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Review

Strength assessment after proximal hamstring rupture: A critical review and analysis

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ABSTRACT

Background: Muscular strength should be one of the main parameters to assess the interest or not of surgery after proximal hamstring rupture. Yet, this parameter is difficult to compare between the different studies because of the heterogeneous assessment methods.

Methods: We realized a critical review of strength assessment methods used to evaluate treatments performed after proximal hamstring rupture. The studies were selected from several medical databases with the keywords: “proximal hamstring rupture” OR “proximal hamstring avulsion” AND “strength” OR “isokinetic”.

Findings: 24 articles evaluated muscular strength after proximal hamstring rupture. 7 have been excluded because the method was not described. 6 types of dynamometric evaluation were used: 2 with an isometric method, 3 with a pneumatic isotonic method and 13 with an isokinetic method. Muscular strengths after non-surgical treatment could not be compared because of the low number of studies and different methods of assessment. After surgery, only isokinetic results measured at the angular speed of 60°/s could have been weighted. A 15% strength deficit was shown at > 12 months after surgery.

Interpretation: Muscular strength assessment methods currently used to evaluate the strength after proximal hamstring rupture are too disparate to clearly define the strength deficit after rupture and surgery. Strength evaluation should be more rigorous in order to prove the real interest of the surgical management.

1. Introduction

Hamstring injuries are well described because they represent 12 to 24% of the lesions in high-level athletes (Dauty and Collon, 2011; Ekstrand et al., 2016; Opar et al., 2012). Yet, proximal lesions represent only 12% of the whole hamstring lesions (Lempainen et al., 2006). The semimembranosus insertion is usually the most often injured one (Davis, 2008; Lempainen et al., 2006). Traumatic proximal complete rupture of the hamstrings with a retraction of > 2 cm, diagnosed in the first 4 weeks in young athletes, seems to be the best surgical indication (Ahmad et al., 2013; Ali and Leland, 2012; Bodendorfer et al., 2017; Lempainen et al., 2015; Piposar et al., 2017; Subbu et al., 2015). However, the treatment of proximal hamstring ruptures remains controversial because of disparate results from 3 recent meta-analyses, based on several criteria of evaluation (Bodendorfer et al., 2017; Harris et al., 2011; van der Made et al., 2015). These evaluations of operative or non-operative treatments reported subjective results thanks to semi-quantitative questionnaires which have explored patients' faculty of compensation: Lower Extremity Functional Scale (LEFS), Harris Hip Score, Single Assessment Numeric Evaluation (SANE), quality of life (SF-12), patients' satisfaction, Marx Score, University of California at Los Angeles Activity (UCLA) Score, pain visual analog scale, return to sport, Tegner Score, self-evaluation of strength. Only 2 quantitative evaluations can be considered objective: the hop test which evaluates global lower limb motor control (Hofmann et al., 2014; Skaara et al., 2013) and the measure of muscular strength of knee flexors. Muscular strength should be considered scientifically the main parameter, because the surgical procedure consists in the proximal reinsertion of the hamstrings. Muscular strength directly informs about the mechanical consequences of the rupture, surgically repaired or not. It can be measured objectively and reproducibly with a dynamometer (Chamorro et al., 2017; de Araujo Ribeiro Alvares et al., 2015; Li et al., 1996). However, results are usually difficult to compare between studies because of different methods of assessment (isometric, isotonic, isokinetic) and different protocols. The measured strength parameters are also different: strength (kg, N or Nw), work (J) or endurance (%).

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Sometimes, there are calculated in the form of hamstring-to-quadriceps ratios (%). The hamstring strength deficit was usually used to know the difference in percentage between the injured and the healthy limb according to the formula: 1- (Hamstring strength of the injured side/ Hamstring strength of the healthy side). In order to better understand the results of muscular strength assessment and to criticize the methods of evaluation, we aimed to perform a critical review and analysis of the studies previously published.

2. Methods

2.1. Search strategy

This systematic review was performed with medical databases: Medline via PubMed, CINAHL and SPORTdiscus via EBSCOhost, Cochrane Library, EMBASE via OvidSP, and Web of Science. Article research extended from 1990 to 2018. Multiple searches were carried out using the following keywords: “Proximal Hamstring Rupture” OR “Proximal Hamstring Avulsion” AND “Strength” OR “Isokinetic”. Only studies in English language were selected. The search was performed independently by 2 assessors (A.F-C, M.D) to assess titles and abstracts of potentially relevant articles, and then the full-text articles were retrieved. In case of doubt, a third assessor's advice was asked (P.M.). After identification of key articles, their reference and citation lists were perused for further information sources.

