Do final rehabilitation volumes influence function after anterior cross ligament reconstruction? A pilot study

Volumes finais de reabilitação influenciam função após reconstrução de ligamento cruzado anterior? Um estudo piloto

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Abstract

Introduction: Rupture of the anterior cruciate ligament (ACL) is one of the frequent traumatic injuries of the knee joint complex, and the isokinetic dynamometer is essential to assess and measure its joint function. **Objective:** To analyze the volume of physical therapy treatment using the same protocol with different duration in patients undergoing ACL reconstruction. **Methods:** This is a prospective observational cohort study. The sample consisted of 13 adult male individuals who underwent ACL reconstruction surgery. Participants were divided into two groups: accelerated treatment (AC) and non-accelerated treatment (NAC). Participants underwent a standardized protocol of post-reconstruction physiotherapy, starting in the immediate postoperative period. The AC group performed the treatment three times a week, with a duration of 4 hours each session for 6 months, while the NAC performed twice a week with duration of two hours each session for eight months. **Results:** The groups showed the same behavior during the post-reconstruction treatment periods, showing that regardless of time, the results were beneficial at the end of the treatment. However, in the accelerated protocol, the injured limb showed a significant difference for extender peak torque (PTEXT) in the preoperative and 4-month postoperative period (230.5 vs 182.6), 4-month postoperative period and final (182.6 vs 242.1) in the AC group, while in the NAC group there was no significant difference between times in this same limb. **Conclusion:** Greater volumes of weekly training characterized better results, showing that rehabilitation time is not a predictor of discharge, but rehabilitation time obtains good results for the variables.

Keywords: Anterior cruciate ligament. Muscle strength. Rehabilitation.

Resumo

Introdução: *A ruptura do ligamento cruzado anterior (LCA) é uma das lesões traumáticas frequentes do complexo articular do joelho, sendo o dinamômetro isocinético fundamental para avaliar e mensurar sua função articular.* ***Objetivo:*** *Analisar o volume de tratamento fisioterapêutico utilizando o mesmo protocolo com diferentes durações em pacientes submetidos à reconstrução do LCA.* ***Métodos:*** *Trata-se de um estudo de coorte observacional prospectivo. A amostra foi composta por 13 indivíduos adultos do sexo masculino submetidos à cirurgia de reconstrução do LCA. Os participantes foram divididos em dois grupos: tratamento acelerado (AC) e tratamento não acelerado (NAC). Os participantes foram submetidos a um protocolo padronizado de fisioterapia pós-reconstrução, com início no pós-operatório imediato. O grupo AC realizou o tratamento três vezes por semana, com duração de 4 horas cada sessão, durante 6 meses, enquanto o grupo NAC realizou duas vezes por semana, com duração de duas horas cada sessão, durante oito meses.* ***Resultados:*** *Os grupos apresentaram o mesmo comportamento durante os períodos de tratamento pós-reconstrução, mostrando que independente do tempo, os resultados foram benéficos ao final do tratamento. No protocolo acelerado, porém, o membro lesionado apresentou diferença significativa para pico de torque extensor (PTEXT) no pré-operatório e pós-operatório de 4 meses (230,5 vs 182,6), pós-operatório de 4 meses e final (182,6 vs 242,1) no grupo AC, enquanto no NAC não houve diferença significativa entre os tempos neste mesmo membro.* ***Conclusão:*** *Maiores volumes de treinamento semanal caracterizaram melhores resultados, mostrando que o tempo de reabilitação não é preditor de alta, mas o tempo de reabilitação obtém bons resultados para as variáveis.*

Palavras-chave: *Ligamento cruzado anterior. Força muscular. Reabilitação.*

Introduction

Rupture of the anterior cruciate ligament (ACL) is one of the most frequent traumatic injuries in the knee joint complex. Surgical reconstruction aims to restore the functional stability of the knee and can be performed using different techniques and graft sites.[1,2] According to international standards and consensus, postoperative ACL rehabilitation is usually performed between 9 and 12 months after surgery. Consequently, long-term rehabilitation protocols for patients with ACL reconstructed are strongly recommended.[3]

On the other hand, accelerated rehabilitation promotes pain relief, recovers active joint mobility, muscle strength and the individual's proprioceptive capacity, allowing them to return to their activities in a short period when compared to non-accelerated rehabilitation.[4] However, the process of returning to physical and sports activities is not based on time, but on the individual's ability to achieve goals, and the time required for this diverges according to the particularities of each one. Rehabilitation after ACL injuries aims to restore muscle strength, improve neuromuscular control, restore range of motion and allow a return to pre-injury activity levels.[5] Patients usually return to activities and sports after reaching muscle strength with a deficit of less than 10-15% compared to the contralateral side, but strength is not the only factor to be considered.[6]

The isokinetic dynamometer is considered the gold standard for strength assessment, being essential to measure knee joint function and rebalance. Isokinetic assessment is essential during ACL rehabilitation, as it is a safe, reproducible and objective assessment method, measuring parameters such as peak torque (Nm), total muscle work (Joules) and muscle power (Watts).[7] Given the aforementioned facts, the objective of this study was to observe whether different volumes of physiotherapeutic treatment using the same protocol in patients undergoing ACL reconstruction would result in better rehabilitation from the point of view of muscle performance components (peak torque, power and work) by the isokinetic dynamometer.

