthroscopic visualization of anatomic footprints).

After utilizing both drilling methods, a quantitative comparison of the tunnel aperture locations in the femoral and tibial tunnels was carried out using the coordinate axis method and 3D-CT reconstruction models. In addition, published information related to the positions of the anatomic double-bundle (AM and PL) tunnels has been employed to verify these measurements.

Patients and Methods

In the comparative randomized study total of 40 subjects were included in this study who were admitted to the Maulana Azad Medical College Delhi, India, at the Department of Orthopedics between November 2016 and October 2018.

Since the procedure is complex and requires specific patient characteristics, the sample size is limited by the number of patients who meet the criteria.

The consent forms were obtained and reviewed for accuracy before the study was initiated, ensuring the safety of all participants. An ACL reconstruction surgery has been performed on 20 participants with a double bundle of ACL reconstruction using a dedicated aimer device (approval of the departmental and institutional committee). Twenty patients underwent drilling of femoral and tibial tunnels by freehand procedure.

In all operated knees, 3D-CT scans had been performed at 6 months from the day of surgery. All the surgeries and subsequent 3D-CT evaluations were done by some senior members of the Arthroscopy and Radiology team, accordingly. The study included patients between the ages of 18 and 50 with an ACL tear diagnosed clinically and radiologically. Patients older than 50 with a history of degenerative alterations in the knee or multiple ligament injuries were not included.

With the aid of an aimer (Smith and Nephew offset Endofemoral aimer and guide), in between 110° and 120° of leg flexion, the femoral holes were drilled. Drilling the tip guides for the ACL was done through the AM and PL tibial tubes of the tibia (Smith and Nephew Anatomic ACL R-PL Tibial aimer) according to direct arthroscopic visualization at their respective insertion locations. Multistranded hamstring sutures were applied in every instance to replace the ACL. Bioabsorbable interference screws were used for fixation on the tibial side, and titanium Endo rivets continuous loop Mersilene tape was used for fixation on the femoral side.

Operative procedure

Of all 40 subjects, 20 of cases, were underwent dedicated aimer (Smith and Nephew offset Endofemoral aimer and Tibial Guide) along with standard ACL instrumentation for femoral and tibial tunnel preparation in double-bundle ACL reconstruction and in rest 20 cases, only standard ACL instrumentation using freehand technique (direct arthroscopic footprint visualization) was used.

The AM and PL bundles need their own openings prepared in the femur as well as tibia for an ACL double-bundle reconstruction. After meticulously locating their landmarks with an AM portal, this was completed. The ACL's AM and PL bundles on the femur and tibia have been found arthroscopically. The insertion locations were marked using RF probes or awls. Prepare the femoral tunnel first in all the participants included in the current investigation.

Tunnel preparation with aimer femoral am tunnel

The AM femoral tube was drilled through the AM portal using an endo-femoral aimer with 6 mm or 7 mm offsets. Subsequently bending the knee to a 90° angle, the guide had placed 7 mm anterior to the back edge of the intercondylar notch. The knee had been slowly flexed between 110° and 120° after the guide became in place to ensure correct orientation.

A drill point guide wire measuring 2.4 mm was inserted into the offset endo-femoral guide and through the lateral femoral cortex. The passing pin was shifted over to move a cannulated 4.5 mm Endobutton drill bit into the lateral femoral cortex. The current research determined the appropriate Endobutton CL by measuring the AM femoral tunnel length using the Endobutton depth probe. The 2.4 mm guide wire had been reinserted through the AM tube.

Femoral posterolateral tunnel

With the leg flexed at 120° or more, PL femoral aimers were put into AM tunnels with the proper-sized posts. In the current research, Aimer was rotated to align the laser mark with the RF probe/awl mark. PL femoral aimers were put into AM tunnels with the proper-sized posts. In the current research, Aimer was rotated to align the laser mark with the RF probe/awl mark. The joint cartilage edge was placed 6–8 mm anterior to the PL femoral guide wire. With a 4.5 mm noncannulated drilled tool, the lateral femoral cortex was punctured. In the current study, the length of the PL tunnel had been measured using the Endobutton depth probe. A drill tip guide wire with a diameter of 2.4 mm has been inserted through the PL tube. PL femoral sockets of the necessary length are made using a drill bit corresponding to the thickness of the graft.

Tibial anteromedial tunnel

The knees were bent 90°. The Tibial guide was placed at 50° for the AM guide wire placement. The native AM bundle's anatomic attachment region corresponds to where the guide tip has located.

A guide wire with a drill tip width of 2.4 mm was inserted into the bone beginning on the medial side of the tibial tubercle. The joint region was drilled with a cannulated drill bit that was the proper size after the tibial guide wire had been placed in the proper location.

Tibial posterolateral tunnel

For PL tunnel, we used Anatomic PL Tibial guide, which consist of replaceable posts fitting the AM tunnel. A post of the appropriate size was placed on the guide and inserted into the AM tunnel. The distal end of the post should be flush with the surface of the tibia. The posterolateral Bundle centre is aligned with the slot at the tip of the Anteromedial post. The bullet was then advanced against the tibia once the correct alignment had been achieved. PL tunnels enter the tibial cortex medially and distally. Through the tibia, a 2.4mm drill tip guide wire was advanced. A cannulated drill bit of the appropriate size was advanced into the joint space once the acceptable placement of the PL tibial guide wire had been determined.

Tunnel preparation with freehand technique (without aimer)

Femoral anteromedial tunnel

PL tunnel guides consisting of replaceable posts were used in the current study to fit AM tunnels.

On the guide, a post of the right size was positioned before it was put into the AM tunnel. The tibia's surface should be level with the distal end of the post. The slot at the AM post's apex and the PL bundle center were lined up. Once the proper alignment was obtained, the bullet was advanced toward the tibia. The medial and distal tibial cortex has where PL tunnels emerge. A 2.4 mm drill point guide wire was inserted through the tibia. Once the location of the PL tibial guide wire had been established as being satisfactory, a cannulated drill bit of the proper size was advanced into the joint space.

The AM portal was used to create an AM femoral tunnel. To position the 2.4 mm guide wire tip over an anatomical footprint or AM bundle remnant for direct arthroscopic viewing, the knee was bent to a 90° angle. To make sure that the AM tunnel was oriented properly after the guide wire had been put in place and the knee had been slowly flexed from 110° to 120°. A tunnel that has been anteriorly directed avoids posterior blowout, provides a long enough tunnel, and offers a secure exit for the guide wire on the side of the thigh. The lateral femoral cortex was penetrated using a 2.4 mm drill point guide wire. The remaining stages all used the same aimer technique as the AM tunnel.

Femoral posterolateral tunnel

An arthroscopic view showed remnants of fibers from the PL bundle when the knee was flexed at 100°–110°. The guide wire should be positioned 6–8 mm anterior to the edge of the joint cartilage to obtain a sufficient bone bridge. To drill and advance the guide wire, a 2.4 mm drill tip was used. All other steps were the same as those used in PL tunnels.

Tibial anteromedial tunnel

AM tunnels were made similar to those made in aimer techniques using tibial guides, the AM guide wire was positioned at 50°.

Tibial posterolateral tunnel

To place the PL guide wire in the PL tunnel, just a tibial guide was used (instead of Anatomical PL Tibial Guide and its replaceable post). PL bundles must be positioned in the center with the PL guide wire centered there. A PL tunnel enters the tibial cortex more medially and distally than a standard tibial tunnel. Drilling the AM tibial tunnel follows the same procedure.