2.2. Eligibility criteria

The studies which evaluated muscular strength after proximal hamstring rupture, were included both in case of surgery or not. Case reports, cases series with fewer than 5 patients and studied with results only in percentages of progression, were excluded.

2.3. Data extraction

From original articles, we extracted the number of subjects of the studied populations, the exact number of patients who had a strength assessment, the patients' mean age, the complete or partial nature of the muscular rupture, the type of treatment and rehabilitation, the delay from the surgery or the delay from the hamstring rupture to the strength evaluation, the method of muscular evaluation with the type of dynamometer used and the protocol of evaluation.

2.4. Statistical analysis

We initially reported raw data from the studies. These results have been expressed in percentage of strength deficit with the standard deviation and/or with minimal and maximal values. Then, the strength deficits were weighted according to the number of evaluated patients in order to compare the studies. Weight means, standard deviation or minimal and maximal values were obtained by pooling the sums of each respective sample size and dividing them by the total sample size (Bodendorfer et al., 2017). The results were separated according to the different methods of muscular strength evaluation (isometric with hand held, isotonic with pneumatic system and isokinetic). Since the inter-machine reliability of the Cybex® (Cybex, division of Lumex Inc., Ronkonkoma, NY, USA) and Biodex® (Biodex Medical Systems, Shirley, NY, USA) isokinetic dynamometers are acceptable (ICC: 0.88–0.92; SEM: 3,7–11,2 Nm; CV: 8,5–10,7%), the studies which used these dynamometers were pooled (de Araujo Ribeiro Alvares et al., 2015). Conversely, studies using other dynamometers such as Isobex® (Cursor AG, Bern, Switzerland) or Isomed® 2000 (D. & R. Ferstl GmbH, Hemau, Germany) were excluded of this pooling, because the reproducibility of the measures was unknown even after research in the medical databases previously cited or on the websites of the manufacturers. The results obtained with pneumatic method, initially described by Cross et al. (Cross et al., 1998), were analyzed separately; the reproducibility of these measures was not known. The results obtained with the isometric method using a hand-held® dynamometer were also analyzed separately because the method was very different from the pneumatic isotonic method or the isokinetic method (Scudder, 1980). The isometric method using a hand-held® dynamometer is reproducible (SEM: 3.8–13.5 kg) but provides results that depends on the strength opposed by the investigator (Chamorro et al., 2017; Lu et al., 2012).

2.5. Quality of the muscular strength assessment

The quality of the muscular strength assessment of the studies was evaluated independently by 2 authors (M.D and A.F-C) using the Physiotherapy Evidence Database (PEDro) scale (de Morton, 2009; Elkins et al., 2010). If no consensus was found, the opinion of a 3rd reviewer was required (P.M.). The PEDro scale has 11 items whose answers are “present” or “absent”, the first item is not taken into account for the calculation of the final score (van der Made et al., 2015). According to PEDro scale, a study has a low-quality if its score is ≤5.

3. Results

3.1. Characteristics of the studies (Fig. 1)

Twenty-four studies were eligible, 7 were excluded: 4 case reports (Blasier and Morawa, 1990; Clark et al., 2011; Sonnery-Cottet et al., 2012), 2 series of cases with fewer than 5 patients (Chakravarthy et al., 2005; Kurosawa et al., 1996; Marx et al., 2009), 1 study with results only in percentages of progression (Aldridge et al., 2012). Seventeen studies were finally included, and they all were of low-quality (Table 1). Indeed, the blinding of participants, therapists and assessors is impossible during muscular strength assessment. Four studies evaluated

