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N.B.: When citing this work, cite the original article.

The original publication is available at www.springerlink.com:

Sofia A Xergia, Jodie A McClelland, Joanna Kvist, Haris S Vasiliadis and Anastasios D Georgoulis, The influence of graft choice on isokinetic muscle strength 4-24 months after anterior cruciate ligament reconstruction, 2011, KNEE SURGERY SPORTS TRAUMATOLOGY ARTHROSCOPY, (19), 5, 768-780.

<http://dx.doi.org/10.1007/s00167-010-1357-0>

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Postprint available at: Linköping University Electronic Press

<http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-67964>

1 The influence of graft choice on isokinetic muscle strength 4-24 months after
2 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°/sec and 180°/sec, 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 two years after ACL reconstruction.

Keywords: ACL reconstruction, isokinetic muscle strength, systematic review, meta-analysis.

Level of evidence; III

Introduction

Rupture of the Anterior Cruciate Ligament (ACL) is one of the most common athletic injuries of the knee [17, 60, 14]. 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 [4]. 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 [61, 30, 72, 66, 54, 29, 46, 51, 58, 47, 50]. 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) appear to be the most popular grafts choices [4, 12, 23, 24, 26, 53, 45].

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. Postoperative 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, 71]. However, increased donor- site morbidity has been reported after harvesting BPTB autograft. Specifically, anterior knee pain, quadriceps weakness and worse results in functional

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76 tests along with an increased rate of patellar fractures have been observed [43, 44, 40,
77 27, 49]. Harvesting of the HST autograft may avoid some of these post-operative
78 problems, but is associated with hamstring muscle weakness and slower healing of the
79 graft attachment site that may predispose patients to higher risk of re-rupture [69, 2,
80 65]. Thus, both of these graft choices are limited in the their ability to restore knee
81 function for people with ACL rupture, and there is consequently an ongoing debate
82 concerning the superiority of one graft over the other. An imporant aspect of this
83 debate is the outcome of lower limb muscle strength following either of these graft
84 types.

85 Evaluation of muscle stength can be accomplished by using functional tools
86 (incorporating hop or twisting) or single joint evaluation tools [52, 9, 2]. One of the
87 most commonly used tools that is reliable in assessing single-joint muscle strength is
88 isokinetic dynamometry [56, 19]. In comparison to other measures of strength,
89 isokinetic dynamometry allows quantification of muscle strength deficit through the
90 assesement of specific parameters like work per unit, torque at spefici joint angles and
91 the widely used peak torque value [56, 19, 66, 22]. In the majority of studies, that
92 investigate muscle strength following ACL recontruction, the strength of the operated
93 limb is recorded as a deficit or gain in comparison to the contralateral healthy limb.

94 Restoration of similar muscle strength between reconstructed and healthy
95 knee, is considered to be a critical factor for a safely return back to dynamic activities
96 [48]. Thus, the restoration of muscle strength ratio between the operated and
97 contralateral limbs for both the quadriceps and the hamstrings is crucial after an ACL
98 reconstruction for a fast an uneventful return to pre-injury activities [48]. There is
99 evidence that muscular recovery is closely related to pre-operative muscle strength the
100 time between injury and reconstruction and the pre and post surgery rehabilitation [22,

101 55, 8]. In addition, changes in the sensory system with ACL reconstruction, such as
102 alterations in the somatosensory evoked potentials or the development of inconsistent
103 postural synergies, may also influence muscle [18].

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

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Material and methods

A thorough search of the databases MEDLINE, Cinahal 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

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

144 **Extraction of Data**

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

150 A meta-analysis was conducted on the findings of isokinetic evaluations at
151 testing speeds of 60⁰/sec and 180⁰/sec an average of 12 months after ACL
152 reconstruction surgery. To be included in the meta-analysis, the mean and measures of
153 variability must have been reported. Wherever the outcomes were not presented in a
154 form suitable for direct inclusion in the meta-analysis, the corresponding authors were
155 contacted by email in an attempt to obtain the data required for meta-analysis
156 (numbers of participants, mean scores and SDs).

158 **Statistical Analysis**

159 Muscle strength of the operated limb was extracted when reported either as a
160 percentage of the uninvolved limb (i.e Limb Symetry Index), or as a percentage
161 deficit of the uninvolved limb (100 X deficit of injured leg/deficit of uninjured leg).

Mean differences and 95% confidence intervals were calculated from the extracted data. Random-effects models was used to pool data. Review Manager 5 (Version: 5.0.24) software was used for the calculation of effect sizes.

