REVIEW

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Long-Term Physiotherapy Outcomes in Anterior Cruciate Ligament Reconstruction: A Systematic Review with Meta-Analysis of Bone-Patellar-Tendon Bone *Versus* Four-Strand Hamstring Autografts

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SUMMARY

Background. Bone patellar-tendon bone (BPTB) autografts and Hamstring tendon (HT) autografts the two common Anterior cruciate ligament reconstruction (ACLR) procedures have varied outcomes. This review aimed to compare the clinical outcomes of athletic/ physically active participants at 2 and ≥ 2 years after ACLR.

Methods. Systematic searches were conducted on PubMed, Scopus, PEDro, and Web of Science. For quality assessment we utilized the PEDro scale. Meta-analysis was performed on six out of seven included studies. The primary outcome studied were pain, laxity, Return to sport (RTS), graft re-rupture rate, ROM deficits, functional outcomes and isokinetic strength deficits on athletic/ physically active participants at 2 and ≥ 2 years of ACLR.

Results. Thirteen randomised studies comprising 1190 participant, were selected after removal of duplicates and applying exclusion criteria. The meta-analysis showed that BPTB autograft has greater effectiveness in instrumental laxity (SMD = -0.22, 95%CI -0.38 to -0.06, Z = 2.77, p = 0.006), RTS (SMD = -0.42, 95%CI -0.72 to -0.13, Z = 2.84, p = 0.005), Flexion ROM deficit (SMD = -1.82, 95%CI -3.66 to 0.02, Z = 1.94, p = 0.05) and Extension iso-kinetic deficit at 60° (SMD = -3.49, 95%CI -5.80 to -1.17, Z = 2.95, p = 0.003) ≤ 2 year post-ACLR. Whereas, HT autograft shows greater effectiveness in Pain > 2 year (SMD = 0.21, 95%CI -0.00 to 0.42; Z = 1.95, p = 0.05) and Extension ROM deficit at both ≤ 2 year (SMD = 1.36, 95%CI 0.45 to 2.27, Z = 2.93, p = 0.003) and > 2 year (SMD = 1.27, 95%CI 0.02 to 2.52; Z = 1.99, p = 0.05) post-ACLR.

Conclusions. Current analysis shows that BPTB autograft at ≤ 2-year post-ACLR have greater effectiveness in instrumental laxity, RTS, Flexion ROM deficit and Extension iso-kinetic deficit at 60°. Whereas HT autograft shows greater effectiveness in pain > 2 year and Extension ROM deficit at both ≤ 2 year and > 2-year post-ACLR.

Study registration. The protocol for this review had been published and registered in the International Prospective Register of Systematic Reviews (PROSPERO) as CRD42022297699.

KEY WORDS

Bone patellar-tendon bone autograft; Hamstring tendon autografts; pain; range of motion; muscle strength; joint laxity.

INTRODUCTION

An anterior cruciate ligament (ACL) tears or ruptures are one of the most common knee injuries seen in the young athletic population (1). The incidence rate of ACL injury was 20.3% compared to all internal knee injuries (2). The injury itself is painful and disabling, causing lost time from both sports and work. ACL tears also result in instability and deficits in neuromuscular control. As it is known that

there is little biological healing potential in ACL therefore, surgical reconstruction of ACL is often indicated to restore functional stability and strength for resuming athletic activity and to prevent early degenerative changes like arthritis in the knee joint (3). An exact number of ACL reconstructions performed in the United States is unknown but using the market scan database with approximately 158 million privately insured patients, reported that 2.83 lakh ACLR (ACL reconstruction) procedures were performed between 2002 and 2014, with no such data available for the Asian population. The incidence of ACLR in the United States rose from 86,687 (32.9 per 100,000 person-years) in 1994 to 129,836 (43.5 per 100,000 person-years) in 2006 (4-6). The large increase in the percentage of ACLR suggests that surgical procedure is a well-accepted norm for ACL injuries, however, the technique (type of graft) chosen by the clinician is contentious.

With recent developments in technology and with an array of ACL graft possibilities at disposal of surgeons, the ACL tear is no more considered a career-threatening injury for the athlete. Surgical reconstruction can be performed using a variety of graft types with each having its share of benefits and disadvantages. The graft selected must have structural and mechanical properties that closely resemble native ACL ligament and should have enough healing potential to adequately integrate into the host bone. Various graft types are available but from a biological healing perspective, autografts (derived from the same patient) are preferred over other grafts because they consist of viable autogenous tissue and avoid the risk of disease transmission, maximizing the speed and likelihood of complete biological integration at the graft-host junction (7). The most used autografts are 1) single bundle Bone patellar-tendon bone (BPTB) grafts harvested typically from the middle third of the ipsilateral patellar tendon or 2) four-strand Hamstring tendon (HT) grafts harvested from the semitendinosus (ST) and gracilis (G) tendons (6, 8-10).

Better biological healing properties of BPTB graft have made it the prime choice of surgeons amongst other grafts utilized for ACLR for many years and its popularity also positions it as a gold standard useful for criterion comparison in research work. Time-based analysis of the physical measures (pain, instability, muscle strength) and kinematic testing (deficits of range of motion, athletic functional impairments) are considered the most useful method for graft comparison. In spite, of advancements in ACLR post-operative impairments like pain, instability, deficits of a range of motion, muscle strength, and athletic functional impairments are commonly seen in clinical practice even after two years or more of surgery. These impairments might preclude the pre-injury level return to sport (RTS) of athletes. As per previous studies, the post-operative disadvantage of BPTB autograft includes donor-site pain (11-16), anterior knee pain, patella fracture, inferior patellar contracture, and loss of knee extension torque despite the anatomically successful replacement of ACL (17-23). Due to the above impairments in BPTB, the use of four-strand HT graft has gained popularity in the past decade. Anatomical studies (24-26) have shown that normal ACL structure mainly consists of 2 bundles, namely the anteromedial (AM) and posterolateral (PL). The double-bundle technique restores both the AM and PL bundles, thus representing a more anatomical sound method. Biomechanical studies have also shown that rotational stability was considerably improved after the reconstruction of the PL bundle (26-28). But the single bundle BPTB ACLR lags the four-strand HT graft in terms of structural strength (BPTB graft: 2977N *vs* HT graft: 4590N) (29, 30). Additionally, the four-strand HT graft also has a few disadvantages namely: failure to achieve immediate rigid fixation, graft loosening at long-term follow-up increased tunnel size, and weakness of the hamstring with difficulty in controlling internal tibial rotation (12, 13, 31-34).

There is conflicting evidence in studies comparing these two types of grafts. According to some previous studies single strand, BPTB autograft has superior outcomes in terms of instability while several other studies have found no significant difference in terms of instrumented laxity measurements (KT-1000), Manual laxity measurements (Lachman test, Pivot-shift test); graft re-rupture rates, Tegner score, extension, and flexion deficits (6, 35-37). The evidence generated on graft re-rupture rate by meta-analytic studies found that around 5.2% of four-strand HT ACLR receivers sustained re-ruptures in comparison to BPTB. The evidence also reported that 83% of elite athletes participating in the highest level of competition for their sport returned to the sport following ACLR within 6-13 months of surgery (6, 35, 37, 38).

Considering the advantages and drawbacks of the two grafts, it becomes scientifically imperative to examine and compare the long-term effects of ACLR on various clinical outcomes of physiotherapeutic relevance. Although a lot of reviews have already been done in past to evaluate the effectiveness of BPTB and HT autograft, they are however marred by a few drawbacks (6, 10, 38-44). Firstly, none of the reviews have evaluated the comprehensive list of long-term effects (up to 2 years and > 2 years) on physical outcomes such as pain, laxity, return to sports (RTS), graft

re-rupture rate, ROM deficits, and knee flexor and extensor isokinetic strength deficits on athletic population. Secondly, most of the systematic reviews have included studies with heterogeneous study designs (randomized controlled studies, cross-over, and cohort studies) resulting in decreased external validity of their result. Thirdly, previous reviews were focused on the relatively shorter timeframe of 1-2 years post-ACLR, however, seeing the recovery potential of ACLR it becomes imperative to assess the outcome parameter in a long-time frame of more than 2 years also. Fourthly, reviews have included studies with a mixture of four-strand and two-strand HT making the comparison with BPTB unequal. Four-strand HT has better rotational stability and higher tensile strength, therefore comparison of outcomes of these studies becomes important in present times. The immediate and short-term effect of ACLR is well documented in the literature but there is a dearth of cumulative evidence on differences in long-term outcomes between the single-strand BPTB and four-strand HT graft in terms of clinical and functional outcomes. This study distinguishes itself by eliminating the limitations of the earlier studies in terms of assessing the clinical and performance outcomes on two long-term follow-up time frames (up to 2 years and > 2 years) in athletic and physically active populations by only including randomized controlled trials comparing the single-strand BPTB with four-strand HT. This knowledge derived from this review with longer follow-up could aid the surgeon and therapist alike by optimizing their clinical decision-making during the choice of the graft type. Thus, the objective of the following study was to perform a systematic review and meta-analysis of the current literature that compare the clinical outcomes of single-bundle BPTB autograft with four-strand HT autograft in terms of pain, laxity, RTS, graft re-rupture rate, ROM deficits, and isokinetic strength deficits on athletic/ physically active participants. We sought to compare the long-term follow-up on two timeframes up to 2 years and > 2 years post-ACLR.

MATERIALS AND METHODS

This systematic review was reported as per the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.

Search Strategy

The review question "*What is the effect of BPTB and HT autograft on pain, knee laxity, ROM, isokinetic strength, graft re-rupture rate, RTS and functional scales after ACL reconstruction?*" was made using the PICO format. The following databases were searched: PubMed, Scopus, WoS (Web of Science), PEDRo (Physiotherapy evidence database), and Google Scholar as shown in **table I**. A combination of search words was framed within 4 major groups: ACL Reconstruction, BPTB, HT, and RTS. The following key terms were used in each category: ("ACL Reconstruction" OR "ACL Repair" OR "Anterior Cruciate Ligament Reconstruction" OR "Anterior Cruciate Ligament Repair" OR "ACL tear") AND ("Bone-Patellar-Tendon-Bone" OR "BPTB" OR "BTB" OR "QT" OR "Patellar Tendon graft") AND ("Hamstring Tendon graft" OR "HT graft" OR "STG graft" OR "Semitendinosus-Gracilis graft" OR "ST graft" OR "Semitendinosus graft" OR "Double-bundle Hamstring" OR "four-strand Hamstring" OR "Double-bundle ST graft" OR "DB Hamstring" OR "DB ST graft" OR "DB STG graft" OR "Double-strand ST graft" OR "Quadrupled HT graft") AND ("Return to sport" OR "RTS" OR "Return to play" OR "RTP" OR "Return to pre-injury level" OR "Resumption to sport"). The term ("autograft" OR "ipsilateral") were also used to exclude trials with participants who underwent allograft or graft from contralateral side surgery. The search targeted studies with the key terms in their titles or abstracts with English language restrictions. Adjustments were made according to each database.

Eligibility Criteria

To develop the targeted question for this study, the PICOS acronym was utilised. The structured PICOS format was detailed as follows:

P (Population): Athletes, recreationally active, physically active, and healthy individuals were included, within the

Table I. Search Strategy Key Words.

Search term	Article found in the database of PubMed, Scopus, WoS, PEDRo, and Google Scholar
ACLR	27,356
ACLR AND BPTB	1,262
ACLR AND HT	2,079
ACLR AND BPTB AND HT	789
ACLR AND RTS	1,350
ACLR AND autograft	5,581
ACLR OR BPTB OR HT AND autograft AND RTS	14,088

Table II. Criteria for included studies.