The tunnels of the AM bundle typically have a diameter of 6–8 mm. While those of the PL bundle typically have a width of 5–7 mm. All the subjects received multistranded hamstring transplants in place of their ACLs. Bioabsorbable fasteners were used to treat the tibial side, while titanium Endobutton and continuous loop mersilene tape were used to treat the femoral side.

Associated meniscal tears were treated with a meniscectomy during the same procedure.

Patients included in the current investigation did not undergo meniscal repair. The intercondylar notch was free from impingement even with full extension or flexion of the lateral condyle wall. In due course, none of the study participants underwent notchplasty.

Computed tomography-scan evaluation

An axial (helical) multi-detector CT scanner was used for the examination of the knee (Somatom Definition AS, 128 slices) using 0.625 mm-thick slices and 0.6 mm increments without intravenous contrast. Models of the proximal tibia and distal femur were created by volume rendering technique (VRT) and used for assessing the position of native ACL tunnels in the operated knee.

Femoral tunnels position

The distal femur model was first constructed with both femoral condyles placed horizontally. At the highest position of the anterior aperture of the inter-condylar notch, where the medial femoral condyle had been essentially removed, the condyle remained behind. The center of the femoral AM and PL tunnels became identified by measuring the notch area of the lateral femoral condyle of the operated knee while the model ensued rotated to the tight lateral position [Figure 1].

This study determined the position of femoral tunnels posteriorly to anteriorly and proximally to distally along each anatomical axis.

Therefore, the percentage difference between the line (F1) passing through the posterior edge of the medial wall and the line (F2) passing through the most anterior point of the notch was used to establish where the lateral condyle should be located. The distance between a line (F3) going through the proximal border of a notch and a line (F4) passing through its distal end was divided to determine the proximal to distal distances [Figure 1].

Posterior to the anterior tunnels, the AM and PL tunnels have the following dimensions: B/C and A/C, respectively. A/C and B/C are the proximal-distal distances.

A = Posterior to anterior distance of posterolateral tunnel from F1 line (mention above)

B = Posterior to anterior distance of anteromedial tunnel from F1 line

C = Distance between F1 and F2

a = Anteromedial tunnel distance from F3 line proximally to distally

b = Proximal to distal distance of posterolateral tunnel from F3 line

c = Distance between F3 and F4

Tibial tunnels position

Initially, the posterior view was used to place the proximal tibial model. The superior feature of the proximal tibia was visible after rotating the model. Internal and external rotations were used to align the most posterior portions of the medial and lateral tibial condyles horizontally at the same location. The medial tibial articular border aligning with the visual plane was considered sufficient for the top view of the proximal tibia.

The top view of the proximal tibia was measured to evaluate AM and PL tibial tunnel position through the coordinate axis method.

All measurements were taken at the workstation [Figure 1].

The anterior to posterior positions were determined using the distance between the lines (T1) that cross the anterior border of the tibial plateau and (T2) that cross the most posterior border of the plateau. The ratio of the distance between the lines (T3) traversing the medial and lateral borders of the tibial plateau has been utilized to ascertain the lateral to the medial position (T4) [Figure 1].

The anterior-to-posterior border lengths of the AM and PL passages are A/C and B/C, respectively. The ratios a/C and b/C show the separations between the median and lateral.

A = Anterior to posterior distance of anteromedial tunnel from T1 line (mentioned above)

B = Anterior to posterior distance of posterolateral tunnel from T1 line

C = Distance between T1 and T2 line

a = Medial to lateral distance of anteromedial tunnel from T3 line

b = Medial to lateral distance of posterolateral tunnel from T3 line

c = Distance between the T3 and T4 line

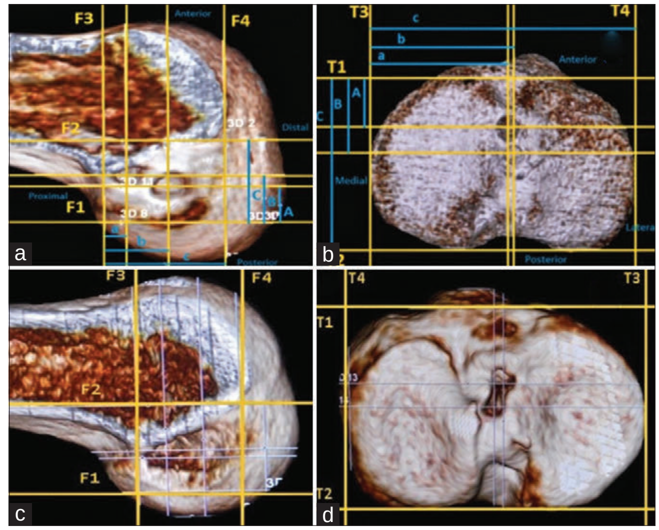

Figure 1: (a) Lateral position of femoral condyle (medial femoral condyle was virtually removed), Measurement of femoral AM and PL tunnel by co-ordinate axis method, (b) Top view of proximal tibia, tibial AM and PL tunnels measurement by co-ordinate axis method, (c) Merging of femoral AM and PL tunnels at aperture, (d) Merging of tibial AM and PL tunnels at aperture. AM: Anteromedial, PL: Posterolateral

Observer reliability was assessed using two observers. There was an average of 3 weeks between repeat measurements and the reliability findings can only be extrapolated to people with comparable levels of expertise.

Statistical analysis

In qualitative data, percentages were used. Means and standard deviations are used to express quantitative data. In groups with normally distributed data, an independent *t*-test was used to analyze differences in means between groups. $P < 0.05$ was considered statistically significant. By calculating the intra-class correlation coefficient and were able to calculate the interobserver and intraobserver reliability of the coordinate axes method.

Results

The overall age of all 40 operated patients ranged from 18 to 42 years majority of patients (75%) in both groups were belonging to <30 years of age. The mean age of the patients in the aimer group and freehand group was 26.4 years and 24.6 years, respectively. All the patients were male. A total of 40 subjects have been categorized into two groups of 20 each after careful randomization: Aimer group and freehand group. 3D-CT scan was performed on all 40 operated knees. The location of AM and PL femoral and tibial tunnels was measured through the anatomic coordinate axis method [Table 1].

Interobserver and intraoserver reliability

Anatomically positioned tibial and femoral tunnels can be assessed using the coordinate axis method on 3D-CT models with excellent interobserver and intraobserver reliability (Intraclass correlation coefficient [ICC] range of 0.844–5.995) [Table 1].

Table 1: Interobserver & Intraobserver Reliability for Anatomic Co-Ordinate Axis Method

Intraclass correlation coefficient					
Intraobserver femur	A/c	0.960	Interobserver femur	A/c	0.966
	B/c	0.917		B/c	0.917
	A/c	0.969		A/c	0.961
	B/c	0.844		B/c	0.861
Intraobserver tibia	A/c	0.982	Interobserver tibia	A/c	0.983
	B/C	0.994		B/C	0.983
	a/c	0.992		a/c	0.989
	b/c	0.995		b/c	0.984

Table 2: Measurement of femoral tunnel in both groups by co-ordinate axis method

Femur	Operated with aimer (cm) Mean±SD	Operated with Free hand (cm) Mean±SD	*P*
A/C	0.345±0.050	0.405±0.090	*P*=0.081
B/C	0.468±0.074	0.564±0.031	*P*=0.345
a/c	0.241±0.071	0.259±0.067	*P*=0.565
b/c	0.616±0.048	0.648±0.064	*P*=0.219

SD: Standard deviation

Table 3: Tibial tunnel measurements in both groups by coordinate axis method

TIBIA	Operated with freehand (cm) Mean±SD	Operated with Aimer (cm) Mean±SD	*P*
A/C	0.288±0.043	0.297±0.025	*P*=0.838
B/C	0.472±0.036	0.469±0.038	*P*=0.854
a/c	0.475±0.029	0.452±0.025	*P*=0.763
b/c	0.506±0.028	0.534±0.031	*P*=0.653

