

Rotational stability after ACL reconstruction using anatomic double bundle technique versus anatomic single bundle technique plus anterolateral ligament augmentation

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ABSTRACT

Background: A residual pivot shift seen in up to quarter of ACL reconstructions using anatomic single bundle (ASB) technique. Light has been thrown on the importance of the Posterolateral (PL) bundle and its role in rotational stability, hence the concept of anatomic double bundle (ADB) reconstruction. Anterolateral ligament (ALL) reconstruction; an added extra-articular procedure, is proposed to be responsible for rotational knee stability. The aim of this study was to assess functional outcomes and rotational stability of the knee after ADB versus ASB reconstruction plus ALL augmentation.

Patients and methods: Between January 2015 and December 2015, a randomized controlled trial (RCT) was conducted on 40 patients suffering from chronic ACL injuries or acute injuries with high grade knee jerk or are high demand athletes. Twenty patients (group A) were treated with ASB ACL reconstruction and ALL augmentation. The other 20 patients (group B) underwent ADB ACL reconstructions. All patients were assessed pre and post-operatively using the Lysholm and IKDC (international knee documentation committee) scores and KT-1000 arthrometer. At the final follow-up, internal rotation kinematics of the knee was assessed using motion analysis in a gait lab.

Results: All were followed-up for a mean of two years. At the final follow-up, there was no statistically significant difference regarding the total Lysholm score, IKDC score and KT-1000 side to side difference; P-values 0.821, 0.732, 0.533 respectively. Group 'A' demonstrated better rotational stability than group 'B' as measured from internal tibial rotation angle with a p-value of 0.001.

Conclusion: ALL augmentation is an added extra-articular procedure that superseded ADB reconstruction in achieving better knee internal rotation kinematics. Level of evidence: II.

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1. Introduction

Techniques for ACL reconstruction are continuously being modified in attempt to restore the native anatomy and kinematics of the knee. The standard anatomical single bundle (ASB) reconstruction yields good results regarding antero-posterior stability, however; it is still questionable in terms of rotational stability.¹ Several studies concluded that ASB fail to confer control of

rotational stability and does not reduce risk of knee arthritis.²

In the light of better knee rotational stability, several new techniques and procedures are being developed for reconstruction of an ACL that closely resembles the native ACL in anatomy and function. Some proposed a more horizontal graft position (lower femoral tunnel),³ others added an extra-articular procedure (modified Macintosh). Recently light have been thrown on the ALL and its precise anatomy,^{4,5} which contributes to the rotatory stability of the knee.^{6–8} Anatomical double bundle (ADB) reconstruction was proposed after biomechanical studies have proven the ACL to be functionally composed of two bundles; anteromedial (AM) and posterolateral (PL). Though it is technically more demanding, a more lengthy procedure and not applicable for individuals with a narrow notch, it is postulated to yield more

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promising results^{3,9} Up to the authors' knowledge, no previous studies compared ADB with ACL plus ALL reconstruction.

2. Patients and methods

After approval of the ethical committee of, a prospective randomized controlled trial (RCT) was conducted from January 2015 till December 2015 to compare the results, IKDC, Lysholm scores and rotational stability of the knee after ASB ACL reconstruction with ALL augmentation versus ADB ACL reconstruction.

A total of 40 patients with ACL injury (chronic injuries or injuries with knee jerk GIII) were included in the study and allocated randomly into one of two groups. An informed consent was obtained from all patients. Twenty patients underwent ASB ACL reconstruction plus ALL augmentation (Group A) while the remaining 20 underwent ADB ACL reconstruction (Group B). All patients with acute ACL injuries with a knee jerk GIII or a lower jerk grade in a highly demanding athlete and chronic ACL injuries, whether isolated or associated with meniscal injuries were included in the study. Patients with bilateral ACL injuries, revision cases, those with associated ligamentous tears and patients with severe osteo-arthritis were excluded.

2.1. Patient demographics

The patients' age ranged from 15 to 42 years with a mean of 25.78. Mean age for group 'A' was 24.9 (standard deviation (S.D.) of ± 7.2 , range 15–37 years). Mean age for Group 'B' was 26.6 (S.D. ± 7.2 ranging from 18 to 42 years). Group 'A' included 17 males (85%) and 3 females (15%). In group 'B' all 20(100%) patients were males and none were females. In group 'A', 14 (70%) had sustained injury to the right knee while 6 (30%) had their left knee injured. In group 'B', 13 (65%) had right knee injury, while 7 (35%) suffered a left knee injury. Six (30%) out of 20 in group 'A' were professional athletes as compared to 5 (25%) out of 20 patients in group 'B'.