Methods

This pilot study was approved by the Human Research Ethics Committee at the Universidade Estadual do Norte do Paraná (opinion number 4.312.851). The sample was selected for convenience and composed by 13 adult male individuals who were recreational athlete and underwent surgery to reconstruct the anterior cruciate ligament. Exclusion criteria were patients with a history of neurological disease (stroke, degenerative diseases of the central nervous system or peripheral nervous system), who were using medication for psychotropic purposes during the treatment period

or who were hypertensive. The sample was defined by convenience. Participants were divided into two groups, one undergoing accelerated treatment (AC; n = 8) and the other non-accelerated (NAC; n = 5).

Rehabilitation program

All participants underwent a standardized protocol of physical therapy (Appendix 1) after anterior cruciate ligament reconstruction, supervised by the same group of students with experience in the sports field. Rehabilitation started in the immediate postoperative period. The AC group performed the treatment three times a week, four hours each session, for six months; that is, the AC group performed the protocol with the highest volume of interventions, while the NAC group performed the treatment twice a week, lasting two hours each session, for eight months, therefore, with a smaller volume of physiotherapeutic interventions. Treatment began with techniques to reduce the inflammatory process and edema, including electrotherapy (laser and ultrasound) and manual therapy (massage and lymphatic drainage), and techniques to improve range of motion, muscle strength, proprioception and coordination exercises, focusing on neuromuscular control of the involved knee. From the beginning, gait training was performed on a parallel bar, with the patient still on crutches, respecting the percentage of weight bearing.

Strengthening training was performed using muscle electrical stimulation with isometric contraction, progressing to concentric and eccentric contraction, first in closed kinetic chain and later in open kinetic chain. Initially, strengthening exercises were performed against gravity and progressing to manual resistance, tubes/elastic bands, and shin guards until the patient was referred to the gym. Likewise, mobilizations started in a passive way, performed by the physical therapist according to pain tolerance, moving on to assisted active mobilization of all injured lower limbs.

Functional training was progressively performed after the application of some criteria, such as symmetry, ability to jump on one leg without pain, absence of edema, pain, and full range of motion assessed by clinical examination. In the final phase of treatment, patients started training with the sport specificity in a dynamic way, using balls, trampoline and other instruments on the ground and on the field. All exercises were gradually progressed and carefully according to the patient's tolerance. The addition of intense exercises safety and effectiveness were fully monitored and prior to the performance they were accompanied by verbal feedback to help the patient to develop safe movements.

Isokinetic evaluation

The isokinetic evaluation took place in the laboratory of the Health Sciences Center at the Universidade Estadual do Norte do Paraná (CCS-UENP) in the preoperative period, in the 4-month postoperative period, and at the end, in the 6-month postoperative period in the AC group and in the 8-month postoperative period in the NAC group. The same evaluators performed the bilateral knee evaluation during all periods, using a Biodex Multi-Joint Pro isokinetic dynamometer. Participants were evaluated for knee flexion and knee extension using the following protocol: prior to the test, an active warm-up for 5 minutes using an exercise bike with an intensity of 50 J and then the evaluation was started. Participants were evaluated in a sitting position. Stabilization straps were applied to the trunk and thighs, and a resistance pad placed at a level of 3 cm above the malleolus. All participants underwent uninvolved limb testing first and the knee range of motion during the test was set to 0-90°. Bilateral tests (concentric/concentric) of knee extension and knee flexion were performed with the protocol of 60°/s (5 repetitions) and 180°/s (5 repetitions), with a 30 seconds interval between sets. Verbal encouragement during the test was consistent and standardized. Peak torque (Nm), muscle power (Watts), total work (Joules) and agonist/antagonist ratio, automatically calculated by the device, were analyzed.

Statistical analysis

Statistical analysis was performed using the SPSS 20.0 statistical program. The Shapiro-Wilk test was used to verify data normality, which are presented as mean and standard deviation. The analysis of variance test for repeated measures was used to compare the moments of assessment (pre, post-4 months and post-6 months or post-8 months) for the AC and NAC groups. The independent t test was used to compare NAC and AC groups for all variables in both limbs (injured and uninjured). An additional analysis was used to observe the effects of time, group and time x group, which are presented in graphs. Analysis of variance (ANOVA) for

repeated measures was used, in which the assumption of sphericity was tested using the Mauchly test. In case of violation of the sphericity assumption, the Greenhouse-Geisser correction was used. When necessary, the post-hoc Bonferroni test was used. Eta square (ES) values greater than or equal to 0.14 represent large effect size. The larger the effect size, the greater the impact that the central variable is having and the more important the fact that it has a contribution to the analyzed issue.

Results

Data referring to the sample number and anthropometric profile (age, weight, height and fat percentage) were collected during the first isokinetic assessment and are detailed in Table 1. The sample was considered homogeneous with no significant differences between groups.

