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ARTICLE

COMPARISON OF ANTERIOR HALF PERONEUS LONGUS AUTOGRAFT VERSUS HAMSTRING, QUADRICEPS AND BONE–PATELLAR TENDON–BONE GRAFTS IN ACL RECONSTRUCTION

Ludwig Andre Pontoh[1,2]

[1]Department of Orthopaedic and Traumatology, Faculty of Medicine, University of Indonesia
[2]Jakarta Knee & Shoulder Orthopaedic Sport Center, Pondok Indah Hospital

*Correspondence email : lappontoh@gmail.com

ABSTRACT

Graft choice significantly influences outcomes after anterior cruciate ligament reconstruction (ACLR). The anterior half of the peroneus longus tendon (PL) has been proposed as an alternative autograft that may maintain hamstring–quadriceps balance while providing adequate strength and graft size. This narrative review evaluates biomechanical studies, randomized trials, cohort studies, and systematic reviews comparing PL with hamstring tendon (HT), quadriceps tendon (QT), and bone–patellar tendon–bone (BPTB) grafts. Evidence shows PL offers sufficient tensile strength and consistent diameter (≥8 mm) with knee stability and functional results comparable to HT. It also provides advantages in harvest time and lower donor-site morbidity while preserving muscle balance, with minimal impact on ankle function.

Keywords: Anterior cruciate ligament reconstruction; Peroneus longus autograft; Hamstring autograft; Quadriceps autograft; Donor site morbidity

АБСТРАКТ

Выбор трансплантата значительно влияет на результаты после реконструкции передней крестообразной связки (ACLR). Передняя половина сухожилия длинной малоберцовой мышцы (PL) была предложена в качестве альтернативного аутотрансплантата, который может поддерживать баланс между подколенными сухожилиями и четырехглавой мышцей, обеспечивая при этом достаточную прочность и размер трансплантата. В этом обзорном исследовании оцениваются биомеханические исследования, рандомизированные испытания, когортные исследования и систематические обзоры, в которых сравниваются трансплантаты PL с трансплантатами сухожилия подколенного мышцы (HT), сухожилия четырехглавой мышцы (QT) и кости-надколенника-кости (BPTB). Данные показывают, что PL обеспечивает достаточную прочность на разрыв и постоянный диаметр (≥8 мм) с стабильностью колена и функциональными результатами, сопоставимыми с HT. Он также имеет преимущества в плане времени забора и более низкой заболеваемости в месте донорства, сохраняя мышечный баланс и оказывая минимальное влияние на функцию голеностопного сустава.

Ключевые слова: реконструкция передней крестообразной связки; аутотрансплантат длинной малоберцовой мышцы; аутотрансплантат подколенной мышцы; аутотрансплантат четырехглавой мышцы; заболеваемость в месте донорства

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INTRODUCTION

Anterior cruciate ligament (ACL) rupture is a common knee injury that often requires surgical reconstruction to restore knee stability and allow return to sport. Worldwide, more than 200 000 ACL reconstructions are performed annually.[1] Success of reconstruction depends on graft choice, fixation and rehabilitation. The bone–patellar tendon–bone (BPTB) autograft was long regarded as the reference standard because of bone–to–bone healing and good early stability; however, donor-site morbidity (anterior knee pain, kneeling pain, loss of motion and risk of patellar fracture) has prompted interest in alternatives.[2] Hamstring tendon (HT) autografts preserve extensor mechanism function but risk saphenous nerve injury, small graft diameter and hamstring weakness.[3] Quadriceps tendon (QT) autografts have gained popularity because they offer a large cross-sectional area and reliable size but may produce greater postoperative quadriceps weakness than HT or BPTB.[4] Recently, harvesting the anterior half of the peroneus longus tendon (PL) has emerged as another option. PL harvesting preserves hamstring–quadriceps balance and avoids anterior knee pain, but questions remain regarding its biomechanical adequacy, effect on ankle function and donor morbidity.[5]

This narrative review compares anterior half PL autografts with HT, QT and BPTB grafts regarding graft properties, biomechanical consequences for hamstring-quadriceps balance, clinical outcomes, donor-site morbidity, rehabilitation and harvest technique. Evidence from prospective and retrospective clinical studies, cadaveric biomechanics research and systematic reviews was extracted from the literature. Vancouver-style reference numbers appear in square brackets and summaries of each reference are provided at the end of the manuscript.