Inclusion criteria	Exclusion criteria
Randomized controlled trials.	Study on animal model.
Studies examining effect of surgical treatment with BPTB or 4-strand HT autograft of ipsilateral side.	Study having follow-up period of less than 1 year.
Studies in which study population have primary ACL injuries.	Allograft or contralateral side graft is used.
Peer-reviewed articles from specified database.	Studies in which patients have significant associated other ligament injury and are undergoing multi-ligament surgery (MCL, PCL, LCL).
English language accessible text articles.	Cross-sectional or case studies.
	Studies with PEDRo score < 5.
	Studies in which athletes are undergoing revision ACL reconstruction.
	Skeletally immature patients (under 12 years of age).
	Grey literature (*e.g.*, abstracts, conference proceedings and editorials).

age group of 12- 53 years, and without any restriction on sex and ethnicity as described in **table II**.

I (Intervention): Physiotherapy intervention after ACLR (Bone-patellar-tendon-bone autograft and 4-strand Hamstring tendon autograft).

C (Comparison): Physiotherapy intervention after ACLR (4-strand Hamstring tendon autograft).

O (Outcomes): Pain measured using VAS (1-100); Laxity measured using KT-1000 (side-to-side laxity), Lachman test, and Pivot-shift test; Functional scales using Tegner score (1-100 score) and single-leg hop test (SLH); RTS (pre-injury level and compromised level), ROM deficit (up to 5mm); Isokinetic strength deficit; graft re-rupture rate.

S (Study design): Only Randomized studies were included in the present review. RCT occupies a high level in the hierarchy of evidence. Case reports, case series, literature reviews, and uncontrolled trials were not included, nor were animal-based or ongoing studies. The search was performed with English language restrictions.

Exclusion Criteria

The criteria for exclusion were non-randomized studies, animal studies, the availability of only conference papers or abstracts, and studies with subjects with a history of hip osteoarthritis or knee osteoarthritis, previous fractures, hip surgery, or spinal surgery, total hip arthroplasty, acute trauma, systemic, inflammatory, or infective diseases, neurological diseases, neoplasm, *etc*.

Data Extraction

Five researchers (ID, NA JK, SS, RKS) independently extracted data from selected studies. The extracted data included author, year of publication, research design; the number of participants in each group; characteristics of participants; intervention provided; follow-up period; outcomes, and conclusions. A sixth researcher (SS) confirmed the extracted data and resolved any discrepancies between the initial five researchers who performed the data extraction. The finalized information was summarized in a table and reviewed in a group discussion.

Operational definitions

Included studies collected data on the following outcomes Pain (VAS), Knee joint laxity (KT-1000, Lachman test, Pivot-shift test), RTS (pre-injury level or compromised level), Graft re-rupture rate, Functional scales (Tegner scale, Single-leg hop test), ROM deficits (Flexion and extension deficit up to 5°) and Isokinetic strength deficits (Flexors and Extensors at 60° and > 60°) up to 2 years and > 2-year post-ACLR.

The visual analogue scale (VAS) is a psychometric response scale to measure subjective characteristics of anterior knee pain administered by the participant itself. In this review, the VAS was measured by 2 methods. Firstly, extreme limits to be measured from 0 (no pain at all) to 100 (worst pain possible) or 0 scores (worst possible) to 100 score (Normal) (34, 45) or having subjective anterior knee pain if they register pain during stair-walking, sitting with 90° knee flexion and during or after activity (46-49). The participant marks on the line the point that they perceive as pain perception. The score is determined by measuring the point from 0 that the participant marks.

KT-1000 knee arthrometer is an objective laxity measuring instrument (MEDmetric Corp., San Diego, California) used

to measure anterior tibial motion relative to femur pre and post-operatively. It was measured with participants placed supine lying with the testing knee in 30° flexion and heel in a shallow rubber cup on the plinth. The arthrometer unit is placed on the anterior tibia and secured with 2 velcro straps around the calf. Two pads are located on top of the device, the first sensor pad is positioned on the patella and the second TTA pad is on the anterior tibial tuberosity. Then arthrometer handle applied a force on the tibia usually of 67N (47), 89N (48, 50), and 134N (47, 50-52), and alternatively maximal manual force (50-53) is used and the injured and non-injured legs compared for side-to-side measurement. Tibial translation (to nearest 0.5 mm) was measured by the change in relative alignment of 2 pads placed. The test cycle was repeated until 3 successive tests indicated the same excursion (within 1 mm) (50). The mean value difference in displacement between both legs was recorded. Mean displacement of ≥ 3mm for 89N and manual maximal manual force are diagnostic for ACL tear whereas a 2-2.5 mm difference is equivocal laxity.

The Manual Lachman test is a specific clinical exam technique used to evaluate a patient with laxity by evaluating the anterior translation of the tibia with the femur. The Lachman test was measured with the participant positioned supine with an injured knee in 20-30° flexion while slightly externally rotating the injured leg. The examiner uses one hand to stabilize the distal femur while using the other hand to grasp the proximal tibia in an attempt to sublux-ate the tibia forward. The anterior translation is measured and compared with the opposite leg. It was graded based on translation as 0 (Normal), 1+ (Mild) (0-5 mm), 2+ (Moderate) (6-10 mm) and 3+ (Severe) (11-15 mm) (45, 46, 49-51).

The pivot-shift test is a dynamic but passive test for measuring knee laxity. It is administered with the participant lying supine with legs relaxed and the examiner grasping the heel of the involved leg with the opposite hand placed laterally on the proximal tibia just distal to the knee. The examiner then applies valgus stress and axial load while internally rotating the tibia as the knee is moved into flexion from the fully extended position. Graded on displacement as 0 (3 mm), 1+ (5 mm), 2+ 10 mm), 3+ (15 mm) (34, 45, 50-52, 54).

The Tegner activity scale was first described in 1985 and initially designed by a physician for administration after ACL and meniscal injuries. Tegner activity score has been a frequently used self-administered activity rating system. The Tegner activity scale graded activity based on work and sports activities on a scale of 0 to 10. Zero represents disability because of ACLR and 10 represents the ability to participate in national/international level competitive participation like soccer (55). Score was compared with contralateral side (34, 45, 46, 48, 51-53).

The SLH was performed three times with each leg, hopping and landing on the same leg with the hands behind the back. The best of three distances for the injured leg and the uninjured legs were used. Distance covered < 150 cm is diagnostic of an ACL tear. Reference normative value is 177 cm (45, 46, 48, 52, 56).

ROM deficit was measured to the nearest 5° by a long-arm goniometer (47-49, 51,52) in comparison with the contralateral limb. In some studies, extension deficits were recorded by having participants prone to lying as described by Sachs (23). In this technique, the difference in heel height is converted to extension deficit in degrees by using a formula based on heel difference and participant height (47-49, 51, 52).

Isokinetic strength deficit was measured with Cybex dynamometer (47, 51) and Biodex machine (52). Measurements were made at 60°/s, 180°/s, and 240°/s speeds for peak isokinetic torque of the quadriceps and hamstring muscle group. Deficits were recorded relative to the contralateral limb (47, 51). Graft re-rupture rate determines the number of participants who had their graft ruptured due to a traumatic or atraumatic event (47, 49, 51, 57). RTS means the athlete has returned to the sport at pre-injury level or compromised level not before 6 months post-ACLR. The decision of RTS was made by both surgeon and physiotherapist (47, 49, 51, 57).

Methodological Quality Assessment

A quality assessment was performed independently by five researchers (ID, NA, JK, SS, RKS) using PEDro scale (58). The PEDro scale is an 11-item rating scale that can be used to determine the external and internal validity of a clinical trial or group comparison study. Criterion 1 on the scale relates to external validity and is not counted in the final methodological quality rating score which is out of 10. Criterion 2-9 assesses internal validity and addresses biases before the treatment phase (random allocation, concealed allocation, and groups being statistically similar at baseline) performance biases during treatment (blinding of participants, therapists, and assessors), and biases at data analysis (drop-out rates and intention to treat analysis). Criterions 10 and 11 assess the interpretability of the findings by looking at group statistical comparisons and the reporting of point estimates and measures of variability. PEDro score of 0-3 considered "poor", 4-5 score is considered "fair", 6-8 score as "good" and 9-10 score is

considered "excellent". The evidence strength was initially rated by five independent researchers (ID, NA, JK, SS, RKS, who filled in the PEDro table. A sixth researcher (SS) then reviewed and compared the three tables. Discrepancies were resolved in a group discussion, with professional statistical advice.

Quantitative Synthesis

For the meta-analysis, we used the Review Manager software (version 5.3) The Nordic Cochrane Centre, Copenhagen, Denmark) to perform the quantitative analysis. The analysis was carried out on seven outcome measures: 1) pain score; 2) laxity measured by KT-1000, Lachman test, and Pivot-shift test; 3) RTS; 4) graft re-rupture rate; 5) Functional scale measured by Tegner score and single-leg hop test; 6) ROM deficits and 7) isokinetic strength deficit. All the outcome measures in this analysis were continuous in terms of measurement. Therefore, standardized mean difference (SMD) and 95% confidence interval (CI) were calculated using the extracted data to compare effect sizes. A random-effect model was chosen based on the different characteristics of the included studies because the study results came from different population sizes and estimates of effect sizes. Statistical heterogeneity was calculated using the Higgins I^2 test. Higgins I^2 values were categorized as low, moderate, and high with values of 25%, 50%, and > 50%, respectively. The level of significance was set at $p<0.05$. To analyse the publication bias of the articles included in the systematic review and meta-analysis, we utilised the Cochrane risk of bias tool for randomised trials and crossover trials. We chose 6 questions from 5 domains (performance, selection, attrition, reporting, and detection) and 1 from the other bias source.

RESULTS

Flow of study selection

The search strategy used in databases is shown below. Results are outlined in **table III**. After searching 5 electronic databases, a total of 681 publications were retrieved. After the removal of 74 duplicates, 607 papers were screened by titles and abstracts. A total of 460 papers were excluded because they 1) were not focused on post-ACL Reconstruction; 2) were not specifically related to single-strand BPTB or four-strand HT autograft; 3) were not focused on physical therapy outcomes; 4) were not focused on the ipsilateral side of graft; 4) had study designs that did not fit the inclusion criteria. The full texts of the remaining 147 studies were assessed for eligibility. 130 studies were subsequent-

Table III. Advanced search strategy.