Table 1 - Anthropometric profile for the accelerated (AC) and non-accelerated (NAC) groups

	AC (n = 8)	**NAC** (n = 5)
Age	24.5 ± 4.7	25.8 ± 4.1
Weight (kg)	88.8 ± 11.1	100.8 ± 32.9
Height (m)	1.8 ± 0.0	1.8 ± 0.0
Fat percentage	19.9 ± 6.3	24.3± 13.0

Note: Values expressed as mean ± standard deviation.

Table 2 shows the results of the intra and intergroup analysis of variance for the peak torque (PT) in Nm, for both knee extensors (EXT) and knee flexors (FLX) muscles. Regarding extender peak torque (PTEXT), in AC rehabilitation, the injured limb (I) showed a tendency to increase throughout the treatment, with 12.4% higher values when comparing the pre and the final stages. However, the difference was not significant. As for the NAC protocol for this same limb, from the preoperative to the 4-month post-operative period, there was a significant loss of 20.7% for PTEXT. However, during the rehabilitation period there was an increase of 32.5% from the 4-month postoperative period to the end of treatment. The uninjured limb (NI), on the other hand, showed a tendency to maintain or increase its strength during the treatment period, with this increase being greater in the NAC group (15%) compared to the AC (4.8%) from the preoperative period to the end. For PTFLX, the gain in I was progressive, showing an increase of 16.9% in the AC protocol and 12.1% in the NAC at the end of the treatment. In the NI, both protocols showed a significant increase in PT, 6.7% for AC and 20.9% for NAC; although AC rehabilitation stood out for gain of PT in I compared to NAC for NI. The two maintained the same results during rehabilitation and no significant differences were found between groups.

In Table 3, the results of the intra and intergroup analysis for potency (POT) in Watts show that both EXT and FLX are represented. POTEXT in AC rehabilitation for L showed a progressive increase from the beginning to the end of the treatment of 17.2%, being significant from the postoperative period of 4 months to the end, with a difference of 16.3%. In NAC rehabilitation, there was a significant reduction of 32.9% from pre to postoperative period of 4 months, and an increase of 30.6% to the end, almost equivalent to the reduction values.

For POTFLX, L in the AC treatment showed a progressive improvement in all evaluation periods, all of which were significant, while in the NAC rehabilitation a tendency to reduction was observed, which decreased by 8.1% when comparing the preoperative period with the final period. In the NI from the preoperative period to the end of rehabilitation, the AC group showed a significant increase of 9.6%, while the NAC treatment had a reduction of 8.1%. Therefore, AC rehabilitation was more beneficial to POTFLX for both the injured leg and the uninjured leg. Although both groups showed reductions during the treatment periods, accelerated rehabilitation presented smaller reductions, being more beneficial for POTEXT in both limbs.

The results of total work (TT) in Joules, of EXT and FLX are shown in Table 4. In both groups, there were reductions from the preoperative to the 4-month post-operative period, both for the extensor and for the flexor. For TTEXT in AC rehabilitation for I, there was a 9.5% reduction between the pre and postoperative period of 4 months, but between the pre and the end, and postoperative period of 4 months to the end there was an improvement of 6.6% and 17.9% respectively, being significant in the second case. Also for this limb, for NAC rehabilitation there was a significant reduction of 24.4% between the pre and postoperative period of 4 months and a significant increase of 30.6% from the

postoperative period of 4 months to the end. Although there was an increase during the treatment, when comparing the initial value to the end, a loss of 1.2% in the injured limb was verified. For NI in AC rehabilitation, there was a reduction during the entire treatment period, being significant from pre to postoperative period of 4 months. In NAC rehabilitation, there was an improvement of 2.2% from pre to end of treatment. Therefore, although it showed a significant reduction between pre and post, AC rehabilitation still showed improvements at the end of the treatment for I.

For TTFLX, the I in AC rehabilitation progressively increased during treatment, resulting in a significant increase of 16.6% from postoperative period of 4 months to the end, and 17.5% when comparing pre and end of treatment. In the NAC rehabilitation, there was a progressive reduction during the treatment, being 2.9% when comparing the pre and end of treatment.

Table 2 - Analysis of intra and intergroup variances for peak torque

	PTEXT						
	Preoperative		4-month post-operative		End of treatment		Deficit Bilateral (%)
	NI	I	NI	I	NI	I	
AC	282.1 ± 38.9	222.8 ± 28.1	282.5 ± 21.0	225.2 ±24.3	295.7 ± 21.4	250.6 ± 36.5	15.4 ± 9.2
NAC	260.8 ± 38.7	230.5 ± 51.3*	302.5 ± 80.5	182.6 ± 30.2*▲	300.1 ± 72.0	242.1 ± 48.1▲	17.9 ± 12.4
	ns	ns	ns	ns	ns	ns	ns
	PTFLX						
	Preoperative		4-month post-operative		End of treatment		Deficit Bilateral (%)
	NI	I	NI	I	NI	I	
AC	139.4 ± 13.5	125.8 ± 14.1*	145.7 ± 16.1	138.7 ± 23.5	148.8 ± 18.8	147.1 ± 24.9*	0 .0 ±16.3
NAC	127.1 ± 22.7▲	124.7 ± 22.5	135.1 ± 30.0▪	132.1 ± 34.1	153.7 ± 23.2▲▪	139.8 ± 32.2	9.8 ± 8.3
	ns	ns	ns	ns	ns	ns	ns

Note: PTEXT = extender peak torque; PTFLX = flexor peak torque; NI = uninjured; I = injured; AC = accelerated; NAC = non-accelerated; ns = not significant. *▪▲p ≤ 0.05. Equal symbols inform significant difference between periods. Values expressed as mean ± standard deviation.

