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Original Research

Isokinetic eccentric training is more effective than constant load eccentric training on the quadriceps rehabilitation following partial meniscectomy: A randomized clinical trial

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ABSTRACT

Objectives: To compare the effects of conventional (constant load) eccentric training and isokinetic eccentric training on quadriceps muscle mass, strength and functionality of recreational athletes following partial meniscectomy.
Design: Randomized controlled trial.
Setting: XXXX, Brazil.
Participants: 32 recreational male athletes (~27 years old) who underwent partial meniscectomy performed a 6-week quadriceps strength training program in one of the experimental groups: conventional group (CG) or icokinetic group (IG).
Main outcome measures: Quadriceps muscle mass, strength, and patients' objective and self-reported function.
Results: Both groups enhanced muscle mass, strength and functionality outcomes. The IG presented higher increases than CG for muscle mass (ES = 0.99–1.41), strength (ES = 1.48–2.35), and Lysholm score (ES = 1.0). The magnitude-based inference supports that results 'very likely' or 'almost certainly' favour IG compared to CG for all outcomes, except for the single leg hop test (i.e., between-group similar change).
Conclusion: After partial meniscectomy, isokinetic eccentric training is more effective than conventional eccentric training to restore quadriceps muscle mass, strength, and functional capacity.

1. Introduction

The menisci are crucial structures for knee homeostasis (Scotti, Hirschmann, Antinolfi, Martin, & Peretti, 2013). In the United States of America, about 500,000 people experience meniscal injury every year, which generates annual costs of approximately US$ 4.0 billions (Cullen, Hall, & Golosinskiy, 2009). Degenerative meniscal injuries progress within a long time-course and usually affect middle-aged individuals (Beaufils et al., 2017), while traumatic meniscal injuries usually occur in young and physically active adults (Englund, Roemer, Hayashi, Crema, & Guermazi, 2012), mainly during sports practice (Ferry, Bergström, Hedström, Lorentzon, & Zeisig, 2014). According the competitive level, athletes usually return to sport between 53 and 88 days after a meniscal injury (Kim, Nagao, Kamata, Maeda, & Nozawa, 2013). However, despite advances in rehabilitation strategies, it is surprising that only 44% of patients return to pre-injury performance level in up to three years (Stein, Mehling, Welsch, von Eisenhart-Rothe, & Jager, 2010).

Despite partial meniscectomy presenting similar effects as sham surgery (Sihvonen et al., 2013), this arthroscopic surgery is still the first-choice treatment for patients with meniscal injuries reporting pain associated to instability and/or knee joint block (Scotti et al., 2013). Studies have described positive prognosis following this procedure in relation to pain, joint function and patient satisfaction

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(Osteras, Osteras, & Torstensen, 2012; Yim et al., 2013). However, deficits of quadriceps strength, muscle mass and activation may be found after meniscectomy in both medium (six months) and long (four years) term (Ericsson, Roos, & Dahlberg, 2006; Glatthorn, Berendts, Bizzini, Munzinger, & Maffiuletti, 2010). Therefore, it is not unusual that athletes return to sport showing muscle strength imbalances between the operated and the unaffected limbs (McLeod, Gribble, Pfile, & Pietrosimone, 2012). Such deficits affect negatively the landing mechanics in functional tests (Hsu, George, & Chmielewski, 2016), as well as increase the risk of re-injury in this joint and/or the development of knee osteoarthritis (Hall et al., 2013).

Quadriceps muscle strengthening is a key factor in rehabilitation programs following partial meniscectomy (McLeod et al., 2012). Although strength training is usually performed with the same external load during concentric and eccentric phases, exercise performed with eccentric overload optimizes the strength and muscle mass gains (Douglas, Pearson, Ross, & McGuigan, 2017). Eccentric training has been shown to be effective in quadriceps strengthening of well-conditioned athletes (Brughelli et al., 2010), young adults (Baroni et al., 2013a), healthy elderly (Dias et al., 2015), and subjects affected by multiple musculoskeletal disorders, such as knee ligament injuries (Friedmann-Bette et al., 2018; Lepley, Wojtys, & Palmieri-Smith, 2015). Nonetheless, to the best of our knowledge, there is a lack of studies with eccentric training for rehabilitation of individuals who underwent partial meniscectomy.

