

The influence of graft choice on isokinetic muscle strength 4–24 months after anterior cruciate ligament reconstruction

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Abstract

Purpose Regaining adequate strength of the quadriceps and hamstrings after anterior cruciate ligament (ACL) reconstruction is important for maximizing functional performance. However, the outcome of muscle strength after either BPTB or hamstrings autograft is unclear given the plethora of published studies that report post-operative muscle strength. The purpose of this study was to systematically compare the muscle strength of patients who have

undergone ACL reconstruction using either Bone Patellar Tendon Bone (BPTB) or Hamstrings (HST) autograft.

Methods The databases of MEDLINE, Cinahal and EMBASE were systematically searched for articles that report muscle strength outcome following ACL reconstruction. The quality of the studies was evaluated and a meta-analysis of the muscle strength outcomes was conducted on reported data.

Results Fourteen studies were included in this systematic review: eight Randomized Control Studies (RCT) and six non-Randomized Control Studies (non-RCT). A meta-analysis was performed involving eight of the included studies (4 RCTs & 3 non-RCTs). At 60°/s and 180°/s, patients with BPTB graft showed a greater deficit in extensor muscle strength and lower deficit in flexor muscle strength compared with patients with HST.

Conclusion This systematic review of Level III evidence showed that isokinetic muscle strength deficits following ACL reconstruction are associated with the location of the donor site. These deficits appear to be unresolved up to 2 years after ACL reconstruction.

Level of evidence III.

Keywords ACL reconstruction · Isokinetic muscle strength · Systematic review · Meta-analysis

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Introduction

Rupture of the Anterior Cruciate Ligament (ACL) is one of the most common athletic injuries of the knee [14, 17, 61]. Lyman et al. recently estimated that the frequency of ACL reconstruction is increasing in the United States and that younger patients are at a higher risk for re-rupture of the ACL graft [41]. The consequences of an ACL rupture to

the function of the involved limb are multifaceted and possibly include a decrease in joint stability, muscle weakness, meniscal damage, pain and, in the long term, development of osteoarthritis [29, 30, 46, 47, 50, 51, 54, 58, 62, 67, 73]. In an attempt to prevent these deficits in joint function, reconstruction of ACL has become one of the most common orthopaedic interventions. Although many different surgical techniques and an increasing number of graft types have been described in the literature, autograft reconstruction using Bone Patellar Tendon Bone (BPTB) or Hamstrings Tendon (HST) appears to be the most popular graft choices [4, 12, 23, 24, 26, 45, 53].

Despite a plethora of recently published comparative studies, the relative effectiveness of the different grafts used for the reconstruction of ACL remains unclear [4, 6, 7, 11, 12, 15, 23, 24, 27, 33]. Maximizing knee stability after ACL reconstruction is one of the most important criteria for the choice of graft. Post-operative stability allows the performance of rehabilitation protocols that aimed to restore normal function and thus safe and fast return to pre-injury activity level [48]. The superior post-operative stability afforded by BPTB autograft is likely to be related to enhanced healing from bone-to-bone attachments [3, 59, 72]. However, increased donor-site morbidity has been reported after harvesting BPTB autograft. Specifically, anterior knee pain, quadriceps weakness and worse results in functional tests along with an increased rate of patellar fractures have been observed [27, 40, 43, 44, 49]. Harvesting of the HST autograft may avoid some of these post-operative problems, but it is associated with hamstring muscle weakness and slower healing of the graft attachment site that may predispose patients to higher risk of re-rupture [2, 66, 70]. Thus, both of these graft choices are limited in the ability to restore knee function for people with ACL rupture, and there is consequently an ongoing debate concerning the superiority of one graft over the other. An important aspect of this debate is the outcome of lower limb muscle strength following either of these graft types.

Evaluation of muscle strength can be accomplished using functional tools (incorporating hop or twisting) or single-joint evaluation tools [2, 9, 52]. One of the most commonly used tools that is reliable in assessing single-joint muscle strength is isokinetic dynamometry [19, 56]. In comparison to other measures of strength, isokinetic dynamometry allows quantification of muscle strength deficit through the assessment of specific parameters such as work per unit, torque at specific joint angles and the widely used peak torque value [19, 22, 56, 67]. In the majority of studies that investigate muscle strength following ACL reconstruction, the strength of the operated limb is recorded as a deficit or gain in comparison to the contralateral healthy limb. Restoration of similar muscle strength between reconstructed and healthy knee is considered to be a critical factor for a

safely return back to dynamic activities [48]. Thus, the restoration of muscle strength ratio between the operated and contralateral limbs for both the quadriceps and the hamstrings is crucial after an ACL reconstruction for a fast and uneventful return to pre-injury activities [48]. There is evidence that muscular recovery is closely related to pre-operative muscle strength, the time between injury and reconstruction and the pre- and post-surgery rehabilitation [8, 22, 55]. In addition, changes in the sensory system with ACL reconstruction, such as alterations in the somatosensory evoked potentials or the development of inconsistent postural synergies, may also influence muscle [18].