	Search strategy
#1	Search ACL Reconstruction OR ACL Repair OR Anterior Cruciate Ligament Reconstrution OR Anterior Cruciate Ligament Repair OR ACL tear OR Anterior Cruciate Ligament Tear OR "anterior cruciate ligament reconstruction"[MeSH Terms]
#2	Search Bone-Patellar Tendon-Bone OR BPTB OR BTB OR QT OR Patellar Tendon graft OR "bone-patellar tendon-bone grafts"[MeSH Terms]
#3	Search Hamstring Tendon graft OR HT graft OR STG graft OR Semitendinosus-Gracilis graft OR ST graft OR Semitendinosus graft OR Double-bundle Hamstring OR Four-strand Hamstring OR Double-bundle ST graft OR DB Hamstring OR DB ST graft OR DB STG graft OR Double-strand ST graft OR Quadrupled HT graft
#4	Search #1 OR #2 OR #3
#5	Search autograft OR ipsilateral OR skeletally mature athletes OR "athletes"[MeSH Terms]
#6	Search Return to sport OR RTS OR Return to play OR RTP OR Return to pre-injury level OR Resumption to sport OR "return to sport"[MeSH Terms]
#7	Search Pain OR Strength OR isokinetic strength OR Laxity OR Instability OR Graft failure OR "pain"[MeSH Terms] OR "joint instability"[MeSH Terms]
#8	Search medline/ pubmed OR web of science OR WOS OR science direct
#9	Search randomized controlled trial OR RCT OR Randomly OR Randomized OR clinical trial
#10	Search #8 OR #9
#11	Search #4 AND #5 AND #6 AND #7 AND #10

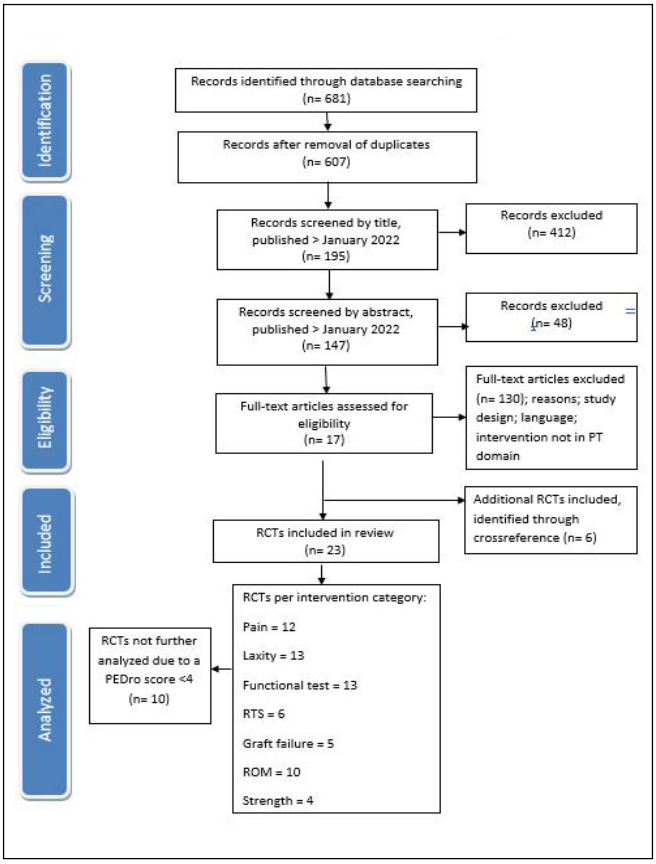


Figure 1. PRISMA Flowchart.

ly excluded after full-text review, and 17 RCTs were finally included for review with additional 6 studies via a cross-reference. The reason for the exclusion of studies is mentioned in the PRISMA flow chart in **figure 1** and PRISMA checklist is attached as **figure 2**.

Characteristics of selected studies

A total of 13 RCTs met all the criteria and were ultimately included as sources of data for the present systematic review. Studies included involved 1,190 participants according to eligibility criteria. The characteristics of included studies are summarized in **tables IV** and **V**.

Intervention

We included studies having surgical reconstruction of ACL tear as a procedure with either BPTB autograft or 4-strand HT autograft from the ipsilateral side. All studies have used almost similar rehabilitation protocols for both groups. The early motion was instituted from the day of surgery (46-48, 50, 54, 57) as tolerance progressed from passive to the active motion of operated knee following "accelerated rehabilitation after ACLR" (58). All the rehabilitation program focus was on gaining good quadriceps strength through isometric exercises, early ROM, and patellar mobilization from the day of surgery. Closed chain strengthening, static cycling, and squats were allowed only after 2 weeks (46, 54, 56, 59). Proprioception exercises were emphasized after 4 weeks (49, 57). After 6 weeks of surgery, agility training and light jogging were permitted, and only after 10 weeks, increased agility workouts, and maximum strength training was permitted (56). Participants were allowed full weight-bearing in a hinged brace for 3 weeks (34) whereas some allowed immediate weight-bearing without a brace (46-48, 56, 59). Return to running was allowed at approximately 2 months (49, 50, 53, 54), and pivoting activities were recommended at 3-4 months post-operative (53, 54, 59). Time to return to sports participation varied among studies depending on functional testing, and physician and therapist clearance but none were allowed sooner than six months after surgery.

Quality assessment

The strength of the body of evidence was evaluated using PEDro score (**table VI**). Studies having PEDro score of ≥ 5 are included.

Risk of bias across outcomes and within studies

The results of the Cochrane risk of bias tool and the PEDro score are shown in **tables VI** and **VII** and **figure 2**. The mean score for PEDro scale was 6 out of 10 (range 5-7). The common shortcomings in methodological assessments were inadequate concealed treatment allocation (n = 9) (34, 47, 49, 50-54, 56), lack of participant and assessor blinding (n = 13) (34, 45-54, 56, 57). 13 studies reported randomization and drop-out rate (34, 45-54, 56, 57).

VAS: 11 studies evaluated the VAS for assessment of anterior knee pain. 3 studies had a low risk of bias (46, 56, 57), 3 studies had a moderate risk of bias (47, 48, 51) and 5 studies had a high risk of bias (45, 49, 50, 52, 54).

KT-1000: 9 studies evaluated the KT-1000 for assessment of laxity. 3 studies had a low risk of bias (46,56,57), 3 studies had a moderate risk of bias (47, 48, 51) and 3 studies had a high risk of bias (50, 52, 53).

Lachman test: 5 studies evaluated the Lachman test for assessment of laxity. 1 study had a low risk of bias (46), 1 study had a moderate risk of bias (51) and 3 studies had a high risk of bias (45, 49, 50).

Pivot-shift test: 7 studies evaluated the Pivot-shift test for assessment of laxity. 1 study had a moderate risk of bias (51)

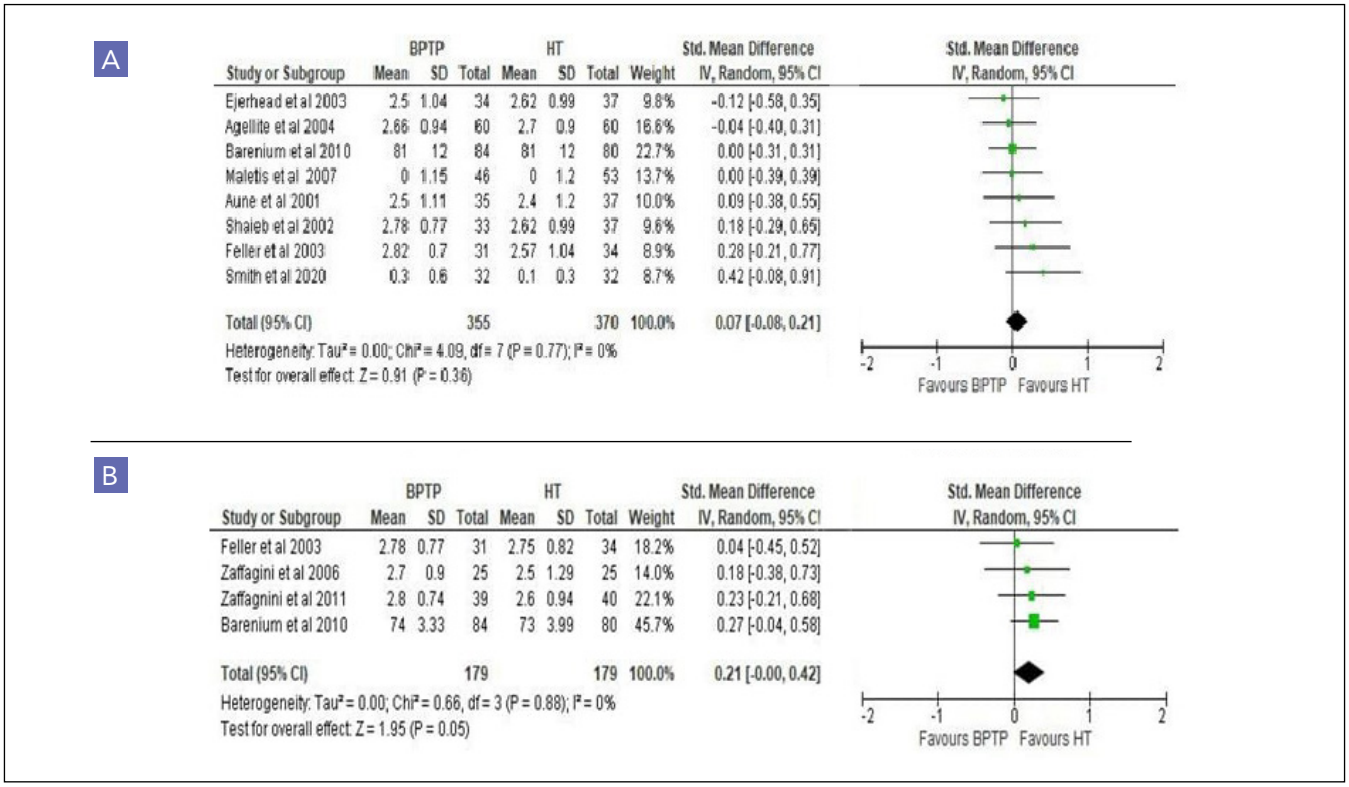


Figure 2. (A) Forest plot of effect of BPTB and HT autograft for VAS at 2-year follow-up post ACLR; **(B)** Forest plot of effect of BPTB and HT autograft for VAS > 2-year follow-up post ACLR.

and 6 studies had a high risk of bias (34, 45, 49, 50, 52, 54).
RTS: 4 studies evaluated the RTS. 1 study had a low risk of bias (57), 2 studies have a moderate risk of bias (47, 51) and 1 study had a high risk of bias (49).
Graft re-rupture rate: 5 studies evaluated the graft re-rupture rate. 2 studies had a low risk of bias (56, 57) and 3 studies had a high risk of bias (34, 50, 54).
Tegner scale: 5 studies evaluated the Tegner scale. 1 study had a low risk of bias (46), 1 study had a moderate risk of bias (48) and 3 studies had a high risk of bias (45, 52, 53).
SLH: 6 studies evaluated the SLH. 2 studies had a low risk of bias (46, 56), 1 study had a moderate risk of bias (48) and 3 studies had a high risk of bias (34, 45, 52).
ROM deficit: 9 studies evaluated the ROM deficit for flexion and extension. 1 study had a low risk of bias (46), 3 studies had a moderate risk of bias (47, 48, 51) and 5 studies had a high risk of bias (34, 45, 49, 52, 54).
Iso-kinetic deficit: 4 studies evaluated the Iso-kinetic deficit for flexor and extensor groups of muscles. 2 studies had a low risk of bias (46, 56), 1 study have a moderate risk of bias (51) and 1 study had a high risk of bias (52).

Qualitative summary of strength of evidence

The paucity of data is available to describe the prognosis post-ACLR for athletes and physically active participants. Three studies with a low risk of bias (45, 50, 54), three studies with moderate risk of bias (47, 48, 51), and seven studies with a high risk of bias (34, 45, 49, 50, 52-54) were included in this systematic review. Therefore, studies with a low risk of bias were used to obtain the best evidence. Neither, the surgical procedure, graft type nor the rehabilitation was the same in these three studies. Ejerhed *et al.* (46) used arthroscopic transtibial surgical technique for BPTB autograft, used ST graft for HT autograft, and tensioning both the grafts with firm traction with the knee in hyperextension. Smith *et al.* (57) used ST graft with AIST surgical technique and 25 knee cycle with the knee in extension for graft tensioning for HT autograft, and surgical technique for BPTB autograft was not reported: with tensioning graft in full extension of the knee. Aune *et al.* (56) did not report a surgical technique for both the groups but used ST plus G graft for HT autograft and performed knee cycles with 89N force at 0° flexion for graft tension-

Table IV. Summary of included studies.