Table 3 - Analysis of intra and intergroup variances for potency

	POTEXT						
	Preoperative		4-month post-operative		End of treatment		Deficit Bilateral (%)
	NI	I	NI	I	NI	I	
AC	347.3 ± 18.6	280.2 ± 55.4	334.2 ± 30.0	282.4 ± 48.4*	360.2 ± 32.6	328.6 ± 31.5*	8.7 ± 4.4
NAC	325.6 ± 67.0	294.7 ± 64.8▪▲	281.7 ± 98.6	197.5 ± 44.4▪♦	297.4 ± 78.3	258 ± 55.8▲♦	11.2 ± 13.6
	ns	ns	ns	ns	ns	ns	ns
	POTFLX						
	Preoperative		4-month post-operative		End of treatment		Deficit Bilateral (%)
	NI	I	NI	I	NI	I	
AC	194.5 ± 30.5▲	143.2 ± 36.5*	203.4 ± 34.0	164.9 ± 33.0*	213.2 ± 39.5▲	219.6 ± 36.8*	-4.4 ± 17.4
NAC	186.1 ± 43.1	176.4 ± 29.2	157.0 ± 46.2	146.0 ± 30.8	170.9 ± 28.9	162.0 ± 41.5	5.8 ± 12.2
	ns	ns	ns	ns	ns	ns	ns

Note: POTEXT = extender potency; POTFLX = flexor potency; NI = uninjured; I = injured; AC = accelerated; NAC = non-accelerated; ns = not significant. *▪▲♦ p ≤ 0.05. Equal symbols inform significant difference between periods. Values expressed as mean ± standard deviation.

In the NI limb for both groups there was a reduction in the postoperative values, with an increase after 4 months to the end. However, when evaluated pre and end of treatment, the AC gained 1.3% and the NAC lost 7.6%. Thus, for TTFLX gain, AC rehabilitation proved to be more effective for limb I and NI.

Regarding bilateral deficits at the end of treatment, for the PT of the extender group, the participants of the NAC had bilateral deficits greater than the AC, which was above the recommended in the literature. For this same variable, both the knee extensors and the knee flexors, the values were close to what was expected, being better in the flexors. As for the PT, the deficits are also within the ideals. However, the participants of the AC group presented better results.

The agonist-antagonist relationship is shown in Table 5. It is possible to observe that, in the preoperative period, both NI and I had similar values in both groups, showing that all participants had values close to PT. In the 4-month postoperative period, the I of the NAC group had higher values than the AC, which is related to the significant reductions in PTEXT values. With the progressive increase in the EXT values from 4 months after the end of treatment, an improvement in the agonist-antagonist ratio in both groups can also be observed.

Table 4 - Analysis of intra and intergroup variances for total work

	TTEXT						
	Preoperative		4-month post-operative		End of treatment		Deficit Bilateral (%)
	NI	I	NI	I	NI	I	
AC	1398.4 ± 109.0♦	1104.2 ± 209.7	1244.3 ± 78.0♦	998.7 ± 223.1*	1326.3 ± 118.0	1178.1 ± 278.8*	10.3 ± 23.1
NAC	1419.2 ± 272.4	1197 ± 184.1▪	1393.8 ± 284.4	904.9 ± 70.8▪▲	1451.4 ± 331.7	1182.1 ± 185.6▲	16.9 ± 11.3
	ns	ns	ns	ns	ns	ns	ns
	TTFLX						
	Preoperative		4-month post-operative		End of treatment		Deficit Bilateral (%)
	NI	I	NI	I	NI	I	
AC	818.4 ± 125.9	666.1 ± 158.3*	787.4 ± 128.2	671.6 ± 165.0▲	829.8 ± 140.6	783.3 ± 219.2*▲	5.7 ± 20.7
NAC	806.5 ± 172.1	721.2 ± 147.1	730.5 ± 175.8	678.4 ± 133.9	744.8 ± 109.4	699.8 ± 173.1	6.7 ± 11.2
	ns	ns	ns	ns	ns	ns	ns

Note: TTEXT = extender total work; TTFLX = flexor total work; NI = uninjured; I = injured; AC = accelerated; NAC = non-accelerated; ns = not significant. *▪▲$p \leq 0.05$. Equal symbols inform significant difference between periods. Values expressed as mean ± standard deviation.

Table 5 - Analysis of intra and intergroup variances for the agonist/antagonist ratio

	Preoperative		4-month post-operative		End of treatment	
	NI	I	NI	I	NI	I
Accelerated	50.30 ± 7.5	56.7 ± 5.8	51.8 ± 7.3	62.7 ± 15.3	50.2 ± 7.1	56.0 ± 11.1
Non-accelerated	48.8 ± 6.8	54.9 ± 8.7	45.3 ± 4.4	73.0 ± 18.9	52.4 ± 7.9	57.8 ± 7.3
	ns	ns	ns	ns	ns	ns

Note: NI = uninjured; I = injured; ns = not significant. Values expressed as mean ± standard deviation.