Eccentric exercise of the knee extensor muscle is usually performed with overload during the eccentric phase of movement in conventional (constant load) gym machines in the clinical setting (Baroni, Pinto, Herzog, & Vaz, 2015). Other option is the eccentric exercise performed in the isokinetic dynamometer, a device that enables maximal intensity muscle contractions in constant angular velocity and pre-determined range of motion (Wernbom, Augustsson, & Thomeé, 2007). It means the exercise can be performed at the individual maximal muscle strength level at each joint angle, and minimizes the risk of loading above the patient's tolerance (Kannus, 1994). Therefore, isokinetic exercise has been adopted in rehabilitation regimes in order to optimize muscle strengthening, especially in high-performance athletes (Roi et al., 2005). However, a question remains to be answered in sports physical therapy: does isokinetic exercise produce larger and/or faster quadriceps strengthening than conventional exercise in patients following partial meniscectomy?

This study aimed at comparing the effects of conventional eccentric training and isokinetic eccentric training on quadriceps muscle mass, strength and functional performance in recreational athletes following partial meniscectomy. Our hypothesis was that isokinetic eccentric training would lead to greater increments on quadriceps muscle mass, strength and functional performance compared to conventional eccentric training.

2. Methods

2.1. Study design

The current study was a randomized controled trial and blinded for assessors. All participants underwent partial meniscectomy surgery, and were randomly allocated to Conventional Group (CG) or Isokinetic Group (IG). After 14 days engaged in a standard rehabilitation program, patients initiated either the conventional eccentric training or the isokinetic eccentric training for a 6-week period. Assessments of quadriceps muscle mass (through magnetic resonance imaging - MRI), maximal strength (through isokinetic dynamometry) and functionality (through questionnaire and single leg hop test) were performed one week prior to eccentric training commencement and one week after conclusion (Fig. 1). This study was approved by the XXXXX ethics committee (protocol number 1.461.842) and previously registered at Clinical Trials website. The Consolidated Standards of Reporting Trials (CONSORT) was followed during the writing process of this article.

2.2. Participants

From January to November of 2017, male subjects who underwent partial meniscectomy surgery at the XXXX Hospital (XXXX, Brazil) were invited to the study. To be included, participants should be 18–40 years old recreational athletes (i.e., sports practice at least once a week), with body mass index between 18.5 and 24.9 kg/m^2, and unilateral partial meniscal injury diagnosed through clinical evaluation and MRI. Participants were excluded in the following cases: re-injury; injury event longer than 90 days; associated ligament injury; patellofemoral pain syndrome; thigh muscle injury in the previous 6 months; respiratory or cardiovascular limiting condition; consumers of ergogenic supplements or anabolic steroids. All eligible participants received instructions relative to the aims and procedures of the study and signed a consent form.

2.3. Sample size

The number of participants was estimated using the free-access software WinPepi. The knee extension peak torque is considered a primary outcome in the current study, so results reported by Koutras, Letsi, Papadopoulos, Gigis, and Pappas (2012) were used in the sample size estimation. Power was set as 80%, with an alpha level of 5%, resulting in a sample size of 16 subjects per group.