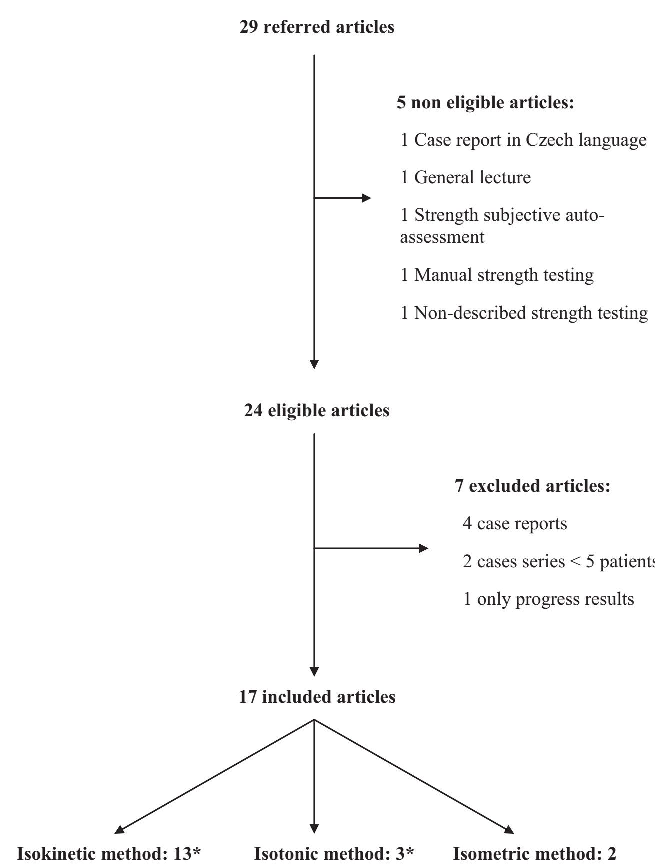

Fig. 1. Flow-chart.

Table 1
Quality assessment of the studies (PEDro scale).

Studies	Eligibility criteria	Random allocation	Concealed allocation	Similar baseline	Participant blending	Therapist blending	Assessor blending	> 85% Follow-up	Intention-to-treat	Comparison between-groups	Variability measures	Total Score/10
Cross et al., 1998	−	−	+	−	−	−	−	− (77%)	+	−	−	2
Klingele and Sallay, 2002	−	−	+	−	−	−	−	+	+	+	+	5
Brucker and Imhoff, 2005	−	−	−	−	−	−	−	+	+	−	+	3
Sallay et al., 1996	−	−	+	−	−	−	−	− (68%)	+	−	−	2
Folsom and Larson, 2008	+	−	+	−	−	−	−	− (33%)	+	+	+	4
Wood et al., 2008	−	−	−	−	−	−	−	+ (86%)	+	−	−	2
Konan and Haddad, 2010	−	−	−	−	−	−	−	+	+	−	+	3
Birmingham et al., 2011	−	−	+	−	−	−	−	− (67%)	+	−	+	3
Chahal et al., 2012	−	−	+	−	−	−	−	+ (92%)	+	−	−	3
Lefevre et al., 2013	−	−	−	−	−	−	−	− (50%)	+	−	+	2
Skaara et al., 2013	−	−	−	−	−	−	−	+ (97%)	−	−	+	3
Hofmann et al., 2014	−	−	+	−	−	−	−	+	+	−	−	3
Barnett et al., 2015	+	−	−	−	−	−	−	+	+	+	−	3
Sandmann et al., 2016	+	−	−	−	−	−	−	− (80%)	+	−	−	1
Piposar et al., 2017	−	−	+	−	−	−	−	+	+	−	+	4
Shambaugh et al., 2017	−	−	+	−	−	−	−	+ (85%)	+	+	−	4
Fouasson-Chailloux et al., 2019	+	−	−	−	−	−	−	+	+	−	+	3
Mean												2.94 ± 0.96

Table 2
Characteristics of the studied populations.

