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The Effectiveness of an Isokinetic Training Protocol on Muscular Imbalances in Professional Soccer Players Following an ACL Reconstruction

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Abstract It has been indicated that strength imbalances following an ACL reconstruction are essential indicators of incomplete rehabilitation programs and increased risk for re-injury. This study evaluated the effectiveness of an isokinetic training protocol on muscular imbalances in soccer players who underwent ACL surgery. Twenty-four elite male soccer players who were found to have strength imbalances six months post-surgery were recruited and randomly assigned to either the control or the experimental group. The isokinetic knee strength was assessed before and after the 5-week intervention program. Two-way analysis of variance (ANOVA) revealed a significant main effect of training intervention on torque production for the quadriceps [F(1,22)= 34.95, p<0.001, η_p^2 = 0.61] and the hamstring [F(1,22)= 11.49, p<0.05, η_p^2= 0.34] of the operated leg. Furthermore, there was a significant interaction between the exercise condition and torque production for the quadriceps [F(1,22)= 23.46, p<0.001, η_p^2= 0.52] and the hamstring of the operated leg [F(1,22)=6.27, p<0.05, η_p^2= 0.22]. Planned comparisons revealed that the experimental group produced significantly greater quadriceps [t(11)= -5.42, p<0.01, d=1.22] and hamstring [t(11)=-3.09, p<0.01, d=0.45] torque post-training compared to the pre-training intervention. Additionally, there was a main effect of training intervention on the deficits of the quadriceps [F(1,22)=67.95, p<0.01, η_p^2= 0.76] and a significant interaction between the exercise intervention and quadriceps deficits for the two groups [F(1,22)= 32.48, p<0.001, η_p^2= 0.59]. Our results indicate that the isokinetic training program efficiently restored the muscular imbalances post-surgery, and therefore physical therapists and rehabilitation experts should consider incorporating this program into their therapy protocols.

Keywords Knee Asymmetries, Imbalances, Rehabilitation, Post-Surgery

1. Introduction

Anterior cruciate ligament (ACL) rupture is a major concern in sports, especially in soccer, which predisposes athletes to a high risk of an ACL injury [1]. Research demonstrates that significantly more ruptures occur in a non-contact situation, in which sudden decelerations, landing, and pivoting actions are performed [1,2]. Treatment usually entails surgery and multicomponent rehabilitation programs. The advances in surgical techniques and rehabilitation protocols have increased the possibility for an athlete to return to sports [3]. However, convincing evidence demonstrates that athletes with ACL reconstruction who return to their pre-injury levels are at a higher risk for a second ACL injury than those who do not return or have no previous injury history [4-7]. More specifically, 42% of the soccer players who returned to soccer after an ACL reconstruction had a new ACL injury [7], while they were more likely to have a contralateral ACL tear [4,5]. Concurrently, younger individuals were more prone to suffer a graft rupture within the first postoperative year [5], which indicates that the timing of return to sport is an essential factor to consider.

Criteria to assess readiness before an athlete returns to sports have been extensively examined [8-10], although consensus is lacking as to which criteria are the most effective [8]. These criteria include knee stability, isokinetic strength assessment, time after ACL surgery, hop performance, and self-reported questionnaires [8,9]. Research indicated that athletes who do not meet the specific criteria before returning to professional sports have a four times greater risk of suffering an ACL graft rupture than those who meet the criteria [8], stating that several athletes do not pass the criteria, despite participating in specific rehabilitation programs [9]. Concurrently, hamstring to quadriceps strength ratio deficits are associated with an increased risk of an ACL graft rupture [8]. Research indicated that more symmetrical quadriceps strength prior to returning to sports substantially reduces the re-injury rate [9]. Furthermore, the re-injury rate is reduced for each month the athlete delays the return to sports until the ninth-month post-surgery, after which the injury risk is no longer reduced [9]. Nonetheless, research indicated that an imbalance in the torque ratios of hamstring to quadriceps muscle groups as well as bilateral differences in quadriceps muscle strength are important indicators of incomplete rehabilitation programs and increased risk for re-injury [8,9]. Optimal concentric hamstring to quadriceps torque ratios have been reported to range between 0.5 and 0.75, while bilateral differences in muscular strength (torque) greater than 15% are considered abnormal and can be used as predictors of injuries or indicators of incomplete rehabilitation programs [10].