SD: Standard deviation

Femoral tunnel location

For AM and PL tunnel center positions, the mean posterior-to-anterior distances in the aimer group and freehand group were 46.8% ± 7.4% (B/C) and 34.5% ± 5.0% (A/C) and 56.4% ± 3.1% (B/C) and 40.5% ± 9.0% (A/C), respectively, as measured from the posterior border of the medial wall of the lateral femoral condyle [from F1 to F2 in Figure 1]. The AM and PL tunnel center positions' mean proximal-to-distal lengths in the aimer group and the freehand group were 24.1% ± 7.1% (a/c) and 61.6% ± 4.8% (b/c) and 25.9% ± 6.7% (a/c) and 64.8% ± 6.4% (b/c), respectively, measured from the proximal border of the lateral condyle medial wall [from F3 to F4 in Figure 1]. In comparison between the center of AM and PL tunnel of femur prepared by two different techniques, the center of AM tunnel in freehand group is slightly anterior (B/C) in comparison with aimer group, but not significant statistically ($P = 0.345$), whereas the center of PL tunnel in the freehand group is more anterior (A/C) and slightly distal (B/C) as compared to aimer group but not significant statistically ($P = 0.081$ and $P = 0.219$, respectively) [Table 2].

Tibial tunnel location

In the aimer and the freehand group the average anterior and posterior distances for the AM and PL tunnel center position had been recorded, i.e., 29.7% ± 2.5% (A/C) and 46.9% ± 3.8% (B/C) and 28.8% ± 4.3 (A/C) and 47.2% ±3.6% (B/C). Based on the anterior border of the tibia [T1 and T2 in Figure 1], all observed data pertain to its anterior to posterior depth. It was found that 45.2% of the aimer group was medial to the lateral distance of the rest of the group for the AM and PL tunnel center positions and 53.4% of the aimer group were medial to the lateral distance of the rest of the group. From the medial border of the tibia [from T3 to T4 in Figure 1], notable values were observed with respect to medial to lateral displacement [Table 3].

Discussion

According to the literature, Forsythe *et al*. used the coordinate axis method to explain femoral and tibial tunnel locations in cadaver knees after evaluating 3D-CT scans.[15] Similarly, the current study evaluated the position of the center of the AM and PL tunnels of the femur and tibia using 3-D reconstructed CT images which showed excellent reliability (ICC value range from 0.844 to 0.995).

Comparison of position of femoral tunnels

A statistical study suggests that there are no appreciable differences between sets of AM and PL tunnels positioned anatomically on the femur. Based on Forsythe *et al*.'s previous research, the results of the current investigation were similar. Compared with the other tunnels, the femoral AM tunnel as well as the PL tunnel of both groups had statistically significantly positioned themselves anterior to posterior, while both tunnels had been identical to one another in proximal to distal directions. The femoral AM tunnel had been significantly anterior and nearly proximal compared to prior research, while the femoral PL tunnel was significantly anterior as well as nearly distal. According to findings, neither femoral tunnel was located posteriorly.

This variation is technique related and dependent on the tunnels position. Lee *et al*. had also conducted a similar study and used anatomic coordinate axes method to evaluate the tunnel location and explained the satisfactory inter and intra-observer reliability for tunnel measurements.[18] On comparison, the Findings of this study were very similar to the present study, in posterior to anterior direction, the position of femoral AM tunnel and PL tunnel were also statistically significantly anterior to previous literature but comparatively posterior to the present study and in proximal to distal direction position of femoral AM and PL tunnels were very similar to the current study [Table 4].

Comparison of the position of tibial tunnels

A statistical comparison of the centers of AM and PL tibial tunnels prepared by two different approaches did not show any significant differences.

Table 4: Measurement of femoral tunnel

Mean±SD (Percentage)	A/C	B/C	a/c	b/c
Aimer Group	34.5±5.0%	46.8±7.4%	24.1±7.1%	61.6±4.8%
Freehand Group	40.5±9.0%	56.4±3.1%	25.9±6.7%	64.8±6.4%
Forsythe B *et al*.[15] (on cadaver)	15.3±4.8% (*P*<0.05)	23.1±6.1% (*P*<0.05)	28.2±5.4%	58.1±7.1%
Lee YS *et al*.[19]	27.1% (15-33) (*P*<0.05)	28.5% (17-36) (*P*<0.05)	26.6% (19-35)	62.9% (47-73)

SD: Standard deviation

Table 5: Measurement of tibial tunnel

Mean±SD (Range)	A/C	B/C	a/c	b/c
Aimer group	29.7±2.5%	46.9±3.8%	45.2±2.5%	53.4±3.1%
Free Hand group	28.8±4.3%	47.2±3.6%	47.5±2.9%	50.6±2.8%
Forsyth B *et al*. [15] (Cadaver)	25.0±2.8%	46.4±3.7%	50.5±4.2%	52.4±2.5%
Lee YS *et al*.[19]	25.7% (21-28)	44.7% (39-53)	50.4% (45-54)	51.4% (45-54)
Tsukada H *et al*.[20]	37.6±3.6% (*P*<0.05)	50.1±5.0 (*P*<0.05)	46.5±3.2	51.2±2.4

SD: Standard deviation

This study found that the average position of the anterior-posterior and medial-lateral directions of the tibial AM tunnel and tibial PL tunnel was very similar compared to earlier research by Forsyth *et al*.[15] As a consequence, the PL tunnel in the tibia was very similar to those described in the literature even though the AM tunnel was almost posterior and almost medial. Lee *et al*. had also conducted a similar study and used the anatomic coordinate method to evaluate the tunnel location.[18] On comparison, findings of this study were very similar to the current study as well as pervious literature in the posterior to the anterior direction and medial to the lateral direction. In another study, Tsukada *et al*.[19] use a very similar method of measurement of the position of tibial tunnels, on comparison of this study with the present study and previous literature by Forsyth *et al*.,[15] in anterior to posterior direction, the position of tibial AM and PL tunnels was significantly posterior but in medial to lateral direction, position was very similar [Table 5].

Several studies have indicated that drilling two tunnels in the tibia and femur with maintaining an intact bone bridge between them and merging the tunnels is the major challenge of a double-bundle ACL reconstruction. In one of their study patients, their CT scan showed a merging of the tibial tunnel at the aperture, so they used the same dedicated aimer used in the present study.[20]

In one of the freehand group patients, there was evidence of merging at the femoral aperture, and another patient in the same group showed evidence of merging at the tibial aperture.

One reason could be due to erroneous technique while placing tunnels, which signifies that with freehand technique, in double-bundle ACL reconstruction, there are minor chances of merging of tunnels at the aperture, and so, aimer is marginally superior to freehand method in the placement of femoral and tibial tunnels. One more reason could be due to the widening of tunnels at 6 months leading to merging of tunnels.

Limitations

Some limitations of the study should be made note of. This was a short-term study with a follow-up of only 6 months. The authors also suggest that an immediate postoperative CT scan should be done as after 6 months, there are always chances of widening of tunnels.

Conclusion

Radiological evaluation was done on 3D-CT reconstruction models (VRT) using coordinate axis method, which is suggestive of good intra-observer and inter-observer reliability. Anatomical placement of tunnels with this method will be easier for surgeons. Chances of errors are more with freehand technique in femoral as well as tibial tunnel placement, as it shows merging of tunnels in 5% of patients of the current investigation, so, the Zig method seems to be more reliable.

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Conflicts of interest

There are no conflicts of interest.