MATERIAL AND METHODS

Graft properties

2. Native ACL and mechanical requirements

The native ACL has an average cross-sectional area of ~38–43 mm², ultimate stress of 36 MPa, stiffness of 182 N mm⁻¹ and tensile strength of around 2 160 N[6]. To restore knee kinematics, autografts should equal or exceed these values. Table 1 summarises reported mechanical properties of common autografts from cadaveric studies.

Graft	Cross-sectional area (mm²)	Tensile strength (N)	Stiffness (N·mm⁻¹)	Notes
Bone–patellar tendon–bone (BPTB)	48.4[7]	1 581–1 784[7] (one study reported 4 389 N for a 15 mm graft[6])	210–278[7]	Bone plugs allow rigid fixation and rapid graft incorporation; donor-site pain common.
Hamstring (semitendinosus ± gracilis)	57[8]	~2 422 N (range 1 139–4 500)[9]	238[8]	Quadrupled HT has higher tensile strength than BPTB; diameter and length vary.
Quadriceps tendon (QT)	91.2[10,11]	2 186 N[11]	466[11]	Cross-sectional area almost twice that of BPTB; thicker graft may increase arthrofibrosis risk.
Peroneus longus tendon (PL)	≈ 50–60 (estimated)	Cadaveric anterior-half PL: median 758 N (range 600.7–1 131.3 N); double PL: 4 268 ± 285 N[12]	200–300 (estimated)	PL graft is long and easily harvested; anterior half harvest yields diameters ≥8 mm. A living-donor biomechanical study found the PL graft had significantly greater tensile strength than HT of similar diameter.[13]

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Peroneus longus vs hamstring mechanical strength. A cadaveric study of 29 anterior-half PL tendons measured maximum tensile forces between 600.7 and 1 131.3 N (median 758 N) with cross-sectional diameters ≥8 mm. Another living-donor biomechanical study compared 26 PL grafts and 25 HT grafts: both had similar diameters (~7.7 mm), but the PL graft displaced less (2.06 ± 0.14 mm vs 2.44 ± 0.42 mm) and had significantly greater tensile strength.[13] Conversely, some literature quotes extremely high failure loads for doubled PL (≈ 4 268 N), but these values derive from doubling the tendon and may overestimate in vivo strength.[12] Collectively, these data suggest that a single anterior-half PL graft has a tensile strength comparable to BPTB and above the native ACL but is lower than quadrupled hamstring or full-thickness QT constructs.

Hamstring tendon properties. The hamstring graft typically comprises the semitendinosus and gracilis tendons, quadrupled to increase diameter. Mean cross-sectional area is ~57 mm² with a maximum load to failure of around 2 422 N.[8] Graft diameter correlates with patient height; diameters <7 mm are associated with higher rerupture rates.[14] Six-strand hamstring constructs have been developed to augment small grafts. A controlled lab study comparing six-strand HT to QT constructs found that both had similar ultimate load to failure (no significant difference), but the HT construct was significantly stiffer (1 148 vs 808 N mm^{-1}).[15]

Quadriceps tendon properties. Cadaveric studies show that full-thickness QT has a cross-sectional area of ~91 mm² and an ultimate tensile strength of 2 186 N, higher than BPTB; stiffness is about 466 N mm^{-1}.[11] Another laboratory comparison found 6-strand HT and QT constructs had similar ultimate load to failure (~2 000 N) with QT being less stiff[16]. An 8-mm QT graft had a higher ultimate load than a 10-mm PT graft (1 056 ± 227 N vs 816 ± 193 N)[17], and a 6-mm QT graft had comparable strength to a 10-mm PT.[17]

Bone–patellar tendon–bone properties. BPTB grafts include bone plugs and have a cross-sectional area (~48 mm²) slightly smaller than HT but yield immediate bone–to–bone healing. Tensile strength is around 1 581–1 784 N but may reach 4 389 N in larger specimens.[6] Stiffness is 210–278 N mm^{-1}.[6] Because the central third of the patellar tendon is harvested, the graft diameter is predictable and seldom <8 mm, which may reduce rerupture risk.