Therefore, this study aimed to assess the effectiveness of an isokinetic training protocol on muscular imbalances and asymmetries in professional soccer players who underwent an ACL surgery.

2. Materials and Methods

2.1. Subjects

Twenty-four elite male soccer players who were found to have strength asymmetries or imbalances six months post-ACL surgery participated in this randomized controlled trial. Muscular strength asymmetries greater than 15% were considered abnormal and were used as an inclusion criterion. The players' testing was done as part of their team's evaluation before they returned to official games, but participation in the study was completely voluntary. It should be noted that only participants who had an ACL reconstruction using hamstring tendon autograft were recruited for the study. Inclusion criteria after the ACL surgery were: 1) age between 19 and 32 years old, 2) sustained the injury during a soccer game or training, 3) participating in a rehabilitation program in order to return to professional soccer games, 4) first ACL surgery, 5) having completed phase IV of the rehabilitation program and 6) having muscular imbalances or deficits six months post-surgery as indicated by the isokinetic measurements of knee extensors and flexors. Players were excluded if they had knee instability of the injured knee, experienced pain or swelling, or had a multi-ligament knee injury or meniscus problems.

Eligible players were randomly assigned to either the control or the experimental group. Both groups were tested six months post-surgery as well as five weeks after the intervention. The control group continued the traditional rehabilitation program while the experimental group performed the same rehabilitation protocol in addition to the isokinetic strength training that they performed three times per week for five weeks.

Before enrolling in the study, all soccer players participated in a traditional rehabilitation program at the physical therapy center. During the initial face of the rehabilitation (1-6 weeks), the players performed a passive and active range of motion (ROM), straight-leg raises, balance and proprioceptive training, and closed kinetic exercises with limited ROM. Subsequently, they increased balance and proprioceptive training and performed more closed kinetic chain exercises in addition to frontal and lateral step-ups, lunges, stair master, and heel raises. At about 3-4 months post-surgery, they started including open kinetic chain exercises and closed kinetic exercises with full ROM; they increased balance and proprioceptive training and started running and plyometric training. After that, they increased running and plyometric exercises between five to six months and incorporated sport-specific drills in their rehabilitation routines. It should be noted that even though they followed the same rehabilitation protocol, the training volume was individualized. Despite following the aforementioned rehabilitation program, they demonstrated asymmetries and imbalances at six months, and therefore they did not meet the criteria to return to professional soccer games. Players' participation in this study was completely voluntary, and each player was briefed on the procedures before they signed an institutionally approved written informed consent form. The study was carried out in accordance with the Declaration of Helsinki and was approved by the University's ethics committee board and the National Committee on Bioethics.

2.2. Testing Protocol

The isokinetic knee strength was assessed utilizing the Humac Norm and Rehabilitation device (CSMI, Stoughton, MA, USA). Before the isokinetic testing, players performed a 5-min self-paced warm-up on a mechanically braked cycle ergometer (Monark 894 E Peak Bike, Weight Ergometer, Vansbro, Sweden). The testing began with the players sitting with their thigh at an angle of 85 ° to the trunk while the axis of rotation of the dynamometer was aligned with the lateral epicondyle of the knee joint. The range of motion at the knee joint was 100 °. The upper body, the thigh and ankle were fixed using the machine's straps. Once the players were appropriately positioned on the isokinetic device, they performed five sub-maximal repetitions of concentric knee flexion and extension for familiarization. Testing included three maximal concentric flexion and extension repetitions at an angle speed of 60 °/s. Appropriate calibration and gravity correction were performed prior to the testing and training sessions. Testing was performed at the beginning and the end of the training intervention by the same experienced tester.