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Significance of the Ancillary Posterior Knee Soft-Tissue Edema Sign in Traumatic Knee Injuries

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Abstract

Introduction/Background: Traumatic soft-tissue injuries of the knee involve a spectrum of pathologies of the soft-tissue envelope, menisci or rupture of supporting tendinous or ligamentous structures. Magnetic resonance imaging (MRI) is an excellent, noninvasive modality to assess these injuries to guide patient management and improve patient outcomes. **Objective:** To highlight and explore the clinico-radiological significance of posterior knee soft-tissue edema (PKSTO) ancillary sign in traumatic knee injuries. **Materials and Methods:** MRI of 150 consecutive young adults undergoing within 1 week of an acute knee injury were reviewed. The area of interest behind the knee was specifically assessed for the presence of PKSTO sign. MRI of patients with PKSTO was analyzed further for associated ligament and meniscal injuries. **Results:** There were 18 patients with PKSTO sign with a mean age of 21.7 years (range 9–39 years). There was a male preponderance. The most common associated injury found was of the anterior cruciate ligament with four patients having multiple injuries. The average volumetric area of PKSTO was 68.5 cm^3 (1.5 cm^3–486 cm^3) with a proportional increase depending on the severity/number of ligamentous or meniscal pathologies. **Conclusion:** Detection of the PKSTO ancillary sign on sagittal MRI sequences is associated with clinically relevant knee soft-tissue injuries including multi-ligament and meniscal tears.

Keywords: Anterior cruciate ligament, knee injuries, magnetic resonance imaging, meniscus, posterior knee soft-tissue edema, soft-tissue injuries

Introduction

Traumatic soft-tissue injuries of the knee encompass a continuum of pathologies depending on the velocity, momentum, and the position of the lower limb at the time of the incident. The spectrum involves sports injuries (low energy and low velocity) to motor vehicle accidents (high energy and high velocity), although frequently, the distinction is blurred.[1,2] These can result in significant morbidity in some patients whilst in the background of traumatic knee fracture dislocations, multi-ligament injury can be devastating and potentially limb threatening.[3] The clinical presentation in the acute setting is variable dependent on the mechanism of injury and degree of trauma. Consequently, clinical assessment needs to be focussed and may be difficult due pain or associated swelling.[4]

Early detection of knee ligament or meniscal injuries with prompt intervention leads to better patient-related outcomes and decreased morbidity. Although there is a debate about early surgical intervention and delayed, staged surgery, radiological investigations are crucial in understanding the anatomical site, degree, and components of internal derangement of the injured knee.[5,6]

Diagnostic imaging plays a key role in the management algorithm of patients with traumatic soft-tissue knee injuries knee.[7,8] Magnetic resonance imaging (MRI) in particular is a key imaging tool in the noninvasive assessment of the injured knee and evaluation of patient with history of acute knee trauma, pain, or locking symptoms.[9-11]

Various radiological signs have been described to highlight specific injuries to menisci and cruciate ligament [Table 1]. These traditional and secondary signs, e.g. "Anterior Drawer

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Sign," "Buckled PCL sign," "Kissing contusions," "Deep notch sign," "Buckling of proximal patellar tendon," "Straight LCL sign," "Gupta Botchu" Sign for anterior cruciate ligament (ACL) injuries and "Absent bow tie sign," "Double PCL sign," "The Flipped Meniscus sign," "The double ACL sign," "Coronal Truncated meniscus sign" alert the reporter to actively look for potential underlying pathology or affirm the diagnosis in cases of equivocal appearances.[10,12-15]

However, there are the challenges to radiological interpretation due to the acuteness of the injury, swelling of soft tissues, and artefacts.[16] For example, the appearances of an ACL tear can be variable in sub-acute or chronic stages, and even in the acute stage, individual fibers of ACL or the posterior cruciate ligament (PCL) may be difficult to identify due to gross disruption and separation by hemorrhage and/or edema.

The posterior knee soft-tissue (PKST) region of the knee is an anatomical window behind the distal part of the femur. The caudal extent of this is at the level Blumensaat line (which corresponds to the roof of the intercondylar fossa of the femur) and extends up to 5 cm cranially [Figure 1]. It contains popliteal fat, soft tissue, and neurovascular structures which can be stretched, torn and result in oedema but can be assessed on MRI sequences [Table 2].

We believe that in patients with acute knee injury, presence of edema in the posterior soft-tissue region (PKSTO Sign) proximal to the notch is the secondary sign of severe ligamentous or meniscal injury. Biomechanically, hypertension injury or pivot shift pattern of knee injury leads to such characteristic appearance on MRI. The presence of the PKSTO sign can alert the reporting radiologist to a significant underlying menisci, ligamentous or internal derangement of the knee.

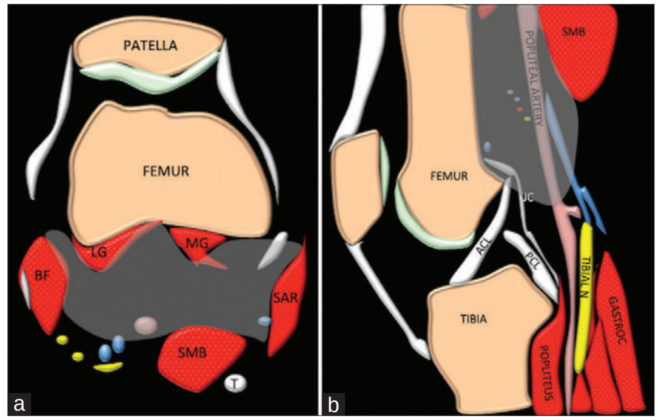

Figure 1: Schematic axial (a) and sagittal (b) of the knee at the level of the distal femora showing the region of posterior knee soft tissue of interest where edema is seen (gray). BF: Biceps femoris, SAR: Sartorius, SMB: Semimembranosus, MG: Medial gastrocnemius, LG: Lateral gastrocnemius, T: Semitendinosus, JC: Joint capsule, GATROC: Gastrocnemius

Table 1: Commonly described signs for assessing anterior cruciate ligament, meniscal tears, and soft tissue ligamentous injuries of the knee on magnetic resonance imaging

Name	MRI sequence Sagittal/coronal/axial	Description	Significance/ assesses injury of	Reference
		ACL injuries		
Anterior drawer sign	Sagittal	Anterior translation of tibia in relation to femur		Ng *et al*.[12]
Buckled PCL sign	Sagittal	Buckling of PCL	Buckling of PCL	
Kissing contusions	Sagittal and coronal	Osseous edema of the lateral femoral condyle and posterior part of the proximal tibia (pivot shift pattern of osseous edema)		
Deep notch sign	Sagittal	Notch in lateral femoral condyle		
Buckling of proximal patellar tendon	Sagittal	Mild buckling of proximal patellar tendon		
Straight LCL sign	Coronal	LCL seen in one coronal image		
Gupta botchu sign	Sagittal and coronal	Notch in the medial femoral condyle		Saad *et al*.[13]
		Meniscal tears of the knee		
"Absent bow tie sign"	Sagittal	Loss of normal configuration-anterior and posterior horn of LM are of same size on sagittal images	Displaced BHT of the meniscus	Ahn *et al*.[14]
Double PCL sign	Sagittal	Displaced meniscal fragment in the intercondylar notch inferior to PCL	Almost exclusively with BHT of the MM	
The flipped meniscus sign	Sagittal	Absent posteriorly horn and bulky anterior horn or two meniscal fragments anteriorly	Displaced BHT of the meniscus	
The double flipped meniscus sign	Sagittal	Two displaced meniscal fragments adjacent to anterior horn	Displaced double BHT of the LM	
The double ACL sign	Sagittal	Displaced meniscal fragment in intercondylar notch parallel to ACL	Displaced BHT of either LM or MM	
Coronal truncated meniscus sign	Coronal	Attenuated meniscus on coronal image		Bolog and Andreisek[15]

MRI: Magnetic resonance imaging, PCL: Posterior cruciate ligament, BHT: Bucket-handle meniscal tear, LM: Lateral meniscus, MM: Medial meniscus, ACL: Anterior cruciate ligament, LCL: Lateral collateral ligament

This article highlights and explores the clinico-radiological significance of PKST edema (PKSTO) ancillary sign in traumatic knee injuries.