Authors	n patients	Age (years)	Hamstring rupture	Surgery or not (N)	Rehabilitation
Cross et al., 1998	9	34	C	Ethibond or Stay-Tec sutures	Brace: 8w Full weight bearing:12w
Klingele and Sallay, 2002	11	41	C	Mitek suture anchors	Suspension device: 4w Full weight bearing: 6w
Brucker and Imhoff, 2005	8	40	5C/3P	Mitek suture anchors	Knee orthosis: 6w Full weight bearing: 6w
Sallay et al., 1996	22	43	C	FiberWire and Ethibond sutures	Brace: 4-6w Full weight bearing:?
Folsom and Larson, 2008	21	44	C	Mitek suture anchors Achilles tendon autograft	Brace: 6w Full weight bearing: 6w
Wood et al., 2008	71	40	63C/7P/2os	Ethibond and Super Quick Anchors Plus suture anchors	Brace: 8w Full weight bearing: 6w
Konan and Haddad, 2010	10	29	3C/?	Mitek suture anchors	Brace: 6w Full weight bearing: 6w
Birmingham et al., 2011	34	46	C	Mitek suture anchors	Hip-Knee orthosis: 6w Full weight bearing: 6w
Chahal et al., 2012	13	44	C	Corkscrew suture anchors	Brace: 6w Full weight bearing: 6w
Lefevre et al., 2013	34	39	C23C/11P	Mitek suture anchors	Brace: 6w Full weight bearing: 6w
Skaara et al., 2013	31	51	C/?	Mitek suture anchors	No brace Full weight bearing: 6w
Hofmann et al., 2014	17	58	C	Nonoperative	No brace, full weight bearing
Barnett et al., 2015	132	42	96C/36P	Ethibond and Super QuickAnchors Plus	No brace Full weight bearing: 6w
Sandmann et al., 2016	15	47	C/?	Mitek suture anchors and Krackow stitches	Hip-Knee orthosis: 6w Full weight bearing:?
Piposar et al., 2017	44	48vs55	P	19 cases: Nonoparative 25 cases: Q-Fix suture	No brace, full weight bearing Hip brace: 4w Full weight bearing: 6w
Shambaugh et al., 2017	24	58vs50	C	11cases: Nonoperative 13 cases: Q-Fix suture and Krackow stitches	No brace, Full weight bearing Brace: 4w Full weight bearing: 8w
Fouasson-Chailloux et al., 2019	16	34	6C/10P	Nonoperative	No brace, full weight bearing

Abbreviations: C and P: complete and partial rupture; N: nonoperative treatment; operative treatment, w: weeks.

non-operated ruptures (Table 2). Three studies reported a follow-up of the muscular strength recovery (Folsom and Larson, 2008; Fouasson-Chailloux et al., 2019; Sallay et al., 1996). Six dynamometric methods were used: isometric (Hand-Held®) (Hofmann et al., 2014; Shambaugh et al., 2017), isotonic with a Keiser leg-press® pneumatic system (Barnett et al., 2015; Cross et al., 1998; Wood et al., 2008), isokinetic with Biodex® system (Folsom and Larson, 2008; Lefevre et al., 2013; Piposar et al., 2017; Shambaugh et al., 2017; Skaara et al., 2013), Cybex® system (Birmingham et al., 2011; Brucker and Imhoff, 2005; Fouasson-Chailloux et al., 2019; Klingele and Sallay, 2002; Konan and Haddad, 2010), Isobex® system (Chahal et al., 2012) and Isomed® 2000 (Sandmann et al., 2016). One study used an isokinetic method but did not mention the dynamometer used (Sallay et al., 1996). Another study used 2 different methods, isometric measurements for non-operated patients and isokinetic measurements for operated patients (Shambaugh et al., 2017). The protocols of strength evaluation were different and were unknown in 3 studies (Chahal et al., 2012; Klingele and Sallay, 2002; Sallay et al., 1996). During isokinetic assessment, the angular speed mostly used was 60°/s (7 times) but other speeds were sometimes studied. Only one study reported results on an eccentric mode (Fouasson-Chailloux et al., 2019). Four studies searched for correlation between the hamstring strength and the patients' age, the length of the muscular retraction, the delay between the injury and the surgery, the return to sport, the functional scores UCLA and LEFS, the subjective perception of strength loss and finally the single hop-test (Birmingham et al., 2011; Lefevre et al., 2013; Shambaugh et al., 2017; Skaara et al., 2013).

3.2. Studies' raw data (Table 3)

The delay of the hamstring strength assessment was inconstant from one study to another, varying from 4 months to 100 months. The studies included 512 patients and 446 were evaluated, that is to say 87.1%. Before surgery, the hamstring strength deficit was 46% in case of incomplete rupture and 76% in case of complete rupture (Barnett et al., 2015).

If no surgery was performed, the mean strength deficit between 4 months and 100 months was decreasing from 40% ± 25 to 25% ± 16. At 2 years of follow-up, extreme values ranged from a complete recovery to a persistent strength deficit of 70% (Fouasson-Chailloux et al., 2019; Hofmann et al., 2014). On an eccentric mode, a deficit of 40% ± 17 [17–70%] persisted 24 months after the injury whereas the deficit of strength was reduced to 25% ± 16 on a concentric mode (Fouasson-Chailloux et al., 2019).