Author (year)	Study design	Participants details	Type of surgery	Follow-up	Outcome measurement tools	Conclusions
Smith *et al.*, 2020 (57)	RCT	N = 64 Age = 13-24 years M = 28 F = 36 EG = 32 CG = 32 Athlete	BPTB HT (4 strand)	1 and 2 year	VAS (anterior knee pain) Laxity (KT-1000) Functional test (IKDC-2000) RTS Graft rupture	At 2-year follow-up, no statistical difference existed between variables.
Zaffagnini *et al*, 2011 (54)	RCT	N = 79 Age = 26 and 27 (mean) M = 42 F = 37 EG = 40 CG = 39 Athlete and healthy	BPTB HT (4 strand)	8 year	VAS (anterior knee pain) Laxity (pivot-shift test) Functional test (Tegner score, IKDC-2000) ROM Graft rupture	2B HT group showed significantly higher Tegner level, higher passive range of motion recovery, faster RTS, lower pivot-shift phenomenon and lower objective degenerative changes on radiographs compared with BPTB group.
Barenius *et al*, 2010 (45)	RCT	N = 153 Age = 15-45 year M = 89 F = 64 EG = 75 CG = 78 Athlete	BPTB HT (4 strand)	8 year	VAS (anterior knee pain) Laxity (Lachman test, Pivot-shift test) Functional test (Lysholm score, Tegner score, Single-leg hop, IKDC-2000) ROM	No significant difference found between BPTB and HT group.
Volpi *et al.*, 2010 (53)	RCT	N =40 Age = 18-45 year M = 32 F = 8 EG = 20 CG=20 Athlete	BPTB HT (4 strand)	2 year	Laxity (KT-1000) Functional test (Lysholm score, Tegner score, IKDC-2000) RTS	No significant difference regarding the post-operative Lysholm score, Tegner activity scale and the KT-1000 have been observed.HT group were able to return to sports at a pre-injury level.
Maletis *et al.*, 2007 (52)	RCT	N = 99 Age = 14-48 year M = 76 F = 23 EG = 53 CG = 46 Healthy	BPTB HT (4 strand)	1 and 2 year	VAS (Kneeling pain) Laxity (KT-1000, Pivot-shift test) Functional test (Lysholm score, Tegner score, Single-leg hop, IKDC-2000) ROM Isokinetic strength	No differences in IKDC, Lysholm score, Tegner activity level, ROM, single-legged hop test, KT-1000 were found. The BPTB group had better flexion strength and a greater number of patients returning to preinjury Tegner level.

Author (year)	Study design	Participants details	Type of surgery	Follow-up	Outcome measurement tools	Conclusions
Zaffagnini *et al.*, 2006 (49)	RCT	N = 75 Age = 15-49 year M = 49 F = 26 EG = 25 CG = 25 Athlete	BPTB (N = 25) HT (4 strand) (N = 25) HT (2 strand) (N = 25)	5 year	VAS (anterior knee pain and Kneeling pain) Laxity (Lachman test, Pivot-shift test) Functional test (Tegner score, IKDC-2000) RTS ROM	The study shows that BPTB and HT can be equivalent options for ACL reconstruction.
Laxdal *et al*, 2005 (48)	RCT	N=118 Age = 12-52 M = 79 F = 39	BPTB (N = 40) HT (4 strand) (N = 39) HT (3 strand) (N = 39)	2 year	VAS (anterior knee pain) Laxity (KT-1000) Functional test (Lysholm score, Tegner score, Single-leg hop, IKDC-2000) ROM	No significant differences found after two years of ACL reconstruction.
Aglietti *et al.*, 2004 (61)	RCT	N = 120 Age = 16-39 year M = 92 F = 28 EG = 60 CG = 60 Athlete and Healthy	BPTB HT (4 strand)	1 and 2 year	VAS (anterior knee pain and Kneeling pain) Laxity (KT-1000, Lachman test, Pivot-shift test) Functional test (IKDC-2000) RTS ROM Isokinetic strength	No significant differences found after two years of ACL reconstruction.
Ejerhed *et al.*, 2003 (46)	RCT	N = 71 Age = 14- 49 Year M = 46 F = 20 EG = 37 CG = 34	BPTB HT (4/3 strand)	2 year	VAS (anterior knee pain) Laxity (KT-1000, Lachman test) Functional test (Lysholm score, Tegner score, Single-leg hop, IKDC-2000) ROM Isokinetic strength	At the 2-year follow-up, no differences were found in terms of the Lysholm score, Tegner activity level, KT-1000, single-legged hop test, or IKDC results.

Author (year)	Study design	Participants details	Type of surgery	Follow-up	Outcome measurement tools	Conclusions
Feller *et al.*, 2003 (47)	RCT	N = 65 Age = 18-40 year M = 47 F = 18 EG = 34 CG = 31 Healthy	BPTB HT (4 strand)	1, 2 and 3 year	VAS (anterior knee pain and Kneeling pain) Laxity (KT-1000) Functional test (IKDC-2000) RTS ROM Isokinetic strength	Pain on kneeling and extension deficits were greater in the BPTB group.
Shaieb *et al.*, 2002 (50)	RCT	N = 70 Age = 14-53 year M = 47 F = 23 EG = 37 CG = 33 Athlete	BPTB HT (4 strand)	2 year	VAS (anterior knee pain) Laxity (KT-1000, Lachman test, Pivot-shift test) Functional test (Lysholm score) RTS ROM Graft rupture	HT grafts performed similarly to BPTB grafts, although fewer patients in the HT group had patellofemoral pain and loss of motion.
Aune *et al.*, 2001 (56)	RCT	N = 72 Age = 15-50 year M = 40 F = 32 EG = 37 CG = 35	BPTB HT (4 strand)	1 and 2 year	VAS (anterior knee pain and Kneeling pain) Laxity (KT-1000) Functional test (Single leg hop test, IKDC-2000) Graft rupture	No differences were found between the groups with respect to KT-1000 results, single-legged hop test, extension strength and anterior knee pain.
Eriksson *et al.*, 2001 (34)		N = 164 Age = 15-45 year M = 96 F = 68 EG = 80 CG = 84 Athlete and healthy	BPTB HT (4 strand)	31 months	VAS (anterior knee pain) Laxity (Lachman test, Pivot-shift test) Functional test (Lysholm score, Tegner score, Single-leg hop test) ROM Graft rupture	No significant differences were found between the groups regarding the Single-leg hop test, Tegner activity level, Lysholm score, patellofemoral pain score, IKDC score.

BPTB: Bone-Patellar-Tendon bone; HT: Hamstring tendon, RCT: Randomized controlled trial; EG: Experimental group; CG: Control group, M: Male; F: Female, VAS: Visual analog scale; IKDC: International knee documentation committee; ROM: Range of Motion; RTS: Return to Sport.

Table V. Surgical Techniques.

Author (year)	BPTB						HT					
	Surgical technique Incision site (length)	Incision site (length	Graft fixation		Tensioning of graft	Defect filling	Surgical technique	Graft harvested	Incision site (length)	Graft fixation		Tensioning of graft
			Femoral end	Tibial end						Femoral end	Tensioning of graft	
Smith *et al.*, 2020 (57)	N.R	Longitudinal incision	Biocomposite interference screw (23*7 mm)	Biocomposite interference screw (23*10 mm)	In full extension	Bone grafting	AIST	ST	Posterior approach	Suspensory fixation	Tight rope ABS button	25 knee cycles with knee extension
Zaffagnini *et al.*,2011 (54)	LBPTB	Longitudinal incision	Interference screw (7-9mm)	Interference screw (7-9mm)	20 knee cycles and with maximum manual force at 20° flexion	N.R	N.R	ST+G	Lateral incision	2 staples	1 staple	20 knee cycles
Barenius *et al.*, 2010 (45)	Arthroscopic technique with notchplasty	Longitudinal incision (5cm) or 2 horizontal incision[b] (3cm)	Non-absorbable interference screw (20*7mm)	Non-absorbable interference screw (20*9mm)	10 knee cycle with manual force in knee extension	Not grafted	N.R	ST	Vertical incision (5cm)	Endobutton	Interference screw	10 knee cycles with manual force in knee extension
Volpi *et al.*,2010 (53)			2 re-absorbable pins	Tibial rigid fix and re-absorbable pins			Transtibial technique			pins	Metal staples or bioscrew	
Maletis *et al.*, 2007 (52)	Arthroscopic single incision technique	Longitudinal incision (6-7cm)	Poly L-lactide bioabsorbable interference screw (23*7 mm)	Poly L-lactide bioabsorbable interference screw (28*9 mm)	20 knee cycles with maximum manual force at 20° flexion and posterior drawer applied	Patellar defect only with autologous bone chips	Arthroscopic single incision technique	ST+G	Lateral incision (3cm)	Poly L-lactide bioabsorable interference screw	2 Poly L-lactide bioabsorable interference screw(20 and 17 mm)	20 knee cycles with maximum manual force at 20° flexion and posterior drawer applied
Zaffagnini *et al.*, 2006 (49)		Longitudinal incision	Metal interference screw (Smith and Nephew Endoscopy) (7-9mm)	Metal interference screw (Smith and Nephew Endoscopy) (7-9mm)	10 knee cycles with maximum manual force at 20° flexion	No grafting	N.R	ST+G	Medial incision on pes anserinus	Flipped endobutton	Polylactic absorable interference screw (Smith and Nephew Endoscopy, USA)	10 knee cycles with maximum manual force at 20° flexion
Laxdal *et al.*, 2005 (48)	Arthroscopic transtibial technique	Longitudinal incision (6-8cm)	Acufex silk interference screw (7mm)	Acufex silk interference screw (9mm)	Knee hyperextension	No grafting	N.R	ST+G	Oblique incision over pes anserinus (3cm)	RCI interference screw (Smith and Nephew)	RCI interference screw (Smith and Nephew)	Knee hyperextension