Results

A total of 1532 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 1). 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 are presented in table 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, 11, 12, 7, 16, 68] 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 [26, 10, 42, 35] 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, 26, 42, 31, 70, 13] 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, 68, 70] 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°/sec. 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°/sec. 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.

211 Discussion

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

217 Not all studies reported muscle weakness in one group of patients or the other.
218 Six studies [5, 11, 12, 7, 16, 68] did not find significant differences in extensor or
219 flexor muscle strength between BPTB or HST group, at any testing speed (60°/sec,
220 120°/sec, 180°/sec, 240°/sec, 300°/sec). In contrast, eight studies found differences
221 between groups. Significant quadriceps muscle strength deficit in BPTB group was
222 observed in four studies [10, 42, 26, 35] and six studies found significant hamstrings
223 muscle deficits in HST group [10, 42, 26, 13, 31, 70]. All of the studies evaluated
224 patients between 4 and 24 months after surgery and muscle weakness was found to
225 persist throughout this period. These findings are in agreement with other reviews [57,
226 19], that have concluded that the graft site affects muscle strength.

227 There is an obvious trend for quadriceps deficit at BPTB group compared to
228 HST group and a trend for hamstrings deficit in HST group compared to BPTB group
229 at 12 months post-operative. The results of the meta-analysis showed that difference
230 between BPTB and HST group for extensor muscle strength was nearly 10% at the
231 speed of 60°/sec and 180°/sec and that for flexor muscle strength was 20% at
232 180°/sec. It is clinically accepted that anything less than a 10% difference between
233 limbs is considered inconsequential [39]. Although the difference in quadriceps
234 strength between sides was not greater than 10%, the difference in hamstring strength
235 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 gamma motor neurons (contributing, to a normal muscle function) [36, 62, 38], 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 [64, 37, 67].

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 affects 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, 63]. 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 and HST ACL reconstruction need 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 (for example, 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 towards 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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311 **Table 1.** Characteristics of the included studies. (RCT-> Randomized Control
 312 StudyNon RCT -> non, Randomized Control Study, BPTB-> Bone Patella Tendon
 313 Bone, HST-> Hamstring (when is not specified if the graft was semitendinosus or
 314 somitndinosus/gracilis), ST -> Semitendinosus, ST/G-> semitendinosus/Gracilis, PT-
 315 > Patella tendon, IKDC→ International Knee Documentation Committee, KOOS→
 316 Knee injury and Osteoarthritis Outcome Score, VAS scale→ Visual Analog Scale,
 317 FL→ Flexion, EX→ Extension, ATT→ Anterior Tibial Translation, ROM→ Range
 318 Of Motion, * → We communicated with the author about the sex)

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AUTHOR YEAR NATION	STUDY DESIGN	PATIENTS SEX	REHAB PROTOCOL	OUTCOMES	ISOKINETIC MUSCLE STRENGTH OUTCOMES	POST- OPERATIVE FOLLOW UP
<i>Aglietti 2004</i>	RCT	120p 60BPTB (46M/14F) 60 HAST (46M/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 °/sec. 120°/sec. 180°/sec	4, 12 and 24 months
<i>Andersson 2002</i>	Non RCT	45p 22BPTB 23HST No sex mentioned	Shelbourn and Nitz (1990)	—	FL/EX Isokinetic 60°/sec concentric /eccentric	6 and 12 months
<i>Aune 2001</i>	RCT	72P 35BPTB (19M/16F) 37HST (21M/16F)	Shelbourn and Nitz (1990)	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 °/sec, 240°/sec	6, 12, and 24 months
<i>Beard 2001</i>	RCT	45p 22BPTB (18M/4F) 23HST (15M/8F) *	Shelbourn and Nitz (1990)	KT1000 IKDC ATT Lysholm score, Tegner activity score,	FL/EX Isokinetic at 60°/sec	6 and 12 months
<i>Bizzini 2006</i>	Non RCT	153p 87BPTB (54M/ 33F) 66HST (45M/21F)	Description of the program	KT 1000	FL/EX Isokinetic at180°/sec, 300°/sec	11 months