2.4. Randomization and blinding

Participants were randomly allocated in one of two groups by

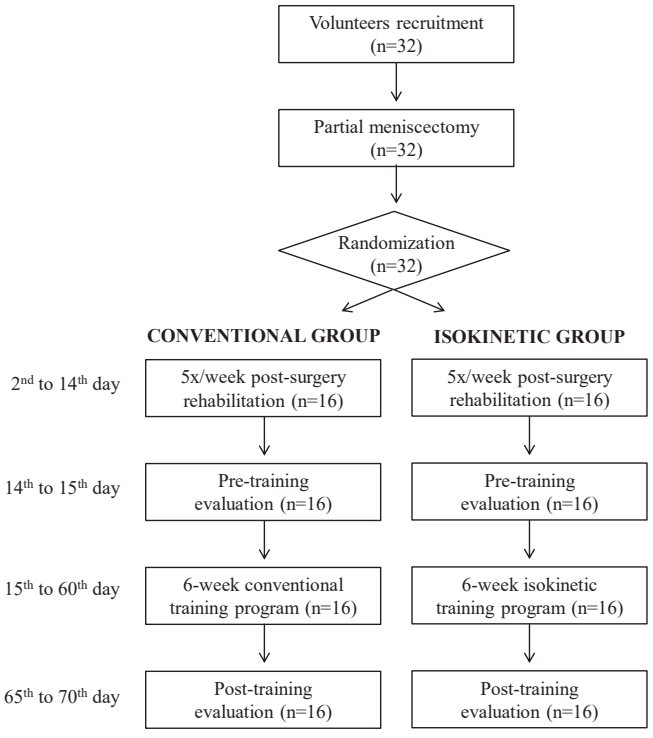

Fig. 1. Flowchart of the study.

flipping a coin (heads - CG, tails - IG). This procedure was performed by an independent researcher not involved in the outcome measures. The surgeons and researchers responsible for assessments were blinded for participants' allocation. The clinicians who applied the training programs did not participate in the assessments.

2.5. Partial meniscectomy surgery

All surgeries were performed by the same two knee surgeons who had at least 15 years of experience with partial meniscectomy. They used videoarthroscopy technique with access via anterolateral and anteromedial portals.

2.6. Post-surgery rehabilitation

Following surgery, participants received a standard physical therapy protocol with 60-min daily sessions, from the 2nd to the 14th day after partial meniscectomy (Vidmar et al., 2016). The focus was restoring range of motion, neuromuscular activation, proprioceptive skills, and gait. At the end of each session, cryotherapy was applied on the affected knee for 20 minutes to alleviate pain and reduce edema. Participants' adherence was of 100% and no adverse effects were reported.

2.7. Eccentric training

IG performed the eccentric training program for the knee extensor muscles using a Biodex™ Multi Joint System 3 Pro isokinetic dynamometer (Biodex Medical System, United States of America). The isokinetic eccentric training program was applied by 6 weeks, twice a week, with a minimal interval of 72h between sessions. Training sessions were preceded by a warm-up protocol with 10 submaximal concentric repetirions at 90°/s. In each training session, participants performed three (1st mesocycle: weeks 1–3) or four sets (2nd mesocycle: weeks 4–6) of 10 maximal intensity knee extensor eccentric contractions at 60°/s (30°–90° of knee flexion) (Baroni et al., 2013a-2013b). A 1-min resting interval was given between sets. The concentric phase was performed (from 90° to 30° of knee flexion) was performed by the physiotherapist, while the patient performed only the eccentric phase actively (Baroni et al., 2013a-2013b).

CG performed the eccentric training program for the knee extensor muscles using a commercially available extensor chair (Kenkorp, Brazil). Training duration, weekly frequency and volume (number of sets and repetitions) were the same adopted for IG. During the eccentric exercise on the extensor chair, the concentric phase (from 90° to 30° of knee flexion) was performed by the physiotherapist. From this position, participants were instructed to perform a knee extensor eccentric contraction to return their legs to 90° of knee flexion in a controlled manner. An electronic metronome was used to maintain a standard cadence of 2 s for each movement phase. The load for the first training session was estimated at 80% of the knee extensor eccentric peak torque. The exercise load was increased progressively throughout the training program according to the individual patient feedback (i.e., self-perception of ability) and his muscle strength response (i.e., once the patient could perform an 11th repetition into a set, the load was increased in the next set or training session).