Author (year)	BPTB						HT					
	Surgical technique Incision site (length)	Incision site (length	Graft fixation		Tensioning of graft	Defect filling	Surgical technique	Graft harvested	Incision site (length)	Graft fixation		Tensioning of graft
			Femoral end	Tibial end						Femoral end	Tensioning of graft	
Aglietti *et al.*, 2004 (61)	Transcondylar screw fixation	Longitudinal incision (8cm)	Transcondylar screw fixation (Tunneloc screw)	Soft Silck cannulated screw	10 knee cycle with 20N force in knee extension	autologous bone chips	Endoscopic fixation of double-looped STG	ST+G	Vertical incision (3-4cm)	Bone mulch screw	WasherLoc device	10 knee cycle with 20N force in knee extension
Ejerhed *et al.*, 2003 (46)	Arthroscopic transtibial technique	2 Longitudinal incisions (2.5cm each)[a]	Acufex silk interference screw (7mm)	Acufex silk interference screw (9mm)	Firm traction with knee in hyperextension	Not grafted	N.R	ST	Oblique incision over pes anserinus (3cm)	RCI interference screw (Smith and Nephew) (7mm)	RCI interference screw (Smith and Nephew) (7mm)	Firm traction with knee in hyperextension
Feller *et al.*, 2003 (47)	Arthroscopically assisted single-incision ACLR	Longitudinal incision	EndoButton (Smith and Nephew Endoscopy) attached with doubled 3mm polyester tape	Cannulated metallic interference silk screw (Smith and Nephew Endoscopy)	Pre-tensioning-89N Further tensioning-manual force at 70° flexion	Tibial tubercle defect only with Autologus bone chip	Arthroscopically assisted single-incision ACLR	ST+G	Oblique antero-medial incision	EndoButton (Smith and Nephew Endoscopy) attached with doubled 3mm polyester tape	Acufex fixation post (Smith and Nephew Endoscopy)	Pre-tensioning-89N Further tensioning-manual force at 70° flexion
Shaieb *et al.*, 2002 (50)	Single-incision technique with a notchplasty	Longitudinal incision	Cannulated, noncutting, metallic interference screw (Smith and Nephew Endoscopy)	Tibial interference screw	N.R	No grafting	Single-incision technique with a notchplasty	ST+G	antero-medial incision (3cm)	Cannulated, noncutting, metallic interference screw (Smith and Nephew Endoscopy)	Tibial interference screw	N.R
Aune *et al.*, 2001 (56)	N.R	Longitudinal incision	Titanium femoral interference screw (25*7mm)	Tibial interference screw (25*7mm)	Knee cycled with 89N force at 0° flexion	N.R		ST+G	Vertical incision	Titanium endobutton	RCI interference screw and 2 barbed staples	Knee cycled with 89N force at 0° flexion
Eriksson *et al.*, 2001 (34)	Arthroscopic technique with notchplasty	Longitudinal incision (5cm) or 2 horizontal incisionb (3cm)	Non-absorable interference screw (20*7mm)	Non-absorable interference screw (20*9mm)	10 knee cycle with manual force in knee extension	Not grafted	N.R	ST	Vertical incision (5cm)	Endobutton	Interfernce screw	10 knee cycles with manual force in knee extension

N.R: Not Recorded; AIST: All inside quadrupled semitendinosus; LBPTB: Lateralized single:-bundle bone-patellar tendon-bone; naDBH: Non-anatomical autologous double-bundle hamstring technique; ST: Semitendinosus tendon; ST+G: Semitendinosus and Gracilis tendon; PT: Patellar tendon; Interference screw: It is a compression device that relies on the screw threads to engage and compress the graft for fixation; Biocomposite interference screw: has a stepped tapered design; Longitudinal incision: over Medial aspect of PT; Lateral incision: 5 cm below the medial joint line and 2 cm medial to tibial tubercle, a) One over apex of patella and other above tibial tubercle; leaving major part of paratenon intact b) One at distal pole of patella and other oblique incision over tibial tuberosity.

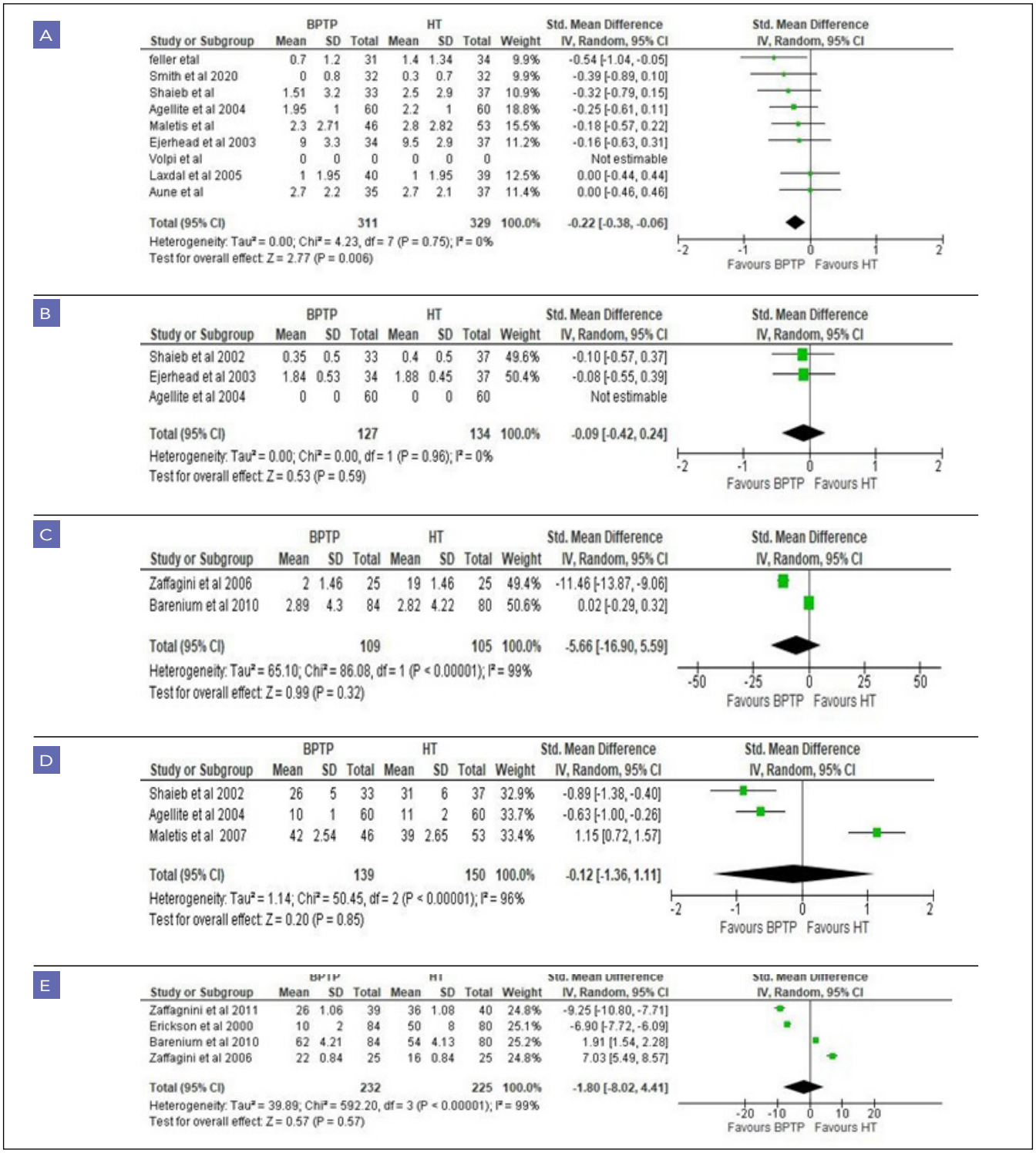


Figure 3. (A) Forest plot of effect of BPTB and HT autograft for KT-1000 at 2-year follow-up post ACLR; **(B)** Forest plot of effect of BPTB and HT autograft for Lachman test at 2-year follow-up post ACLR; **(C)** Forest plot of effect of BPTB and HT autograft for Lachman test > 2-year follow-up post ACLR; **(D)** Forest plot of effect of BPTB and HT autograft for Pivot-shift test at 2-year follow-up post ACLR; **(E)** Forest plot of effect of BPTB and HT autograft for Pivot-shift test > 2-year follow-up post ACLR.

ing. An early motion was initiated as tolerated (46,57) with immediate weight-bearing without a brace (46, 56). Aune *et al.* (56) allowed closed-chain exercises after 2 weeks and agility training only after 6 weeks of surgery. The above findings can be summarised in the form that arthroscopic transtibial surgical technique for BPTB autograft, ST graft for HT autograft with knee cycles performed in forced hyperextension for graft tensioning. Post-operative physiotherapy which is also important component of management emphasized graduated progression of exercises to functional training level with unprotected sports training drills starting at 6 weeks. The summary must be taken with caution as it has been synthesized from limited low-bias studies.

Meta-analysis

Quantitative analysis of pain

Eight studies used VAS to measure anterior knee pain (n = 725) up to 2 years (45-47, 50, 52, 56, 57, 59). The obtained result found non-significant result with SMD 0.07 (95%CI -0.08, 0.21); p = 0.36; I^2 = 0%) as shown in **figure 2A**. Four studies (n = 358) provided data for follow-up outcomes at > 2 years' post-ACLR (45, 47, 49, 54). The obtained results found significant result in favour of HT group SMD 0.21 (95%CI -0.00, 0.42); p = 0.05; I^2 = 0%) as shown in **figure 2B**.

Quantitative analysis of Laxity (KT-1000, Lachman test, and Pivot-shift test)

Nine studies (n = 640) pooled data for laxity up to 2-year follow-up post ACLR by KT-1000 (46-48, 50, 52, 53, 56, 57, 59). The obtained result found significant result in favour of BPTB group with SMD -0.22 (95% CI -0.38. -0.06) p = 0.006; I^2 = 0%) as shown in **figure 3A**. Three studies provided data for the Lachman test up to 2 years (n = 261) (46, 50, 59). The obtained result found non-significant findings between BPTB and HT group up to 2-year follow-up post ACLR with SMD -0.09 (95%CI -0.42, 0.24) p = 0.59; I^2 = 0%) as shown in **figure 3B**. Two studies compared the effect of BPTB and HT autograft for the Lachman test > 2 years' follow-up post-ACLR (n = 214) (45, 49). Overall effect was non-significant with SMD -5.66 (95%CI -16.90, 5.59) p = 0.32; I^2 = 99%) as shown in **figure 3C**. Three studies (n = 289) measured laxity with a pivot-shift test up to 2 years follow-up post-ACLR (50, 52, 59). The effect for BPTB *versus* HT autograft was found non-significant with SMD -0.12 (95CI -1.36, 1.11); p = 0.85; I^2 = 96%) as shown in **figure 3D**. Four studies analysed data for pivot-shift > 2 years follow-up post-ACLR (45, 46, 49, 54). Data synthesis found non-significant effect in between groups with SMD -1.80 (95%CI -8.02, 4.41); p = 0.57; I^2 = 99% as shown in **figure 3E**.

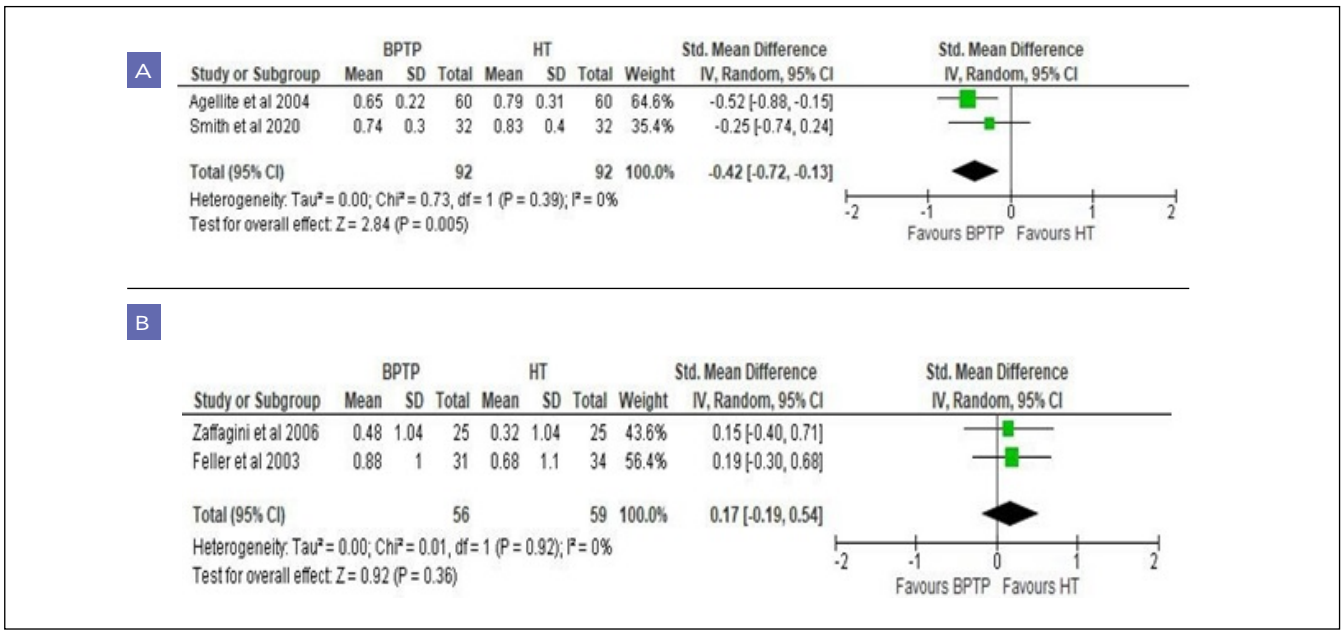


Figure 4. (A) Forest plot of effect of BPTB and HT autograft for RTS up to 2-year follow-up post ACLR; **(B)** Forest plot of effect of BPTB and HT autograft for RTS > 2-year follow-up post ACLR.