2.3. Training Protocol

Both groups underwent supervised rehabilitation three times per week. The players randomized to the control group performed a supervised rehabilitation program which included running and plyometric exercises, cuttings, and sports-specific drills, while the experimental group performed the same program in addition to the isokinetic training protocol (Table 1). The creation of our training protocol was based on a previously applied protocol that was indicated to be effective in reducing imbalances and deficits in soccer players without an ACL surgery [11]. The isokinetic protocol was performed on the same day as the traditional rehabilitation program, and the players executed the program first with the non-injured leg and then with the injured one. In addition, both groups performed a 5-minute self-paced warm-up on a bike. The set-up for the isokinetic training was the same as the one for the isokinetic testing.

2.4. Statistical Analysis

SPSS 26.0 for Windows (SPSS Inc., Chicago) was used to analyze the results. Means and Standard Deviations were calculated for all the parameters. The homogeneity of variance and normality assumptions were verified. Two-way mixed analysis of variance (ANOVA) was utilized to identify between- and within-group differences. G power analysis revealed that a total sample of 36 participants was required for this statistical test to have an effect size f of 0.25, at $p<0.05$ and 95% power. Effect sizes were interpreted as follows: large (partial Eta square of 0.14 or more), medium (partial Eta square of 0.06 or more), and small (partial Eta square of 0.01 or more). Thereafter, means were compared using a paired-samples t-test. Cohen's d was used to determine the effect size. Effect sizes based on Cohen's d were interpreted as follows: small (0.2-0.4), medium (0.5-0.7), and large (0.8-1.4) [12]. For all statistical analyses, statistical significance was set at $p < 0.05$.

Table 1. Isokinetic training protocol

Week	Set (No)	Speed (°/s)	Repetition (No)	Rest (min)
Week 1-2	1	120	12	1
	2	120	12	1
	3	150	12	1
	4	150	12	1
	5	120	12	1a
	6	120	12	1a
	7	180	15	1a
	8	150	15	1a
Week 3-4	1	120	15	1
	2	120	15	1
	3	150	15	1
	4	150	15	1
	5	120	15	1a
	6	120	15	1a
	7	180	15	1a
	8	150	15	1a
Week 5	1	120	15	1
	2	120	15	1
	3	150	15	1
	4	150	15	1
	5	150	15	1a
	6	120	15	1a
	7	180	15	1a
	8	150	15	1a

a. Performed only by the muscles with an imbalance or deficit.

3. Results

The twelve participants in the experimental group (age=24.25±4.73yrs., height=177.75±5.48cm, weight pre=75.58±8.07kg, weight post=76.33±7.58) were compared to the same number of participants in the control group (age=23.83±3.86yrs., height=176.58±3.78cm, weight pre=72.75±5.03kg, weight post=72.88 ±6.43) to identify between and within-group differences following the five-week intervention. Pre- and post-intervention comparisons are presented in Table 2.

Table 2. Peak muscle torques of the quadriceps and hamstring muscles of both groups measured initially and at the end of 5-weeks at 60 °/s

	Experimental group (n=12)		Control group (n=12)	
	Pre	Post	Pre	Post
Quadriceps operated	185.17±42.06	235.50±40.17*	177.50±42.06	182.50±40.08*
Quadriceps healthy	258.25±45.33	251.92±43.99	252.83±50.27	243.33±42.21
Hamstring of operated leg	153.17±33.69	167.58±30.87*	149.42±33.24	151.58±30.65
Hamstring healthy	166.17±28.91	172.75±26.10	166.17±31.44	168.00±34.64

* Values are presented as mean ± standard deviation, Pre-post significance difference *p<0.05.