In case of surgical procedure, the mean deficit of strength was from 17 to 26%, 6 months after surgery (Folsom and Larson, 2008; Klingele and Sallay, 2002; Konan and Haddad, 2010) and from 2 to 16%, 12 months after surgery (Folsom and Larson, 2008; Lefevre et al., 2013; Sallay et al., 1996; Wood et al., 2008). Yet, concerning the studies with a follow-up superior to 2 years, the mean deficit remained between 10 and 40% (Barnett et al., 2015; Birmingham et al., 2011; Brucker and Imhoff, 2005; Chahal et al., 2012; Cross et al., 1998; Klingele and Sallay, 2002; Sandmann et al., 2016; Shambaugh et al., 2017; Skaara et al., 2013). Considering only isokinetic assessments, the mean deficit at 60°/s was from 11 to 22%, 2 years after surgery, with extreme values from 50% of persistent deficit to 50% of strength improvement, compared to the healthy side (Birmingham et al., 2011; Brucker and Imhoff, 2005; Chahal et al., 2012; Klingele and Sallay, 2002; Shambaugh et al., 2017; Skaara et al., 2013). The work parameter decreased of 20% and the endurance from 7 to 14% (Birmingham et al., 2011; Skaara et al., 2013). Concerning the calculated parameters, the hamstring-to-quadriceps ratio at 60°/s was between 0.39 and 0.56 [0.28–0.84] on the

Table 3
Hamstring strength deficit after of proximal muscle rupture.

Studies	Tested Patients	Delay of test (months)	Dynamometer	Protocol	Mean deficit	Max/min
Cross et al., 1998	7/9	48	Isotonic	6 rep	39.1%	57/12%
			Keiser	Endurance	42.9%	74/0%
Klingele and Sallay, 2002	11	> 12 (36?)	Cybex	60°/s?	14.7%	50–2%
Brucker and Imhoff, 2005	8	33 [12–59]	Cybex	60°/s	11.2%	37/+14%
				ROM/25°	H/Q60: 0.55	0.44–0.61
Sallay et al., 1996	15/22	6–12	Isokinetic?	?	11%	31/0%
		> 12			2%	28/+76%
Folsom and Larson, 2008	7/21	6	Biodex	60°/s	29.3%	37/10%
		> 12		180°/s	9.8%	23/ +4
				60°/s	8.4%	37/ +15%
				180°/s	11.9%	24/+7%
					H/Q60: 0.28–0.67	H/Q180: 0.45–0.90
Wood et al., 2008	61/71	> 12?	Isotonic	6 rep	16%	57/+22%
			Keiser	Endurance	11%	26/+61%
Konan and Haddad, 2010	10	4	Cybex	60°/s	17.2%	62/+17%
					H/Q60: 0.55	0.33–0.84
Birmingham et al., 2011	23/34	43 [12–108]	Cybex	180°/s	10%	40/+24%
				240°/s	7%	32/+31%
				Endurance = W?	H/Q180: 0.48	H/Q240: 0.56
				Correlation	180: 9%	64/+53%
					240: 19%	45/+58%
Chahal et al., 2012	12/13	36?	Isobex	?	22 ± 6%	12/26%
Lefevre et al., 2013	17/34	11 ± 5.6	Biodex	90°/s	7.3 ± 18%	?
				180°/s	6.2 ± 16.2%	?
				240°/s	+0.8 ± 12.5%	?
				Correlation	H/Q240: 0.54 ± 8	
Skaara et al., 2013	30/31	30	Biodex	60°/s	16.4 ± 22.3%	51/+50%
				Correlation	H/Q60: 0.39 ± 9	36/+27%
				W60	19.3 ± 21.1	
Hofmann et al., 2014	17	31 [8–156]	Handheld	45 et 90° flex	38 et 34%	?
Barnett et al., 2015	132	Pré-op	Isotonic	6rep	C76 ± 24%	46 ± 37%
		24	Keiser	Endurance	63 ± 54%	29 ± 54%
					19 ± 22%	15 ± 19%
					+6 ± 49%	9 ± 59%
Sandmann et al., 2016	12/15	56? [24–112]	Isomed2000	60°/s x 3rep	13.2 ± 20%	?
				Rom/5°(0/110)		
Piposar et al., 2017	44	35 ± 30 vs 30 ± 19	Biodex	60°/s	4.2 ± 17% vs	?
				180°/s	+1.2 ± 23%	?
					5.6 ± 11.2%vs	
					8.5 ± 17.2%	
Shambaugh et al., 2017	24	30 ± 44 vs 42 ± 25	Handheld	45 et 90° flex	43.5 ± 7.8% and	?
			Biodex	300°/s	37 ± 18.8%	?
					9.2 ± 16.3%	
Fouasson-Chailloux et al., 2019	16	4 to 100	Cybex	c60°/s (4 m)	40 ± 25%	69/4%
				c60°/s (100 m)	25 ± 16%	70/14%
				e60°/s (4 m)	45 ± 17%	
				e60°/s (100 m)	40 ± 17%	

Abbreviations: H/Q: Hamstring-to-quadriceps ratio; c and e: Concentric and eccentric mode; m: months.

injured side versus between 0.53 and 0.66 [0.36–0.72] on the healthy side, without any significant difference (Folsom and Larson, 2008; Konan and Haddad, 2010; Skaara et al., 2013).