Mean time from injury to surgery in group 'A' was 8.8 months ± 21.2 while in group 'B' it was 10.0 months ± 10.6 ; p-value was 0.874 (NS). Twenty-five patients have sustained a non-contact injury while only 15 had direct contact trauma.

2.2. Pre-operative evaluation

Clinical evaluation; History taking for the mode and time of trauma, giving way, knee pain, knee swelling, locking, limping and previous interventions. Full knee examination was done in the outpatient clinic. Lysholm knee score and IKDC score were done for all patients.

Radiographic evaluation; Plain radiographs in the AP and Lateral views and MRI were the studies used in all cases.

2.3. Operative details and procedure

All surgeries were performed in the supine position, under general (in 20 patients) or spinal anesthesia (in the other 20 patients). A post was placed at the side of the operating table to abut the thigh facilitating valgus maneuvering during arthroscopic examination of the medial compartment. Routine examination under anesthesia (EUA) was performed as the first step for all patients. The grade of knee jerk was noted and documented. A tourniquet cuff connected to a digital timer was secured over the proximal thigh. The limb was exsanguinated and the cuff inflated to a pressure of approximately 350 mmHg (200 mmHg above the systolic pressure). The anatomic landmarks for the ALL were identified and marked with a marker pen for group 'A' patients. The whole limb was then sterilized with povidone iodine and draped.

2.3.1. Graft harvesting

In both group 'A' and 'B', harvesting of the hamstring tendons (semi-T and Gracilis) was performed in the figure-of-four position through a small oblique incision. A closed stripper was used to harvest the tendons one following the other, after they were freed from the connections.

2.3.2. Arthroscopic procedure

Diagnostic knee arthroscopy (DKA) was performed as a routine step in all cases. Any meniscal lesions were treated prior to ACL reconstruction, either by performing partial meniscectomy or meniscal repair.

2.3.3. Tunnel placement and drilling

In group A; a C-guide, adjusted to 55°; was used to introduce a single tibial guide wire in the center of the tibial anatomic footprint. The position of the wire is checked and that full extension could be achieved without impingement, followed by drilling of the tunnel. Through accessory anteromedial (AAM) portal, with the knee flexed 120°, a single femoral tunnel is created. This allows its precise placement in the center of the foot print, at the level if the intercondylar ridge just posterior to the bifurcate ridge. First a guide pin is introduced, then the tunnel is drilled corresponding to the graft diameter.

In group B; two tibial and femoral tunnels are created. The AM tunnel is drilled first then separate femoral and tibial PL aimers from the double bundle set available from Smith and Nephew are used to guide placement of the PL femoral (Fig. 1a) and tibial tunnels (Fig. 1b) respectively. On the femoral side, after measurement of the condyle diameter with a depth gauge, the AM tunnel is drilled over a guide pin introduced behind the bifurcate ridge and below intercondylar ridge. A 4.5 mm drill bit is used to drill the entire depth of the tunnel, followed by a 6/7 mm drill bit corresponding to the size of the graft. The PL tunnel is then drilled in the same fashion but anterior to the bifurcate ridge, leaving a 2 mm bony bridge between both tunnels. On the tibial side, the AM tunnel is drilled first over a guide pin placed anterior and medial in the tibial footprint. This is followed by PL tunnel drilling, allowing 1 cm cortical distance to avoid tunnel collision.

2.3.4. Anterolateral ligament (ALL)

This form of extra-articular augmentation was done in group 'A' only. After drilling of the ACL tunnels, before passage of the ACL graft, femoral and tibial tunnels are created for ALL. The femoral tunnel was drilled over a guide pin introduced just above and posterior to the lateral epicondyle, aiming antero-superiorly to

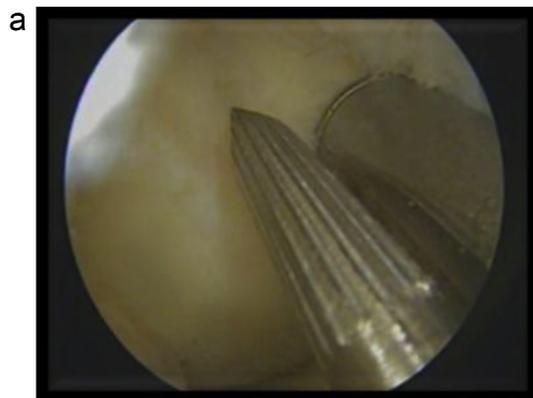


Fig. 1a. Femoral PL aimer used to introduce the guide pin for the PL femoral tunnel after drilling of the AM tunnel.