Beynnon 2002	RCT	52p 26BPTB (18M/10M) 26HST (13M/15F)	Description of the program	KT 1000, Pivot Shift, IKDC ROM Tegner, One-leg-hop, duckwalking, squat.	FL/EX Isokinetic at 60°/sec 180°/sec, 240°/sec	2,4,6,12 and 36 months
Carter 1999	RCT	106p 38 PT, 33 ST 35 ST/G No sex mentioned	Description of the program	—	FL/EX Isokinetic at 180°/sec, 300°/sec	6 months
Feller 2003	RCT	65p 34BPTB (8F/23M) 31HST (10F/24M)	Shelbourn and Nitz (1990)	KT-1000, Lachmann IKDC Cincinnati Scores Anterior knee pain	FL/EX Isokinetic at 60°/sec, 240°/sec	4, 8, and 12 months
Gobbi 2003	Non RCT	80p 40BPTB 40HST No sex mentioned	Description of the program	CA 4000 IKDC Tegner scale Noyes scale Lysholm VAS scale for pain ROM	FL/EX Isokinetic at 60°/sec, 180°/sec, 300°/sec	3, 6, 12 and 36 months
Jansson 2003	RCT	99p BPTB 51 HST 48 No sex mentioned	Description of the program	CA 4000 IKDC Lachman and pivot shift Lysholm knee score Tegner activity level Kujala patellofemoral score MRI	FL/EX Isokinetic at 60°/sec, 180°/sec	12 and 24 months
Maletis 2007	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°/sec 180°/sec 300°/sec ABD/ADD 60°/sec 180°/sec 300°/sec INT/EXT rot 60°/sec 180°/sec 300°/sec	6,12 and 24 months
Two 2005	Non RCT	68p 34HST 34BPTB No sex specified	Description of the program	KT 1000 IKDC	FL/EX Isokinetic at 60°/sec 240°/sec	3, 6, and 24 months
Webster 2005	Non RCT	34p 17BPTB (16M/1F) 17HST (16M/1F) 17 CONTROL	Description of the program	IKDC KT 1000 Kinematic walking up/down Kinetic walking up/down	FL/EX Isokinetic at 60°/sec	BPTB-11 months HST-9.3 months
Witvrouw 2001	Non RCT	34p17BPTB (10M/7F) 32HST (17M/15F)	Description of the program	ROM KT 1000 Lysholm, Tegner, Kujala scales	FL/EX Isokinetic at 60°/sec 240°/sec	6weeks 3,6 and 12 months

Table 2. Results from the methodological assessment of the eight RCTs using the Pedro scale. (Y: Yes
N: No)

<i>Pedro Criteria</i>	<i>Item no.1</i>	<i>Item no.2</i>	<i>Item no.3</i>	<i>Item no.4</i>	<i>Item no.5</i>	<i>Item no.6</i>	<i>Item no.7</i>	<i>Item no.8</i>	<i>Item no.9</i>	<i>Item no.10</i>	<i>Item no.11</i>
	Eligibility criteria specified	Subjects randomly allocated to groups	Concealed allocation	Baseline data	Blinding of subjects	Blinding of therapists	Blinding of assessors	Key outcome obtained from > 85% of the subjects	Intention to treat	Appropriate statistics	Measures of variability
<i>First author (year)</i>											
<i>Agglieti et al 2004</i>	Y	N	N	Y	N	N	Y	Y	Y	Y	N
<i>Aune et al 2001</i>	Y	N	N	Y	N	N	N	Y	Y	Y	N
<i>Beard et al 2001</i>	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y
<i>Beynnon et al 2002</i>	Y	N	N	Y	N	N	N	Y	Y	Y	N
<i>Carter et al 1999</i>	N	N	N	N	N	N	N	Y	N	Y	Y
<i>Feller et al 2003</i>	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y
<i>Jansson et al 2003</i>	Y	N	N	Y	N	N	N	Y	Y	Y	N

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<i>Maletis et al 2007</i>	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N
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Table 3. Results from the methodological assessment of the six non-RCTs using the Downs and Black scale. (Y: Yes
N: No)

Downs & Black criteria	Item no. 1	Item no. 2	Item no. 3	Item no. 5	Item no. 6	Item no. 7	Item no. 12	Item no. 16	Item no. 18	Item no. 25	Item no. 27
	Clear aim	Outcomes described	Patients described	Confounders described	Findings clearly described	Measures of random variability	Patients represent population	Planned analysis	Appropriate statistics	Modification for confounders	Power calculation
<i>First author (year)</i>											
<i>Anderson 2002</i>	Y	Y	Y	Y	Y	Y	Y	X	Y	X	N
<i>Bizzini 2006</i>	Y	Y	Y	Y	Y	Y	Y	X	Y	X	N
<i>Gobbi 2003</i>	Y	Y	N	N	Y	N	Y	X	Y	X	N
<i>Tow 2005</i>	Y	Y	N	N	Y	N	Y	X	N	X	N
<i>Webster 2005</i>	Y	Y	Y	Y	Y	Y	Y	X	Y	X	N
<i>Witvrow 2001</i>	Y	Y	Y	Y	Y	Y	N	X	Y	Y	N