Although many authors have compared lower limb muscle strength in patients with ACL reconstruction after either BPTB or HST grafts, the plethora of information is difficult to interpret. Therefore, a systematic review of the literature is warranted to synthesize reported findings of the isokinetic muscle strength in studies comparing ACL reconstruction using either BPTB or HST autografts. Clarification of muscle strength recovery after ACL reconstruction using either graft type will enhance decision-making with regard to graft choice and rehabilitation.

Materials and methods

A thorough search of the databases MEDLINE, Cinahl and EMBASE for articles that compared muscle strength using isokinetic dynamometry between patients that had undergone ACL reconstruction with either BPTB or HST autograft was completed in September 2009. Full text articles published in English were searched using variations and combinations of the following terms: anterior cruciate ligament reconstruction, knee reconstruction, dynamometry, strength, weakness, and torque.

To be included in this review, articles must have:

- compared two groups of patients that had undergone ACL reconstruction: one of the groups must have received BPTB autograft and one HST autograft;
- evaluated knee flexor and extensor isokinetic muscle strength between 4 and 24 months after ACL reconstruction surgery;
- been published in English language.

The following criteria were used to exclude articles from the systematic review. Studies were not included if:

- studies did not include original data;
- any participants had undergone revision of ACL;
- participants had undergone multiple-ligament reconstruction.

Studies of different methodological design were included in this systematic review and are subject to different

biases. Therefore, multiple tools were used to assess the quality of included studies. Randomized Control Trials (RCT) were assessed for quality using the PEDRO scale [20] which assesses the quality of studies based on 11 criteria. All other study designs were assessed using the tool described by Downs and Black [21]. The assessment of methodological quality was completed by 2 reviewers independently. Disagreement was resolved by discussion with a 3rd reviewer.

Extraction of data

Two independent reviewers read all of the articles in the final yield and systematically extracted pre-defined relevant data. Demographic details of participants were extracted from all articles in addition to the descriptive variables of isokinetic strength assessment at all speeds.

A meta-analysis was conducted on the findings of isokinetic evaluations at testing speeds of 60°/s and 180°/s, an average of 12 months after ACL reconstruction surgery. To be included in the meta-analysis, the mean and measures of variability must have been reported. Wherever the outcomes were not presented in a form suitable for direct inclusion in the meta-analysis, the corresponding authors were contacted by email in an attempt to obtain the data required for meta-analysis (numbers of participants, mean scores and SDs).

Statistical analysis

Muscle strength of the operated limb was extracted when reported either as a percentage of the uninvolved limb (i.e. Limb Symmetry Index) or as a percentage deficit of the uninvolved limb ($100 \times$ deficit of injured leg/deficit of uninjured leg). Mean differences and 95% confidence intervals were calculated from the extracted data. Random-effects models were used to pool data. Review Manager 5 (Version: 5.0.24) software was used for the calculation of effect sizes.

Results

A total of 1,532 published studies were identified in the original search of databases. Following the application of inclusion and exclusion criteria, a final yield of 14 studies were included in this systematic review as presented in the flow chart (Appendix). Of the 14 included studies, eight were RCT and six non-Randomized Control Trials (non-RCT).

The study design and the characteristics of each study included in this review are presented in Table 1.

Quality assessment of the RCTs and the non-RCTs is presented in Tables 2 and 3. Inadequate randomization may allow the introduction of bias; however, only 3 of the 8 RCTs reported the process of patient randomization. Although blinding of the patient and surgeon is not always possible in this field of research, only 2 studies reported that assessors were blinded to the group allocation of patients.

Muscle strength outcomes

The muscle strength outcomes that were reported from all studies are presented in Tables 4 (for RCTs) and 5 (for non-RCTs).

Six studies [5, 7, 11, 12, 16, 69] found no significant difference between BPTB and HST for isokinetic muscle strength for knee extensors or knee flexors at follow-up times between 4 and 24 months after reconstruction.