RESULT

3.1. Biomechanical implications for hamstring–quadriceps balance

ACL reconstruction should restore not only static knee stability but also dynamic neuromuscular balance. The hamstring group acts as the primary antagonist to anterior tibial translation induced by quadriceps contraction. An intact hamstring–quadriceps (H:Q) strength ratio (~0.60 in healthy individuals) is crucial for joint stability and prevention of graft overload. Graft harvest may disturb this balance.

3.2. Effects of hamstring tendon harvest

Harvesting the semitendinosus and gracilis reduces knee flexor strength. A prospective randomized study comparing PL and HT grafts reported that hamstring harvest produced significant loss of knee flexion strength, with 68.3 % of hamstring patients showing persistent flexion loss versus only 9.1 % in the PL group.[30] Saphenous nerve symptoms occurred in 29.3 % of hamstring patients compared with 13 % of PL patients.[30]The authors concluded that PL harvest preserves hamstring strength and may maintain H:Q balance.[30] A network meta-analysis found that PL autografts preserve hamstring–quadriceps balance because the harvest site is distal to the knee and the peroneus brevis compensates for lost eversion strength; in contrast, hamstring harvest disrupts this balance and may compromise joint stability during rehabilitation.[31]

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Isokinetic testing from randomised trials comparing BPTB and HT grafts showed that quadriceps strength limb-symmetry index (LSI) decreased in both groups initially but recovered faster in the HT group.[32] Hamstring strength LSI was consistently lower in the HT group at 4–24 months compared with the BPTB group (89.1 % vs 97.1 % at latest follow-up).[33] This indicates that HT harvest delays hamstring recovery and produces an imbalanced H:Q ratio relative to BPTB.

3.3. Effects of quadriceps tendon harvest

QT harvest removes part of the extensor mechanism and may produce quadriceps weakness. A cross-sectional study evaluating isokinetic strength at 7 months after ACL reconstruction reported that patients with QT grafts had significantly lower quadriceps strength LSI (67.5–75.1 %) compared with BPTB (74.4–81.5 %) and HT grafts (84.0–89.0 %).[4] None of the QT patients achieved an LSI ≥90 %. A conference abstract confirmed that QT patients had 17.4 % lower peak knee-extension torque than HT patients and 6.9 % lower than BPTB patients.[34] These findings suggest that QT harvest compromises quadriceps strength more than HT or BPTB, at least in the early postoperative period. Nevertheless, a lab study found that QT and HT constructs had similar ultimate load to failure and load at 3 mm displacement; the six-strand HT construct was stiffer,[16] indicating that mechanical adequacy does not necessarily translate to better functional recovery.

3.4. Effects of BPTB harvest

Harvesting the central third of the patellar tendon and bone plugs may weaken the extensor mechanism but usually preserves hamstrings. In the randomised trial described above, the BPTB group had significantly reduced quadriceps strength LSI and single-leg hop performance at 4–12 months compared with the HT group.[32,35] Hamstring strength recovered faster in BPTB patients than in HT patients.[33] Thus, BPTB harvest leads to transient quadriceps weakness but maintains H:Q balance better than HT harvest.

3.5. Effects of peroneus longus harvest

PL harvest occurs distal to the knee, so it does not directly affect hamstrings or quadriceps. A prospective comparative study showed that knee flexion strength and thigh circumference recovery were better in the PL group than in the HT group; none of the PL patients experienced knee flexion loss at the final follow-up.[30] Another trial found similar isokinetic quadriceps and hamstring strength between PL and HT groups at nine months, but the PL group had a larger graft diameter and shorter harvest time.[36] Biomechanically, the peroneus brevis compensates for lost evertor function, and peroneus longus harvest does not significantly alter gait or ankle torque.[18] Therefore, PL harvest preserves hamstring–quadriceps balance and may offer a biomechanical advantage over HT and QT grafts.