3.3. Correlations with hamstring strength

In case of operative treatment, the isokinetic hamstring strength was only significantly correlated with the LEFS score ($r = 0.48$; $p = 0.007$) (Skaara et al., 2013) and with the UCLA score ($r = 0.49$; $p < 0.05$) (Lefevre et al., 2013). The delay to return to sport had a negative correlation with isokinetic hamstring strength ($r = -0.40$; $p = 0.05$) but no significant correlation with the degree of tendon displacement or the hamstring tear chronicity (Birmingham et al., 2011). However, a trend to a negative correlation between the degree of retraction and hamstring total work at 180°/s suggested that great tendon displacement may lead to a lower hamstring strength ($r = -0.53$; $p = 0.06$) (Birmingham et al., 2011). In case of tendon retraction superior to 5 cm, with or without sciatic nerve lesion, Wood et al. reported a significant greater deficit of strength measured with a Keiser leg-press® pneumatic system, but without providing the results they obtained (Wood et al., 2008). No correlation was shown between isometric or isokinetic hamstring strength and subjective perception of strength after operative or non-operative treatment (Shambaugh et al., 2017).

3.4. Weighted results (Table 4)

The isometric method with Hand-Held® was used for non-operated ruptures in only 2 studies with common authors (Hofmann et al., 2014; Shambaugh et al., 2017). These 2 studies did not provide minimal and maximal values and standard deviation; we only calculated weighted means. At 45° and 90° of knee flexion, the strength deficit was respectively 40.1% and 35.1%, in 28 subjects with a mean follow-up of 24 months after injury.

Three studies, with common authors, used the pneumatic method to evaluate muscular strength and endurance (Barnett et al., 2015; Cross et al., 1998; Wood et al., 2008). Only 68 operated patients were evaluated, 12 months after surgery. The mean strength deficit was 18.3% [−57% ± 20.9%] and the deficit of endurance was 14.2% [−30.9 ± 54.7%]. In their study, Barnett et al. described the smallest deficit, that is to say 6.8% ± 51 in 132 patients.

Table 4
Weighted results according to the number of patients in each study.

Method	Patients	Mean (%)	[Min/max %]	NOP or OP	Study
Isometric 45° (> 12 M)	(28/28)	40.1	–	NOP	Hofmann et al. & Shambaugh et al.
Isometric 90° (> 12 M)	(28/28)	35.1	–	NOP	Hofmann et al. & Shambaugh et al.
Isotonic pneumatic (> 12 M)	(68/80)	18.3	57/+20.9	OP	Cross et al. & Wood et al.
	(132/132)	17.9 ± 21.1	–		Barnett et al.
Endurance (> 12 M)	(68/80)	14.2	30.9/+54.7	OP	Cross et al. & Wood et al.
	(132/132)	6.8 ± 51.7	–		Barnett et al.
Isokinetic 60°/s (4–6 M)	(17/31)	22.1	51.7/+5.3	OP	Folsom et al. & Konan et al.
Isokinetic 60°/s (> 12 M)	(56/71)	14.3	47/+30.2	OP	Brucker et al., Folsomet al., Skaara et al. & Klingele et al.
Isokinetic 180°/s (> 12 M)	(30/56)	10.4	36.2/+20	OP	Birmingham et al. & Folsom et al.
	(32/59)	7.5 ± 16.8	–	OP	Lefevre et al. & Piposar et al.
Isokinetic 240°/s (> 12 M)	(40/68)	+3.6	–	OP	Lefevre et al. & Birmingham et al.

Abbreviation: Patients: Number of patients with force measurement/number of patients studied; NOP: nonoperative patients; OP: operative patients.