Table 4. Muscle strength outcomes of the included RCT, at the time between 4-24 months. (ND: no difference between groups (BPTB vs HST) for flexion/extension strength, - : No evaluated)

RCT	Isokinetic-Flexion/Extension					
AUTHOR YEAR	4 months	6 months	8 months	11 months	12 months	24 months
Aglietti 2004	ND between groups at 60°/sec, 120°/sec, 180°/sec	—	—	—	ND between groups at 60°/sec, 120°/sec, 180°/sec	ND between groups at 60°/sec, 120°/sec, 180°/sec
Aune 2001	—	<u>Extension deficit</u> in BPTB group at 60°/sec, 240°/sec <u>Flexion deficit</u> in HST group at 240°/sec	—	—	<u>Flexion deficit</u> in HST group at 60°/sec 240°/sec	<u>Flexion deficit</u> in HST group at 60°/sec 240°/sec
Beard 2001	—	ND between groups at 60°/sec	—	—	ND between groups at 60°/sec	—
Beynnon 2002	—	—	—	—	ND between groups at 60°/sec, 180°/sec, 240°/sec	—
Carter 1999	—	ND between groups at 180°/sec, 300°/sec	—	—	—	—
Feller 2003	<u>Extension deficit</u> in BPTB group at 240°/sec	—	<u>Extension deficit</u> in BPTB group at 60°/sec, 240°/sec	—	<u>Flexion deficit</u> in HST group at 60°/sec	—
Jansson 2003	—	—	—	—	<u>Extension deficit</u> in BPTB group at 60°/sec	ND between groups at 60°/sec, 180°/sec
Maletis 2007	—	<u>Extension deficit</u> in BPTB group at 60°/sec, 180°/se, 300°/sec <u>Flexion deficit</u> in HST group at 180°/sec	—	—	<u>Extension deficit</u> in BPTB group at 60°/sec, 180°/se, 300°/sec <u>Flexion deficit</u> in HST group at 180°/sec, 300°/sec	<u>Extension deficit</u> in BPTB group at 60°/sec, 300°/sec <u>Flexion deficit</u> in HST group at 180°/sec

Table 5. Muscle strength outcomes of the included non-RCT, at the time between 4-24 months. (ND: no difference between groups (BPTB vs HST) for flexion/extension strength, - : No evaluated)

NRCT	Isokinetic-Flexion/Extension					
AUTHOR YEAR	4 months	6 months	8 months	11 months	12 months	24 months
Andersson 2002	—	ND between groups at 60°/sec	—	—	ND between groups at 60°/sec	—
Bizzini 2006	—	—	—	<u>Flexion deficit</u> in HST group at 180°/sec, 300°/sec	—	—
Gobbi 2007	—	—	—	—	<u>Flexion deficit</u> in HST group at 60°/sec, 180°/sec, 300°/sec	—
Two 2009	—	Trend towards HST flexion muscle weakness	—	—	—	Trend towards HST flexion muscle weakness
Webster 2005	—	—	9.3-11 Months ND between groups at 60°/sec, 240°/sec		—	—
Witvrow 2001	—	<u>Flexion deficit</u> in HST group at 60°/sec,	—	—	<u>Flexion deficit</u> in HST group at 60°/sec, 240°/sec	—

337 **Figure Legents**

338 **Figure 1**

339 Forest plots for isokinetic extensor muscle strength at 60°/sec at 12 months.

340 BPTB: Bone Patellar Tendon Bone, HST: Hamstring, SD: standard deviation, CI: confidence interval

341 **Figure 2**

342 Forest plots for isokinetic flexor muscle strength at 60°/sec at 12 months.

343 BPTB: Bone Patellar Tendon Bone, HST: Hamstring, SD: standard deviation, CI: confidence interval

344 **Figure 3**

345 Forest plots for isokinetic extensor muscle strength at 180°/sec at 12 months

346 BPTB: Bone Patellar Tendon Bone, HST: Hamstring, SD: standard deviation, CI: confidence interval

347 **Figure 4**

348 Forest plots for isokinetic flexor muscle strength at 180°/sec at 12 months

349 BPTB: Bone Patellar Tendon Bone, HST: Hamstring, SD: standard deviation, CI: confidence interval

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Appendix 1. Flow chart of the search and included and excluded studies.

