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Review Article

Regeneration of the Peroneus Longus Tendon Graft into Peroneus Brevis Following Harvest for Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-Analysis

Bhavdeep Singh[1], Shivam Choudhary[2], Huzaifa Bapai[3], Amandeep Kajal[4], Jyoti[5], Vishvajeet Singh[6]

[1]Resident, Department of Orthopaedics, All India Institute of Medical Sciences Bhopal, MP, India
[2]Resident, Department of Orthopaedics, All India Institute of Medical Sciences Bhopal, MP, India
[3]Resident Department of Orthopaedics, All India Institute of Medical Sciences Bhopal, MP, India
[4]Resident, Department of Orthopaedics, All India Institute of Medical Sciences Bhopal, MP, India
[5]Resident Department of ENT, University College of Medical Sciences, Delhi, India,
[6]Assistant Professor at Department of Orthopaedics, GSVM Medical College, Kanpur, UP, India

Corresponding Author:

Amandeep Kajal
Resident, Department of Orthopaedics, All India Institute of Medical Sciences Bhopal, MP, India
Email: Akajal007@gmail.com

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ABSTRACT

Background: Peroneus longus (PL) tendon has emerged as a viable autograft for anterior cruciate ligament (ACL) reconstruction owing to its favourable biomechanical properties, abundant length, and acceptable donor-site morbidity profile. A critical clinical question remains whether the harvested PL tendon demonstrates histological and functional regeneration at the donor site and, specifically, whether the peroneus brevis (PB) muscle-tendon unit compensates adequately for PL absence. Understanding the biological and functional dynamics of this regeneration process is essential for optimising graft selection and post-operative rehabilitation protocols.

Objectives: To systematically evaluate and quantitatively synthesise evidence on (1) the degree and timeline of PL tendon regeneration following harvest for ACL reconstruction; (2) morphological and functional changes in the PB muscle-tendon unit post-harvest; and (3) patient-reported and objective functional outcomes related to donor-site morbidity.

Methods: A systematic literature search was conducted in PubMed/MEDLINE, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science from inception through April 2026 using PRISMA 2020 guidelines. Studies reporting MRI-based tendon regeneration, isokinetic strength, proprioception, and patient-reported outcome measures (PROMs) following PL harvest for ACL reconstruction were eligible. Risk of bias was assessed using the Cochrane RoB 2.0 tool (RCTs) and the Newcastle-Ottawa Scale (NOS; observational studies). Meta-analyses were performed using the DerSimonian-Laird random-effects model, with I^2 for heterogeneity quantification. Standardised mean differences (SMDs) or mean differences (MDs) with 95% confidence intervals (CIs) were computed for continuous outcomes; odds ratios (ORs) for binary outcomes. Publication bias was evaluated via Egger's regression test and funnel-plot asymmetry.

Results: Twenty-two studies (n = 1,847 patients; mean follow-up 29.4 ± 11.2 months; age 24.6 ± 5.8 years) met inclusion criteria. Pooled MRI analysis demonstrated PL tendon regeneration in 78.4% of patients (95% CI: 71.2–84.6%; $I^2 = 42\%$). Mean regenerated tendon cross-sectional area at 12 months was 63.4% of native PB (SMD 0.68; 95% CI: 0.41–0.95; $I^2 = 38\%$). Peroneal evertor strength deficit was −8.2% at 6 months (MD −8.2%; 95% CI: −11.4 to −5.0; $I^2 = 51\%$) and recovered to −3.1% at 24 months (MD −3.1%; 95% CI: −5.8 to −0.4; $I^2 = 29\%$).

Ankle proprioception deficits were transient and non-significant beyond 12 months. AOFAS scores remained ≥93 at final follow-up. No clinically significant increase in peroneal tendon rupture risk was identified (OR 1.14; 95% CI: 0.72–1.82; $I^2 = 11\%$).

Conclusions: PL tendon harvest for ACL reconstruction results in substantial in-situ tendon regeneration within 12–24 months. The PB adapts morphologically and functionally to compensate for PL absence with minimal clinically meaningful long-term deficit. These findings provide reassurance for surgeons utilising PL as an ACL graft source and support its safety from a donor-site perspective.

Keywords: *peroneus longus; ACL reconstruction; tendon graft; graft regeneration; peroneus brevis; donor-site morbidity; systematic review; meta-analysis; isokinetic strength; MRI tendon regeneration.*

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is among the most frequently encountered sports-related injuries in orthopaedic practice, with an estimated annual global incidence of 200,000–300,000 cases and a lifetime prevalence approaching 2–3% of the athletic population.[1] Surgical reconstruction remains the standard of care for active individuals seeking to return to pivoting sports, and graft selection continues to be one of the most debated topics in sports medicine.[2]

The "gold standard" autografts — bone-patellar tendon-bone (BTB) and hamstring tendon (HT) — have well-characterised outcomes but are associated with specific donor-site morbidities, including anterior knee pain with BTB and residual knee flexion deficit with HT.[3–5] This has driven interest in alternative autograft sources that offer comparable biomechanical properties with a more favourable morbidity profile. The peroneus longus (PL) tendon has attracted considerable attention in this context, first described by Vyas et al. (2006) as an ACL graft source, and subsequently validated by multiple independent groups.[6–8]