Figure 1 shows the results of the analysis of sphericity for the groups in time and time*group. The time 1 represents the preoperative period, time 2 the 4-month postoperative period and time 3 the end of treatment (6 months for accelerated and 8 months for non-accelerated). The time values demonstrate the

interaction of the evaluation moments within each group, being significant in the AC protocol for I (PTFLX, POTEXT, POTFLX, TTEXT, TTFLX) and for NI (POTFLX, TTEXT), as in the NAC protocol for I (PTEXT, POTEXT, TTEXT) and for NI (PTFLX) (Figure 1, image 1), as seen in previous analyses. The time*group analysis, on the other hand, refers to the results between groups. There were different results between AC and NAC, with significance observed in the power of knee extensors (I) and power of knee flexors (I and NI), as shown in the graphs. Both groups showed similar results during the treatment period, however the AC group, proved superior to NAC.

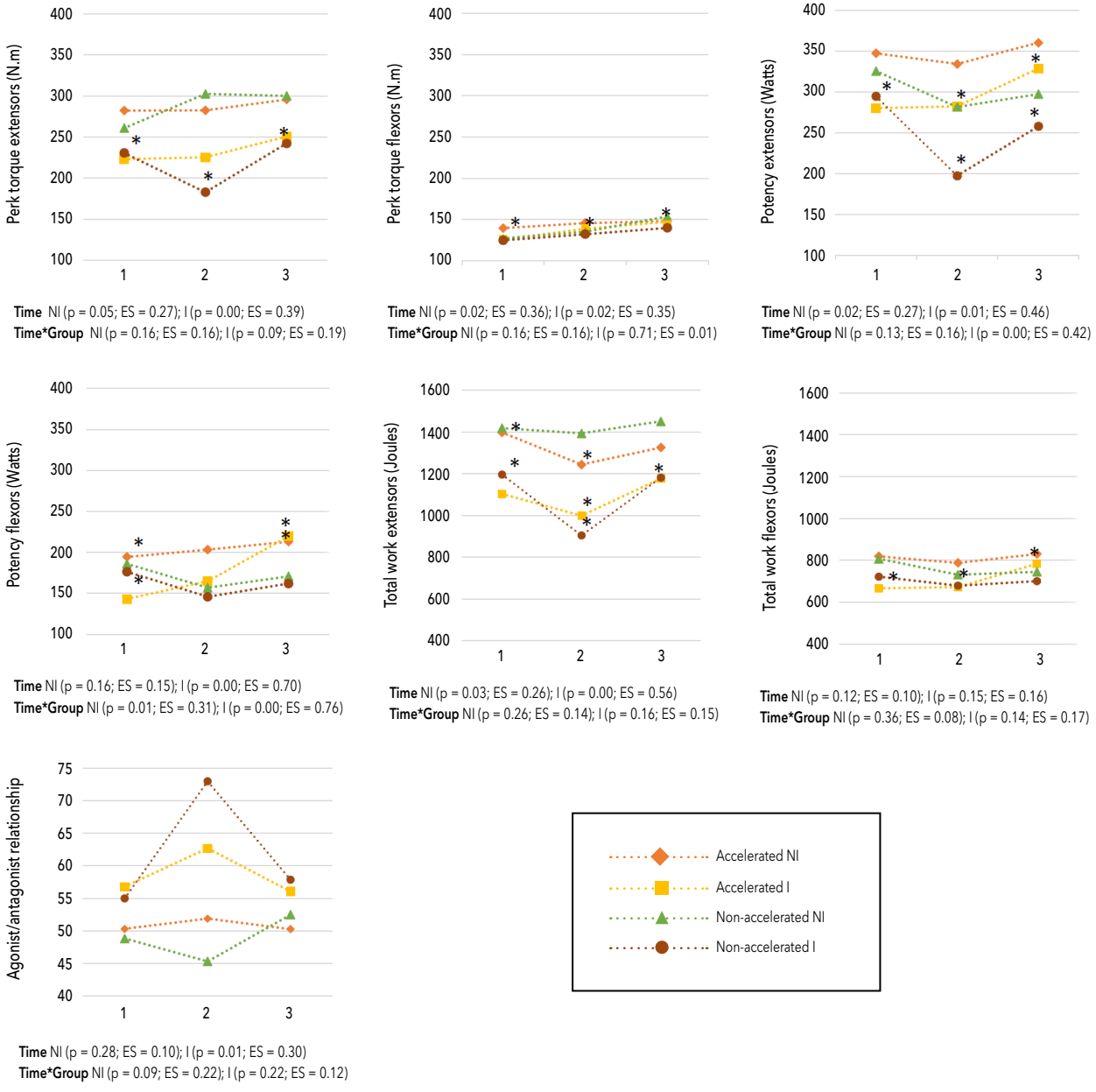

Figure 1 - Analysis of the sphericity of groups in time and time*group.