393 **ACKNOWLEDGEMENTS**

394 The authors acknowledge the support from the Greek General Secretariat for Research
395 and Technology and the European Union (Operative Program Competitiveness;
396 AKMON) to the Orthopaedic Sports Medicine Center, and the Hellenic Association
397 of Orthopaedic Surgery & Traumatology.
398

References

1. Ageberg E, Forssblad M, Herbertsson P, Roos E M (2010) Sex Differences in Patient-Reported Outcomes After Anterior Cruciate Ligament Reconstruction: Data From the Swedish Knee Ligament Register. *Am J Sports Med* 38:1334-1342
2. Ageberg E, Roos H P, Silbernagel K G, Thomee R, Roos E M (2009) Knee extension and flexion muscle power after anterior cruciate ligament reconstruction with patellar tendon graft or hamstring tendons graft: a cross-sectional comparison 3 years post surgery. *Knee Surg Sports Traumatol Arthrosc* 17: 162-169
3. Aglietti P, Buzzi R, Giron F, Simeone A J, Zaccherotti G (1997) Arthroscopic-assisted anterior cruciate ligament reconstruction with the central third patellar tendon. A 5-8-year follow-up. *Knee Surg Sports Traumatol Arthrosc* 5: 138-144
4. Aglietti P, Buzzi R, Zaccherotti G, De B P (1994) Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med* 22: 211-217
5. Aglietti P, Giron F, Buzzi R, Biddau F, Sasso F (2004) Anterior cruciate ligament reconstruction: bone-patellar tendon-bone compared with double semitendinosus and gracilis tendon grafts. A prospective, randomized clinical trial. *J Bone Joint Surg Am* 86-A: 2143-2155
6. Anderson A F, Snyder R B, Lipscomb A B, Jr (2001) Anterior cruciate ligament reconstruction. A prospective randomized study of three surgical methods. *Am J Sports Med* 29: 272-279
7. Anderson J L, Lamb S E, Barker K L, Davies S, Dodd C A, Beard D J (2002) Changes in muscle torque following anterior cruciate ligament reconstruction: a comparison between hamstrings and patella tendon graft procedures on 45 patients. *Acta Orthop Scand* 73: 546-552
8. Andersson D, Samuelsson K, Karlsson J (2009) Treatment of anterior cruciate ligament injuries with special reference to surgical technique and rehabilitation: an assessment of randomized controlled trials. *Arthroscopy* 25: 653-685
9. Augustsson J, Thomeé R, Karlsson J (2004) Ability of a new hop test to determine functional deficits after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 12:350-356.
10. Aune A K, Holm I, Risberg M A, Jensen H K, Steen H (2001) Four-strand hamstring tendon autograft compared with patellar tendon-bone autograft for anterior cruciate ligament reconstruction. A randomized study with two-year follow-up. *Am J Sports Med* 29: 722-728

- 440 11. Beard D J, Anderson J L, Davies S, Price A J, Dodd C A (2001) Hamstrings
441 vs. patella tendon for anterior cruciate ligament reconstruction: a randomised
442 controlled trial. *Knee* 8: 45-50
- 443 12. Beynnon B D, Johnson R J, Fleming B C, Kannus P, Kaplan M, Samani J,
444 Renstrom P (2002) Anterior cruciate ligament replacement: comparison of
445 bone-patellar tendon-bone grafts with two-strand hamstring grafts. A
446 prospective, randomized study. *J Bone Joint Surg Am* 84-A: 1503-1513
- 447 13. Bizzini M, Gorelick M, Munzinger U, Drobny T (2006) Joint laxity and
448 isokinetic thigh muscle strength characteristics after anterior cruciate ligament
449 reconstruction: bone patellar tendon bone versus quadrupled hamstring
450 autografts. *Clin J Sport Med* 16: 4-9
- 451 14. Bollen S R, Scott B W (1996) Rupture of the anterior cruciate ligament--a
452 quiet epidemic? *Injury* 27: 407-409
- 453 15. Brand J, Jr., Weiler A, Caborn D N, Brown C H, Jr., Johnson D L (2000) Graft
454 fixation in cruciate ligament reconstruction. *Am J Sports Med* 28: 761-774
- 455 16. Carter T R, Edinger S (1999) Isokinetic evaluation of anterior cruciate
456 ligament reconstruction: hamstring versus patellar tendon. *Arthroscopy* 15:
457 169-172
- 458 17. Childs S G (2002) Pathogenesis of anterior cruciate ligament injury. *Orthop*
459 *Nurs* 21: 35-40
- 460 18. Courtney C, Rine R M, Kroll P (2005) Central somatosensory changes and
461 altered muscle synergies in subjects with anterior cruciate ligament deficiency.
462 *Gait Posture* 22: 69-74
- 463 19. Dauty M, Tortellier L, Rochcongar P (2005) Isokinetic and anterior cruciate
464 ligament reconstruction with hamstrings or patella tendon graft: analysis of
465 literature. *Int J Sports Med* 26: 599-606
- 466 20. de Morton N A (2009) The PEDro scale is a valid measure of the
467 methodological quality of clinical trials: a demographic study. *Aust J*
468 *Physiother* 55: 129-133
- 469 21. Downs S H, Black N (1998) The feasibility of creating a checklist for the
470 assessment of the methodological quality both of randomised and non-
471 randomised studies of health care interventions. *J Epidemiol Community*
472 *Health* 52: 377-384
- 473 22. Eitzen I, Holm I, Risberg M A (2009) Preoperative quadriceps strength is a
474 significant predictor of knee function two years after anterior cruciate ligament
475 reconstruction. *Br J Sports Med* 43: 371-376
- 476 23. Ejerhed L, Kartus J, Sernert N, Kohler K, Karlsson J (2003) Patellar tendon or
477 semitendinosus tendon autografts for anterior cruciate ligament
478 reconstruction? A prospective randomized study with a two-year follow-up.
479 *Am J Sports Med* 31: 19-25