2.8. Muscle mass assessment

The anatomical cross-sectional area (ACSA) of the quadriceps femoris muscle was measured using images taken from participants' thigh through T2-weighted MRI (3.0 T Magnetom, Siemens, Berlim, Germany; repetition time 4,260 ms, echo time 95 ms, means: 3, vision field of 200 x 200, cutting thickness of 4 mm). Cross-sectional images were taken at 50% of the distance between the minor trochanter and the lateral femoral condyle. All assessments were taken by the same technician with 12 years of experience in this evaluation. MRI scans were analyzed using the Image-J software (National Institute of Health, USA). The perimeter of each muscle (vastus medialis, vastus intermedius, vastus lateralis and rectus femoris) was assessed manually by a single researcher blinded to the groups allocation, and the average of three measures from each muscle was used for analysis (Blazevich, Cannavan, Coleman, & Horne, 2007). The quadriceps ACSA was estimated by summing the perimeters of these muscles.

2.9. Muscle strength assessment

The knee extensor strength capacity was measured using a Biodex™ Multi Joint System 3 Pro isokinetic dynamometer (Biodex Medical System, United States of America). All participants performed a familiarization session two days before the pre-training evaluation to minimize learning effects. After specific warm-up (10 submaximal concentric repetitions at 90°/s), isometric peak torque was assessed though three 5-s maximal isometric contractions of the knee extensor muscles at 60° of knee flexion (0° = full extension) (Baroni et al., 2013a). Concentric and eccentric peak torques were measured through three maximal contractions at 60°/s with ranges of motion between 90° to 10° and 30°–90°, respectively (Baroni et al., 2013a). Participants rested for 2 minutes between tests. A single researcher with experience in isokinetic evaluation and blinded to groups allocation was responsible for all assessments. He provided standard instructions, feedback and encouragement during tests.

2.10. Functionality assessment

Functional performance was assessed using the Lysholm score (version translated to Brazilian Portuguese) and the single leg hop test, just as described by previous studies (Peccin, Ciconelli, & Cohen, 2006; Tegner, Lysholm, Lysholm, & Gillquist, 1986).

2.11. Statistical analysis

The Shapiro-Wilk test was used for assumption of data normality. Baseline characteristics (age, height, weight, and body mass index) of CG and IG were compared through independent samples *t*-test. A two-way repeated measures ANOVA [group (CG; IG) x time (pre-training; pos-training)], followed by a LSD post-hoc test when appropriate, was applied to assess the interventions' effect on each outcome related to muscle mass, strength and functional capacity. A significance level of 5% ($p < 0.05$) was used for all comparisons.

Data were analyzed for practical significance using magnitude-based inference because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to clinicians than statistical significance (Hopkins, Marshall, Batterham, & Hanin, 2009). Within-group analysis included the percent change calculation (Δ% = post-training/pre-training-1), as well as the effect size (ES) calculation through the Cohen's d. Training effects were considered as "trivial" ($ES < 0.2$), "small" ($ES > 0.2$), "moderate" ($ES > 0.5$) or "large" ($ES > 0.8$) (Cohen, 1988).

Longitudinal percent changes (pre-to post-training) were used to assess the chances of a possible substantial effect favorable to CG or IG [i.e., greater that the smallest worthwhile change (0.2 multiplied by the between-subject standard deviation)].

Table 1
Baseline characteristics of conventional (CG) and isokinetic (IG) groups.

	CG (n = 16)	CG (n = 16)
Age (years)	27.2 ± 4.3	27.6 ± 6.0
Weigth (kg) *	77.3 ± 4.0	70.4 ± 8.1
Height (m)	1.77 ± 0.04	1.73 ± 0.09
BMI (kg/m^2)	24.6 ± 1.7	23.9 ± 2.6

BMI = body madd index; * Between-groups difference ($p < 0.05$).

Quantitative chances of trivial effects and substantial effects for each group were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75% = possibly; 75–95% = likely; 95–99% = very likely; >99% = almost certain (Batterham & Hopkins, 2006). When the CG and IG values were both >5%, the inference was classified as unclear (Batterham & Hopkins, 2006).

3. Results

There were no significant differences between CG and IG ($p > 0.05$) for subjects' characteristics, except for weitgh ($p < 0.001$) (Table 1).