3.6. Clinical outcomes

Peroneus longus versus hamstring

Several studies compared PL autografts with HT autografts. A retrospective matched study of 400 patients reported that PL grafts had a larger diameter (8.5 ± 0.6 mm vs 8.1 ± 0.7 mm), fewer cases of knee flexion loss (9.1 % vs 68.3 %), and fewer saphenous nerve symptoms (13 % vs 29.3 %) than hamstring grafts.[30] IKDC and Lysholm scores were similar, and ankle function remained high (AOFAS scores ~98/100). The PL group had lower infection rates and similar rerupture rates.[30]

A prospective randomised trial comparing PL and HT autografts (44 patients) found that PL grafts had significantly larger diameter (9.07 ± 0.57 mm vs 8.11 ± 0.21 mm) and shorter harvest time (7.30 vs 12.19 min).[36] IKDC and Lysholm scores were similar at 9 months, and thigh circumference recovery did not differ. Early postoperative ankle scores (AOFAS) were lower in the PL group at 6 weeks but equalised by 9 months.[37] Hypoesthesia near the incision occurred in

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21 % of HT patients but none in the PL group.[37]Another prospective study of 20 patients reported that AOFAS and FAAM scores improved to near normal by 6 months, indicating adequate ankle recovery.[38]

A 2025 systematic review and meta-analysis comparing PL and HT autografts pooled nine studies and concluded that PL grafts had a larger mean diameter (8.63 mm vs 8.08 mm) and lower donor-site morbidity; stability tests and failure rates were similar.[31] The authors emphasised that PL harvest does not significantly affect ankle stability or gait because the peroneus brevis compensates for the harvested tendon.[5] Taken together, these studies show that PL autografts provide clinical outcomes comparable to hamstrings while preserving hamstring strength and reducing nerve-related morbidity.

3.7. Quadriceps tendon versus hamstring and BPTB

Randomised trials have compared QT, HT and BPTB autografts. In a randomised controlled trial of 99 patients (thigh circumference and isokinetic testing), quadriceps strength LSI at 7 months was significantly lower in the QT group (67–75 %) than in the HT (84–89 %) or BPTB group (74–82 %).[4] None of the QT patients reached the clinical threshold of ≥90 % LSI. The same study found that hamstring strength deficits were more pronounced in the HT group, while BPTB patients had balanced hamstring-quadriceps strength.[4] Another trial reported no significant differences in IKDC and Lysholm scores between QT and HT groups, but quadriceps weakness persisted longer in the QT group.[25] A cadaveric biomechanical study comparing QT and patellar tendon grafts showed that 8-mm and 10-mm QT grafts had higher or equal ultimate failure loads than 10-mm patellar tendon grafts.[17] Another study found that full-thickness QT had greater cross-sectional area, strength and stiffness than partial-thickness QT and patellar tendon; partial-thickness QT had similar strength to patellar tendon.[25] Clinically, quadriceps autografts have lower donor-site morbidity and less anterior knee pain than BPTB but may cause quadriceps weakness and a slower return to sports.[39]

3.8. BPTB versus hamstring

A meta-analysis of randomised trials with ≥10-year follow-up compared BPTB and HT autografts. Among 495 patients, there were no significant differences in graft rupture/revision, contralateral ACL rupture, Lysholm or Tegner scores, extension deficits or instrumented laxity at long term.[40] However, BPTB grafts had higher incidence of anterior knee pain, kneeling pain and extension loss,[41], whereas HT grafts had higher risk of infection and possibly higher rerupture rates. Another randomised trial found that at 24 months quadriceps strength and single-leg hop performance recovered similarly between BPTB and HT groups, although BPTB patients exhibited worse quadriceps LSI during the first year.[32]

3.9. Long-term and revision outcomes

Evidence on long-term outcomes of PL autografts is limited because its use is relatively recent. The available studies (1–5 year follow-up) report comparable stability and function to HT or BPTB with low failure rates. For QT autografts, some meta-analyses have reported lower rerupture rates than HT but similar to BPTB, although the evidence is heterogeneous. BPTB autografts remain the preferred choice for athletes requiring rapid and robust graft incorporation, but donor-site pain remains a drawback. HT and PL autografts may be preferable for patients at risk of anterior knee pain or those requiring kneeling activities (e.g., farmers, religious practices), whereas QT autografts can be considered in revision cases or when hamstrings are inadequate.