Materials and Methods

Study design

A retrospective evaluation of our radiology information system and Picture Archiving and Communication System was performed to identify all MRI studies undertaken for patients who were referred to the radiology department for the assessment of their recent knee injury. MRI of 150 consecutive young adults (105 males and 45 females with age <40 years) undergoing within 1 week of an acute knee injury were included. Patients with a history of previous surgery, orthopedic implants, osteoarthritis or existing joint pathologies such as rheumatoid arthritis were excluded. MRI studies included Proton density Fat Suppressed (PDFS) axial, coronal and sag, and T1 coronal. Local Ethical Committee approval was obtained for the study.

Image analysis

Images from each of the MRI study were reviewed by the senior author (single reviewer, RB), a fellowship-trained musculoskeletal radiologist with more than 10 years' experience.

Patients with significant posterior knee edema in the area of interest were identified [Figures 2 and 3].

Defining the posterior knee soft tissue oedema area of interest

The PKSTO area of interest is behind the knee. It's a square window on the posterior surface of the distal femur. The caudal extent of this is at the level Blumensaat line which corresponds to the roof of the intercondylar fossa of the femur and the attachment of posterior capsule of the knee joint. Consequently, it includes the superior half of the popliteal fossa. Cranially, the space this extends 5 cm proximally above the Blumensaat line. The superomedial border is formed by medial hamstrings and lateral hamstrings (biceps femoris) forms the superolateral border [Figure 1]. The contents are highlighted in Table 2.

Table 2: Landmarks, boundaries and contents of posterior knee soft-tissue area of the assessment in the study

Landmark	Borders posterior knee area of interest
Distal border	At the level Blumensaat line is a line which corresponds to the roof of the intercondylar fossa Includes superior half of the popliteal fossa
Proximal border	5 cm above the roof of the intercondylar fossa of the femur
Superomedial border	By medial hamstrings
Superolateral border	Lateral hamstrings (biceps femoris)
Floor	Popliteal fat, distal femoral surface
Roof	Fascia, skin
Contents	1. The popliteal artery and its branches 2. The popliteal vein and its tributaries 3. The tibial nerve with its branches 4. The common peroneal nerve and branches 5. Posterior cutaneous nerve of the thigh 6. Genicular branch of the obturator nerve 7. Popliteal lymph nodes 8. Fat

Based on the MRI findings, the patients were divided into two cohorts, i.e. those with edema involving the PKST just proximal to the notch (n = 18) and those without edema (n = 132). The extent of PKSTO was also measured in axial, coronal, and sagittal planes and volume of PKSTO was calculated (volume = anteroposterior dimension × axial width × craniocaudal dimension). MRI of patients with PKSTO was analyzed in detail for any ligamentous injury or meniscal tear. Other associated injuries were also documented.

Statistical analysis

The demographics (age and sex) and clinical indications in each case which demonstrated (n = 18) PKSTO was obtained. Microsoft Excel data sheet was used for the data collection to extract the descriptive statistics.

Results

There were 18 patients with PKSTO sign out of the total 150 patients reviewed in the study. There was a male preponderance with a mean age of 21.7 years (range 9–39 years). Patient variables and descriptive statistics are shown in Table 3.

ACL injuries were present in 9 out of 18 patients with PKSTO. Further injuries identified in this cohort of patients were medial meniscus tears,[9] lateral meniscus tears,[3] medial collateral ligament (MCL) tears,[5] patellar dislocation[1] and patellar chondral defect[1] [Table 4]. One patient had a large effusion with synovitis without any ligamentous injury whilst four patients had multiligament injuries. There was no pattern of osseous edema in our cohort. No cases of neurovascular injuries were noted in our cohort.

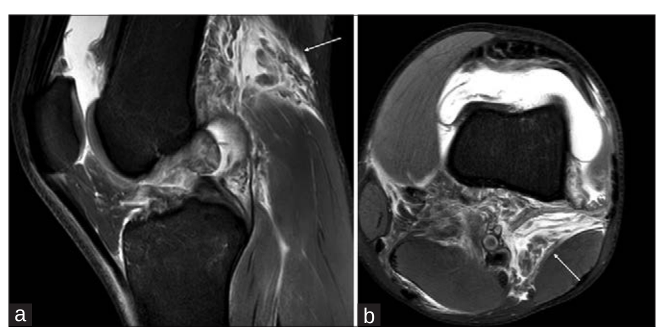

Figure 2: PDFS sag (a) and axial (b) showing marked edema of the PKSTO (arrow) in a 21-year-old male with ACL tear. PDFS:Proton density fat suppressed, PKSTO: Posterior knee soft-tissue edema, ACL: Anterior cruciate ligament

The average volumetric area of edema was 68.5 cm^3 (1.5 cm^3–486 cm^3). There was a direct proportional increase in the volume of PKSTO with an increased severity of ligamentous or meniscal injury. Those with larger volume of PKSTO had more severe multi-ligamentous injuries.

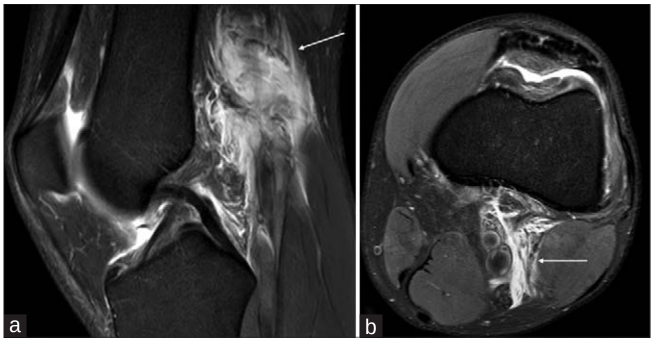

Figure 3: PDFS sag (a) and axial (b) showing marked edema of the PKSTO (arrow) in a 25-year-old male with medial meniscal tear. PDFS: Proton density fat suppressed, PKSTO: Posterior knee soft-tissue edema

Discussion

Although the imaging anatomy and pathology of soft-tissue structures such as menisci, ACL, PCL, and the corners of the knee have been widely described, posterior capsular region is sparsely commented upon in the literature.[17] We highlight the clinic-radiological significance of the PKSTO in a series of patients with acute knee injuries, which to our knowledge has not been highlighted before.