Group-time interaction was found for isometric peak torque ($p = 0.010$), eccentric peak torque ($p = 0.031$), and Lysholm score ($p = 0.008$); while a significant time effect was observed in the following outcomes: VM and RF muscles ACSA ($p = 0.001$; $p = 0.041$); isometric, concentric and eccentric peak torques ($p < 0.001$; $p = 0.003$; $p = 0.007$); Lysholm score and single leg hop test ($p < 0.001$; $p = 0.012$) (Table 2).

The IG presented higher increases than CG for quadriceps muscle mass (effect sizes ranging between 0.99 and 1.41), muscle strength (effect sizes from 1.48 to 2.35), and Lysholm Score (effect size of 1.0). The magnitude-based inference supports that results 'very likely' (chances of 98–99%) or 'almost certainly' (chances >99%) favour IG compared to CG for these outcomes, while unclear effects were observed for the single leg hop test (Fig. 2).

4. Discussion

This clinical trial used rehabilitation programs based on eccentric exercise, either in conventional (constant load) or in isokinetic conditions, to increase quadriceps muscle mass, strength and functional performance of recreational athletes who underwent partial meniscectomy. Both training programs promoted improvements in the three analyzed domains; however, the effect magnitudes were greater in IG compared to CG. Thus, our initial hypothesis was confirmed.

Quadriceps muscle strength loss found in patients submitted to partial meniscectomy is fundamentally related to neuromuscular inhibition (Cobian, Koch, Amendola, & Williams, 2017), pain and articular swelling (Koutras et al., 2012). Quadriceps strengthening is a crucial component of the rehabilitation programs following this surgery (McLeod et al., 2012). Pain, swelling, joint stiffness and patient apprehension are factors that limit the execution of dynamic exercises in the initial stage of post-surgery rehabilitation; thus, voluntary isometric exercises and neuromuscular electrical stimulation are frequently administered during this period (Hasegawa et al., 2011). To date there is no consensus on the appropriate moment when dynamic exercises must be commenced. St-Pierre et al. (1992) suggested that the introduction of strength training in the second week after surgery does not produce better results compared to the same program starting at 6 weeks after meniscectomy. In opposition, Moffet, Richards, Malouin, Bravo, and Paradis (1994) e Koutras et al. (2012) reported that accelerated implementation of strengthening programs immediately after operation results in moderate strength recovery within 1-month period. Such studies (St-Pierre et al., 1992; Moffet et al., 1994; Koutras et al., 2012) that used accelerated protocols did not demonstrate adverse events during the rehabilitation process. The present study corroborates these findings showing that eccentric exercise in open kinetic chain can be safely introduced in early stages after partial meniscectomy, either with the isokinetic dynamometer or with the extensor chair.

Research comparing the muscular adaptations to training with constant external load and isokinetic devices have been found in the literature since the 70's (Pipes & Wilmore, 1975). To our knowledge, however, Guilhem, Cornu, Maffiuletti, and Guével (2013) was the only study that compared eccentric training programs in these two conditions. Their findings support that eccentric training with constant load was more effective than with isokinetic dynamometry to increase quadriceps muscle strength and structure (Guilhem et al., 2013), which contradicts our results. It is noteworthy that those authors (Guilhem et al., 2013) customized an isokinetic dynamometer to match the amount of work perfoemed in the two groups; instead, we employed a clinical approach to the conventional group using a commercially available extensor chair. In addition, Guilhem et al. (2013) assessed healthy males without

Table 2
Muscle mass, strength and functional performance pre-training and post-training of conventional (CG) and isokinetic (IG) groups.