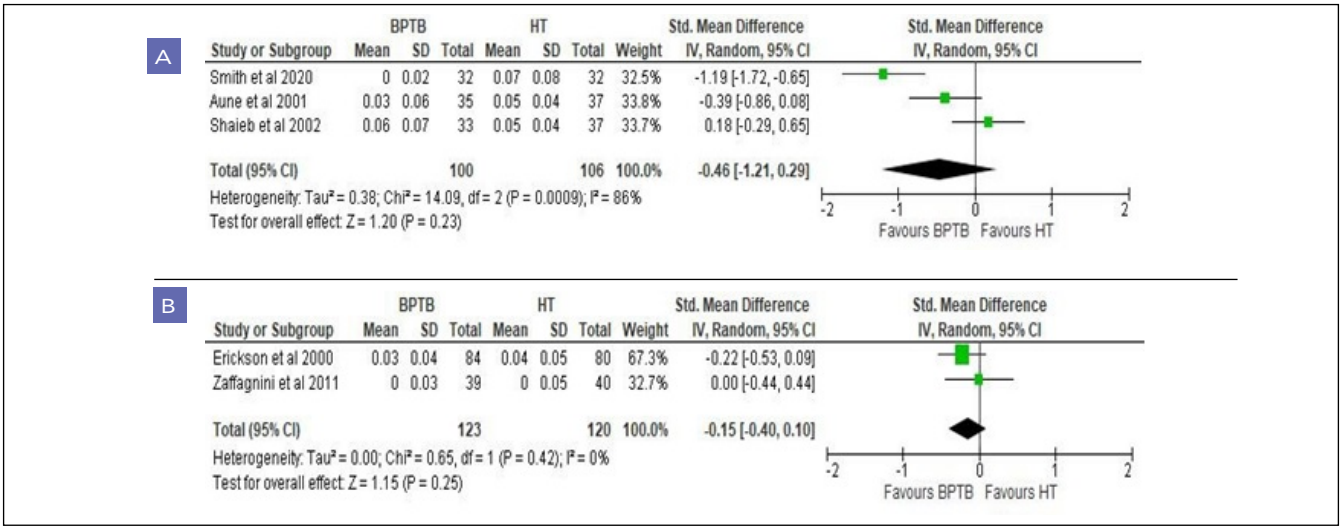


Figure 5. (A) Forest plot of effect of BPTB and HT autograft on graft re-rupture rate at 2-year post-ACLR; **(B)** Effect of BPTB and HT autograft on graft re-rupture rate > 2-year post-ACLR.

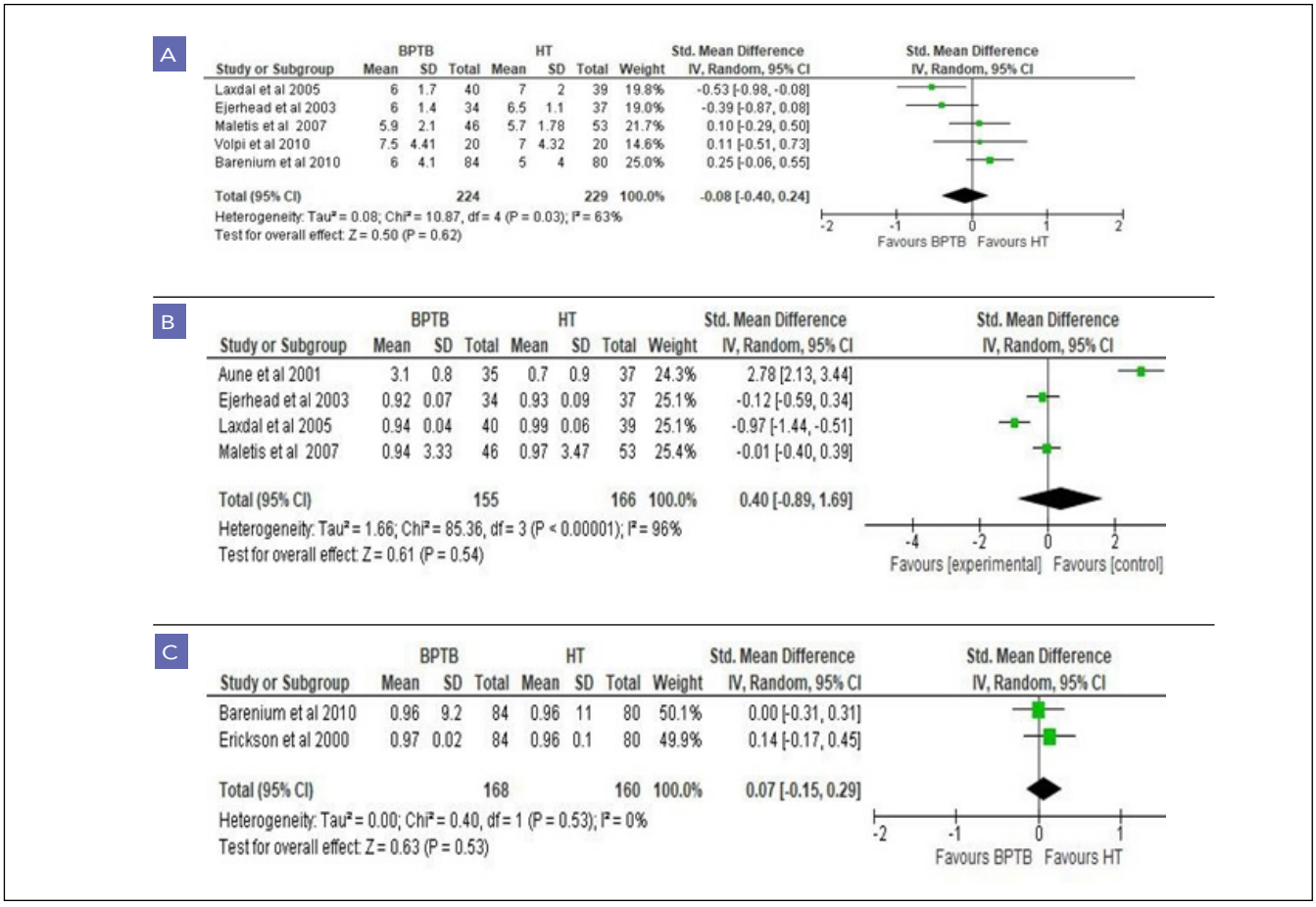


Figure 6. (A) Effect of BPTB and HT autograft on Tegner scale at 2-year post-ACLR; **(B)** Effect of BPTB and HT autograft on SLH test at 2-year post-ACLR; **(C)** Effect of BPTB and HT autograft on SLH > 2-year post-ACLR.

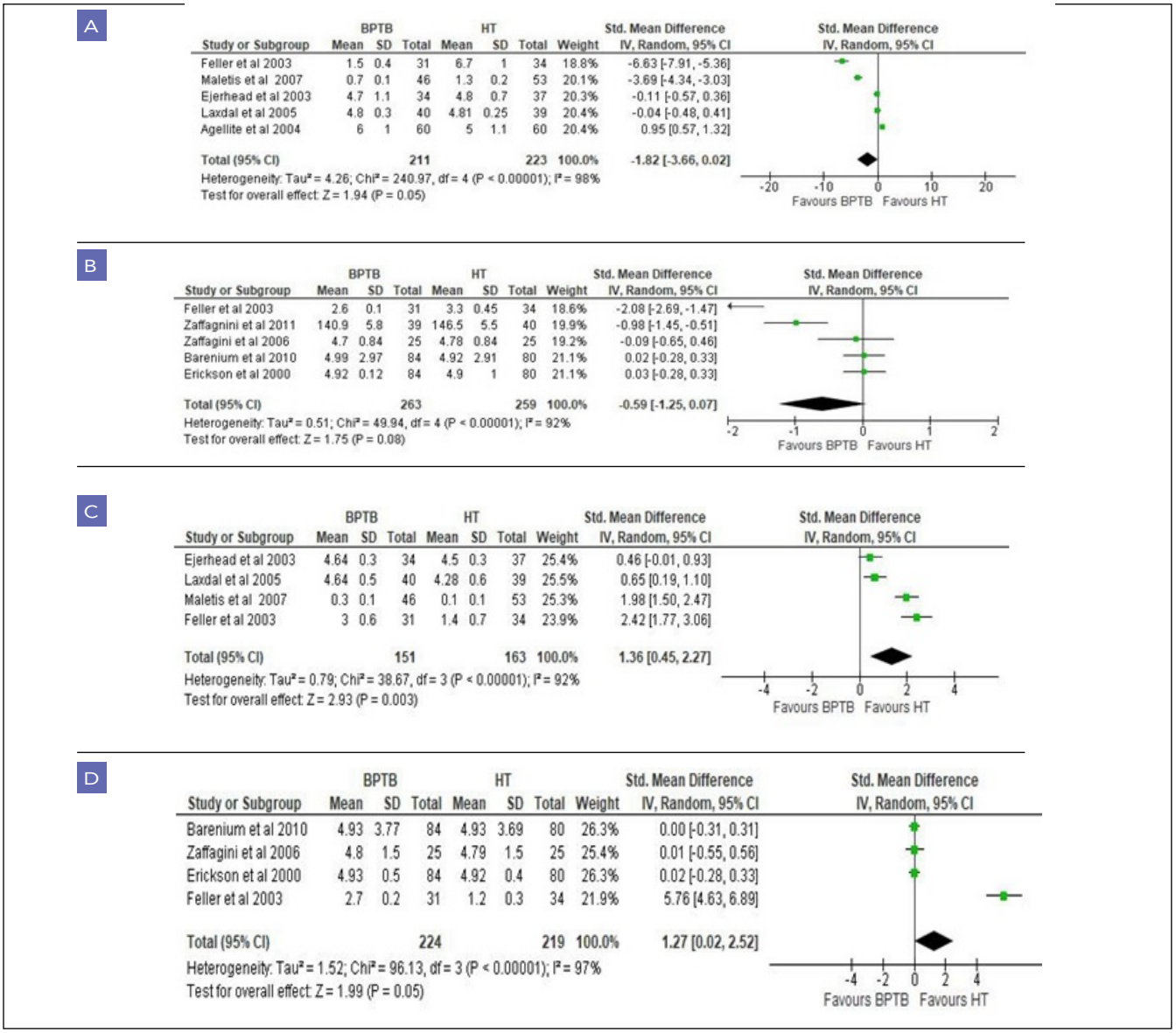


Figure 7. (A) Effect of BPTB and HT autograft on Flexion ROM deficit at 2-year post-ACLR; **(B)** Effect of BPTB and HT autograft on Flexion ROM deficit > 2-year post-ACLR; **(C)** Effect of BPTB and HT autograft on Extension ROM deficit ≤ 2-year post-ACLR; **(D)** Effect of BPTB and HT autograft on Extension ROM deficit > 2-year post-ACLR.