Four studies [10, 26, 35, 42] found significant extensor muscle strength deficit in the operated limb in the BPTB group compared to the HST group at different follow-up times between 4 and 24 months. In addition, six studies [10, 13, 26, 31, 42, 71] found significant deficits of the flexor muscles in the operated limb in HST group compared to the BPTB group at different follow-up times between 4 and 24 months.

Sufficient data were provided in only four of the RCTs [11, 16, 26, 42] and three of the non-RCTs [13, 69, 71] to conduct a meta-analysis on findings 12 months after ACLR.

Figures 1 and 2 show forest plots that summarize quadriceps and hamstring strength for patients at a speed of 60°/s. There were 3 articles where muscle strength of the operated limb was reported as a percentage of the uninvolved limb. For patients with HST graft, quadriceps strength was an average of 9% stronger and hamstrings strength was 8% weaker than patients with BPTB graft. Two articles reported muscle strength of the operated limb as percentage deficit of the uninvolved limb. Similarly, patients with HST graft showed a 3% lower deficit in quadriceps strength and 9% greater deficit in hamstrings strength than patients with BPTB.

Figures 3 and 4 show forest plots that summarize quadriceps and hamstring strength for patients at a speed of 180°/s. There were 2 articles where muscle strength of the operated limb was reported as a percentage of the uninvolved limb. For patients with HST graft, quadriceps strength was an average of 7% stronger and hamstrings strength was 9% weaker than patients with BPTB graft. Two articles reported muscle strength of the operated limb as percentage deficit of the uninvolved limb. Similarly, patients with HST graft showed a 1% lower deficit in quadriceps strength and 20% greater deficit in hamstrings strength than patients with BPTB.

Table 1 Characteristics of the included studies

Author	Study design	Patients' sex	Rehab protocol	Outcomes	Isokinetic muscle strength outcomes	Post-operative follow up
Aglietti et al. [5]	RCT	120p 60BPTB (46M/14F) 60 HAST (46 M/14F)	Description of the program	KT-1000 IKDC KOOS VAS scale for analyzing subjective knee complaints ROM Functional knee score for anterior knee pain. Radiography	FL/EX Isokinetic at 60°/s, 120°/s, 180°/s	4, 12 and 24 months
Andersson et al. [8]	Non-RCT	45p 22BPTB 23HST No sex mentioned	Shelbourne and Nitz [60]	–	FL/EX Isokinetic 60°/s concentric/eccentric	6 and 12 months
Aune et al. [10]	RCT	72P 35BPTB (19M/16F) 37HST (21M/16F)	Shelbourne and Nitz [60]	KT-1000 VAS scale for patient satisfaction VAS scale for kneeling problems Cincinnati knee score system Stairs Hopple test Single-legged hop test	FL/EX Isokinetic at 60°/s, 240°/s	6, 12, and 24 months
Beard et al. [11]	RCT	45p 22BPTB (18M/4F) 23HST (15 M/8F) ^a	Shelbourne and Nitz [60]	KT1000 IKDC ATT Lysholm score, Tegner activity score	FL/EX Isokinetic at 60°/s	6 and 12 months
Bizzini et al. [13]	Non-RCT	153p 87BPTB (54M/33F) 66HST (45M/21F)	Description of the program	KT 1000	FL/EX Isokinetic at 180°/s, 300°/s	11 months
Beynnon et al. [12]	RCT	52p 26BPTB (18M/10 M) 26HST (13M/15F)	Description of the program	KT 1000, Pivot Shift, IKDC ROM Tegner, One-leg-hop, duckwalking, squat	FL/EX Isokinetic at 60°/s, 180°/s, 240°/s	2, 4, 6, 12 and 36 months

Table 1 continued

Author	Study design	Patients' sex	Rehab protocol	Outcomes	Isokinetic muscle strength outcomes	Post-operative follow up
Carter and Edinger [16]	RCT	106p 38 PT, 33 ST 35 ST/G No sex mentioned	Description of the program	–	FL/EX Isokinetic at 180°/s, 300°/s	6 months
Feller and Webster [26]	RCT	65p 34BPTB (8F/23 M) 31HST (10F/24 M)	Shelbourne and Nitz [60]	KT-1000, Lachmann IKDC Cincinnati Scores Anterior knee pain CA 4000 IKDC	FL/EX Isokinetic at 60°/s, 240°/s	4, 8, and 12 months
Gobbi et al. [31]	Non-RCT	80p 40BPTB 40HST No sex mentioned	Description of the program	Tegner scale Noyes scale Lysholm VAS scale for pain ROM CA 4000 IKDC	FL/EX Isokinetic at 60°/s, 180°/s, 300°/s	3, 6, 12 and 36 months
Jansson et al. [35]	RCT	99p BPTB 51 HST 48 No sex mentioned	Description of the program	Lachman and pivot shift Lysholm knee score Tegner activity level Kujala patellofemoral score MRI	FL/EX Isokinetic at 60°/s, 180°/s	12 and 24 months
Maletis et al. [42]	RCT	99p 46BPTB (31M/15F) 53 HAST (45M/8F)	Description of the program	KT1000 IKDC Lysholm Tegner Physical examination ROM Single hop test Short form SF 36	FL/EX Isokinetic at 60°/s 180°/s, 300°/s ABD/ADD 60°/s 180°/s 300°/s INT/EXT rot 60°/s, 180°/s, 300°/s	6, 12 and 24 months
Tow et al. [66]	Non-RCT	68p 34HST 34BPTB No sex specified	Description of the program	KT 1000 IKDC	FL/EX Isokinetic at 60°/s, 240°/s	3, 6, and 24 months