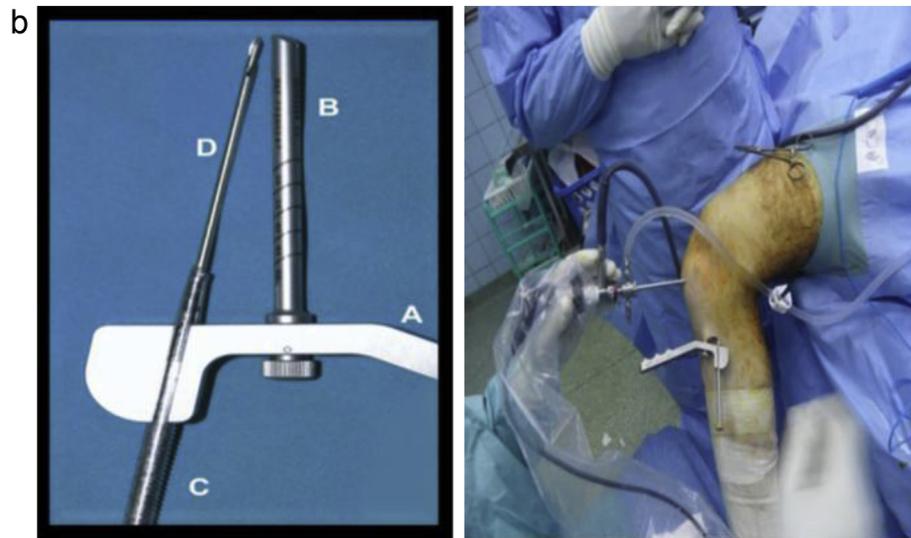


Fig. 1b. PL aimer from the double bundle set provided by Smith and Nephew used to introduce the tibial PL pin.

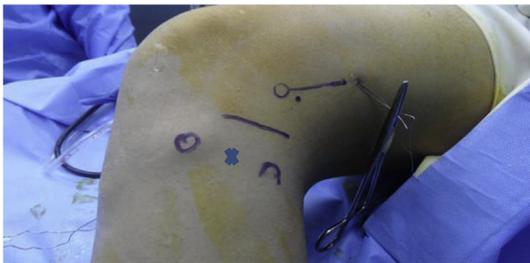


Fig. 2. Landmarks marked with a marker pen for the sites chosen to create tunnels for ALL reconstruction. On the femoral side a point is chosen just above and behind the lateral epicondyle. On the tibial side a point is chosen 7 mm below the joint line midway between Gerdy's tubercle and the head of fibula.

avoid collision with ACL tunnel. The tibial tunnel was drilled half-way between the fibular head and the Gerdy's tubercle, 7 mm below the joint line (Fig. 2).

2.3.5. Graft preparation

Meanwhile the notch was being prepared and the tunnels drilled, the graft was prepared by an assistant on the back table with help of a graft tensioner. In group A; the tendons were separated; the ST was tripled and prepared as the ACL graft. The "G" was doubled and prepared as the ALL graft. In group B; Here the ST is prepared into the AM bundle. The graft size and length are then measured. The "G" is prepared into the PL bundle in the same manner but is usually smaller in diameter.

2.3.6. Passage and fixation of the grafts

In group A; both ACL and ALL grafts are fixed with bio-screws on tibial and femoral sides, starting with ACL graft first. In group B; the PL bundle is shuttled first and fixed in extension, followed by the AM bundle which is fixed in 90° flexion. Both bundles are fixed with an endo-button on the femoral side and bio-screws on the tibial side. The bundles are parallel near full extension, but are crossed in flexion.

2.4. Post-operatively

Patients stay in the hospital for one or two nights, in the ward,

where they receive intravenous antibiotics, cryotherapy, anti-edematous modalities, anticoagulation and start static quadriceps exercises. Patients were discharged on oral antibiotics (3rd generation cephalosporin), anticoagulation and analgesics for 1 week. Full weight-bearing is allowed aided by 2 crutches for balancing. After 1 week, aspiration was done in cases of moderate or severe effusion. After 2 weeks, one crutch is discarded and at 1 month post-operative, weight bearing is allowed without crutches.