Quantitative analysis of RTS

Two studies pooled data for RTS up to 2 years follow-up post-ACLR for comparison of BPTB and HT autograft (n = 184) (57, 59). The obtained result found significant result in favour of BPTB group for up to 2 years with 42% more athletes returning to their sport with SMD -0.42 (95%CI -0.7, -0.13); p = 0.005; I^2 = 0%) as shown in **figure 4A**. Two studies compared RTS > 2 years follow-up post-ACLR (47 ,49). Overall effect was non-significant with SMD 0.17 (95%CI -0.19, 0.54); p= 0.36; I^2= 0%) as shown in **figure 4B**.

Quantitative analysis of graft re-rupture rate

Three studies analysed data for graft re-rupture rate up to 2 years follow-up post-ACLR for BPTB and HT autograft (n

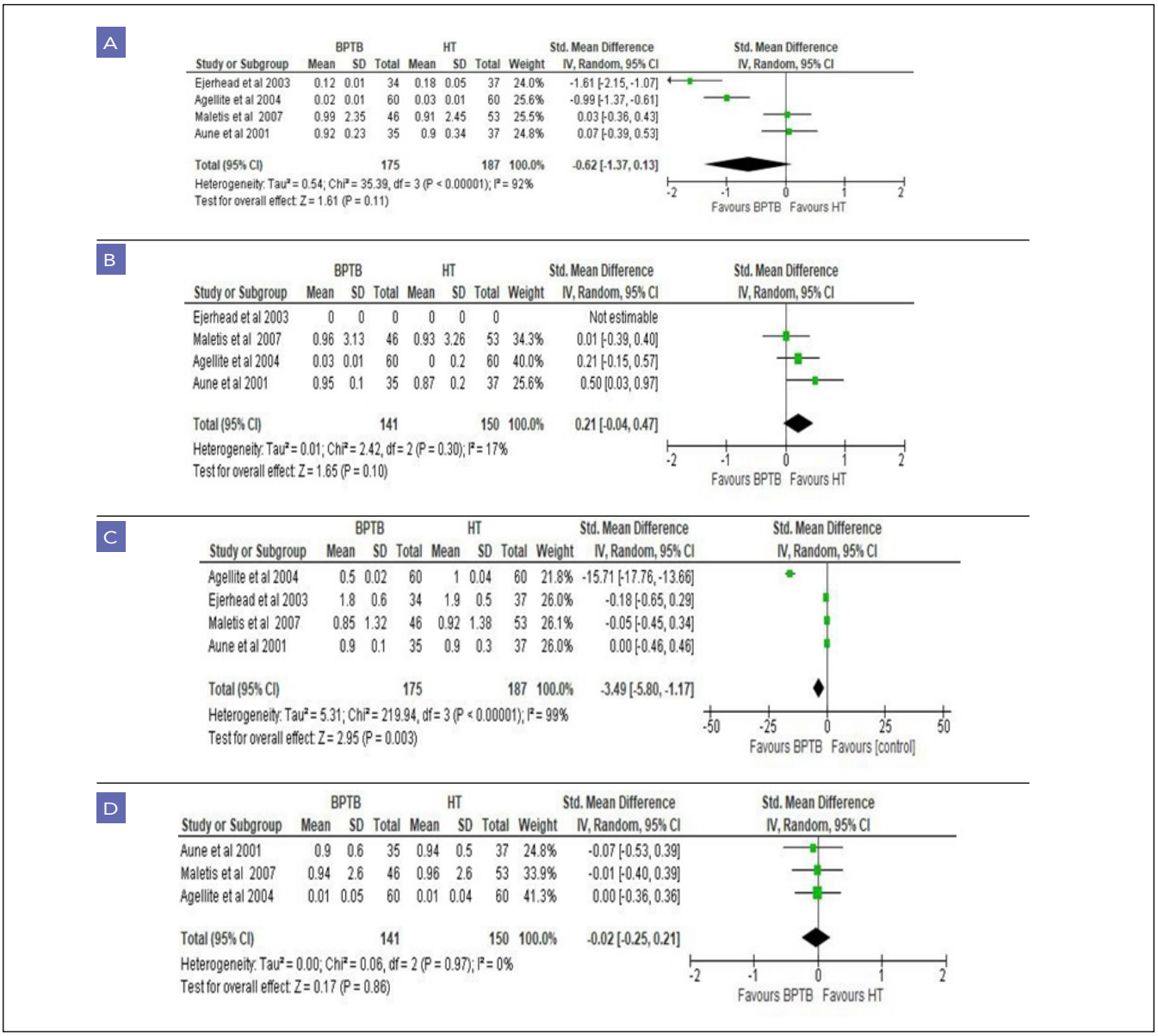


Figure 8. (A) Effect of BPTB and HT autograft on isokinetic flexion strength at 60° ≤ 2-year post-ACLR; **(B)** Effect of BPTB and HT autograft on isokinetic flexion strength > 60° at > 2-year post-ACLR; **(C)** Effect of BPTB and HT autograft on isokinetic extension strength at 60° ≤ 2-year post-ACLR; **(D)** Effect of BPTB and HT autograft on isokinetic extension strength >60° at ≤ 2-year post-ACLR.

= 206) (50-57). The cumulative overall effect was non-significant between the autografts with SMD -0.46 (95%CI -1.21, 0.29); p = 0.23; I^2 = 86%) as shown in **figure 5A**. Two studies (n = 243) compared graft re-rupture rate at > 2 years follow-up post-ACLR (34, 54) showing non-significant result with SMD -0.15 (95%CI -0.41, 0.10); p = 0.25; I^2 = 0% as shown in **figure 5B**.

Quantitative analysis of functional scales (Tegner score, SLH)

Five studies (n = 453) provided data on Tegner scale (45, 46, 48, 52, 53). Pooled data shows non-significant result for BPTB and HT autograft up to 2 years follow-up post-ACLR with SMD -0.08 (95%CI -0.40, 0.24); p = 0.62; I^2 = 63% as shown in **figure 6A**. Four studies (n = 321) analysed data

Table VI. PEDro score of selected articles.

Variable	Eligibility criteria	Randomized allocation	Concealed allocation	Comparable at baseline	Blinding of subjects	Blinding of therapist	Blinding of assessors	Adequate follow-up	Intention-to-treat analysis	Comparison between groups	Point estimates and variability	Total score
Smith *et al.*, 2020 (57)	+	+	+	+	-	-	-	+	-	+	+	6
Zaffagnini *et al.*, 2011 (54)	+	+	-	+	-	-	+	+	-	+	+	6
Barenius *et al.*, 2010 (45)	+	+	+	+	-	-	-	+	-	+	+	6
Volpi *et al.*, 2010 (53)	+	+	-	+	-	-	-	+	+	+	+	6
Maletis *et al.*, 2007 (52)	+	+	-	+	-	-	-	+	+	+	+	6
Zaffagnini *et al.*, 2006 (49)	+	+	-	+	-	-	+	+	+	+	+	7
Laxdal *et al.*, 2005 (48)	+	+	+	+	-	-	+	+	-	+	+	7
Aglietti *et al.*, 2004 (61)	+	-	-	+	-	-	+	+	+	+	+	6
Ejerhed *et al.*, 2003 (46)	+	+	+	+	-	-	+	+	-	+	+	7
Feller *et al.*, 2003 (47)	+	+	-	+	-	-	+	+	-	+	+	6
Shaieb *et al.*, 2002 (50)	+	-	-	+	-	-	+	+	-	+	+	5
Aune *et al.*, 2001 (56)	+	+	-	+	-	-	+	-	-	+	+	5
Eriksson *et al.*, 2001 (34)	+	+	-	+	-	-	-	+	-	+	+	5

LR: low risk, HR: high risk.

Table VII. Risk of bias.

Author	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Drop-out	Selective reporting bias	Other bias	Total
Smith *et al.*, 2020	2 LR	2 LR	0 HR	0 HR	2 LR	2 LR	2 LR	10
Zaffagnini *et al.*, 2011	2 LR	0 HR	0 HR	1 UC	2 LR	0 HR	0 HR	5
Barenius *et al.*, 2010	2 LR	2 LR	0 HR	0 HR	2 LR	0 LR	0 HR	6
Volpi *et al.*, 2010	2 LR	0 HR	0 HR	0 HR	2 LR	0 HR	0 HR	4
Maletis *et al.*, 2007	2 LR	0 HR	0 HR	0 HR	2 LR	2 LR	0 HR	6
Zaffagnini *et al.*, 2006	2 LR	0 HR	0 HR	2 LR	2 LR	0 HR	0 HR	6
Laxdal *et al.*, 2005	2 LR	2 LR	0 HR	2 LR	2 LR	0 HR	0 HR	8
Aglietti *et al.*, 2004	2 LR	0 HR	0 HR	2 LR	2 LR	1 UC	2 LR	9
Ejerhed *et al.*, 2003	2 LR	2 LR	0 HR	2 LR	2 LR	0 HR	2 LR	10
Feller *et al.*, 2003	2 LR	0 HR	0 HR	2 LR	2 LR	0 HR	2 LR	8
Shaaieb *et al.*, 2002	2 LR	0 HR	0 HR	2 LR	2 LR	0 HR	0 HR	6
Aune *et al.*, 2001	2 LR	0 HR	0 HR	2 LR	2 LR	2 LR	2 LR	10
Eriksson et al, 2000	2 LR	0 HR	0 HR	0 HR	2 LR	0 HR	1 UC	5

LR: low risk, HR: high risk.

for the SLH test 2 years follow-up post-ACLR (46, 48, 52, 56). Pooled data shows non-significant result on comparison of BPTB with HT autograft with SMD 0.40 (95%CI -0.89, 1.69); p = 0.54; I^2 = 96%) as shown in **figure 6B**. Two studies (n = 328) compared SLH at > 2 years follow-up post-ACLR (34, 45) showing non-significant result with SMD 0.07; 95%CI -0.15, 0.29; p = 0.53; I^2 = 0% as shown in **figure 6C**.

Quantitative analysis of ROM deficit (Knee flexion and extension)

Five studies (n = 434) pooled data for flexion ROM deficit of up to 5° as compared to the contralateral limb up to 2 years follow-up post-ACLR (46-48, 52, 59). The result comparing both groups was significant for BPTB with SMD -1.82 (95%CI -3.66, 0.02); p = 0.05; I^2 = 98% as shown in **figure 7A**. Five studies (n = 522) analysed data for Flexion deficit for > 2 years follow-up post ACLR (34, 45, 47, 49, 54) with analysis showing a non-significant result with SMD -0.59 (95%CI -1.25, 0.07); p = 0.08; I^2 = 92% as shown in **figure 7B**. Four studies (n = 314) pooled data for extension ROM deficit up to 2 years follow-up post-ACLR (46-48, 52). The analysis of BPTB and HT autograft shows significant difference favouring HT autograft group with SMD 1.36 (95%CI 0.45, 2.27); p = 0.003; I^2 = 92% as shown in **figure 7C**. Whereas four studies (n = 443) pooled data for > 2 years follow-up post-ACLR (34, 45, 47, 49) showing a significant difference between both the groups favouring the HT group with SMD 1.27 (95%CI 0.02, 2.52); p = 0.05; I^2 = 97% as shown in **figure 7D**.