Note: NI = uninjured; I = injured; ES = eta squared; *p ≤ 0.05

Discussion

The main focus of our study was to examine the effect of two different rehabilitation protocols for post-operative ACL patients, demonstrated by the knee joint dynamic stabilizers muscle parameters through isokinetic assessment. The strength of the knee extensors of the injured limb is weaker preoperatively, and remains significantly reduced four months after reconstruction, as in the study by Hallaginet al.[8] After reconstruction, participants demonstrated a reduction of knee extensors PT compared to preoperative, which was expected in both groups. However, this difference was significant only in the NAC group and, although the AC group did not show a reduction in these values, no large increases were found. This reduction is in agreement with those reported by Hart et al.,[9] who also found persistent quadriceps weakness in post-reconstruction patients. These results can be explained by the reduction of muscle mass as a result of the surgery.

In the post-surgery period, reduction of muscle mass, balance and proprioception is common.[10] One of the factors responsible is the arthrogenic muscle inhibition that prevents the quadriceps from being fully activated. Other studies have also demonstrated these changes and attributed this reduction to a change in the muscle's neurological response.[11] However, our results show that in both groups the final result was better than the initial one, indicating the effectiveness of both treatments, with a predominance for the AC. Current approaches investigating muscle atrophy after ACL reconstruction emphasize early postoperative movement in addition to the use of electrical stimulation. All participants in this research started physical therapy immediately, performing daily exercises in a rehabilitation protocol which included all the approaches mentioned above.

Improving knee flexor strength progressively without reduction during treatment may be related to the purpose of the training. The objective during rehabilitation was to improve, mainly, the strength of this muscle group in order to improve joint rebalancing, which resulted in a different AG/ANT in the four months postoperative moment in the NAC group. Therefore, the tendency and expectation were that they would increase as seen in the study. The reduction in power and total work values in the NAC group in the 4-month postoperative period may be related to the reduction in peak torque values, showing that changes in strength will lead to changes in these abilities. Accordingly, it is important that during rehabilitation goals are set for these abilities, in addition to strength.

The hamstring/quadriceps muscles strength ratio has been used as an indicator of balance.[12] It is a very significant parameter in estimating the time to return to sports activities. At the end of the treatment, our patients had results close to those expected for the population at the recommended level that allows them to return to sports activities. In the knee, the ratio between the peak torque of the flexors/extensors should be around 60%. Therefore, the difference between the extensors and the flexors should not be greater than 40%.[13-15] In the uninjured limb, the ratio with lower values can be explained by the dominance of the limbs. A large part of our sample had the dominant limb uninjured, and in these cases, the knee extensor muscles are stronger due to dominance, providing a lower agonist/antagonist ratio. Although they presented a lower ratio for the uninjured limb, the participants maintained joint stability.

In fact, the goal of rehabilitation was fulfilled, as both groups improved at the end and there was no significant difference between the groups in any of the evaluated moments. The reductions presented at the end of the treatment are within the expected range in the literature, between 10 and 15%,[16] showing that the patients maintained joint rebalancing, despite the reductions during treatment. Isokinetic assessment is a
great method to treatment when it comes to ACL post-operative period, as it allows to objectively quantify the variables and describe them throughout the physical therapy treatment. Furthermore, it is recommended that the isokinetic knee evaluation be used as one of the criteria to decide whether the patient should return to activities or not.[17]

Conclusion

With this study, it was possible to observe that greater volumes of weekly training characterized better results, since in the accelerated protocol the injured limb showed a significant difference for PTEXT in the preoperative and postoperative period of 4 months (230.5 vs 182.6), 4 months and final postoperative period (182.6 vs. 242.1), while the non-accelerated one did not show a significant difference between the times in this same limb. However, both groups (AC and NAC) showed no significant difference at the end of treatment, showing

that regardless of the time, the results are beneficial at the end, and whenever available, use standardized and validated instruments such as isokinetic for patient follow-up.

Authors' contributions

All authors contributed to the conception, design, analysis, interpretation, writing and critical review of the manuscript and assume responsibility for the work.

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Appendix 1

Rehabilitation protocol after reconstruction of the anterior cruciate ligament (ACL)

1st and 2nd week

Objectives: To reduce the inflammatory process, eliminate edema, gain mobility, achieve full active knee extension equal to the uninvolved side, increase the range of motion for flexion, strengthen the muscles, assist in the healing process, gain proprioception, normalize gait.