Physiotherapy was started, following the accelerated rehabilitation program for 6 months. Flexion is limited to 90° in cases of meniscal repair. At the final follow-up at 2 years, patients were assessed using the Lysholm, objective IKDC scores and KT-1000 instrumented Lachman. Rotational stability was assessed in gait lab using computerized kinematic analysis.

2.5. Statistical methods used

The statistical analysis was done using SPSS v22.0 IBM statistical package for social sciences & Microsoft Office 2013. The significance level was set at $p < 0.05$ & marked with S, while highly statistical significance was set at $p < 0.01$ & marked with HS. The statistical insignificance was set at $p > 0.05$ & marked by NS. The categorical data were subjected to descriptive analysis using frequency & percentage while for the scale data mean & standard deviation SD was used. Tests for inferential statistics & correlation were Chi Square test, independent *t*-test, paired *t*-test & Wilcoxon Rank test for paired results.

3. Results

Mean operative time in group 'A' was 95 min ranging from 70 to 120 min. Group 'B'; 120 min (range 90–170 min), statistically significant with P-value 0.004. The mean blood loss was negligible. The mean follow-up was 2 years (24 months) ranging from 22 to 26 months. In group 'A' 3 patients (15%) had meniscal repairs, while 9 (45%) had partial menisectomies (PM). In group B there were 3 (15%) meniscal repairs and 8 (40%) had PM.

3.1. Subjective outcomes (Lysholm score)

Pre-operatively: In group A; none had an excellent score (95–100). One patient (5%) had a good score (84–94) while 6 (30%)

had a fair score (65–83) and 13 (65%) had a poor score (<64). *In group B*; none of the patients had an excellent score (95–100). Three (15%) had a good score (84–94), while 5 (25%) had a fair score (65–83) and 12 (60%) had a poor score (<64). Post-operatively: *In group A*; 7 patients (35%) had an excellent score (95–100). Twelve (60%) had a good score (84–94) while only one (5%) had a fair score (65–83) and none of the patients had a poor score (<64). *In group B*; 10 patients (50%) had an excellent score (95–100). Seven (35%) had a good score (84–94) while 3 (15%) had a fair score (65–83) and none of the patients had a poor score (<64). No statistically significant difference existed between both groups neither pre nor post-operatively with p-values of 0.521 and 0.331 respectively.

3.2. Objective outcomes

3.2.1. IKDC score

All patients were scored for these items before and after the surgery. Four grades were determined for each group: *Grade A = normal, Grade B = nearly normal, Grade C = abnormal and Grade D = severely abnormal* (Table 1).

3.2.2. KT-1000 instrumented Lachmann

There was no statistically significant difference between both groups regarding post-operative anterior translation measured by KT-1000 arthro-meter in the sound and injured limbs and side to side difference (Table 2).

3.2.3. Rotational stability

It is measured as internal tibial rotation angle for the injured and sound limbs in each group. Then the side to side difference was

Table 1
Showing pre-operative and post-operative objective IKDC scores in group 'A' and 'B'.

IKDC parameter	Pre-operatively		Post-operatively Final follow-up	
	Group A	Group B	Group A	Group B
Effusion				
A: none	13 (65%)	11(55%)	18 (90%)	18 (90%)
B: mild	4 (20%)	6 (30%)	2 (10%)	2 (10%)
C: moderate	3 (15%)	2 (10%)	None	None
D: severe	None	1 (5%)	None	None
Motion deficit				
Lack of Extension (EXT.)				
A: <3°	11 (55%)	12 (60%)	18 (90%)	15 (75%)
B: 3–5°	6 (30%)	4 (20%)	2 (10%)	4 (20%)
C: 6–10°	3 (15%)	3 (15%)	none	1 (5%)
D: > 10°	None	1 (5%)	none	None
Lack of flexion (flex.)				
A: 0–5°	10 (50%)	9 (45%)	18 (90%)	18 (90%)
B: 6–15°	3 (15%)	5 (25%)	1 (5%)	1 (5%)
C: 16–25°	7 (35%)	4 (20%)	1 (5%)	1 (5%)
D: >25°	None	2 (10%)	None	None
Ligament examination:				
Lachmann:				
A: 0–2 mm	None	None	15 (75%)	16 (80%)
B: 3–5 mm	1 (5%)	1 (5%)	4 (20%)	2 (10%)
C: 6–10	14 (70%)	8 (40%)	1 (5%)	2 (10%)
D: >10	5 (25%)	11 (55%)	None	None
Pivot shift test:				
A: equal	None	None	18 (90%)	16 (80%)
B: glide(+)	1 (5%)	2 (10%)	2 (10%)	3 (15%)
C: clunk(++)	3 (15%)	5 (25%)	None	1 (5%)
D: Gross(++++)	16 (80%)	13 (65%)	None	None
Functional test (one leg hop test)				
A: ≥ 90%	None	None	16 (80%)	15 (75%)
B: 89–76%	2 (10%)	2 (10%)	3 (15%)	3 (15%)
C: 75–50%	5 (25%)	7 (35%)	1 (5%)	2 (10%)
D: <50%	13 (65%)	11 (55%)	None	None