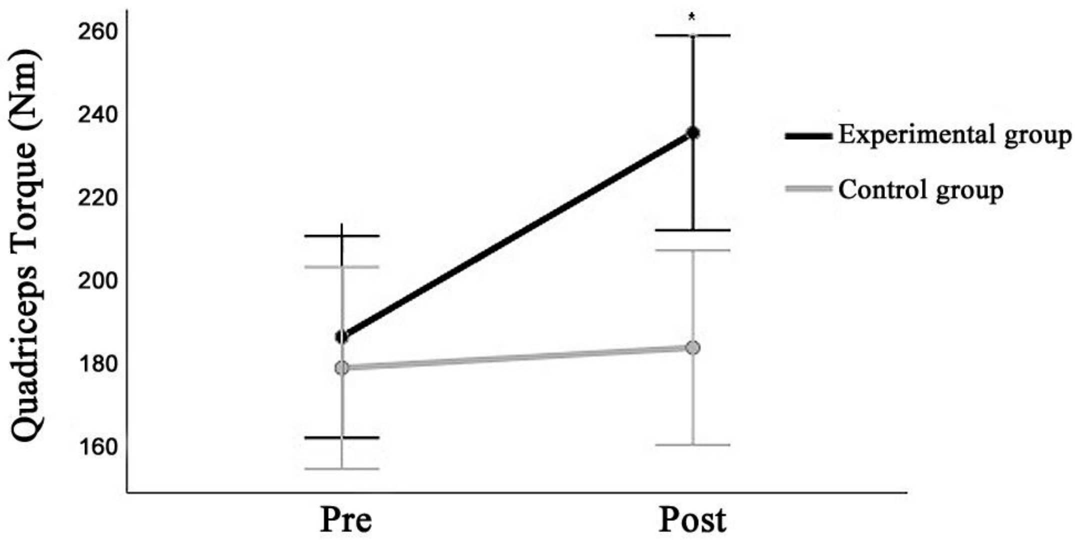

Figure 1. Torque production (Nm) of operated quadriceps pre- and post-intervention

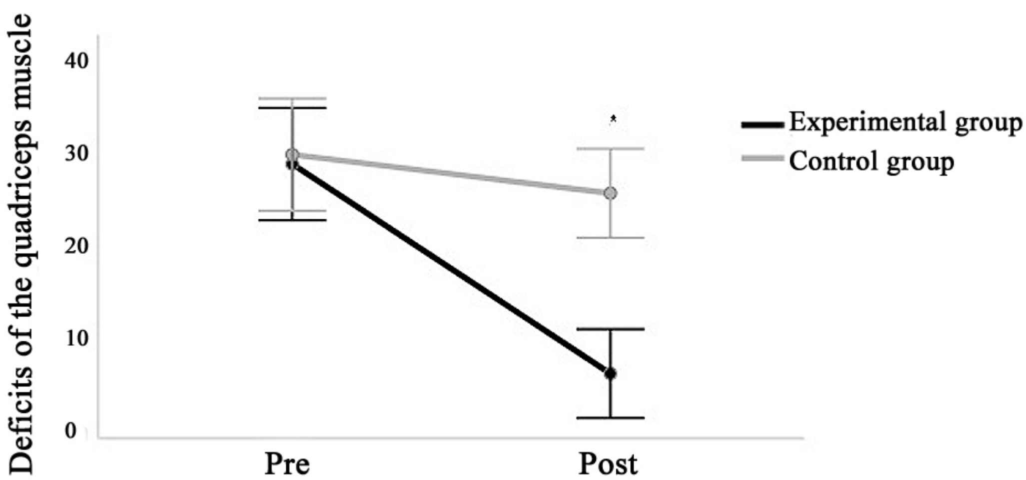

Figure 2. Deficits of the quadriceps muscle before and after the intervention

Table 3. Deficits between the operated and healthy muscle groups

	Experimental group (n=12)		Control group (n=12)	
	Pre	Post	Pre	Post
Quadriceps Deficits	28.42 ±10.09	6.25 ±6.05*	29.42 ±9.76	25.33 ±9.14*
Hamstring Deficits	10.25 ±9.62	5.25 ±4.16	12.17 ±9.13	10.83 ±7.54

Values are presented as mean ± standard deviation, *p<0.05 pre-post significance difference.

Table 4. Hamstring to quadriceps ratio percentage (HQR%) of the operated and healthy legs.