Table 1 continued

Author	Study design	Patients' sex	Rehab protocol	Outcomes	Isokinetic muscle strength outcomes	Post-operative follow up
Webster et al. [69]	Non-RCT	34p 17BPTB (16 M/1F) 17HST (16 M/1F) 17 CONTROL	Description of the program	IKDC KT 1000 Kinematic walking up/down Kinetic walking up/down	FL/EX Isokinetic at 60°/s	BPTB-11 months HST-9.3 months
Witvrouw et al. [71]	Non-RCT	34p 17BPTB (10M/7F) 32HST (17M/15F)	Description of the program	ROM KT 1000 Lysholm, Tegner, Kujala scales	FL/EX Isokinetic at 60°/s, 240°/s	6 weeks 3,6 and 12 months

RCT randomized control study, *Non-RCT* non-randomized control study, *BPTB* bone patella tendon bone, *HST* hamstring (when is not specified if the graft was semitendinosus or semitendinosus/gracilis), *ST* semitendinosus, *ST/G* semitendinosus/Gracilis, *PT* patella tendon, *IKDC* International Knee Documentation Committee, *KOOS* Knee injury and Osteoarthritis Outcome Score, *VAS scale* visual analog scale, *FL* flexion, *EX* extension, *ATT* anterior tibial translation, *ROM* range of motion

^a We communicated with the author about the sex

Table 2 Results from the methodological assessment of the eight RCTs using the Pedro scale

Pedro criteria	Item no. 1 Eligibility criteria specified	Item no. 2 Subjects randomly allocated to groups	Item no. 3 Concealed allocation	Item no. 4 Baseline data	Item no. 5 Blinding of subjects	Item no. 6 Blinding of therapists	Item no. 7 Blinding of assessors	Item no. 8 Key outcome obtained from >85% of the subjects	Item no. 9 Intention to treat	Item no. 10 Appropriate statistics	Item no. 11 Measures of variability
First author											
Aglietti et al. [5]	Y	N	N	Y	N	N	Y	Y	Y	Y	N
Aune et al. [10]	Y	N	N	Y	N	N	N	Y	Y	Y	N
Beard et al. [11]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y
Beynon et al. [12]	Y	N	N	Y	N	N	N	Y	Y	Y	N
Carter and Edinger [16]	N	N	N	N	N	N	N	Y	N	Y	Y
Feller and Webster [26]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y
Jansson et al. [35]	Y	N	N	Y	N	N	N	Y	Y	Y	N
Maletis et al. [42]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N

Y yes, N no

Table 3 Results from the methodological assessment of the six non-RCTs using the Downs and Black scale

Downs and black criteria	Item no. 1 Clear aim	Item no. 2 Outcomes described	Item no. 3 Patients described	Item no. 5 Confounders described	Item no. 6 Findings clearly described	Item no. 7 Measures of random variability	Item no. 12 Patients represent population	Item no. 16 Planned analysis	Item no. 18 Appropriate statistics	Item no. 25 Modification for confounders	Item no. 27 Power calculation
First author											
Anderson et al. [7]	Y	Y	Y	Y	Y	Y	Y	X	Y	X	N
Bizzini et al. [13]	Y	Y	Y	Y	Y	Y	Y	X	Y	X	N
Gobbi et al. [31]	Y	Y	N	N	Y	N	Y	X	Y	X	N
Tow et al. [66]	Y	Y	N	N	Y	N	Y	X	N	X	N
Webster et al. [69]	Y	Y	Y	Y	Y	Y	Y	X	Y	X	N
Witvrouw et al. [71]	Y	Y	Y	Y	Y	Y	N	X	Y	Y	N

Y yes, N no

Discussion

The most important finding of the present study was the apparent trend for muscle weakness that is specific to the graft donor site following ACL reconstruction. The meta-analysis performed showed that extensor muscle strength deficit exists in ACL reconstructed knees using BPTB autograft and that flexor muscle strength deficit exists in ACL reconstructed knees using HST autografts, 12 months post-operatively.