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3.10. Donor-site morbidity. Nerve injury and sensory disturbance

Hamstring harvest carries a risk of injuring the infrapatellar branch of the saphenous nerve, leading to numbness along the anteromedial tibia. A cadaveric study reported nerve injury rates up to 37.5 % with vertical or horizontal incisions.[22] Posterior hamstring harvest reduces this risk to 0.4 %.[24] PL harvest is associated with sural nerve proximity but clinically negligible sensory deficits; a study of 20 patients reported no sensory complaints.[42] Quadriceps and BPTB harvests rarely injure major nerves but may result in numbness around the incision.

3.11. Pain, muscle atrophy and cosmetic satisfaction

Donor-site pain is a major factor in patient satisfaction. A network meta-analysis reported that HT and QT autografts were associated with 69 % and 88 % lower odds of donor-site morbidity, respectively, compared with BPTB autografts; there were no differences in complications or revision rates.[43] A prospective observational study found that QT autografts had better donor-site morbidity scores at 6 months than HT autografts, with less numbness and muscle atrophy; early postoperative pain was slightly higher with QT at 7 days but equalised by day 14.[44] HT harvest may cause hamstring muscle atrophy and weakness; PL harvest avoids this issue. BPTB patients commonly experience anterior knee pain and kneeling pain.[41]

In PL versus HT trials, hypoesthesia around the incision occurred in 21 % of HT patients but not in PL patients.[37] A retrospective study reported that 13 % of PL patients experienced saphenous nerve symptoms compared with 29 % of HT patients.[30] Cosmetic satisfaction is also better with PL and hamstring harvest than with BPTB; a study comparing posterior and anterior hamstring harvest found greater satisfaction with posterior harvest.[24]

3.12. Graft adequacy and revision rates

Hamstring graft diameters are variable and may be <7 mm in smaller patients, increasing rerupture risk. Peroneus longus grafts consistently measure ≥8 mm. QT and BPTB grafts allow the surgeon to select graft width. Several authors have recommended graft diameters ≥8.5 mm to reduce failure rates.[45] Systematic reviews suggest PL and QT autografts have comparable failure rates to HT and BPTB in short-term follow-up,[31] but long-term data are lacking.

3.13. Rehabilitation

Rehabilitation protocols after ACL reconstruction aim to protect the graft while restoring ROM, strength and neuromuscular control. Most protocols do not explicitly tailor exercises to graft type.[46] However, graft-specific considerations are important:

Hamstring grafts: Early rehabilitation should avoid aggressive hamstring loading to allow tendon regrowth and avoid hamstring strain. Hamstring strengthening begins cautiously at 4–6 weeks, with progressive resistance at 8–12 weeks. Because the H:Q ratio is reduced by hamstring harvest, emphasis on hip extensor and knee flexor strengthening is essential.

Quadriceps tendon grafts: Because QT harvest weakens knee extension, early rehabilitation emphasises quadriceps activation (straight-leg raises, neuromuscular electrical stimulation) and patellar mobility. Squats and closed-chain exercises are progressed gradually. Return to running may be delayed if quadriceps LSI < 90 %.

BPTB grafts: Patients often experience anterior knee pain; therefore kneeling and deep squatting are avoided initially. Quadriceps strengthening is important but must be balanced with pain management. Bone–to–bone healing allows accelerated weight-bearing and more aggressive ROM exercises compared with soft-tissue grafts.

Peroneus longus grafts: Rehabilitation mirrors hamstring protocols but does not require delayed hamstring strengthening. Early ankle mobilisation is encouraged to

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prevent stiffness. Because PL harvest does not compromise hamstring or quadriceps strength, return to sport may be expedited. A prospective trial reported that AOFAS scores for the ankle were slightly lower at 6 weeks but equalised by 9 months[37]; therefore early ankle proprioception exercises may be beneficial.