	CG (n = 16)				IG (n = 16)			
	Pre	Post	Δ%	ES	Pre	Post	Δ%	ES
Muscle mass								
$ACSA_{VM}$ (cm^2) *	16.2 ± 2.6	17.5 ± 3.0	8.4 ± 5.4	0.48$^{\#}$	17.3 ± 2.3	20.6 ± 2.8	19.5 ± 13.9	1.33$^{£}$
$ACSA_{VI}$ (cm^2)	15.2 ± 3.2	15.7 ± 3.1	3.9 ± 4.3	0.16	13.1 ± 2.7	14.7 ± 2.6	13.2 ± 10.6	0.62$^{\&}$
$ACSA_{VL}$ (cm^2)	29.9 ± 4.0	31.1 ± 4.2	4.0 ± 3.2	0.30$^{\#}$	24.5 ± 4.4	26.9 ± 4.1	10.5 ± 8.3	0.58$^{\&}$
$ACSA_{RF}$ (cm^2) *	8.0 ± 1.6	8.5 ± 1.7	9.6 ± 4.1	0.31$^{\#}$	7.3 ± 1.8	8.7 ± 1.8	20.0 ± 9.1	0.80$^{£}$
$ACSA_{QUAD}$ (cm^2)	69.4 ± 9.2	72.6 ± 9.5	4.6 ± 2.3	0.35$^{\#}$	61.6 ± 7.8	70.5 ± 7.0	15.4 ± 12.4	1.24$^{£}$
Strength								
Isometric PT (Nm) *	193.0 ± 27.6	214.8 ± 34.5	11.2 ± 7.7	0.72$^{\&}$	195.5 ± 22.2	256.0 ± 30.4	31.2 ± 8.8	2.35$^{£}$
Concentric PT (Nm) *	179.5 ± 37.4	197.6 ± 36.9	11.0 ± 7.5	0.43$^{\#}$	164.7 ± 26.1	202.5 ± 36.0	22.7 ± 7.8	1.24$^{£}$
Eccentric PT (Nm) *	139.7 ± 46.4	143.9 ± 33.6	8.4 ± 12.1	0.11	120.3 ± 25.2	166.3 ± 34.5	39.2 ± 19.6	1.57$^{£}$
Functionality								
Single leg hop (cm) *	132.3 ± 37.4	148.0 ± 31.8	11.5 ± 5.9	0.47$^{\#}$	147.0 ± 25.4	169.9 ± 21.7	13.9 ± 7.7	1.00$^{£}$
Lysholm score (a.u.) *	82.81 ± 7.65	96.75 ± 2.72	17.6 ± 8.8	2.52$^{£}$	77.31 ± 7.59	99.00 ± 1.79	29.2 ± 13.3	4.12$^{£}$

ACSA = anatomical cros-sectional area; ES = effect size (pre-to post-training); $_{QUAD}$ = quadriceps; PT = peak torque; $_{VI}$ = vastus intermedius; $_{RF}$ = rectus femoris; $_{VL}$ = vastus lateralis; $_{VM}$ = vastus medialis; Δ% = percent change (pre-to post-training).
* significant time-effect (pre-to pos-training; $p < 0.05$).
$^{\#}$small effect size; $^{\&}$moderate effect size; $^{£}$large effect size.

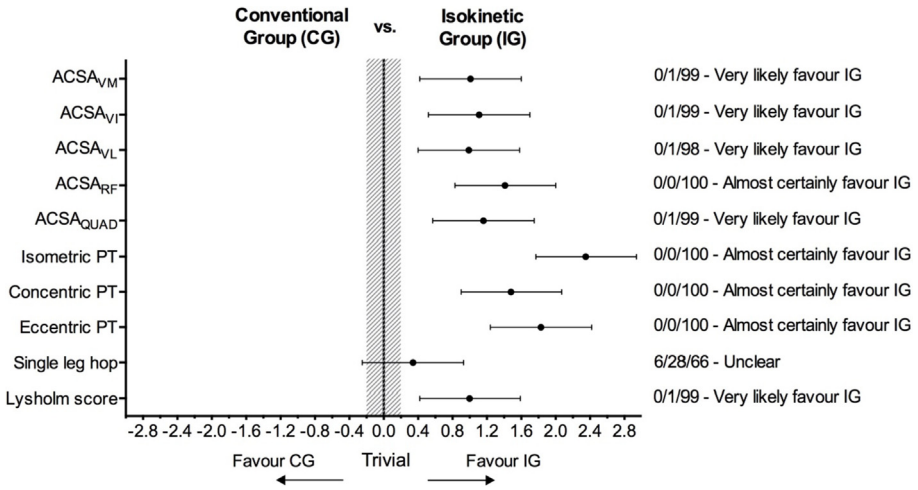

Fig. 2. Forest plot: standardized mean differences and 95%CI for conventional group (CG) and isokinetic group (IG); Right column: chances for results favorable to CG, trivial effects, or results favorable to IG (percent values and interpretation).