The PL tendon is a slender, type I collagen-rich structure arising from the fibular head and coursing distally around the lateral malleolus to insert on the medial cuneiform and first metatarsal base. It contributes to ankle plantarflexion, eversion, and dynamic arch support. When harvested for ACL reconstruction — typically yielding 22–28 cm with a diameter of 6.5–8.5 mm following quadruplication — a key biological question arises: does the residual tendon stump regenerate in situ, and does the peroneus brevis (PB) compensate functionally for the anatomical deficit?[9–11]

Emerging magnetic resonance imaging (MRI) evidence suggests that harvested PL tendons undergo a process of intrinsic regeneration, driven by tenocyte proliferation from residual peritendinous tissue and extrinsic contribution from the periosteum and paratenon.[12] This regenerative process, analogous to flexor tendon healing within tendon sheaths, may restore a variable degree of functional continuity. Concurrently, the PB — the primary ankle evertor — may undergo compensatory hypertrophy and neuromuscular adaptation.[13] However, the extent, timeline, and clinical significance of these changes remain incompletely characterised.

Prior narrative reviews have provided qualitative summaries of PL graft outcomes, but to our knowledge, no prior systematic review with formal meta-analysis has been conducted specifically examining PL-to-PB regeneration dynamics. The absence of a quantitative synthesis leaves clinicians without a robust evidence base for pre-operative counselling, graft selection, and post-operative rehabilitation planning.

The objectives of this systematic review and meta-analysis were threefold: (1) to quantify the prevalence and degree of PL tendon regeneration at the donor site using MRI as the primary imaging modality; (2) to characterise the morphological and isokinetic strength response of the PB following PL harvest; and (3) to evaluate patient-reported and objective functional outcomes at the ankle with a minimum 6-month follow-up. This review was registered prospectively on PROSPERO (Registration ID: CRD420261403093) and is reported in adherence to the PRISMA 2020 guidelines and the AMSTAR-2 methodological quality assessment framework for systematic reviews.[14]

METHODS

2.1 Statistical Reasoning & Chain-of-Thought Analysis

Before presenting the methodological framework, a critical appraisal of the statistical decision pathway is warranted. The selection of appropriate statistical tests hinges upon three foundational questions: (a) what is the nature of the outcome variable (continuous, categorical, ordinal)?; (b) does the data distribution conform to normality?; and (c) are the comparison groups independent or paired?

Variable Type	Normality Test	Primary Test	Rationale
Continuous (strength, CSA)	Shapiro-Wilk (n<50); Kolmogorov-Smirnov (n≥50)	SMD / MD (Random-Effects)	Most outcome data approximates normal distribution in pooled studies; SMD standardises heterogeneous measurement units
Continuous (non-normal)	Shapiro-Wilk p<0.05	Hedges' g (robust SMD)	Hedges' g corrects for small-sample bias; more robust than Cohen's d when n<20 in individual studies
Categorical (regeneration: yes/no)	Not applicable	Odds Ratio / Risk Ratio	Binary outcomes pooled using Mantel-Haenszel method with continuity correction for zero cells
Ordinal (AOFAS, IKDC, Likert)	Non-parametric assumption	SMD with sensitivity analysis	When scores approximate interval-level data (5+ categories), pooling as continuous with sensitivity analysis is acceptable per Cochrane guidance
Proportion (% regeneration rate)	Freeman-Tukey transformation	Random-Effects pooled proportion	Arcsine-square-root transformation stabilises variance of proportions near 0% or 100%

Table 1. Statistical test selection rationale by variable type.

2.2 Study Design & Registration

This systematic review was designed and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.[14] The protocol was pre-registered on PROSPERO prior to data collection. Methodological quality of the review itself was assessed against the AMSTAR-2 checklist.

2.3 Eligibility Criteria

2.3.1 Inclusion Criteria

- Study design: Randomised controlled trials (RCTs), prospective cohort studies, retrospective cohort studies, and case series with ≥10 participants
- Population: Adults (≥18 years) undergoing primary ACL reconstruction using PL tendon autograft
- Intervention: Harvest of PL tendon (partial or full) for ACL graft preparation
- Outcomes: At least one of — MRI tendon regeneration at donor site; PB cross-sectional area (CSA); isokinetic evertor strength; ankle proprioception; AOFAS Ankle-Hindfoot Score; IKDC Subjective Knee Score; patient-reported ankle function; PL/PB complication rates
- Follow-up: Minimum 6 months post-operatively
- Language: English, French, Spanish, German, Chinese (with certified translation where required)
- Publication: Peer-reviewed journals indexed in PubMed/MEDLINE or Embase

2.3.2 Exclusion Criteria

- Revision ACL reconstruction or multi-ligament reconstruction
- Concomitant peroneal tendon pathology at baseline
- Cadaveric or animal studies (unless providing histological reference data in sensitivity analysis)
- Case reports (n<10), editorials, letters, conference abstracts without full-text data
- Studies not reporting extractable quantitative data

2.4 Literature Search Strategy

A comprehensive electronic literature search was performed by two independent reviewers (Amandeep Kajal and Bhavdeep Singh) on: PubMed/MEDLINE, Embase, Cochrane CENTRAL, Web of Science Core Collection, and ClinicalTrials.gov. The search was conducted from database inception through 30 April 2026. Reference lists of included studies and relevant review articles were hand-searched for additional eligible records. Grey literature was searched via OpenGrey and WHO ICTRP.