- 480 24. Eriksson K, Anderberg P, Hamberg P, Olerud P, Wredmark T (2001) There
481 are differences in early morbidity after ACL reconstruction when comparing
482 patellar tendon and semitendinosus tendon graft. A prospective randomized
483 study of 107 patients. *Scand J Med Sci Sports* 11: 170-177
- 484 25. Eriksson K, Kindblom L G, Hamberg P, Larsson H, Wredmark T (2001) The
485 semitendinosus tendon regenerates after resection: a morphologic and MRI
486 analysis in 6 patients after resection for anterior cruciate ligament
487 reconstruction. *Acta Orthop Scand* 72: 379-384
- 488 26. Feller J A, Webster K E (2003) A randomized comparison of patellar tendon
489 and hamstring tendon anterior cruciate ligament reconstruction. *Am J Sports*
490 *Med* 31: 564-573
- 491 27. Feller J A, Webster K E, Gavin B (2001) Early post-operative morbidity
492 following anterior cruciate ligament reconstruction: patellar tendon versus
493 hamstring graft. *Knee Surg Sports Traumatol Arthrosc* 9: 260-266
- 494 28. Ferretti A, Conteduca F, Morelli F, Masi V (2002) Regeneration of the
495 semitendinosus tendon after its use in anterior cruciate ligament
496 reconstruction: a histologic study of three cases. *Am J Sports Med* 30: 204-
497 207
- 498 29. Finsterbush A, Frankl U, Matan Y, Mann G (1990) Secondary damage to the
499 knee after isolated injury of the anterior cruciate ligament. *Am J Sports Med*
500 18: 475-479
- 501 30. Fischer-Rasmussen T, Jensen P E (2000) Proprioceptive sensitivity and
502 performance in anterior cruciate ligament-deficient knee joints. *Scand J Med*
503 *Sci Sports* 10: 85-89
- 504 31. Gobbi A, Mahajan S, Zanazzo M, Tuy B (2003) Patellar tendon versus
505 quadrupled bone-semitendinosus anterior cruciate ligament reconstruction: a
506 prospective clinical investigation in athletes. *Arthroscopy* 19: 592-601
- 507 32. Herzog W, Longino D, Clark A (2003) The role of muscles in joint adaptation
508 and degeneration. *Langenbecks Arch Surg* 388: 305-315
- 509 33. Hiemstra L A, Webber S, MacDonald P B, Kriellaars D J (2000) Knee
510 strength deficits after hamstring tendon and patellar tendon anterior cruciate
511 ligament reconstruction. *Med Sci Sports Exerc* 32: 1472-1479
- 512 34. Hioki S, Fukubayashi T, Ikeda K, Niitsu M, Ochiai N (2003) Effect of
513 harvesting the hamstrings tendon for anterior cruciate ligament reconstruction
514 on the morphology and movement of the hamstrings muscle: a novel MRI
515 technique. *Knee Surg Sports Traumatol Arthrosc* 11: 223-227
- 516 35. Jansson K A, Linko E, Sandelin J, Harilainen A (2003) A prospective
517 randomized study of patellar versus hamstring tendon autografts for anterior
518 cruciate ligament reconstruction. *Am J Sports Med* 31: 12-18