- Laser HeNe around the stitches and scan on the stitches;
- A s G a punctual laser over the graft tendon and scan over it;
- US 1mHz pulsed in case of resorbable screw;
- Manual lymphatic drainage;
- Multidirectional patellar mobilization;
- Fibular head mobilization;
- Active-assisted hip mobilization against gravity;
- Side lying hip and knee mobilization with mild progressive manual resistance associating with PNF. Patient performs hip flexion and knee flexion while therapist resists;
- Active ankle mobilization against gravity;
- Active-assisted knee mobilization up to pain limit;
- Active-assisted knee mobilization with elastic band on the calcaneus;
- Russian current on the quadriceps. Position: sitting with legs supported along the stretcher with pillow below the knee holding the bending position;
- Russian current on the hamstring. Position: prone position with cushion on the supra patellar and a roll on the front of the ankle, requesting maximum flexion;
- Training of hamstring eccentric contraction with manual guidance and support without resistance to suprapatellar region;
- CORE training in supine position (bridge with bipedal support);
- Seated proprioception;
- Proprioception standing on the parallel bar in front of the mirror performing a weight bearing of 30 to 50% of body weight;
- Gait training with parallel bar;
- Cryotherapy for 20 minutes (PRICE method);
- Stitches dressing;
- Guidance for removing crutches;
- Cryotherapy guidance at home with compression 4 times per day for 20 min;
- Hip, knee and ankle active-assisted mobilization orientation with an auxiliary device (crutch);
- At the end of the second week, start proprioception while standing, keeping the weight bearing at 30%.

3rd and 4th week

Objectives: To maintain the full extention, progress toward full flexion range of motion, knee and ankle muscles strengthening, improve proprioception, normalize gait.

Laser HeNe around the stitches and scan on the stitches;

- Punctual AsGa laser over the graft tendon and scan over it;
- US 1mHz pulsed in case of resorbable screw;
- Manual lymphatic drainage
- Fascia release and thigh and leg massage;
- Light transverse massage around the scar after removing the stitches.
- Active-assisted hip mobilization against gravity with slight manual resistance;
- Side lying hip and knee mobilization with mild progressive manual resistance associating with PNF. Patient performs hip flexion and knee flexion while therapist resists;
- Ankle mobilization;
- Multidirectional patellar mobilization;
- Fibular head mobilization;
- Active-assisted knee mobilization to pain limit;
- Active-assisted knee mobilization with elastic band on the calcaneus;
- Russian current on vast medial, vast lateral and vast intermediate (6 points) requesting internal, external rotations and neutral knee position. Sitting position with feet off the stretcher, cushion below the popliteal fossa, requesting knee extension when supporting the chain. Physical therapist maintains manual support if necessary;
- Russian current on hamstrings (4 points) with internal and external rotations. Position: prone position with supra patellar pad, requesting maximum flexion;
- Eccentric contraction of hamstrings training with guidance and manual support with resistance;
- CORE training in supine position (bridge with bipedal support);
- Start abdominal strengthening;
- Standing proprioception with support, on the parallel bar;

• Proprioception while standing on the parallel bar in front of the mirror, bearing 50% of the body weight off, respecting if there are associated injuries;

• Gait training on the parallel bar in front of the mirror;

• Static gait training with an elastic band on the calcaneus;

• Get started on strengthening in closed kinetic chain for quadriceps, hamstrings, gluteus medius, plantiflexores and dorsiflexors (bipedal);

• Quadriceps, hamstrings, abductors and adductors stretching;

• Cryotherapy for 20 minutes (PRICE method).

5th and 6th week

Objectives: To maintain the full extention, progress toward full flexion range of motion, hip, knee and ankle muscles strengthening, improve proprioception, normalize gait with ascent ramp.

Punctual AsGa laser over the graft tendon and scan over it;

• US 1mHz pulsed in case of resorbable screw;

• Fascia release and thigh and leg massage;

• Light transverse massage around the scar after removing the stitches;

• Active-assisted hip mobilization against gravity with manual resistance;

• Ankle mobilization against gravity with manual resistance;

• Active-assisted hip mobilization;

• Side lying hip and knee mobilization with mild progressive manual resistance associating with PNF. Patient performs hip flexion and knee flexion while therapist resists;

• Multidirectional patellar mobilization;

• Fibular head mobilization;

• Active-assisted knee mobilization to pain limit;

• Active-assisted mobilization knee with elastic band on the calcaneus;

• Unilateral and bilateral dynamic inversion technique for lower limbs (KABAT Diagonal): plantiflexion - knee extension - hip adduction and dorsiflexion - knee flexion - hip abduction;

• Russian current on vast medial, vast lateral and vast intermediate (6 points) requesting internal, external rotations and neutral knee position. Sitting position with feet off the stretcher, cushion below the popliteal fossa, requesting knee extension. Physical therapist maintains manual support if necessary.

• Russian current on hamstrings (4 points) with internal and external rotations. Position: standing, patient leans on the Swiss ball;

• Adductors strengthening with manual resistance 2x10 and with elastic light resistance 1x10, gradual progression;

• Abductors strengthening with 2x10 and 1x10 manual resistance with elastic band;

• Plantar arch strengthening 3x10;

• Dorsiflexors strengthening with manual resistance 2x10 and with elastic band 1x10;

• Plantiflexors strengthening with manual resistance 2x10 and with elastic band 1x10;

• Invertors strengthening with manual resistance 2x10 and with elastic band1x10;

• Evertors strengthening with manual resistance 2x10 and with elastic band 1x10;

• Quadriceps strengthening against gravity 2x10;

• Hamstrings strengthening against gravity 3X10;

• Eccentric contraction training with manual resistance 1X10;

• CORE training in supine position (bridge with bipedal support);

• Plank;

• Gait training with parallel bar in front of the mirror;

• Gait training up and down the ramp;

• Proprioception: Lateral Weight Bearing with the hemisphere opposite to the mirror;

• Proprioception: Anteroposterior weight bearing in front of the mirror, inverting the anterior foot;

• Proprioception: Weight Bearing of lower limbs involved on the rocker;

• Continue strengthening in a closed kinetic chain;

• Stretching quadriceps, hamstrings, abductors and adductors;

• Cryotherapy for 20 minutes (PRICE method).