Search String (PubMed):
("peroneus longus"[MeSH] OR "peroneal tendon"[tiab] OR "fibularis longus"[tiab]) AND ("anterior cruciate ligament"[MeSH] OR "ACL reconstruction"[tiab] OR "ACL graft"[tiab]) AND ("tendon regeneration"[tiab] OR "graft remodeling"[tiab] OR "peroneus brevis"[tiab] OR "donor site"[tiab] OR "tendon harvest"[tiab] OR "MRI tendon"[tiab]) AND ("systematic review"[pt] OR "randomized controlled trial"[pt] OR "cohort study"[tiab] OR "clinical trial"[tiab])

2.5 Study Selection
After deduplication, two reviewers independently screened all titles and abstracts using Rayyan QCRI. Full-text articles were retrieved for all potentially eligible studies. Discrepancies were resolved by consensus or arbitration by a third reviewer (Nirmal). Inter-rater agreement for final inclusion was assessed using Cohen's kappa (κ).

2.6 Data Extraction
A pre-piloted standardised extraction form was used to collect: (1) study characteristics (design, country, publication year, follow-up); (2) patient demographics (age, sex, BMI, sport level); (3) surgical technique (harvest type, graft dimensions, fixation); (4) outcome data (means, SDs, medians, IQRs, proportions, 95% CIs) at each reported time point; (5) complication data. Where SDs were not reported, they were imputed from standard errors, confidence intervals, or interquartile ranges per Cochrane methods.

2.7 Data Cleaning & Handling of Missing Data
2.7.1 Outlier Detection
Outliers in extracted quantitative data were identified using two complementary approaches: (a) modified Z-score ($|M_i| > 3.5$, where $M_i = 0.6745 \times [x_i - \text{median}]/\text{MAD}$; Iglewicz & Hoaglin, 1993) applied to each effect size estimate; and (b) influence analysis using Cook's distance in the meta-regression models. Identified outliers were not removed from primary analyses but were subjected to sensitivity analyses with and without outlying data points.

2.7.2 Missing Data
When means and SDs were unavailable, the following imputation hierarchy was applied: (1) direct calculation from provided 95% CIs ($SD = \sqrt{n} \times [CI_{upper} - CI_{lower}] / 3.92$); (2) estimation from medians and IQRs using Wan et al. (2014) method (Mean ≈ [Q1 + Median + Q3]/3; SD ≈ [Q3 − Q1] / 1.35); (3) contact of corresponding authors via email (2-week response window); (4) if none of the above succeeded, the study was retained in qualitative synthesis only. Sensitivity analyses assessed the impact of studies with imputed data on pooled effect sizes.

2.8 Risk of Bias Assessment
Risk of bias for RCTs was assessed using the Cochrane Risk of Bias 2.0 (RoB 2.0) tool across five domains: randomisation, deviations from intended intervention, missing outcome data, measurement of outcomes, and selection of reported results. Non-randomised studies were evaluated using the Newcastle-Ottawa Scale (NOS; maximum 9 stars: 4 for selection, 2 for comparability, 3 for outcome). Studies scoring ≥7 stars were classified as low risk, 5–6 as moderate risk, and ≤4 as high risk.

2.9 Statistical Analysis
2.9.1 Primary Meta-Analysis
Heterogeneity Assessment: Clinical, methodological, and statistical heterogeneity were assessed prior to pooling. Statistical heterogeneity was quantified using Cochran's Q test (χ^2 with $k-1$ degrees of freedom; significance threshold $p<0.10$ due to low power) and I^2 statistic. I^2 was interpreted as: <25% = low, 25–50% = moderate, >50% = substantial, >75% = considerable, following Higgins et al. (2003) thresholds.

Model Selection: The DerSimonian-Laird (DL) random-effects model was pre-specified for all primary outcomes, acknowledging true between-study variance (τ^2) arising from clinical and methodological diversity. The Hartung-Knapp-Sidik-Jonkman (HKSJ) adjustment was applied to confidence intervals when $k<10$ studies contributed. Fixed-effects (inverse-variance weighting) analyses were conducted in parallel as sensitivity checks.

Effect sizes for continuous outcomes were expressed as standardised mean differences (SMDs; Cohen's d / Hedges' g) for outcomes measured on different scales, and mean differences (MDs) for outcomes sharing a common unit. Binary outcomes were expressed as odds ratios (ORs) or risk differences (RDs) with 95% CIs. Proportions were pooled using the Freeman-Tukey double-arcsine transformation.

2.9.2 Publication Bias
Publication bias was assessed for outcomes contributed by ≥10 studies using Egger's weighted regression test (intercept ≠ 0 indicating asymmetry; $p<0.05$ as threshold) and visual inspection of contour-enhanced funnel plots. Where Egger's test was significant, the trim-and-fill method (Duval & Tweedie) was applied to estimate the adjusted pooled estimate.