Table 2

KT-1000 injured side, sound side and side to side difference in both groups post-operatively.

KT-1000	Group A Mean ± SD	Group B Mean ± SD	P
Injured	4.6 ± 1.59	4.1 ± 1.59	0.3 NS
Sound	3.5 ± 1.2	2.9 ± 1.1	0.1 NS
Difference	1.1 ± 0.8	1.3 ± 1.3	0.5 NS

Table 3

Results for internal tibial rotation angle in the injured and sound limbs and side to side difference for group A and B.

Variable	Group A Mean ± SD	Group B Mean ± SD	95%CI		P
			Upper	Lower	
Injured	−13.8 ± 3.1	−17 ± 4.6	5.6	0.6	0.01 S
Sound	−11.8 ± 3.1	−11.9 ± 2.9	2.1	−1.8	0.8 NS
Difference	2 ± 1.17	5 ± 2.7	−1.6	−4.4	0.001 HS

calculated. There is a statistically significant difference regarding internal tibial rotation angle measured in the operated limb and with side to side difference between group A and B, with a better outcome in group A; p-values 0.011 (S) and 0.001 respectively (Table 3).

3.3. Complications

In group A, according to IKDC score; four suffered *compartment pathologies*; 3 were grade "B", moderate changes in the lateral compartment and one patient was grade "C"; moderate changes with mild pain in the medial compartment after a partial meniscectomy (PM) for MM. Two patients suffered pain in the graft harvest site. In group 'B'; Two patients had mild *Harvest site pathologies* (graded B); in the form of intermittent medial pain. Only 1 patient suffered moderate pathology in the form of mild superficial infection that was successfully managed by debridement and IV antibiotics. Three patients had *compartment changes*; two had crepitations of the medial compartment, graded "B". One patient suffered crepitations of anterior and medial compartments with mild pain; graded "C". In one patient the tibial AM tunnel was a little anterior causing the graft to impinge at the roof of the notch. This required notchoplasty in the same session and early strict extension exercises. The patient was able to achieve full range of motion at final follow-up.

4. Discussion

Residual positive pivot shift especially among patients with a high grade knee jerk, chronic tears and highly demanding athletes; led surgeons approach such cases a little bit differently from the currently widely accepted concept of ASB ACL reconstruction.^{10–12} Pivot shift is a multi-planar movement combining anterior translation and rotational elements. It is debatable as to which element contributes more to this complex movement in ACL deficient knees.^{13–15} Zaffagini et al suggests that 20–25% of poor outcome following ACL reconstruction is due to poor internal rotational stability,¹⁶ which is the key to the positive knee jerk post-operatively. Several in vivo and in vitro studies have demonstrated the inability of single bundle reconstructions to restore the rotational stability.^{17–19} Increased laxity is associated with higher chance of meniscal, chondral injuries and secondary osteoarthritis; resulting from more abrupt motion and poorly fitting joint surfaces.^{20–22} Another important issue; is lack of instruments and tools to quantify and assess the complex kinematic ligament

stability and rotation in vivo.