The isokinetic method was the most used. Only patients, who underwent surgery, could be studied. At 60°/s, between 4 and 6 months after surgery, the strength deficit was 22.1% [−51.7 ± 5.3%] in 17 patients (Folsom and Larson, 2008; Konan and Haddad, 2010). Beyond 12 months after surgery, the deficit was 14.3% [47 ± 30.2%] in 56 subjects (Brucker and Imhoff, 2005; Folsom and Larson, 2008; Klingele and Sallay, 2002; Skaara et al., 2013). The study of Piposar et al. was excluded from this analysis because the authors did not report the minimal and maximal values (Piposar et al., 2017). At the angular speed of 180°/s, > 12 months after surgery, the strength deficit was 10.4% [−36.2 ± 20.0%] in 30 patients (Birmingham et al., 2011; Folsom and Larson, 2008) or 7.5% ± 16.8 in 42 patients (Lefevre et al., 2013; Piposar et al., 2017). At the angular speed of 240°/s, only the average strength could be calculated for 40 subjects, without a deficit of strength (+3.6%) (Birmingham et al., 2011; Lefevre et al., 2013). The results expressed in the form of work were not weighted because 2 studies reported this parameter but at different angular speeds (Birmingham et al., 2011; Skaara et al., 2013). For the same reasons, ratios were not weighted, especially since a study did not report values of the healthy side (Brucker and Imhoff, 2005).

4. Discussion

According to this systematic review, it is difficult to quantify exactly the deficit of muscular strength after proximal hamstring rupture depending on the treatment. Considering isokinetic data alone (which is the method of reference (de Araujo Ribeiro Alvares et al., 2015)), a deficit of 25% persists 1 year after the injury in the absence of surgery (Chamorro et al., 2017; Fouasson-Chailloux et al., 2019). In comparison, the surgical management associated to unstandardized rehabilitation, limits this deficit to 15%, with extreme differences, from 47% of deficit to +30% of strength gain. However, there are many approximations about the populations. All the studied subjects did not benefit from a strength assessment, so parameters such as age, delay of strength evaluation and the type of injuries, are not perfectly known.

Common authors used the isometric method and the pneumatic method, which is questionable. It does not limit the interest of the studies because it has permitted to increase the number of data available, but the most recent results may have been influenced by the results previously published. It could be due to the difficulty of the recruitment of patients with proximal hamstring ruptures because of the rarity of these injuries (Fouasson-Chailloux et al., 2019). In 1998, Cross et al. described 7 patients out of 9 with a complete hamstring rupture with the pneumatic method (Cross et al., 1998). Then, Wood et al. described 69 patients out of 71 with partial and complete ruptures in 2008 (Wood et al., 2008). Finally, in 2015, Barnett al. studied 96 complete ruptures and 36 incomplete ruptures (Barnett et al., 2015). The common author of these 3 studies was Wood D. In addition, the pneumatic method cannot precisely measure the hamstring strength because only the strength of the left and right limb are evaluated without dissociating knee flexors (hamstring) from knee extensors (quadriceps) (Redden et al., 2018). So, the relation between the hamstring strength and the tendon displacement or the tendon repair cannot be known.

Concerning studies with isometric methods, 3 studies may have a potential conflict of interest in favor of surgery (Hofmann et al., 2014; Piposar et al., 2017; Shambaugh et al., 2017). Firstly, Hoffman et al. and Shambaugh et al. assessed non operated ruptures, 17 cases and 11 cases, respectively, in 2014 and 2017 (Hofmann et al., 2014; Shambaugh et al., 2017). We do not know if these patients were from the same population. Secondly, Shambaugh et al. performed a comparison with an operated group which was evaluated with an isokinetic method not comparable to the isometric method used for the non-operated group. So, their conclusion in favor of the surgery seems arguable. Both works have the same last author, Miller SL. Thirdly, Miller SL is also the last author of the study of Piposar et al. who concluded that surgery was indicated in case of painful incomplete ruptures (Piposar et al., 2017). It seems that Miller SL was the only surgeon of the study of Piposar et al., but also of the study of Shambaugh et al., both published in 2017. Because of this finding, it appears difficult to know if these 3 studies were really independent. In addition, the isometric method can be influenced by the operator strength (Bohannon, 2019). Testing procedure has to be very rigorous concerning the position of the subject, the stabilization of the body and the point of resistance on the leg. Indeed, a standardized body position is absolutely necessary because the maximum strength generated by the hamstrings is greater when the hip is flexed (Kelln et al., 2008). The effect of the gravity, which helps the knee flexion movement when the subject is evaluated in sitting position, cannot be taken into consideration to increase the precision of the measures contrarily to the isokinetic method.