We believe the presence of this sign has anatomical reasons and associated with characteristic mechanisms of knee injury of either hyperextension or a Pivot shift maneuver, leading to the findings of typical features seen on the MRI [Figure 4]. Anatomically, this region of the knee is a crucial area at the back of the knee, with branches of the genicular artery and short saphenous vein piercing the joint capsule. Bleeding and subsequent soft-tissue edema is attributable to the damage of the tissues. This feature can be visualized on the MRI in the context of imaging anatomy of the region.[18-20]

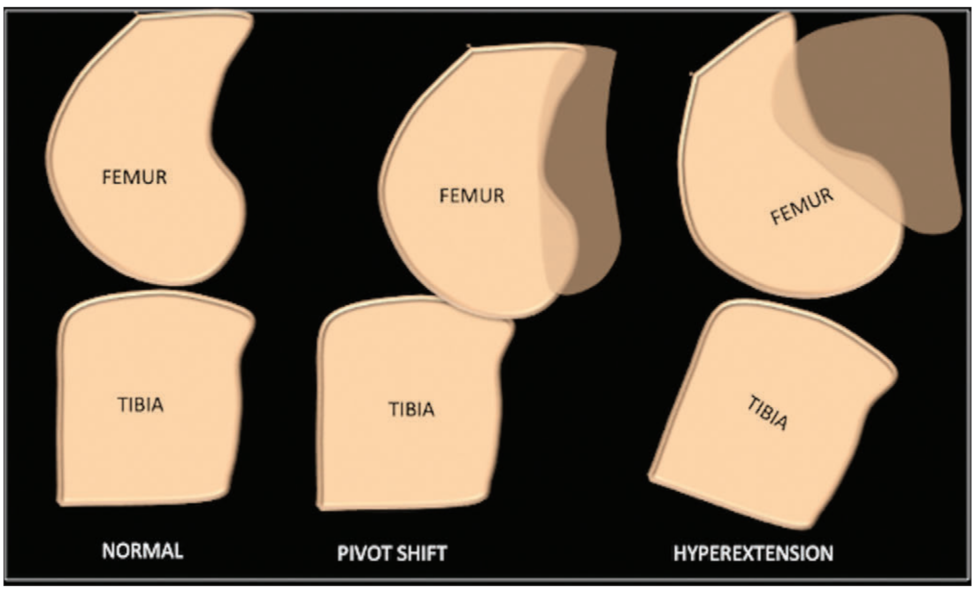

Figure 4: Schematic showing pivot shift and hyperextension pattern of injury with PKSTO posterior to the distal femora. PKSTO: Posterior knee soft-tissue edema

Table 3: Descriptive statistics of the normal and patients with posterior knee soft-tissue edema sign cohorts

Patient variable	Total number of patients (150)	Patients with posterior knee soft tissue oedema 18 patients	No oedema 132 patients
Mean age (years)	22.3	21.7	22.4
Maximum age (years)	39	39	39
Minimum age (years)	9	9	9
Females	45	3	42
Males	105	15	90
SD (years)	0.88	2.2	0.7
SEM (years)	8.05	8.95	8.02
95% CI (years)	21.09–23.69	17.04–26.58	21.1–23.8
Median (years)	22	22.5	22

CI: Confidence interval, SEM: Standard error of the mean, SD: Standard deviation

Table 4: Clinical and radiological osseous and ligamentous injuries found in patients with posterior knee soft-tissue edema sign

Findings	Patients with posterior knee soft tissue oedema
ACL injury	9
Medial meniscus tear	6
Lateral meniscus tear	3
Patella dislocation	1
Patella chondral defect	1
Multiple injuries	4

ACL: Anterior cruciate ligament

Ligamentous or meniscal injuries of the knee are a result of variety of mechanisms which involve direct and indirect forces, for example, in a pivot shift or hyperextension pattern.[16] In pivot shift pattern, a valgus load stresses a slightly flexed knee with an internally rotated tibia (or an externally rotated femur). It is postulated that such pattern stretches the PKSTs, myofascial planes, and also the traversing neurovascular bundle, leading to the visualization of PKSTO sign on MRI sagittal sequences. Our hypothesis is based on a similar mechanism suggested for MCL injuries where subcutaneous and fascial edema in the region are signs of underlying MCL tear.[21] Another possible hypothesis for PKSTO is capsular injury during hyperextension and pivot shift injury resulting in the extension of joint fluid into the posterior soft tissues.

Following a review of the literature, we were unable to find a previously described similar finding or a secondary sign which identifies the location of PKSTO or specifically the volume of the area affected relatable to the type and/or intensity of the soft-tissue knee injury.[10,13,16,21-23] We therefore advocate the PKSTO sign as an adjunct sign while reporting acute knee trauma MRI, to immediately alert the reviewer about the possibility of underlying ligament or meniscal injury. This can be present in patients with nontraumatic joint effusion or synovitis, but the extent and volume of PKSTO are less than what one would expect in those with acute trauma.

Despite the small number of patients with positive findings, our study has also demonstrated an increased severity of trauma correlating with volumetric measurement of PKSTO.

Limitation of the study

Our small pilot study has certain limitations. This is a retrospective review with a small sample size from a single center and thus reduces the robustness of the observations. There were 18 cases with PKSTO from a cohort of 150 consecutive acute knee injuries. However, highlighting the PKSTO sign may encourage other radiologist and clinicians to proactively look for this feature. This will allow clinic-radiological correlation, keeping in mind its association with internal derangement in an acutely injured knee.

Conclusion

Our hypothesis is that in patients with acute knee injury presence of edema in the posterior soft tissue proximal to the notch is the secondary sign of severe ligamentous or meniscal injury. This is due to stretching of the soft tissues over the distal femur as in hypertension injury or pivot shift pattern of injury. Further prospective, multi-center studies may help to reinforce the significance of this radiological finding. The identification of the PKSTO sign can act as an adjunct to reporting clinicians, alerting them to the possibility of underlying significant internal derangement of the knee. This will aid effective clinical diagnosis and direct appropriate patient management.

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Conflicts of interest

There are no conflicts of interest.

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Medial Tibia Cortex Transosseous Sling Fixation for Various Arthroscopic Procedures in the Knee: A Technical Note

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Abstract

The ideal fixation method in the tibia for various arthroscopic procedures in the knee remains questionable, and the authors recommend another fixation in addition to the primary. The numerous implants available have their limitations with cost, inadequate tightening, implant slippage, breakage, and pain due to prominence. In this consideration, implant-free fixations by transosseous suturing methods have been described by various authors; however, the procedural complexity, difficulty to replicate, and risk of fractures with described techniques have been the demerits in the current practice. A novel technique of transosseous fixation in the medial third of the tibia between the medial collateral ligament and tibial tuberosity is created using a 2.5-mm drill hole perpendicular to the anterior medial and posterior surfaces of the tibia. One limb of fiber wire sutures from the graft or structure repaired is shuttled through the hole around the medial border of the tibia and tied to the other limb of sutures over the medial surface of the tibia creating a sling around the medial border of the tibia. There were no neurovascular events or fractures noted. This method is safe, replicable, and adjustable to the length of grafts/tunnels, provides a stable fixation in line of pull of grafts/repaired structures, and can be used as a supplemental fixation or primary fixation for various arthroscopic/open procedures in the knee.

Keywords: Implant-free fixation, knee ligament reconstruction, transosseous suturing methods

Introduction

The ideal fixation in the tibia for various ligaments and meniscus procedures in the knee has always been changing with the trends of arthroscopic practices.[1,2] The selection of implants is influenced by the type and number of procedures, cost-effectiveness, degree of bone osteoporosis, and authors' preferences from experiences.[3] The complications with implant breakage, prominence, and fixation slippage have been observed with the currently available devices.[4,5] In this consideration, implant-free fixation techniques in the tibia are appealing, and various methods of transosseous suturing have evolved as a backup or supplementary fixation.[6-8] However, technical complexity, difficulty in replication, limited applicability, and iatrogenic fractures have been the demerits to practice transosseous suturing for various arthroscopic procedures around the knee. In this study, we describe a variant method of transosseous fixation in the tibia described as the medial tibia cortex transosseous sling fixation that can offer a safe and stable construct on the tibia.