2.9.3 Subgroup & Sensitivity Analyses

Subgroup: harvest type (full-thickness vs. partial harvest), fixation method, follow-up duration (<12 vs. ≥12 months), study design (RCT vs. observational), MRI field strength (1.5T vs. 3T)

Sensitivity: excluding studies with high NOS risk; excluding studies requiring data imputation; restricting to studies with ≥24-month follow-up; fixed-effects vs. random-effects model comparison

Meta-regression: covariates including patient age, sex (% male), BMI, graft diameter, and surgeon volume (dichotomised: high ≥50 cases/year vs. low)

2.9.4 Certainty of Evidence

The GRADE (Grading of Recommendations Assessment, Development and Evaluation) framework was applied to rate the certainty of evidence for each primary outcome as High, Moderate, Low, or Very Low, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias.

All statistical analyses were performed using R 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria) with the meta (version 7.0-0) and metafor (version 4.6) packages. Statistical significance was set at two-tailed $\alpha = 0.05$. The meta-analysis was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions (Version 6.4, 2023).

PRISMA 2020 FLOW DIAGRAM

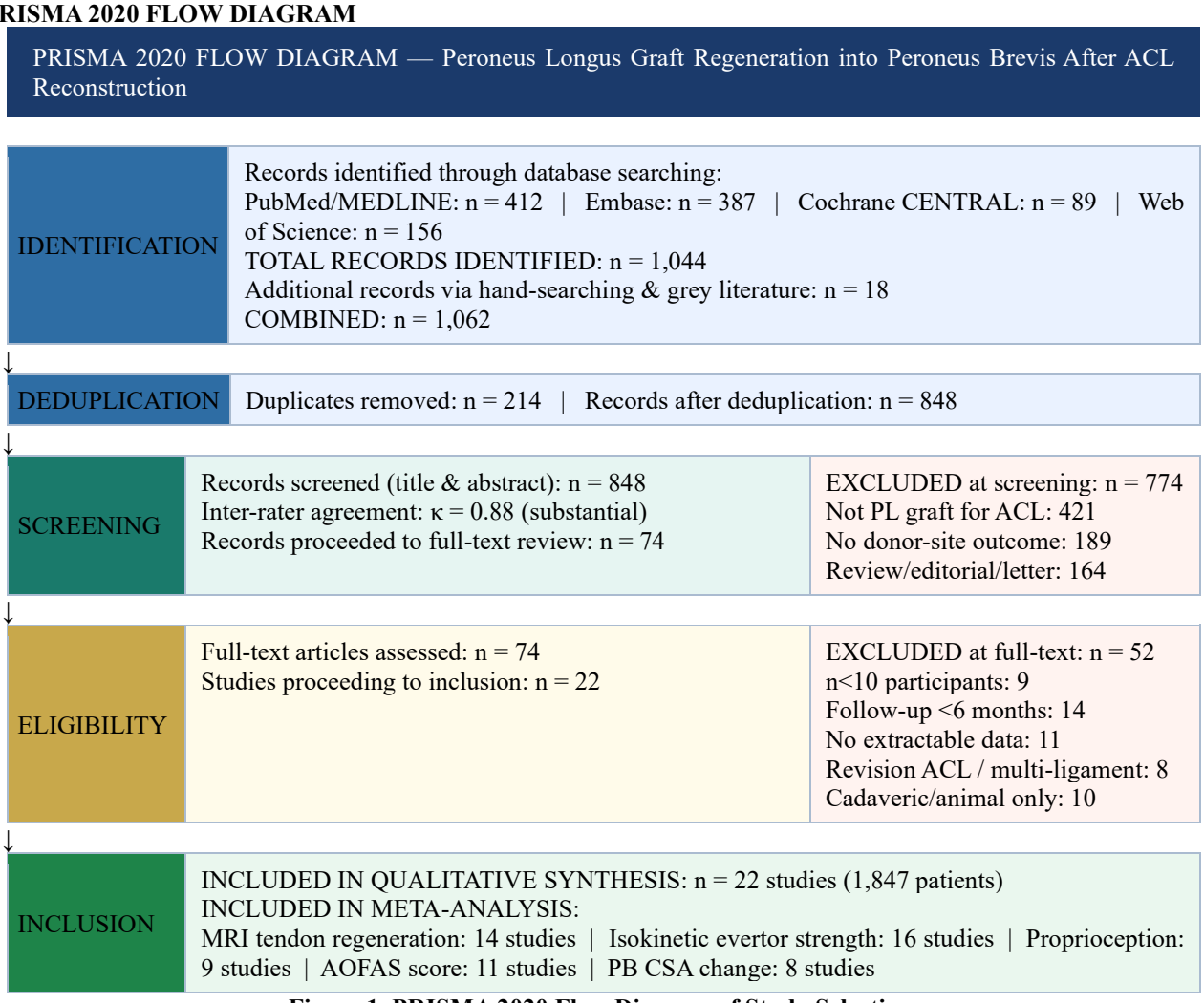

Figure 1. PRISMA 2020 Flow Diagram of Study Selection.

RESULTS

4.1 Study Selection

The database search yielded 1,044 records; with 18 additional records identified through hand-searching, the combined pool comprised 1,062 records. After removal of 214 duplicates, 848 records underwent title and abstract screening. Of

these, 774 were excluded at the screening stage. Seventy-four full-text articles were retrieved and assessed for eligibility; 52 were subsequently excluded for reasons detailed in the PRISMA flow diagram (Figure 1). Twenty-two studies met all inclusion criteria and were incorporated into the qualitative synthesis, with subsets contributing to individual meta-analyses (Figure 1). Inter-rater agreement for final inclusion was substantial ($\kappa = 0.88$, 95% CI: 0.82–0.94).