Not all studies reported muscle weakness in one group of patients or the other. Six studies [5, 7, 11, 12, 16, 69] did not find significant differences in extensor or flexor muscle strength between BPTB and HST groups, at any testing speed (60°/s, 120°/s, 180°/s, 240°/s, 300°/s). In contrast, eight studies found differences between groups. Significant quadriceps muscle strength deficit in BPTB group was observed in four studies [10, 26, 35, 42] and six studies found significant hamstrings muscle deficits in HST group [10, 13, 26, 31, 42, 71]. All of the studies evaluated patients between 4 and 24 months after surgery and muscle weakness was found to persist throughout this period. These findings are in agreement with other reviews [19, 57] that have concluded that the graft site affects muscle strength.

There is an obvious trend for quadriceps deficit at BPTB group compared to HST group and a trend for hamstrings deficit in HST group compared to BPTB group at 12 months post-operative. The results of the meta-analysis showed that difference between BPTB and HST group for extensor muscle strength was nearly 10% at the speed of 60°/s and 180°/s and that for flexor muscle strength was 20% at 180°/s. It is clinically accepted that anything less than a 10% difference between limbs is considered inconsequential [39]. Although the difference in quadriceps strength between sides was not greater than 10%, the difference in hamstring strength exceeded this clinical limit. It is difficult to know what the implications for this asymmetry between limbs are, given that most research has focused on investigating asymmetrical quadriceps weakness. Further research is, therefore, needed to establish whether such a large hamstring weakness in the operated limb of patients with HST graft has any clinical relevance.

The apparent trend for muscle strength weakness related to the donor site may be explained by previous research. It seems that harvesting the patellar tendon autograft during the ACL reconstruction may alter the length–tension relationship of the extensor mechanism [32] and consequently contribute to extensor muscle strength deficit. It is also described that muscle function might be altered due to the attenuation of the gamma loop function caused by the initial ACL injury and that is not restored after the ACL reconstruction. The mechanoreceptors located within the ACL play an important role in enhancing the activity of

Table 4 Muscle strength outcomes of the included RCT, at the time between 4 and 24 months

RCT	Isokinetic-flexion/extension					
	4 months	6 months	8 months	11 months	12 months	24 months
Aglietti et al. [5]	ND between groups at 60°/s, 120°/s, 180°/s	-	-	-	ND between groups at 60°/s, 120°/s, 180°/s	ND between groups at 60°/s, 120°/s, 180°/s
Aune et al. [10]	-	Extension deficit in BPTB group at 60°/s, 240°/s Flexion deficit in HST group at 240°/s	-	-	Flexion deficit in HST group at 60°/s, 240°/s	Flexion deficit in HST group at 60°/s, 240°/s
Beard et al. [11]	-	ND between groups at 60°/s	-	-	ND between groups at 60°/s	-
Beynon et al. [12]	-	-	-	-	ND between groups at 60°/s, 180°/s, 240°/s	-
Carter and Edinger [16]	-	ND between groups at 180°/s, 300°/s	-	-	-	-
Feller and Webster [26]	Extension deficit in BPTB group at 240°/s	-	Extension deficit in BPTB group at 60°/s, 240°/s	-	Flexion deficit in HST group at 60°/s	-
Jansson et al. [35]	-	-	-	-	Extension deficit in BPTB group at 60°/s	ND between groups at 60°/s, 180°/s
Mallett et al. [42]	-	Extension deficit in BPTB group at 60°/s, 180°/s, 300°/s Flexion deficit in HST group at 180°/s	-	-	Extension deficit in BPTB group at 60°/s, 180°/s, 300°/s Flexion deficit in HST group at 180°/s, 300°/s	ND between groups at 60°/s, 180°/s Extension deficit in BPTB group at 60°/s, 180°/s, 300°/s Flexion deficit in HST group at 180°/s, 300°/s

ND no difference between groups (BPTB vs. HST) for flexion/extension strength, -; -: no evaluated

Table 5 Muscle strength outcomes of the included non-RCT, at the time between 4 and 6 months