Surgical Technique

The surgical technique of medial tibia cortex transosseous sling fixation is being demonstrated as an additional fixation of graft for the anterior cruciate ligament (ACL) reconstruction. The same is demonstrated in the saw bone model [Video 1]. A 3-cm linear incision between the posterior medial border of the tibia and tibial tuberosity in the superior medial to inferior lateral direction is made. It can also be performed through the

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incision for hamstring harvest for ligament reconstruction. The area in the anterior medial surface of the tibia between the anterior attachment of the medial collateral ligament (MCL) and the tibial tuberosity is the site of the transosseous tunnel [Figure 1]. The area can be identified easily after the hamstring tendons have been harvested. Blunt dissection is performed in the posterior medial border and 2–3 cm posterior surface of the tibia, and protectors are applied. The distance of the transosseous tunnel and the ACL tunnel can be varied based on the graft length extending beyond the ACL tunnel. A 2.5-mm cortical drill bit is used to create a pilot hole in the near cortex surface of the tibia. Attention to the inclination of the drill being perpendicular to the anterior medial surface of the tibia is followed [Figure 2]. The orientation of the drill bit is changed in the pilot hole such that it is directed perpendicular to the posterior surface of the tibia and within the medial third of the tibia. The far cortex is subsequently drilled with protection between the tibia and gastrocnemius muscle [Figure 3]. The shuttle suture with a needle (number 1 size PROLENE, Ethicon Inc., USA, passed into an 18-gauge spinal needle) is guided into drill hole and exits the far cortex [Figure 4]. A curved suture retrieving instrument is passed posterior to the tibia, and the loop of shuttle sutures is grasped. Confirmation can be made by visualizing the movement of the spinal needle head with the movements of the retrieving device [Figure 5a]. The spinal needle is gradually withdrawn, and the shuttle sutures with the loop end are retrieved from the posterior to the anterior over the medial border of the tibia [Figure 5b]. One limb of sutures from the graft is passed into the loop of the shuttle sutures and shuttled around the medial border of the tibia and then emerging through the transosseous drill hole thereby forming the sling [Figure 5c]. Adjusting the tension, four to five simple knots are made between the sling sutures and sutures from the other limb of the graft. The fixation is secure, extracortical, outside the tunnel, and in line of the fixation of grafts [Figure 6].

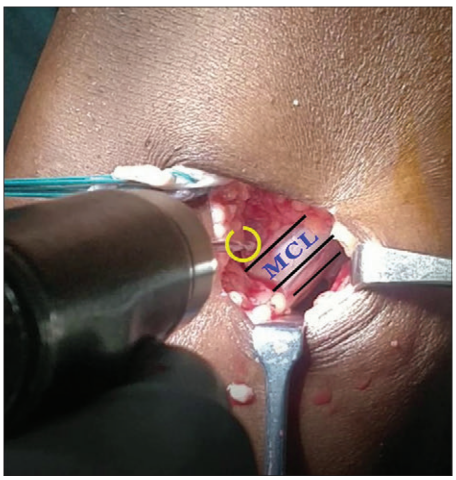

Figure 1: The landmarks for the medial tibia transosseous sling fixation. The same incision for hamstring harvest is used for the procedure. The areas (yellow circle) in the anterior medial surface of the tibia between the anterior fibers, the medial collateral ligament (borders in black and labeled MCL), and the tibial tuberosity are the site of the transosseous drill hole. The distance from the tunnels of repair or reconstructed graft tunnels can be adjusted. A window is created posterior to the tibia by a blunt hemostat, and protectors are applied. MCL: Medial collateral ligament

Discussion

Implant-free fixation methods by transosseous suturing have evolved due to the limitations with implant-related costs, breakages, fixation slippage, and prominence.[8] Pasque and de la Garza performed a transosseous supplementary fixation by making two parallel 2-mm drill hole at the tibial tubercle in the medial to the lateral direction and passed the limb sutures into the tunnel.[6] However, the requirement of a separate incision to secure the knots and the pull of the sutures perpendicular to the line of the tunnel were the demerits. Eisen *et al*. described a method where a 2.5-mm drill hole was made 5–10 mm distal to the tibial tunnel opening and angled into the tunnel such that the drill hole exits into the tunnel.[7] One limb of sutures was retrieved and tied with the other over the bridge of bone. Although the

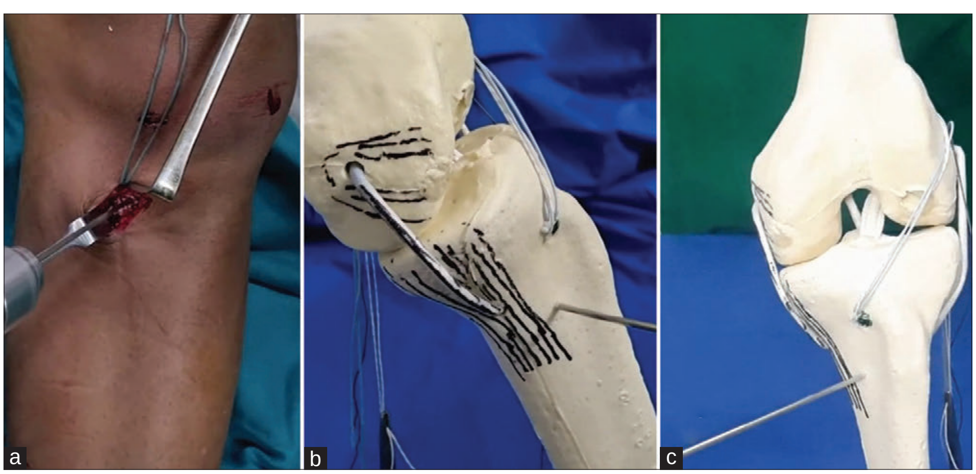

Figure 2: Steps for the near cortex pilot hole. A pilot hole of size 2.5 mm is created using a 2.5 cortical drill bit inclined perpendicular to the anterior medial surface of the tibia (a). The same is shown on a saw bone model in two different views (b and c)

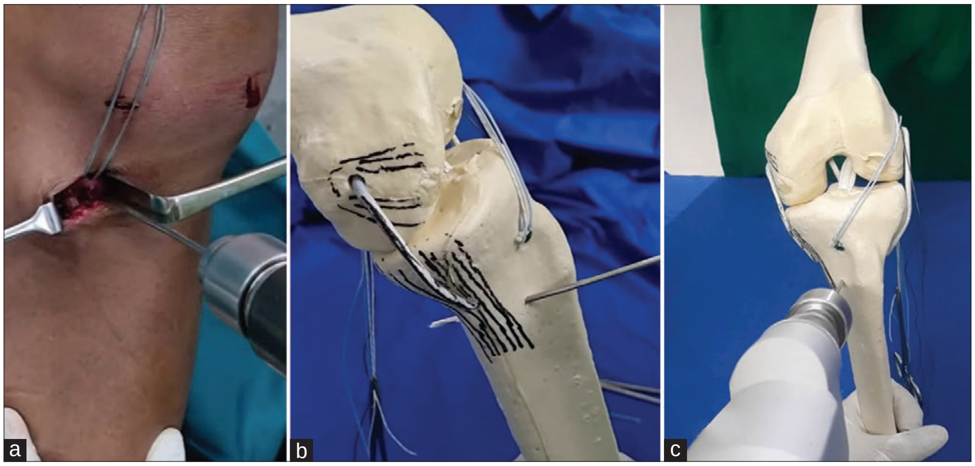

Figure 3: Steps to drill the far posterior cortex exit hole. The inclination of the drill bit is changed in the pilot hole such that it is perpendicular to the posterior surface of the tibia, and the far cortex is drilled to create the exit hole in the medial third of the tibia (a). The change in inclination for the far cortex exit hole can be seen in the model (b and c)