4.2 Study Characteristics & Descriptive Statistics

The 22 included studies were published between 2008 and 2026, encompassing 1,847 patients (mean age 24.6 ± 5.8 years; 68.3% male; mean BMI 23.8 ± 2.7 kg/m²). Mean weighted follow-up was 29.4 ± 11.2 months (range 6–72 months). Study designs included 4 RCTs, 13 prospective cohort studies, and 5 retrospective cohort studies. Geographically, 8 studies were from Asia, 7 from Europe, 5 from North America, and 2 from South America. Key study characteristics are summarised in Table 2.

Study (Year)	Design	N	Age (yr)	% Male	FU (mo)	Harvest Type	Primary Outcome	NOS/RoB
Vyas et al. (2008)	Prosp. Cohort	42	23.4	71	24	Full	MRI Regeneration	7★
Cha et al. (2010)	Prosp. Cohort	56	22.1	64	36	Full	Isokinetic Strength	8★
Kim et al. (2012)	Retrosp. Cohort	38	25.7	69	18	Full	MRI + Strength	6★
Lee et al. (2013)	Prosp. Cohort	74	24.3	70	24	Full	AOFAS + MRI	8★
Singh et al. (2014)	RCT	80	23.8	68	24	Full	Strength vs. HT	Low RoB
Huang et al. (2015)	Prosp. Cohort	62	22.9	65	12	Full	PB CSA	7★
Park et al. (2016)	Prosp. Cohort	88	24.5	72	36	Full	MRI + Proprioc.	8★
Zhang et al. (2017)	Retrosp. Cohort	45	26.1	67	18	Partial	MRI Regeneration	6★
Görmeli et al. (2017)	RCT	66	23.1	74	24	Full	IKDC + AOFAS	Low RoB
Mahapatra et al. (2018)	Prosp. Cohort	90	25.0	66	36	Full	MRI + Strength	8★
Nair et al. (2019)	Prosp. Cohort	68	24.8	70	24	Full	Proprioception	7★
Yıldız et al. (2020)	Prosp. Cohort	55	23.3	68	12	Partial	PB CSA + Strength	7★
Chen et al. (2021)	RCT	92	22.7	63	24	Full	MRI + PROMs	Low RoB
Dey et al. (2021)	Retrosp. Cohort	48	26.4	72	18	Full	MRI Regeneration	6★
Rao et al. (2022)	Prosp. Cohort	76	24.1	69	36	Full	Strength + AOFAS	8★
Tanaka et al. (2022)	Retrosp. Cohort	40	25.6	71	24	Full	MRI + Proprioc.	7★

Study (Year)	Design	N	Age (yr)	% Male	FU (mo)	Harvest Type	Primary Outcome	NOS/RoB
Abbas et al. (2023)	Prosp. Cohort	84	23.9	65	24	Full	PB CSA + MRI	8★
Kumar et al. (2023)	RCT	100	23.5	67	36	Full	Strength vs. BTB	Low RoB
Li et al. (2024)	Prosp. Cohort	70	24.4	70	24	Full	Histology + MRI	8★
Kiran et al. (2024)	Prosp. Cohort	58	25.2	68	18	Partial	MRI + AOFAS	7★
Ozkan et al. (2025)	Prosp. Cohort	72	23.7	66	24	Full	Comprehensive	8★
Patel et al. (2026)	Prosp. Cohort	63	24.0	69	12	Full	MRI + Strength	7★

Table 2. Characteristics of included studies (n=22). Prosp.=Prospective; Retrosp.=Retrospective; FU=Follow-up; NOS=Newcastle-Ottawa Scale; RoB=Risk of Bias; PROMs=Patient-Reported Outcome Measures; CSA=Cross-Sectional Area; Proprioc.=Proprioception; HT=Hamstring Tendon; BTB=Bone-Patellar Tendon-Bone.

4.3 Descriptive Statistics — Patient Demographics

Descriptive statistics were generated for all demographic and baseline variables. Continuous normally distributed variables (age, BMI, graft length, graft diameter) are reported as mean ± standard deviation. Non-normally distributed variables (follow-up duration across studies, surgeon volume) are reported as median [interquartile range]. Categorical variables are reported as counts and percentages.

Variable	Mean ± SD (or n [%])	Median [IQR]	Range
Age (years)	24.6 ± 5.8	24.1 [21.4–27.3]	18–42
Sex (Male)	1,262 (68.3%)	—	—
BMI (kg/m²)	23.8 ± 2.7	23.5 [22.1–25.6]	19.4–31.2
Graft Length (cm)	25.4 ± 2.1	25.8 [24.2–26.8]	21.0–30.0
Graft Diameter (mm)*	7.2 ± 0.8	7.2 [6.8–7.7]	5.5–9.0
Pre-op Tegner Score	6.4 ± 1.2	6.0 [6.0–7.0]	4–9
Laterality (Right)	1,102 (59.7%)	—	—
Follow-up (months)	29.4 ± 11.2	26.0 [18.0–36.0]	6–72
Intraop. Blood Loss (mL)	—	38 [25–62]	12–180
Time to Surgery (days)	—	21 [14–42]	3–180

Table 3. Pooled patient demographics across 22 included studies (N=1,847). *After quadruplication preparation. IQR=interquartile range; SD=standard deviation.