NRCT	Isokinetic-flexion/extension					
	4 months	6 months	8 months	11 months	12 months	24 months
Andersson et al. [8]	–	ND between groups at 60°/s	–	–	ND between groups at 60°/s	–
Bizzini et al. [13]	–	–	–	Flexion deficit in HST group at 180°/s, 300°/s	–	–
Gobbi et al. [31]	–	–	–	–	Flexion deficit in HST group at 60°/s, 180°/s, 300°/s	–
Tow et al. [66]	–	Trend towards HST flexion muscle weakness	–	–	–	Trend towards HST flexion muscle weakness
Webster et al. [69]	–	–	9,3–11 months ND between groups at 60°/s, 240°/s	–	–	–
Witvrouw et al. [71]	–	Flexion deficit in HST group at 60°/s	–	–	Flexion deficit in HST group at 60°/s, 240°/s	–

ND no difference between groups (BPTB vs. HST) for flexion/extension strength, –: no evaluated

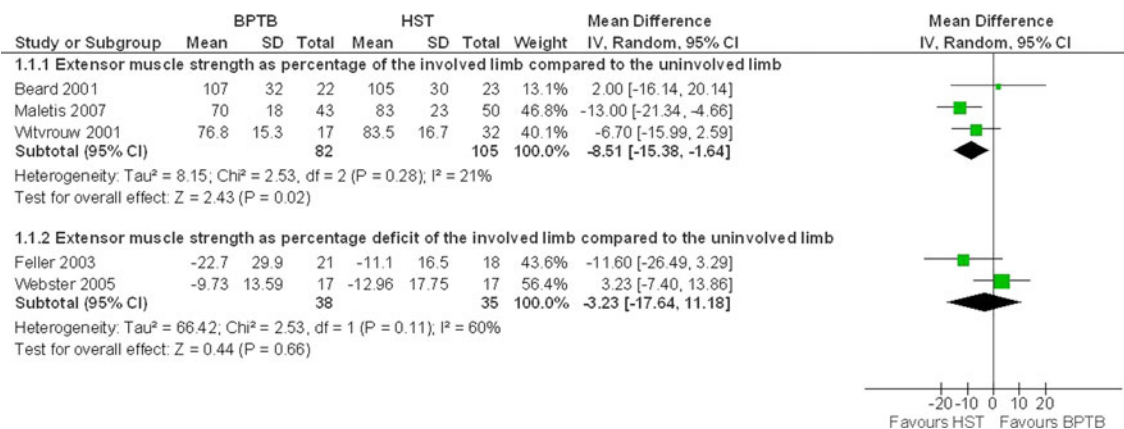


Fig. 1 Forest plots for isokinetic extensor muscle strength at 60°/s at 12 months. BPTB bone patellar tendon bone, HST hamstring, SD standard deviation, CI confidence interval

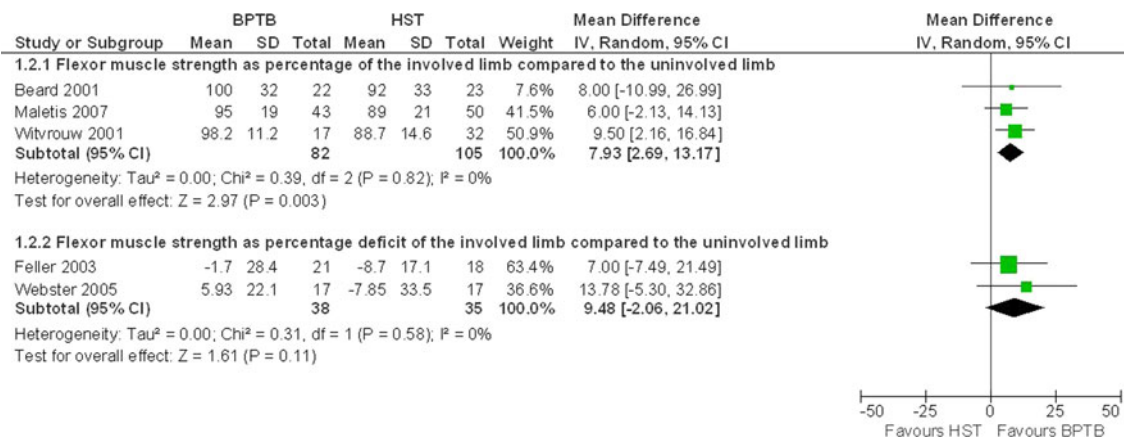


Fig. 2 Forest plots for isokinetic flexor muscle strength at 60°/s at 12 months. BPTB bone patellar tendon bone, HST hamstring, SD standard deviation, CI confidence interval