previous history of knee injury, therefore a quite distinct condition from the participants of our trial who had undergone partial meniscectomy recently. These specificities help to understand the different results between Guillem's study and the present study. However, it should be noted that only the IG patients performed their training sessions on the same equipment used for evaluations, which increases their chances for a learning effect and possible interference on the peak torque results.

Koutras et al. (2012) assessed patients submitted to meniscectomy and posteriorly enrolled in quadriceps strengthening programs in either isokinetic or constant load conditions, both exclusively performed with concentric contractions. Both groups performed nine sessions of knee extension exercises in open kinetic chain between the 15th and 30th post-surgery day resulting in significant increases on muscle strength and patients' functional performance, but no between-group diffrences. On the other hand, our study observed higher gains on quadriceps muscle mass and strength when using isokinetic exercise in athletes submitted to partial meniscectomy. Therefore, exercise type (isokinetic or with constant load) applied during post-meniscectomy rehabilitation seems to have no influence on muscular adaptations to concentric training (Koutras et al., 2012), but impacts significantly the results of eccentric training. Further investigations should explore these specific responses, especially in non-healthy subjects.

The greater muscle recovery in IG compared to CG found in our study seems to be clinically relevant, since athletes who recover quadriceps muscle condition tend to return to sport prematurely (Kim et al., 2013). A better muscular condition allows they initiate proprioceptive neuromuscular exercises, plyometric exercises and restoration of specific sport gestures, which are necessary steps to transit towards sports practice. In addition, long-term deficits in quadriceps strength are found following partial meniscectomy (McLeod et al., 2012), increasing the risk of knee joint degeneration (McLeod et al., 2012) and leading to poor functional/athletic performance (Hsu et al., 2016). Therefore, the current study supports the effectiveness of isokinetic exercise to accelerate the rehabilitation program through the optimization of quadriceps recovery. However, the large-scale use os isokinetic dynamometyers in the clinical setting is limited, so it is important to note that conventional training using a cheaper device (i.e., extensor chair) also worked for quadriceps rehabilitation in the current study and can be used when physiotherapists do not have access to isokinetic devices.

Our experimental groups had similar baseline characteristics (except for weight), but flipping a coin does not ensure a flawless randomization and can be pointed out as a limitation of the current study. Another limitation was that we could not follow the participants up to their discharge from physiotherapy and return to sport. Subsequent evaluations (e.g. 2–3 months after surgery) could have shown the effect caused by each eccentric training program on the rehabilitation process. In addition, we encourage future studies with clinical bias to include the time to return to sport as outcome. Other outcomes related to muscular performance, specially the rate of force development, should be further investigated in subjects following meniscectomy (Buckthorpe & Roi, 2018), as these outcomes were found to be impaired in several musculoskeletal knee disorders (Angelozzi et al., 2012; Ferreira et al., 2019; Hu et al., 2018). Lastly, it is important to mention that no adverse effects occurred during interventions, highlighting the safety of such training regimes when performed as reported here and with a similar population. It encourages researchers to develop new studies as well as physiotherapists to adopt eccentric training (either with constant load or with isokinetic devices) in their rehabilitation programs for patients after partial meniscectomy.

5. Conclusion

Our findings allow us to conclude that isokinetic eccentric training is more effective than conventional eccentric training to restore quadriceps muscle mass, strength, and functional capacity in recreational athletes who underwent to partial meniscectomy.

Conflicts of interest

None declared.

Funding

None declared.

Clinical trial registration

Registered at Clinical Trials website (NCT02961530).

Ethical approval

All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee, and with the 1964 Helsinki declaration and its later amendments. All participants provided written, informed consent. This study was approved by the Universidade Federal de Ciências da Saúde de Porto Alegre ethics committee (protocol number 1.461.842).

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