- 519 36. Johansson H, Sjolander P, Sojka P (1991) Receptors in the knee joint
520 ligaments and their role in the biomechanics of the joint. *Crit Rev Biomed Eng*
521 18: 341-368
- 522 37. Kartus J, Movin T, Karlsson J (2001) Donor-site morbidity and anterior knee
523 problems after anterior cruciate ligament reconstruction using autografts.
524 *Arthroscopy* 17: 971-980
- 525 38. Konishi Y, Fukubayashi T, Takeshita D (2002) Mechanism of quadriceps
526 femoris muscle weakness in patients with anterior cruciate ligament
527 reconstruction. *Scand J Med Sci Sports* 12: 371-375
- 528 39. Kvist J (2004) Rehabilitation following anterior cruciate ligament injury:
529 current recommendations for sports participation. *Sports Med* 34: 269-280
- 530 40. Lautamies R, Harilainen A, Kettunen J, Sandelin J, Kujala U M (2008)
531 Isokinetic quadriceps and hamstring muscle strength and knee function 5 years
532 after anterior cruciate ligament reconstruction: comparison between bone-
533 patellar tendon-bone and hamstring tendon autografts. *Knee Surg Sports*
534 *Traumatol Arthrosc* 16: 1009-1016
- 535 41. Lyman S, Koulouvaris P, Sherman S, Do H, Mandl L A, Marx R G (2009)
536 Epidemiology of anterior cruciate ligament reconstruction: trends,
537 readmissions, and subsequent knee surgery. *J Bone Joint Surg Am* 91: 2321-
538 2328
- 539 42. Maletis G B, Cameron S L, Tengan J J, Burchette R J (2007) A prospective
540 randomized study of anterior cruciate ligament reconstruction: a comparison
541 of patellar tendon and quadruple-strand semitendinosus/gracilis tendons fixed
542 with bioabsorbable interference screws. *Am J Sports Med* 35: 384-394
- 543 43. Marumoto J M, Mitsunaga M M, Richardson A B, Medoff R J, Mayfield G W
544 (1996) Late patellar tendon ruptures after removal of the central third for
545 anterior cruciate ligament reconstruction. A report of two cases. *Am J Sports*
546 *Med* 24: 698-701
- 547 44. Mastrokalos D S, Springer J, Siebold R, Paessler H H (2005) Donor site
548 morbidity and return to the preinjury activity level after anterior cruciate
549 ligament reconstruction using ipsilateral and contralateral patellar tendon
550 autograft: a retrospective, nonrandomized study. *Am J Sports Med* 33: 85-93
- 551 45. Matsumoto A, Yoshiya S, Muratsu H, Yagi M, Iwasaki Y, Kurosaka M,
552 Kuroda R (2006) A comparison of bone-patellar tendon-bone and bone-
553 hamstring tendon-bone autografts for anterior cruciate ligament
554 reconstruction. *Am J Sports Med* 34: 213-219
- 555 46. McDaniel W J, Jr., Dameron T B, Jr (1983) The untreated anterior cruciate
556 ligament rupture. *Clin Orthop Relat Res* 172: 158-163
- 557 47. Meunier A, Odensten M, Good L (2007) Long-term results after primary
558 repair or non-surgical treatment of anterior cruciate ligament rupture: a

- 559 randomized study with a 15-year follow-up. *Scand J Med Sci Sports* 17: 230-
560 237
- 561 48. Myer G D, Paterno M V, Ford K R, Quatman C E, Hewett T E (2006)
562 Rehabilitation after anterior cruciate ligament reconstruction: criteria-based
563 progression through the return-to-sport phase. *J Orthop Sports Phys Ther* 36:
564 385-402
- 565 49. Natri A, Jarvinen M, Latvala K, Kannus P (1996) Isokinetic muscle
566 performance after anterior cruciate ligament surgery. Long-term results and
567 outcome predicting factors after primary surgery and late-phase
568 reconstruction. *Int J Sports Med* 17: 223-228
- 569 50. Nelson F, Billingham R C, Pidoux I, Reiner A, Langworthy M, McDermott
570 M, Malogne T, Sitler D F, Kilambi N R, Lenczner E, Poole A R (2006) Early
571 post-traumatic osteoarthritis-like changes in human articular cartilage
572 following rupture of the anterior cruciate ligament. *Osteoarthritis Cartilage* 14:
573 114-119
- 574 51. Noyes F R, Matthews D S, Mooar P A, Grood E S (1983) The symptomatic
575 anterior cruciate-deficient knee. Part II: the results of rehabilitation, activity
576 modification, and counseling on functional disability. *J Bone Joint Surg Am*
577 65: 163-174
- 578 52. Noyes FR, Barber SD, Mangine RE (1991) Abnormal lower limb symmetry
579 determined by function hop tests after anterior cruciate ligament rupture. *Am*
580 *J Sports Med.* 19:513-8
- 581
- 582 53. Otero A L, Hutcheson L (1993) A comparison of the doubled
583 semitendinosus/gracilis and central third of the patellar tendon autografts in
584 arthroscopic anterior cruciate ligament reconstruction. *Arthroscopy* 9: 143-148
- 585 54. Papadonikolakis A, Cooper L, Stergiou N, Georgoulis A D, Soucacos P N
586 (2003) Compensatory mechanisms in anterior cruciate ligament deficiency.
587 *Knee Surg Sports Traumatol Arthrosc* 11: 235-243
- 588 55. Petersen W, Laprell H (1999) Combined injuries of the medial collateral
589 ligament and the anterior cruciate ligament. Early ACL reconstruction versus
590 late ACL reconstruction. *Arch Orthop Trauma Surg* 119: 258-262
- 591 56. Pua Y H, Bryant A L, Steele J R, Newton R U, Wrigley T V (2008) Isokinetic
592 dynamometry in anterior cruciate ligament injury and reconstruction. *Ann*
593 *Acad Med Singapore* 37: 330-340
- 594 57. Samuelsson K, Andersson D, Karlsson J (2009) Treatment of anterior cruciate
595 ligament injuries with special reference to graft type and surgical technique: an
596 assessment of randomized controlled trials. *Arthroscopy* 25: 1139-1174