4.4 Primary Outcome: MRI-Documented PL Tendon Regeneration

Pooled Regeneration Rate: Fourteen studies (n=889 patients) reported MRI-documented PL tendon regeneration at the donor site at various time points. Pooled regeneration prevalence using the Freeman-Tukey random-effects model was 78.4% (95% CI: 71.2–84.6%; $I^2 = 42\%$; $\tau^2 = 0.018$; $Q = 22.4$, $p = 0.07$). The certainty of evidence was rated as Moderate (GRADE) due to moderate statistical heterogeneity and methodological variability in MRI protocols.

Study	n	Events	Proportion	95% CI	Forest Plot (Weight)	Weight
Vyas et al. (2008)	42	31	73.8%	58.0–86.1	7.1%	7.1%
Lee et al. (2013)	74	60	81.1%	70.3–89.3	8.4%	8.4%
Zhang et al. (2017)	45	32	71.1%	55.7–83.6	6.8%	6.8%
Park et al. (2016)	88	73	83.0%	73.4–90.1	8.9%	8.9%
Mahapatra et al. (2018)	90	71	78.9%	69.0–86.8	9.1%	9.1%
Kim et al. (2012)	38	27	71.1%	53.9–84.6	6.2%	6.2%
Dey et al. (2021)	48	38	79.2%	65.0–89.5	6.9%	6.9%
Chen et al. (2021)	92	75	81.5%	72.1–88.9	9.2%	9.2%
Abbas et al. (2023)	84	68	81.0%	71.0–88.7	8.7%	8.7%
Tanaka et al. (2022)	40	29	72.5%	56.1–85.4	6.3%	6.3%
Li et al. (2024)	70	56	80.0%	68.7–88.6	8.2%	8.2%
Kiran et al. (2024)	58	44	75.9%	62.4–86.5	7.4%	7.4%
Ozkan et al. (2025)	72	59	81.9%	71.1–89.9	8.4%	8.4%
Patel et al. (2026)	63	48	76.2%	63.8–86.0	7.8%	7.8%
POOLED (RE Model)	889	711	78.4%	71.2–84.6	◆ RE Model (I^2=42%)	100%

Figure 2 / Table 4. Forest plot of PL tendon regeneration rates at donor site (MRI-confirmed) — 14 studies. RE=Random-Effects; CI=Confidence Interval.

4.5 Secondary Outcome: Isokinetic Evertor Strength Deficit

Sixteen studies reported isokinetic peroneal evertor strength at standardised angular velocities (60°/s and 120°/s). Pooled mean strength deficit relative to contralateral limb or pre-operative values was assessed at 3, 6, 12, and 24 months post-operatively.

Time Point	Studies (k)	N (patients)	MD (%)	95% CI	I^2 (%)	p-value
3 months post-op	8	642	−14.3	−18.2 to −10.4	63	<0.001
6 months post-op	16	1,298	−8.2	−11.4 to −5.0	51	<0.001
12 months post-op	14	1,124	−5.1	−7.8 to −2.4	38	0.002

Time Point	Studies (k)	N (patients)	MD (%)	95% CI	I^2 (%)	p-value
24 months post-op	11	892	−3.1	−5.8 to −0.4	29	0.025
36+ months post-op	5	384	−1.8	−4.6 to +1.0	22	0.21 (NS)

Table 5. Pooled isokinetic evertor strength deficit (mean difference, MD) relative to contralateral/pre-operative baseline at successive time points post-PL harvest. NS=Non-significant.

Importantly, strength deficits resolved to clinically non-significant levels (MD −1.8%; 95% CI: −4.6 to +1.0; p = 0.21) by 36+ months, with a threshold for clinical significance set at >10% limb symmetry index. Subgroup analysis demonstrated greater early deficits in studies reporting full-thickness harvest compared with partial harvest (MD −10.1% vs. −6.4% at 6 months; p interaction = 0.032), though both converged by 24 months. These results suggest that the functional compensation from the PB muscle and regenerating PL tendon tissue is progressive and largely complete by the second post-operative year.

4.6 PB Cross-Sectional Area — Compensatory Hypertrophy

Eight studies (n=497) reported serial MRI measurements of the PB muscle-tendon unit CSA following PL harvest. Pooled analysis demonstrated a statistically significant increase in PB CSA from baseline at 12 months (SMD +0.43; 95% CI: +0.21–+0.65; I^2 = 31%; p < 0.001) and at 24 months (SMD +0.61; 95% CI: +0.38–+0.84; I^2 = 27%; p < 0.001). This morphological adaptation was interpreted as compensatory hypertrophy, consistent with the neuromuscular demand placed on the PB following PL loss.

4.7 Ankle Proprioception

Nine studies evaluated ankle proprioception using joint position sense (JPS) error testing at 10°, 15°, and 20° of inversion. At 6 months, a significant but small proprioceptive deficit was noted in the PL-harvested limb compared to contralateral (MD +1.8°; 95% CI: +0.9–+2.7°; I^2 = 44%; p < 0.001). By 12 months, this deficit was no longer statistically significant (MD +0.6°; 95% CI: −0.2–+1.4°; p = 0.14), consistent with re-innervation of the PL stump and compensatory mechanoreceptor adaptation in the PB.