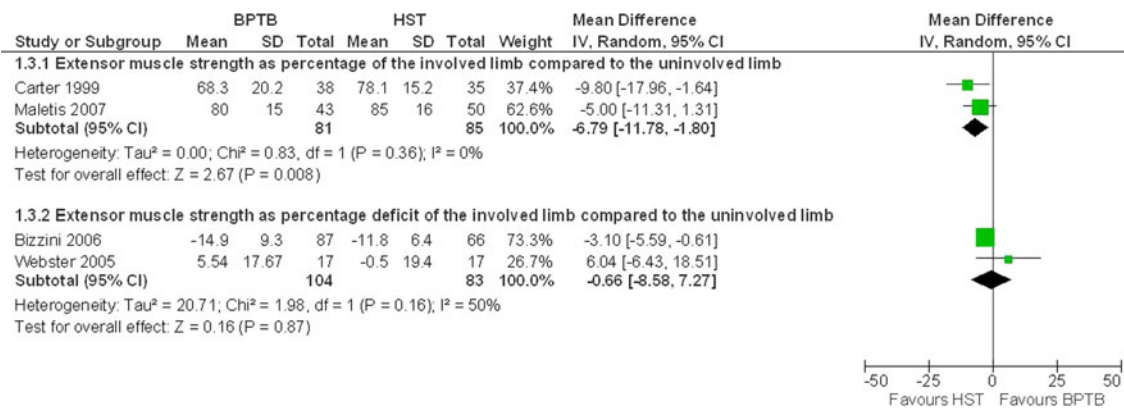


Fig. 3 Forest plots for isokinetic extensor muscle strength at 180°/s at 12 months. *BPTB* bone patellar tendon bone, *HST* hamstring, *SD* standard deviation, *CI* confidence interval

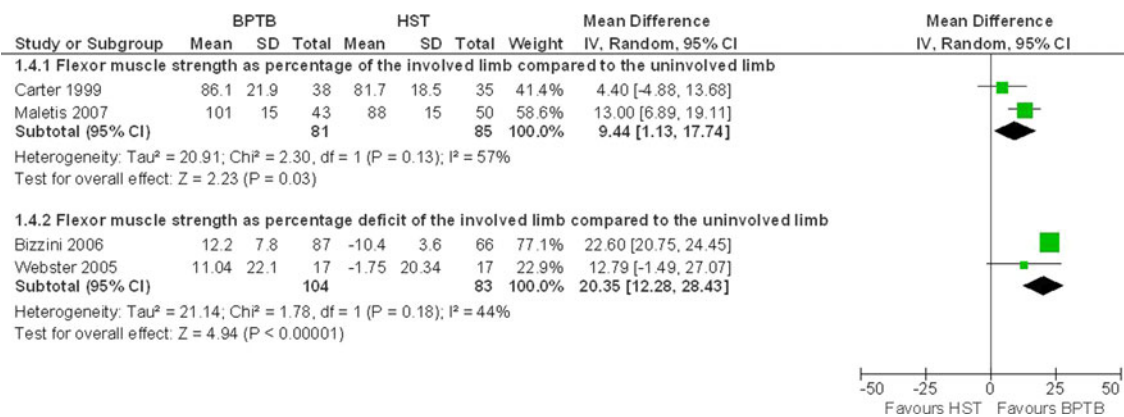


Fig. 4 Forest plots for isokinetic flexor muscle strength at 180°/s at 12 months. *BPTB* bone patellar tendon bone, *HST* hamstring, *SD* standard deviation, *CI* confidence interval

gamma motor neurons (contributing to a normal muscle function) [36, 38, 63]; however, this mechanism is not restored with ACL reconstruction, and may, therefore, also play a role in the extensor muscle weakness seen after harvesting the BPTB graft. Furthermore, knee pain and effusion have been documented up to 12 months following ACL reconstruction and could alter the neural control of the quadriceps [37, 65, 68].

Strength deficits in the knee flexor muscles may be more easily explained. There is evidence that tendon fibers can regenerate following harvesting of the hamstring tendon to become similar to healthy and non-harvested fibers [25, 28]. However, Hioki et al. [34] found an atrophy of hamstrings’ muscle fibers as well as hypertrophy of the semimembranosus and biceps muscles, after harvesting the hamstrings tendon. Moreover, they demonstrated that after harvesting the hamstrings tendon the semitendinosus muscle assumes different shapes and movements and that each pattern was related to different knee flexor strength. It is not clear how these changes in morphology affect muscle and knee function.