Extra-articular procedures have been suggested to achieve better control of rotational stability^{23,24}; however, scar, morbidity and overloading the lateral compartment with subsequent arthritic changes are worrisome complications.²⁵ The ALL; is a new anatomically discovered lateral knee structure, proposed to be responsible for rotational knee stability.^{4,5,7} It is however still debatable whether this is true ligament or a condensation of the capsule and whether it is capsular or purely extra-capsular.²⁶ Objective and subjective outcome of both methods requires comparison along with assessment of rotational knee stability. Subjective scores and knee tests limit our ability to truly gauge differences between ACL reconstruction techniques.^{27,28}

The results of the current study are comparable with those of two clinical trials; **Feretti et al** and **Monaco et al**, who suggest that the PL bundle does not confer more rotational stability.^{29,30} The mean KT-1000 side to side difference in ADB reconstructions of this study are similar to **T.P. Branch et al**; although, they relied on robotic knee testing system.³¹ They were slightly greater than **Hofbauer et al**³² and lower than **Plaweski et al**.³³ **Hofbauer et al** and **Plaweski et al** used computer navigation to assist accurate and precise tunnel placement,³² and to quantify AP laxity using Lachman testing. Despite relying on computer navigation for quantifying knee kinematics in their study, the results in this study were superior to **Plaweski et al**. It is also important to note that our analysis of AP stability was at the final follow-up, providing a good reflection of the patient's functional outcome after re-habilitation. In the studies of **Hofbauer et al** and **Plaweski et al**, measurements taken intra-operatively at time "0"; omit the role of rehabilitation, complications and time which affects the overall functional outcome. Studies suggest that grafts used, lengthen with time.³⁴

In this study that ASB + ALL (group A) had a slightly better reduction of anterior translation as compared to ADB reconstruction indicated by a lower side to side difference with respect to KT-1000 measurements in group 'A' as compared to group 'B', this is consistent with both **Zaffagini et al**³⁵ and **Monaco et al**.²⁴ However, it was not found to be statistically significant.

With respect to pivot shift; in this study patients treated with ASB + ALL reconstruction showed better correction of the pivot shift as compared to those treated with ADB. This is different from the findings of **Zaffagini et al**,³⁵ however; this was not statistically significant, possibly due to our small sample size. **Monaco et al**²⁴ reported better control on internal tibial rotation with extra-articular procedures compared to DB reconstruction. The results in this study are consistent with their findings.

After the precise description of ALL in anatomic and biomechanical studies, light have been thrown on its importance as a secondary knee restraint. Several cadaveric studies evaluated the role of the ALL in control over knee rotational stability. **Matthew T. Rasmussen** et al. studying cadaver knees in **2015**; found a minimal contribution of the ALL to anterior tibial translation, but an important role in resisting internal rotation. They also reported a minimal role of the ACL in resisting internal rotation.³⁶ It is however, argued in other studies in vitro, that the ALL played minimal role in rotational stability. Cadaveric studies may ignore the fact that functional and biomechanical properties of tissues vary in vitro compared to in vivo.

Several cadaveric studies have recently highlighted the importance of the ilio-tibial band and claim that it is the main stabilizer of the knee in the face of internal rotational force.^{29,37} It is important to note that in cadaver knees, soft tissue properties change as compared to in vivo. Secondly, cadavers usually belong to the geriatric population; we believe this poses an element of bias because the biomechanical properties change with age. Thus;

results of cadaveric studies cannot be implied to young individuals who sustain injuries of the ACL. More clinical trials are required to study the role of ALL reconstruction of rotational stability of the knee in young human subjects and to compare ALL reconstruction with the ITB augmentation.

The strength of this study lies in being a randomized controlled trial. To the authors' knowledge, it is the first study to compare ADB ACL reconstruction with ASB and ALL reconstruction. We relied on computerized motion analysis in gait lab to assess the internal tibial rotation angle. However; we believe our weaknesses include the small sample size and that AP translation was measured using KT-1000 arthrometer with inter and intra-observer bias.

5. Conclusion

ASB reconstruction plus ALL augmentation supersedes ADB reconstruction in achieving better internal rotational knee kinematics, however; it did not demonstrate superior functional outcomes. ASB plus ALL augmentation showed a significantly shorter operative time as compared to ADB reconstruction, lower risk for intra-operative complications and hence would be chosen over ADB reconstruction. Recent literature and cadaveric studies consider the ilio-tibial band (ITB) the important secondary stabilizer to AP translation and rotational stability. They advocate ITB tenodesis as an added extra-articular augmentation to achieve better rotational stability. Controlled clinical trials are needed to compare outcomes with ALL versus ITB tenodesis.

Declaration of interest

None.

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