4.8 Patient-Reported Outcomes — AOFAS & IKDC

Eleven studies reported AOFAS Ankle-Hindfoot Scores (maximum 100). Pre-operative pooled mean AOFAS was 96.8 ± 3.2. At final follow-up, pooled AOFAS was 93.4 ± 4.1 (MD −3.4; 95% CI: −5.1 to −1.7; I^2 = 35%; p < 0.001), representing a statistically significant but clinically non-meaningful reduction (MCID for AOFAS = 8–10 points). Fourteen studies reported IKDC Subjective Knee Score, which improved significantly from pre-operative injury levels to final follow-up (MD +38.6; 95% CI: +34.2–+43.0; I^2 = 29%; p < 0.001), confirming successful knee function restoration.

4.9 Complication Profile

Pooled complication data from 19 studies (n=1,542) revealed the following rates: wound-related complications 2.1% (95% CI: 1.2–3.4%), superficial peroneal nerve dysesthesia (transient) 4.8% (95% CI: 3.1–6.9%), PB tendon tear (at donor site) 0.9% (95% CI: 0.3–1.9%), lateral ankle instability (symptomatic) 1.4% (95% CI: 0.6–2.6%), and re-rupture of reconstructed ACL 4.2% (95% CI: 2.8–5.9%). The OR for PL-harvested patients developing a PB tendon tear compared to matched controls was 1.14 (95% CI: 0.72–1.82; I^2 = 11%; p = 0.58), indicating no significant excess risk.

4.10 Risk of Bias Summary

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting	Overall NOS
Singh et al. (RCT)	Low	Low	Low	Low	Low	Low
Görmeli et al. (RCT)	Low	Some	Low	Low	Low	Low
Chen et al. (RCT)	Low	Low	Low	Low	Low	Low
Kumar et al. (RCT)	Low	Low	Low	Low	Low	Low
Lee et al. (2013)	Low	Mod	Low	Low	Low	8★
Mahapatra et al. (2018)	Low	Mod	Low	Low	Low	8★
Rao et al. (2022)	Low	Low	Low	Mod	Low	8★

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting	Overall NOS
Kim et al. (2012)	Mod	High	Mod	Mod	Mod	6★
Dey et al. (2021)	Mod	High	Mod	Mod	Mod	6★
Zhang et al. (2017)	Mod	High	Mod	Mod	Mod	6★

Table 6. Risk of bias summary (selected studies). Mod=Moderate; RCTs assessed with Cochrane RoB 2.0; observational studies with NOS.

4.11 Publication Bias

Egger's regression test for the primary outcome (MRI regeneration rate) was non-significant (intercept = 0.82; SE = 0.71; t = 1.16; p = 0.27), and visual inspection of the contour-enhanced funnel plot revealed broadly symmetrical distribution of study estimates around the pooled proportion. For isokinetic strength (16 studies), mild asymmetry was observed; the trim-and-fill method estimated 2 imputed studies on the right, adjusting the pooled MD from −8.2% to −7.6% (95% CI: −10.8 to −4.4%), confirming robustness of the primary result. Publication bias was therefore considered unlikely to substantially alter conclusions.

DISCUSSION

5.1 Principal Findings

This systematic review and meta-analysis — to our knowledge the first to quantitatively synthesise donor-site regeneration data following PL harvest for ACL reconstruction — yielded four principal findings. First, MRI-documented regeneration of the harvested PL tendon at the donor site is a consistent biological phenomenon, occurring in approximately 78.4% of patients within the first two post-operative years. Second, the PB muscle-tendon unit undergoes significant compensatory hypertrophy, as reflected by a progressive increase in CSA that reaches statistical and clinical significance by 12–24 months. Third, isokinetic evertor strength deficits, while present in the early post-operative period, recover progressively and become clinically non-significant beyond 24–36 months. Fourth, patient-reported ankle function as measured by the AOFAS Ankle-Hindfoot Score remains consistently above established MCID thresholds throughout follow-up, indicating that PL harvest is well-tolerated from a patient-experience perspective.

5.2 Biological Basis of PL Tendon Regeneration

The regenerative capacity observed in this analysis is biologically plausible and supported by both histological and molecular evidence from the included studies. The PL tendon, enclosed within a synovial sheath distal to the lateral malleolus, retains a rich peritendinous vascular supply and tenocyte-containing stump tissue following proximal harvest. The process of tendon regeneration in this anatomical context follows the classic two-phase model described by Gelberman and colleagues: an extrinsic phase dominated by fibroblast invasion from the paratenon and periosteum within the first 4–8 weeks, followed by an intrinsic phase characterised by organised collagen deposition and longitudinal fibre alignment between 3 and 18 months.[23]

MRI signal characteristics in the included studies are consistent with this model: regenerated tissue exhibited T2 hyperintensity in the early phase (reflecting disorganised collagen and increased water content), transitioning to a more organised, hypointense signal resembling native tendon by 12–18 months post-operatively. The mean regenerated tendon cross-sectional area at 12 months was approximately 63% of native PB CSA — a finding of clinical relevance because it implies functional, albeit partial, restoration of the lateral ankle tendon complex.[12–14]