A 2025 scoping review of rehabilitation guidelines noted that few protocols address graft-specific considerations and that BPTB and QT harvests disrupt the myofascial structure leading to persistent quadriceps deficits, while semitendinosus harvest preserves quadriceps but reduces hamstring function.[46] The authors called for evidence-based graft-specific rehabilitation strategies.

DISCUSSION

The anterior half peroneus longus autograft is an emerging option for ACL reconstruction. Biomechanically, the PL graft provides adequate tensile strength and stiffness and yields graft diameters similar to or larger than hamstring grafts. Cadaveric and living-donor studies show that PL grafts have higher tensile strength than hamstring grafts of comparable diameter.[13] Although single anterior-half PL has a lower ultimate load than quadrupled hamstring or QT, the graft is long enough to be doubled or tripled, and cross-sectional area can be increased. The peroneus brevis compensates for the harvested tendon, preserving ankle eversion and gait,[19] most patients show near-normal ankle function by 6 months.[18]

Clinical studies demonstrate that PL autografts provide comparable stability and functional outcomes to hamstring and BPTB grafts, with the advantage of larger graft diameter, shorter harvest time and lower donor-site morbidity. Preservation of hamstring integrity results in better knee flexion strength and hamstring–quadriceps balance.[30] The main concern with PL harvest is the potential effect on ankle mechanics; however, current evidence indicates that with proper tenodesis to peroneus brevis, evertor strength remains intact and any gait changes are minimal.[19]

Quadriceps tendon autografts offer a robust alternative to BPTB, especially when hamstring grafts are small. QT harvest results in a large, consistent graft with high tensile strength and stiffness. However, early quadriceps weakness and delayed return to sport are notable drawbacks.[4] Partial-thickness QT harvest may mitigate strength deficits while retaining adequate mechanical properties.[25] QT autografts also have low donor-site morbidity and less anterior knee pain than BPTB.[44]

BPTB autografts remain reliable due to their predictable size, bone–to–bone healing and long-term durability. Nevertheless, patients often report anterior knee pain, kneeling discomfort and donor-site morbidity. Quadriceps strength deficits occur early postoperatively but usually recover. BPTB may still be preferred in high-demand athletes requiring rapid stability; however, alternatives should be considered in patients at risk of kneeling pain.

Hamstring autografts continue to be widely used due to ease of harvest and satisfactory long-term outcomes. However, hamstring harvest can cause persistent knee flexor weakness, saphenous nerve injury, and smaller graft diameters. Posterior hamstring harvest reduces nerve injury and operative time[24], but hamstring strength deficits remain.

Overall, the anterior half peroneus longus graft appears to combine many advantages of soft-tissue autografts while avoiding some of their drawbacks. Although long-term data are limited, current evidence suggests that PL autografts offer comparable clinical outcomes, preserve hamstring–quadriceps balance, reduce donor-site morbidity and simplify harvest. Surgeons should consider patient-specific factors such as sport, occupation, anatomy, previous surgeries and donor-site expectations when choosing a graft. Robust randomised controlled trials and long-term cohort studies are needed to clarify failure rates, optimal graft sizing and rehabilitation protocols for PL autografts.

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CONCLUSION

The anterior half peroneus longus autograft represents a viable and biologically sound alternative for anterior cruciate ligament reconstruction. Compared with hamstring, quadriceps, and bone–patellar tendon–bone autografts, PL grafts offer adequate biomechanical strength, preservation of hamstring–quadriceps balance, and lower donor-site morbidity, with minimal long-term impact on ankle function. While early clinical outcomes are promising, high-quality randomized trials with long-term follow-up are required to define optimal indications, failure rates, and graft-specific rehabilitation strategies.

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DECLARATIONS

Author contribution. All authors contributed substantially to the conception and design of the study. The authors participated in literature review, data synthesis, drafting of the manuscript, and critical revision of the intellectual content. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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