The weighted results that we reported concerning isokinetic assessments seem to be independent because they are from studies with different teams. The evaluation at the isokinetic angular speed of 60°/s was the most relevant because it has been possible to associate 4 studies. Concerning the other speeds, the use of weighted results was arguable because of the lack of data, and also because the higher the angular speed was, the lower was the deficit, that is to say that at 240°/s no deficit was measurable whereas at 60°/s, there was a significant deficit of 15%, nearly twice the measurement error of the dynamometer (8.7%) (Impellizzeri et al., 2008). It helps understand how Shambaugh et al. have shown excellent post-operative results, using a single isokinetic angular speed of 300°/s (Shambaugh et al., 2017). The most discriminant angular speed to evaluate strength deficit seems to be 60°/s, since it is the case after knee anterior cruciate ligament reconstruction (Dauty et al., 2005). However, the gap between extreme values is surprising, independently of the method of evaluation. Indeed, if a strength deficit of 70% seems possible, a gain of strength of twice the measurement error of the dynamometer appears incomprehensible even after surgery. It seems possible that the contralateral side, considered as the healthy side, was not completely wholesome, especially in the studies with the oldest patients (the mean age in 13 studies out 17 was superior or equal to 40). No study explains clearly the measured strength deficits and the problems that could have occurred during the strength tests, excepted in the study of Chahal et al. (2012). In this study, 8 patients out of 12 had intense cramps on the operated side during isokinetic testing (Isobex®) at 125° of knee flexion (the delay from the surgery was unknown).

The link between the strength deficit and the length of the tendon retraction is not really known (Wood et al., 2008). Likewise, the consequences of post-operative complications on muscular strength had not been studied (Bodendorfer et al., 2017; Harris et al., 2011). Complications of surgery may explain a persistent hamstring strength deficit especially when there has been a rupture recurrence, pain related to surgical anchorage, deep infection requiring surgical resumption or sciatica-type symptoms (Barnett et al., 2015). According to these approximations and misunderstandings, the discussion about the calculated parameters appears not useful. The work which is the resultant of the measured strength and the chosen articular range of motion, thus cumulates 2 possible errors of measurement (Kannus, 1994). The ratios whatever the speed chosen, cumulate in addition of error measurement of the hamstrings, the error measurement of the quadriceps (expressed as a % and not with an international unit of measure).

Eccentric isokinetic strength evaluations were rare whereas the mechanism of hamstring ruptures is usually an eccentric mechanism (Fouasson-Chailloux et al., 2019; Klingele and Sallay, 2002; Sallay et al., 1996). Clark et al. were the first in 2011 to perform eccentric evaluation (Biodex®) in a 26-year-old sprinter, but with no precision concerning the speed used (Clark et al., 2011). They reported, at one year of follow-up, an eccentric strength deficit of 16% and a concentric strength deficit of 12%. This subject had a rupture of the biceps femoris and the semi-tendinosus with a retraction of 2 and 8 cm respectively. Fouasson-Chailloux et al. reported a higher deficit with an eccentric strength deficit of 40% and a concentric strength deficit of 25% in a population at 24 months of follow-up, in case of incomplete and complete ruptures (Fouasson-Chailloux et al., 2019). The eccentric evaluation appears as complementary to concentric evaluation, because the strength deficit measured in eccentric mode seems more discriminant than those observed in concentric evaluation for the same angular speed of 60°/s. Muscle pain, cramps or consequences of incomplete or complete rupture may explain a large strength deficit either by neuromuscular inhibition or by mechanical transmission defect when the hamstring contraction requires a lengthening of this muscle (Fouasson-Chailloux et al., 2019).

5. Conclusions

Muscular strength assessment should be the main parameter of evaluation after non-surgical or surgical managements of proximal hamstring ruptures, despite a relative weakness of the studies. The isokinetic method appears as the method of reference. The angular speed of 60°/s is the most discriminant to show a hamstring strength deficit compared to the contralateral side, a priori non-injured. If this side is not healthy or if there is a bilateral lesion, it should be mention in order to understand the results. Eccentric evaluation should be generalized in order to test more precisely the muscular strength according to a muscular contraction close to the rupture mechanism. Randomized studies would be helpful to determine the interest or not of surgery, at the acute or the chronic phases according to the type of rupture.

Declaration of competing interest

The authors declare that they have no competing interest.

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