Quantitative analysis of isokinetic strength deficit (Knee flexion and extension)

Four studies (n = 362) pooled data for isokinetic flexion strength deficit at 60° up to 2 years follow-up post-ACLR (46, 52, 56, 59). The analysis of BPTB and HT autograft shows non-significant difference with SMD -0.62 (95%CI -1.37, 0.13); p = 0.11; I^2 = 92% as shown in **figure 8A**. Whereas four studies pooled data > 60° at 2-years follow-up post-ACLR (46, 52, 56, 59) showing non-significant difference between both the groups with SMD 0.21 (95%CI -0.04, 0.47); p = 0.10; I^2 = 17% as shown in **figure 8B**. Four studies

(n = 362) pooled data for isokinetic extension strength deficit at 60° up to 2 years follow-up post-ACLR (46, 52, 56, 59). The analysis of BPTB and HT autograft shows a significant difference favouring BPTB with SMD -3.49 (95%CI -5.80, -1.17); p = 0.003; I^2 = 99% as shown in **figure 8C**. Three studies (n = 290) analysed data at > 60° up to 2 years follow-up post ACLR (46, 52, 59) showing non-significant difference between both the groups (SMD -0.02 (95%CI -0.25, 0.21); p = 0.86; I^2 = 0%) as shown in **figure 8D**.

DISCUSSION

The objective of the present study was to evaluate and compare the effects of BPTB and HT autograft undergone ACLR by reviewing and quantitively synthesizing data from previous studies. A total of 5 electronic databases were searched using keywords relevant to the framed PICO, and 13 studies that met the pre-set inclusion criteria were included in the systematic review and meta-analysis. The outcome measure selected were pain score, laxity, RTS at pre-injury level or compromised level, graft re-rupture rate, functional scales, ROM deficits, and isokinetic strength deficit at up to 2 years and more than 2 years post-ACLR because these are the most common measures of physical therapy.

The first outcome measure was pain scored at 2 and > 2 years follow-up post-ACLR. Ten RCTs were included in the analysis (45-47, 49, 50, 52, 54, 56, 57, 59). The result showed that pain score was not significant at 2 years but significant at > 2 years favouring the HT autograft group. Previous studies also reveal concurrent findings that suggest that BPTB autograft causes donor site morbidity due to surgical violation of extensor mechanism, development of motion loss, pain near metal implant on the tibial side, loss of sensory nerve function, palpable persistent defect at harvest site and significant anterior knee scar formation on both MRI and CT scan after 2 years of ACLR (21, 23, 36, 39, 43, 47, 48, 52, 56, 58, 60, 61-63). Ejerhed *et al.* (46), Eriksson *et al.* (34), Kartus *et al.* (16) and Shelbourne KD and Gray T (59) concluded that it is important to preserve anterior knee sensitivity by preserving infrapatellar nerve branches and regaining full extension post-ACLR with early ROM and weight-bearing emphasis to minimize donor-site morbidity.

The second outcome measure was laxity measured by KT-1000, Lachman test, and Pivot-shift at 2 and > 2 years follow-up post-ACLR. Nine RCTs were included for analysis of KT-1000 (46-48, 50, 52, 56, 57, 59) showing significantly lower laxity in the BPTB group. Whereas the Lachman test and pivot-shift test show no significant difference. These results are in synchrony with previous studies that BPTB provides a more functionally stable knee more often than HT autograft (11, 32, 40, 64-68). The clinical reasoning for this obtained result may be because of the reason that KT-1000 is an objective measurement of laxity and more precise (nearest 0.5 mm) as compared to subjective measurements such as the Lachman test and Pivot-shift test. The manual methods depend on the therapist's technique, are difficult to standardize, and do not offer good analysable data. We can elucidate the following five reasons for our obtained result. Firstly, HT autograft stretches over time (37, 44, 69). Secondly, in HT autograft fixation slippage and graft tunnel widening (70, 71) occur. Tunnel widening also depends on screw technique and graft tensioning. Interference screw fixation of the tibial end with cyclic tensioning has the advantage that it shortens the distance between the fixation points to reduce graft creep, resulting in less stress and strain on graft and tunnel (69, 72-74). Graft tensioning strategy also affects the ligamentization process of graft and hence knee laxity, for BPTB 20N tension is sufficient without over-constraining graft tissue (75). Thirdly, in HT there is slower revascularization and remodelling process (76, 77). Fourthly, laxity may increase post-ACLR in the re-tear of graft or normal knee ligament tear following injury. Lastly, biomechanically also, BPTB autograft has similar properties to the native ACL, with a slightly higher ultimate tensile load as compared to HT graft (78). The tensile load of native ACL is 2160N which is lower than BPTB autograft (2977N) and higher than ST autograft load (1216N) (41,79, 80).

The third outcome measure was RTS at pre-injury level or compromised level of play at 2 and > 2 years follow-up post-ACLR. Four studies were included for analysis (47, 49, 57, 59). The result shows a significant difference favouring the BPTB group up to 2 years follow-up post-ACLR *i.e.*, 42% more athletes are returning to their respective sport with BPTB graft. This result is as per trends of a recent meta-analysis (6) where the overall rate of RTS was 73.2%, but the BPTB group had a 10.4% higher overall rate of RTS (81.0%) compared with the HT group (70.6%). The higher percentage obtained between the present and above-mentioned study may be hypothesized for the following reasons, firstly BPTB has a better fixation and graft revascularization, secondly in other studies heterogeneity both in graft type and demographics were present, while we only compared studies with a single strand BPTB and four-strand HT. Thirdly, the difference might be due to confounding factors affecting recoveries

like access to high-quality medical care, physiotherapy, and motivation level. Additionally, BPTB has been generally considered to be a robust autograft with lower revision rates and greater post-operative rotatory stability in comparison to HT autograft. These might be the plausible reasons for earlier return to sports in participants with BPTB autograft. These differences in RTS at and > 2 years follow-up ACLR was found to be non-significant. This could be since by this time the prolonged process of ligamentization of graft is over and the four-strand HT ACL autograft offers a similar level of stiffness (81).

The fourth outcome measure was graft re-rupture rate up to 2 and > 2 years follow-up post-ACLR. Five studies were included for analysis (34, 49, 50, 56, 57). The result shows a non-significant difference up to 2 and > 2 years between the BPTB and HT autografts. Although many studies suggested that the BPTB group has increased chances of patellar fracture (18, 20, 82-85) causing extensor mechanism disruption, higher rate of RTS, and loss of end range of extension but our results are contrary to these findings. This could be due to the greater stiffness of the four-strand HT that could have prevented the re-rupture of the ACL (86, 87). In contrast, concurrent findings to our results by Li *et al.* (87) and Xie *et al.* (37) found no difference in graft re-rupture between BPTB and HT grafts. The primary rationale behind finding the non-significant difference between the two autografts might be the inclusion of studies with four-strand HT ACLR.

The fifth outcome measure was functional scales measured with Tegner score and SLH test for 2 years and more than 2 years post-ACLR. Seven studies were included in the analysis (34, 45, 46, 48, 52, 53, 56). The result shows no significant difference between the groups at both time points. Previous studies also suggest no statistical difference between the two types of autografts (6, 35, 36, 88). The reason for obtained result may be because components of the functional scale comprise very basic activities (squats, lunging, jumping, stair-climbing, and descending) that might not have detected score differences in athletes. These activities are very elementary for athletes and athletes require complex multiplanar activities to detect the minimal clinically important difference.

The sixth outcome measure was ROM deficits for knee flexion and extension up to 5° compared to the contralateral normal knee. Nine RCTs were analysed for flexion ROM deficit (34, 45-49, 52, 54, 59). The result shows a significant difference favouring the BPTB group at 2 years and non-significant at > 2 years. This is in alignment with previous studies that concluded that flexion impairment is present in the BPTB group (50, 51). The clinical reasoning behind this obtained result may be that BPTB grafts have infrapatellar tendon contracture, anterior knee pain, arthrofibrosis, delayed ROM institution in rehabilitation, and large incision pain (21, 23, 36, 39, 43, 47, 48, 52, 58, 60-63, 89-90). Seven RCTs were analysed for extension ROM deficit (34, 45-49, 56). The result shows a significant difference between autografts at both time frames favouring HT autografts. The delayed soft tissue healing capacity of HT and risk of residual muscle tearing could predispose the athlete to impairment in knee extension (81).

The seventh outcome measure was isokinetic strength deficit for flexors and extensor group of muscle at 60° and > 60° compared with contralateral limb up to 2 years' follow-up post-ACLR. Four studies were included in the analysis for the flexor group of muscles (46, 52, 56, 59). The result shows a non-significant difference between the groups. Four studies were included in the analysis for the extensor group of muscles (34, 52, 56, 59). The result shows a significant difference favouring the BPTB group at 60°. According to Ejerhed *et al.* (46), there is no difference in flexion strength with the use of ST graft 2-year post-reconstruction, he explained this result with the regeneration of ST in three-quarters of patients (67, 91-94).

Strength and limitations

The strength of this study is that we included all the randomized studies thus increasing the generalizability of our results. The outcomes that we have reported are all clinically relevant and the surgeons may use this information when choosing an optimal graft as per patient need analysis and provide a guideline for the therapist during ACLR rehabilitation.

There are a few limitations in the present review that should be highlighted. Firstly, most of the studies include patients of different ages, levels of play, and varied surgical procedures causing heterogeneity in pooled data. Secondly, limited studies are available on the Indian population so generalization of results should be done with caution.

For further understanding, RCT studies analysing the long-term effects on the athletic population are required. We suggest standardizing the methodological quality of the ACLR procedure in future studies to increase the quality of the studies.

CONCLUSIONS

In conclusion, synthesized data from previous studies comparing the long-term follow-up of ACLR with either

BPTB autograft or HT autograft, yielded some important findings of clinical interest. In comparison at the 2 years, follow-up individuals with HT autograft had knee extension ROM deficit while BPTB autograft was associated with significantly normal laxity (KT-1000), earlier RTS, knee flexion ROM deficit, and isokinetic knee extensor strength deficit at 60°. At > 2 years follow-up, individuals with HT autograft exhibited greater pain control despite knee extension ROM deficit. No significant differences in manual laxity test, graft re-rupture rate, and functional tests were found between graft types at both follow-up time points. According to the qualitative analysis of this study arthroscopic transtibial surgical technique for BPTB autograft, ST graft for HT autograft with knee cycles performed in forced hyperextension for graft tensioning. Post-operative physiotherapy which is also an important component of management emphasized graduated progression of exercises to functional training level with unprotected sports training drills starting at 6 weeks. The surgeon can use the above synthesised evidence while planning for the choice of graft before surgery.

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DATA AVAILABILITY
Data are available along with the review.

CONTRIBUTIONS
IU, NK, MJK, ShSh, SaSh, RKS: conceptualization. IU, NK, MJK, ShSh, RKS: methodology, findings analysis. All authors: writing – original draft, writing – review & editing.

CONFLICT OF INTERESTS
The authors declare that they have no conflict of interests.

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