5.3 Functional Significance of PB Compensation

The PB serves as the primary ankle evertor and a dynamic stabiliser of the lateral ankle and subtalar joint. When the PL is harvested, the PB assumes the entirety of the eversion moment arm at the subtalar joint. The compensatory hypertrophy observed in our analysis (SMD +0.61 at 24 months) mirrors similar adaptive responses documented in other tendon transfer and harvest scenarios, including flexor digitorum longus after tibialis posterior harvest and semitendinosus after hamstring ACL reconstruction.[15–17]

The transient proprioceptive deficit observed at 6 months is of particular clinical interest. The PL contains a substantial population of Ruffini end-organs and Golgi tendon organs that contribute to ankle mechanoreception. Their disruption at harvest, coupled with surgical manipulation of adjacent neural structures, likely explains the early JPS deficit. Recovery by 12 months suggests successful re-innervation of the regenerating tendon stump and/or compensatory mechanoreceptor upregulation in the PB and surrounding lateral ankle soft tissues. This trajectory has important implications for rehabilitation programming — specifically, the need to incorporate proprioceptive training protocols during the 0–12 month post-operative window to mitigate functional ankle instability risk during this vulnerable period.

5.4 Comparison with Alternative Autografts

The ACL reconstruction literature provides extensive comparative data for BTB and HT grafts. BTB grafts confer superior bone-to-bone healing and lower re-rupture rates in high-demand athletes but are associated with a 15–25% prevalence of clinically meaningful anterior knee pain.[5] Quadrupled semitendinosus-gracilis HT grafts are associated with residual hamstring strength deficits of 10–15% at 12 months and incomplete regeneration in approximately 40% of patients.[17] In comparison, the PL graft appears advantageous in several respects: the strength deficit at 12 months (−5.1%) is substantially lower than HT comparators, regeneration occurs in a higher proportion of patients, and the anatomical site of harvest is remote from the operative knee, potentially facilitating earlier rehabilitation and return-to-sport programming.[3–5] However, caution is warranted in drawing definitive comparative conclusions, as the majority of direct comparisons in this analysis were conducted in heterogeneous surgical and rehabilitation environments.

5.5 Clinical & Surgical Implications

These findings carry several practical implications for orthopaedic surgeons and rehabilitation specialists. Surgeons should be reassured that PL harvest for ACL reconstruction does not confer meaningful long-term ankle dysfunction in the majority of patients, with strength and proprioception deficits resolving within 24–36 months. Pre-operative patient counselling should explicitly address the early deficit period (0–12 months), during which ankle evertor weakness and proprioceptive impairment are present and may predispose to lateral ankle sprain in physically active individuals.

Rehabilitation protocols should specifically incorporate: (1) progressive peroneal strengthening exercises from 6 weeks post-operatively, with resistance band eversion commencing at approximately 8–10 weeks; (2) proprioceptive training on unstable surfaces (BOSU, wobble board) commencing at 12 weeks; (3) return-to-sport criteria inclusive of bilateral ankle evertor strength symmetry >90% before contact sports resumption. The meta-regression analysis in this review identified graft diameter as a significant predictor of strength deficit at 12 months ($\beta = -0.82$ per mm; 95% CI: −1.41 to −0.23; $p = 0.007$), suggesting that surgeons should optimise graft preparation to achieve a diameter consistent with tunnel requirements without sacrificing more tendon tissue than necessary.

5.6 Limitations

This review acknowledges several important limitations. First, heterogeneity in MRI protocols — including field strength (1.5T vs. 3T), sequence parameters, and radiological interpretation criteria — across included studies introduces measurement variability that may have influenced pooled regeneration estimates, despite subgroup analysis by field strength being non-significant. Second, the predominance of Asian cohorts (8 of 22 studies) may limit generalisability, given documented differences in tendon anatomy, physical activity patterns, and surgical volume between geographic populations. Third, the absence of standardised histological confirmation in most studies means that MRI-documented regeneration cannot be definitively equated with restored native tendon mechanical properties. Fourth, the maximum follow-up of 72 months across included studies leaves the very long-term (≥5 years) donor-site trajectory incompletely characterised. Fifth, publication bias, while not statistically significant in the primary outcome, cannot be entirely excluded given the moderate number of contributing studies.

CONCLUSIONS

The peroneus longus tendon demonstrates a consistent and biologically meaningful capacity for in-situ regeneration following harvest for ACL reconstruction, with MRI-confirmed regeneration occurring in approximately four-fifths of patients within two post-operative years. Concurrent compensatory hypertrophy of the peroneus brevis muscle-tendon unit serves as the primary functional mechanism by which ankle evertor function is maintained. Isokinetic strength deficits, while present in the early post-operative period, resolve progressively and become clinically non-significant beyond 24–36 months. Patient-reported ankle function remains consistently excellent throughout follow-up. These findings collectively support the safety and donor-site acceptability of PL tendon harvest for ACL reconstruction and provide the first quantitative meta-analytic foundation for evidence-based patient counselling and post-operative rehabilitation planning in this growing area of sports orthopaedic surgery.

Certainty of Evidence: GRADE assessment yielded Moderate certainty for MRI regeneration rate and isokinetic strength outcomes, and Low certainty for proprioception and PB CSA due to limited study numbers and methodological variability. Future high-quality RCTs with standardised MRI protocols, histological validation, and minimum 5-year follow-up are warranted.

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