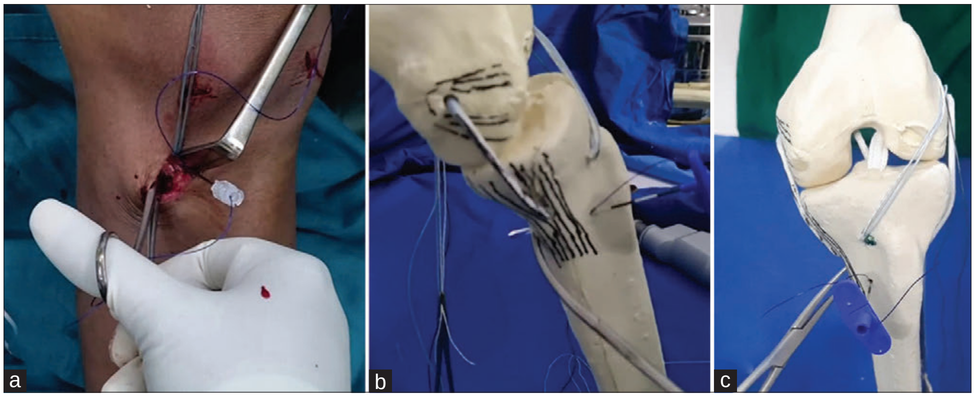

Figure 4: Passage of shuttle sutures in the transosseous hole. The 18-gauge spinal needle with the loop end of the shuttle sutures is introduced into the transosseous hole and exits the posterior cortex (a). The tip of the needle is held with a curved hemostat (b) by passing the instrument close to the posterior surface of the tibia. Confirmation can be made by visualizing the movement of the needle head with the curved hemostat (c)

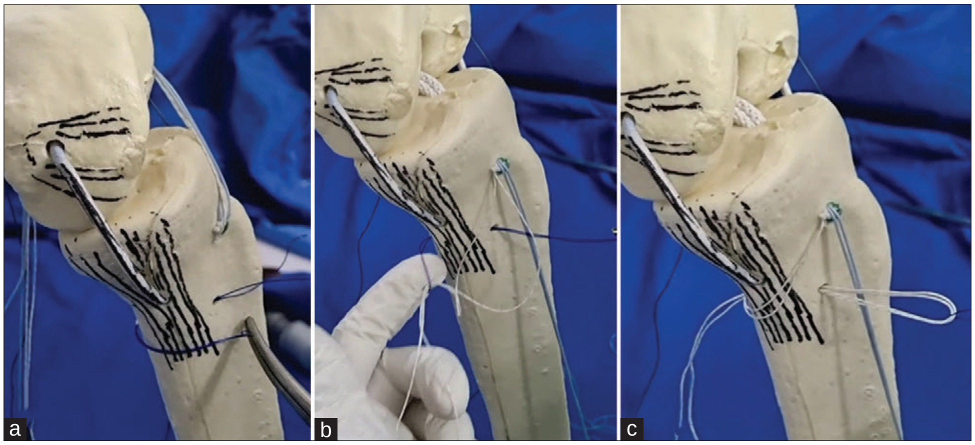

Figure 5: Creating medial sling around tibia. The needle is gradually withdrawn, and the shuttle sutures at the loop end are retrieved with the hemostat (a). There are two limbs of sutures from the graft ends extending from the tibial tunnel. One limb of sutures is passed into the loop of the shuttle suture, which will be the sling suture (b). The shuttle sutures are then pulled at the free end and thereby navigating the graft limb suture around the medial border of the tibia, posterior cortex hole, transosseous tunnel, and the pilot hole in the anterior medial surface of the tibia forming a sling (c)

fixation in this method was in line with the graft and tunnel, it had limited use when the graft was in excess beyond the tibial tunnel, and the risk of fracture due to a thin bridge could not be eliminated. The technique described in this

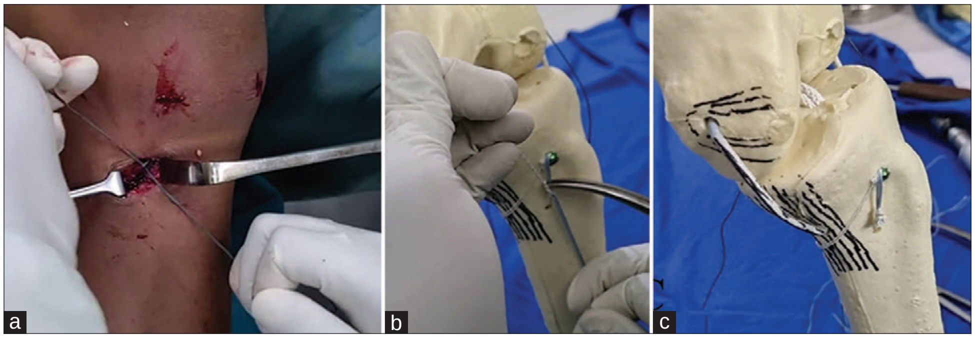

Figure 6: Sling fixation. Four to five simple knots are made between the sling sutures that traverse the transosseous tunnel and the opposite limb of sutures of the graft (a-c)

Table 1: Advantages and disadvantages

Advantages
Fixation is outside the tunnel and over the dense cortical bone
The fixation site can be adjusted from the primary tunnel for grafts/repairs
Technique not limited to supplementary fixation of soft-tissue grafts in ACL/PCL reconstruction
No special instruments/devices required
No separate incisions needed
Easily replicable
Disadvantages
Repairs having only a single limb of suture cannot be executed
Vertical placement and length of skin incision for hamstring graft harvest may affect suture retrieval from the posterior aspect of the tibia

ACL: Anterior cruciate ligament, PCL: Posterior cruciate ligament

study (medial tibia cortex transosseous sling fixation) is a varied form of transosseous suturing that involves the passage of suture limb from grafts/repaired structures into a 2.5-mm transosseous tunnel in the medial third of the tibia between the MCL attachment and tibial tuberosity. The posterior neurovascular structures are safe with posterior protection and by creating the tunnel exit perpendicular to the posterior surface of the tibia. This technique has the advantage of fixation in line with the graft and tunnel, a larger bony bridge, and can be applicable to grafts extending beyond the tibial tunnel [Table 1]. This method can be used as a supplementary fixation or primary fixation for various arthroscopic procedures in the knee.

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Conflicts of interest

There are no conflicts of interest.

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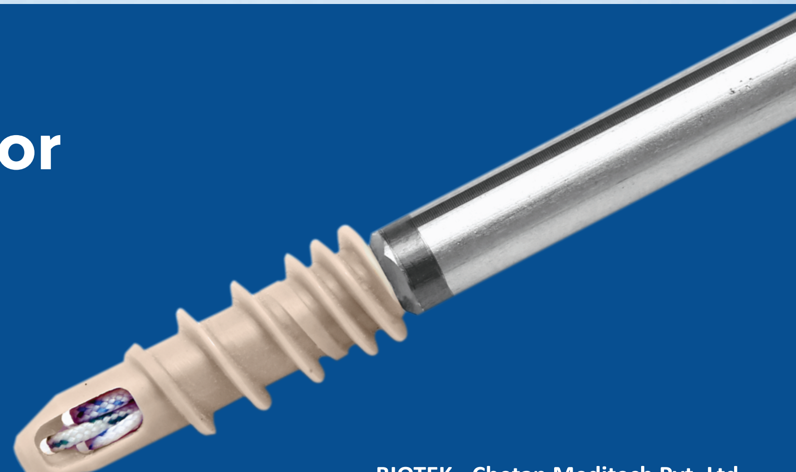

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