	Experimental group (n=12)		Control group (n=12)	
	Pre	Post	Pre	Post
HQR% operated leg	84.58 ±16.37	71.67 ±10.84*	83.42 ±20.11	84.50 ±14.57
HQR% healthy leg	64.75 ±6.4	69.00 ±8.88*	66.08 ±6.02	69.00 ±6.7*

Values are presented as mean ± standard deviation, *p<0.05 pre-post significance difference.

Statistical analysis revealed that there was a significant main effect of training intervention on torque production [F(1,22)= 34.95, p<0.001, η_p^2 = 0.61] for the quadriceps (Fig. 1) and the hamstring muscle group [F(1,22)= 11.49, p<0.05, η_p^2= 0.34] of the operated leg. In addition, it was demonstrated that there was a marginal main effect of the type of training on quadriceps peak torque of the operated leg [F(1,22)=3.59, p=0.07, η_p^2=0.14] (Fig.1). Furthermore, there was a significant interaction between the exercise condition and torque production for the quadriceps [F(1,22)= 23.46, p<0.001, η_p^2= 0.52] and the hamstring of the operated leg [F(1,22)=6.27, p<0.05, η_p^2= 0.22]. Planned comparisons revealed that participants in the experimental group produced significantly greater quadriceps torque post-training compared to pre-training [t(11)= -5.42, p<0.01, d=1.22]. At the same time significantly greater torque production was demonstrated in the control group [t(11)=-4.35, p<0.01, d=0.12]. Furthermore, planned comparisons demonstrated that the hamstring muscle of the experimental group produced significantly greater torque post-training intervention [t(11)=-3.09, p<0.01, d=0.45], while no significant improvements were demonstrated in the control group. When considering the deficits between the healthy and operated side before and after the intervention, results indicated that there was a main effect of training intervention on the deficits of the quadriceps [F(1,22)=67.95, p<0.01, η_p^2= 0.76] (Table 3, Fig. 2). In addition, it was demonstrated that there was a significant main effect of the type of training on quadriceps deficits [F(1,22)=32.48, p<0.001, η_p^2=0.59] (Fig. 2). Furthermore, there was a significant interaction between the exercise intervention and quadriceps deficits for the two groups [F(1,22)= 32.48, p<0.001, η_p^2= 0.59]. Last but not least, hamstring to quadriceps ratios (HQR%) for the experimental group were significantly improved, while for the control group, there was no significant change in the HQR% of the operated leg (Table 4).

4. Discussion

Despite the large number of randomized trials following an ACL reconstruction, there is a lack of clear evidence as to the timing and the most appropriate rehabilitation programs that would promote functional recovery and allow the athletes to return to sports safely. Our study indicated that the isokinetic strength training program (Table 1), in addition to the traditional rehabilitation, resulted in significantly greater strength gains for the quadriceps and hamstring muscle groups than the traditional rehabilitation alone. Furthermore, the deficits that were present six months post-ACL surgery were significantly reduced, with the experimental group demonstrating significantly greater reductions in bilateral imbalances. Notably, the experimental group demonstrated bilateral imbalances of less than 10% (6.25 ±6.05 for the quadriceps and 5.25 ±4.16 for the hamstring). In contrast, the control group demonstrated a bilateral difference in muscular strength greater than 25 ±9.14% for the quadriceps, which is considered abnormal and can be used to predict injuries [10]. Furthermore, the HQR% was significantly improved for the experimental group and was within the recommended values that are reported to range between 0.5 and 0.75 [10]. In contrast, the HQR% of the operated leg did not demonstrate any improvement for the control group.

Similar research studies confirm that the rehabilitation programs should include strength training exercises and emphasize early full hyperextension as well as early weight-bearing and closed kinetic chain exercises [13]. While some researchers suggest that both closed and open kinetic chain exercises should be incorporated early into the rehabilitation programs as they have a beneficial role in early rehabilitation [14], others express a great concern about the safety of open chain exercises for knee extensor training in the early period after ACL reconstruction [15]. Aside from quadriceps strength training, research affirms that isokinetic training of the hamstrings should be incorporated in the early phases of the rehabilitation as it improves knee laxity without a negative impact on knee function [16]. Furthermore, it has been indicated that return to sports participation includes having an isokinetic strength ratio greater than 80% of the contralateral knee in addition to the successful completion of all functional activities [13].