Regardless of the physiological explanations for muscle weakness, it is clear that restoration of muscle strength must focus on increasing muscle strength following ACL reconstruction to maximize functional outcomes. In particular, it appears that patients with different graft types may be susceptible to muscle strength that is specific to graft type. These findings suggest that rehabilitation that addresses muscle weakness specific to graft type may enhance strength outcomes after ACL reconstruction.

The findings of muscle weakness related to graft donor site were not consistent throughout all of the studies included in this review. There were some methodological differences between these studies that may explain this inconsistency. The method of randomization was not reported or was insufficient for the most of the RCTs. Only three [11, 26, 42] used a specific random allocation, which verifies that allocation was concealed. This allows for a bias that potentially could alter the findings of these studies. Although almost all RCTs assessed patients with the same activity level, three did not report the sex of the patients despite the plethora of information that gender

influences outcome after ACL reconstruction. Therefore, the generalizability of the findings reported in these studies may be limited [1, 64]. Although blinding is one of the most important factors to limit bias in a RCT, no patients or therapist and only 2 studies reported that assessors were blinded to patient group allocation. Only in the trials of Aglietti et al. [5] and Maletis et al. [42], the assessors were blinded. Again, the potential for bias in the findings of those studies that did not blind assessors needs to be considered. The studies that were not RCTs were subjected to different biases. Because patients in these studies were not randomized to receive either a BPTB or HST graft, it is important that both groups be similar at baseline on factors that may confound muscle strength findings. However, 3 studies did not adequately describe that groups were similar on important demographic characteristics such as height and weight. These limitations need to be considered when interpreting the findings of this review. Future work that compares the muscle strength outcomes between patients with either BPTB or HST ACL reconstruction needs to consider these factors when designing future research.

There are some limitations that need to be considered when interpreting the findings of this review. The meta-analysis was limited to only half of the studies included in the review because of disparity in the parameters of isokinetic testing (e.g., the speed of testing, and the time since surgery). Nevertheless, studies that did not evaluate muscle strength according to the strict criteria were still included in the systematic review and contribute significantly to the information that details recovery of muscle strength following ACL reconstruction.

Conclusions

Although not all studies reported muscle strength differences between patients with either BPTB or HST graft ACL reconstruction, there was an obvious trend toward greater muscle weakness that was dependent on the graft donor site. Rehabilitation that is specific to this difference in muscle strength between graft types is needed.

Furthermore, more high quality studies need to be conducted assessing the muscle strength recovery after the reconstruction of the torn ACL, in order to reveal a potential superiority of a graft type over the other graft options.

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Appendix

See Fig. 5.

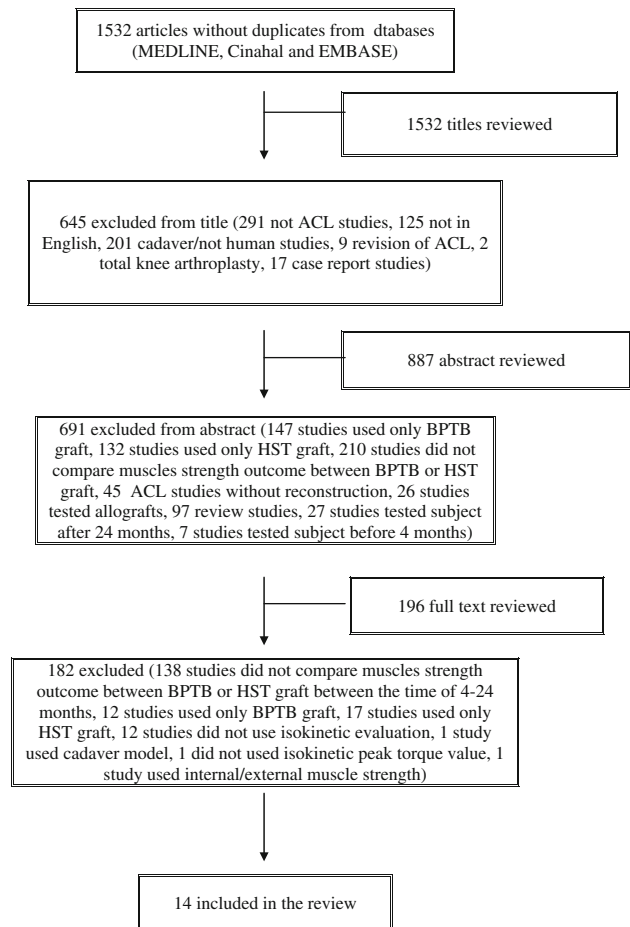


Fig. 5 Flow chart of the search and included and excluded studies

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