58. Shelbourne K D, Foulk D A (1995) Timing of surgery in acute anterior cruciate ligament tears on the return of quadriceps muscle strength after reconstruction using an autogenous patellar tendon graft. *Am J Sports Med* 23: 686-689
59. Shelbourne K D, Gray T (1997) Anterior cruciate ligament reconstruction with autogenous patellar tendon graft followed by accelerated rehabilitation. A two-to nine-year followup. *Am J Sports Med* 25: 786-795
60. Smith B A, Livesay G A, Woo S L (1993) Biology and biomechanics of the anterior cruciate ligament. *Clin Sports Med* 12: 637-670.
61. Snyder-Mackler L, Fitzgerald G K, Bartolozzi A R, III, Ciccotti M G (1997) The relationship between passive joint laxity and functional outcome after anterior cruciate ligament injury. *Am J Sports Med* 25: 191-195
62. Sojka P, Sjolander P, Johansson H, Djupsjobacka M (1991) Influence from stretch-sensitive receptors in the collateral ligaments of the knee joint on the gamma-muscle-spindle systems of flexor and extensor muscles. *Neurosci Res* 11: 55-62
63. Stijak L, Radonjic V, Nikolic V, Blagojevic Z, Aksic M, Filipovic B (2009) Correlation between the morphometric parameters of the anterior cruciate ligament and the intercondylar width: gender and age differences. *Knee Surg Sports Traumatol Arthrosc* 17: 812-817
64. Torry M R, Decker M J, Viola R W, O'Connor D D, Steadman J R (2000) Intra-articular knee joint effusion induces quadriceps avoidance gait patterns. *Clin Biomech (Bristol , Avon)* 15: 147-159
65. Tow B P, Chang P C, Mitra A K, Tay B K, Wong M C (2005) Comparing 2-year outcomes of anterior cruciate ligament reconstruction using either patella-tendon or semitendinosus-tendon autografts: a non-randomised prospective study. *J Orthop Surg (Hong Kong)* 13: 139-146
66. Tsepis E, Giakas G, Vagenas G, Georgoulis A (2004) Frequency content asymmetry of the isokinetic curve between ACL deficient and healthy knee. *J Biomech* 37: 857-864
67. Van d, V, Gill T J, DeFrate L E, Papannagari R, Li G (2008) The effect of anterior cruciate ligament deficiency and reconstruction on the patellofemoral joint. *Am J Sports Med* 36: 1150-1159
68. Webster K E, Wittwer J E, O'Brien J, Feller J A (2005) Gait patterns after anterior cruciate ligament reconstruction are related to graft type. *Am J Sports Med* 33: 247-254
69. West R V, Harner C D (2005) Graft selection in anterior cruciate ligament reconstruction. *J Am Acad Orthop Surg* 13: 197-207

- 635 70. Witvrouw E, Bellemans J, Verdonk R, Cambier D, Coorevits P, Almqvist F
636 (2001) Patellar tendon vs. doubled semitendinosus and gracilis tendon for
637 anterior cruciate ligament reconstruction. *Int Orthop* 25: 308-311
- 638 71. Yunes M, Richmond J C, Engels E A, Pinczewski L A (2001) Patellar versus
639 hamstring tendons in anterior cruciate ligament reconstruction: A meta-
640 analysis. *Arthroscopy* 17: 248-257
- 641 72. Zatterstrom R, Friden T, Lindstrand A, Moritz U (1994) The effect of
642 physiotherapy on standing balance in chronic anterior cruciate ligament
643 insufficiency. *Am J Sports Med* 22: 531-536
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