Even though the present randomized controlled study demonstrated increases in the operated quadriceps' torque production in both the experimental and control groups, it should be noted that the quadriceps strength of the operated leg of the control group was still below the recommended values for professional soccer players [17]. Using isokinetic testing, normative values at 60^0/sec were found to range between 201 and 319Nm for the quadriceps and 114 to 170Nm for the hamstring muscle group [17]. This study revealed that the soccer players generated significantly lower torques at the operated quadriceps before the 5- week intervention program, while the hamstring muscle group was within the normal range for both the experimental and control groups. Following the 5-week intervention, the operated leg of the experimental group generated torques within the reference values, while for the control group, those values remained below 201Nm. Research affirms that isokinetic strengthening exercises result in higher functional performance when compared to the isotonic strengthening exercises only, while the exclusive use of either isotonic or isokinetic exercises do not eliminate bilateral deficits [18]. Therefore, it appears that a combination of isokinetic and isotonic exercises is the most beneficial for the functional rehabilitation of the knee joint [18].

Research reported a positive relationship between isokinetic testing and functional performance, indicating that patients with significant deficits after ACL reconstruction demonstrate abnormal walking and running kinematics [19]. At the same time, even though sprint performance is correlated with peak extensor and flexor torque at all velocities, the strongest correlation is observed between relative knee extensor torque at higher speeds [20]. Undoubtedly, performing isokinetic testing does not replicate angular velocities of many functional activities [21]. Therefore, even though the isokinetic testing in this study was performed at slower speeds in order to determine the maximum isokinetic strength (torque) and deficits as recommended [22], the isokinetic training protocol included only higher speeds. Nevertheless, isokinetic testing and rehabilitation at any angular speed carry an inherent safety factor as athletes will never meet more resistance than they can handle, and the torque production will depend only on the effort they can exert [22].

The isokinetic strength training protocol in this study was effective not only in improving maximal torque production of the operated leg but also in correcting bilateral asymmetries and unilateral ratios. Research indicated that asymmetrical loading increases the potential for re-injury [23]. Additionally, unilateral ratios are particularly important as the stability of the knee joint and prevention of anterior tibial translation during multi-planar movements are contingent upon hamstrings co-activation to resist anterior translation and tibial rotation resulting from the quadriceps contraction [24]. Furthermore, research indicated that co-activation of the hamstrings and quadriceps protects the joint not only against tibial translation but also against knee abduction and dynamic lower extremity valgus [25]. Hence, improving hamstring strength plays an essential role, especially in patients undergoing ACL rehabilitation with the hamstring autograft. Research indicated inferior hamstring strength at all postoperative follow-ups when patients with hamstring tendon autografts were compared to those with bone-patellar tendon-bone autografts [26]. Consequently, the strength gains for both the quadriceps and hamstring muscles that were demonstrated in this study are essential in the rehabilitation process and the safe return of the athletes to the soccer games.

5. Conclusions

Although the decision for the rehabilitation programs is multifactorial, it is evident that those programs should be designed along a continuum, beginning with the safest and gradually progressing to more challenging exercises. Based on the results of our study, clinicians, physical therapist, and rehabilitation experts should consider incorporating the isokinetic training used in our study in their therapy protocols as soccer players with imbalances six months following an ACL reconstruction rehabilitated faster when this program was included in their training routines. Moreover, rehabilitation should be customized, taking into consideration the type of graft used, as each type of graft generates intrinsic muscular deficits.

6. Limitations

A major limitation of this study is the small sample size. Power analysis indicated that a total of 36 players should have participated in the study. However, only 24 players were eligible for participation due to the strict inclusion criteria. Nevertheless, this may serve as a pilot study that demonstrates the potential effectiveness of this rehabilitation protocol. Therefore, future studies with a larger sample size are needed to confirm the results of this study.

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