7th to 8th week

Objectives: Total active range of motion, increase hip, knee, ankle and foot strength, increase proprioception, normalize gait and restore gait on a ramp and stairs.

• Fascia release and thigh and leg massage;

• Light transverse massage around the scar after removing the stitches.

• Multidirectional patellar mobilization;

• Fibular head mobilization;

• Unilateral and bilateral dynamic inversion technique for lower limbs (KABAT Diagonal): plantiflexion - knee

extension - hip adduction and dorsiflexion - knee flexion - hip abduction;

• Side lying hip and knee mobilization with mild progressive manual resistance associated with PNF. Patient performs hip flexion and knee flexion while therapist resists;

• Russian current on vast medial, vast lateral and vast intermediate (6 points) requesting internal, external rotations and neutral knee position. Sitting position with feet off the stretcher, cushion below the popliteal fossa, requesting knee extension. Physical therapist performs manual resistance;

• Russian current on hamstrings (4 points) with internal and external rotations. Position: standing, patient leans on the Swiss ball. Physical therapist performs manual resistance;

• Adductors strengthening with progressive load 3 x 10;

• Abductors strengthening with elastic band 3 x 10;

• Plantar arch strengthening 3x10;

• Dorsiflexors strengthening with elastic band 3x10;

• Plantiflexors strengthening with elastic band 3x10;

• Invertors strengthening with elastic band 3x10;

• Evertors strengthening with elastic band 3x10;

• Quadriceps strengthening with elastic band 3x10;

• Hamstrings strengthening with elastic band 3X10;

• Eccentric hamstring strengthening 1x10;

• CORE training: Bipedal bridge;

• CORE Training: Plank;

• Abdominal exercise progression;

• Gait training with parallel bar in front of the mirror;

• Gait training up and down the ramp;

• Gait training with climbing and descending the stairs;

• Proprioception: Lateral Weight Bearing with the hemisphere opposite to the mirror;

• Proprioception: Anteroposterior weight bearing in front of the mirror, inverting the anterior foot;

• Proprioception: Weight Bearing of lower limbs involved on the rocker;

• Continue strengthening in a closed kinetic chain;

• Stretching quadriceps, hamstrings, abductors and adductors;

• Cryotherapy for 20 minutes (PRICE method).

9th and 10th week

Objectives: To increase the strength of the hip, knee, ankle and foot, to increase proprioception, to normalize the gait and to restore the gait with ascending the ramp and stairs. Start cycling, when start running change to treadmill and stairs.

• Punctual AsGa laser over the graft tendon and scan over it;

• US 1mHz pulsed in case of resorbable screw;

• Fascia release and thigh and leg massage;

• Transverse massage around the scar;

• Multidirectional patellar mobilization;

• Fibular head mobilization;

• Adductors strengthening with 1kg progressive load 3 x 10;

• Abductors strengthening with 1kg 3 x 10;

• Plantar arch strengthening 3x10;

• Dorsiflexors strengthening with 1kg 3x10;

• Plantiflexors strengthening with 1kg 3x10;

• Invertors strengthening with 1kg 3x10;

• Evertors strengthening with 1kg 3x10;

• Quadriceps strengthening with 1kg 3x10;

• Hamstrings strengthening with 1kg 3X10;

• Eccentric hamstring strengthening 1x10;

• CORE training: Bipedal bridge;

• CORE Training: Plank;

• Abdominal exercise progression;

• Gait training with parallel bar;

• Gait training up and down the ramp;

• Gait training climbing and descending stairs;

• Start unipodal proprioception;

• Proprioception: Lateral Weight Bearing with the hemisphere opposite to the mirror;

• Proprioception: Anteroposterior weight bearing in front of the mirror, inverting the anterior foot;

• Proprioception: Weight Bearing of lower limbs involved on the rocker;

• Continue strengthening in a closed kinetic chain;

• Stretching quadriceps, hamstrings, abductors and adductors;

• Cryotherapy for 20 minutes (PRICE method);

By the end of the 3rd month, place proprioception exercises with the parallel bars to in front of the mirror.

11 th and 12 nd week

Objectives: To improve the strength of the hips, knees, ankles and feet, increase proprioception and normalize the gait and restore gait on a ramp and stairs.

• Punctual AsGa laser over the graft tendon and scan over it;

• US 1mHz pulsed in case of resorbable screw;

• Fascia release and thigh and leg massage;

- Light transverse massage around the scar;
- Multidirectional patellar mobilization;
- Fibular head mobilization;
- Adductors strengthening with 2kg 3 x 10;
- Abductors strengthening with 2kg 3 x 10;
- Plantar arch strengthening 3x10;
- Dorsiflexors strengthening with 2kg 3x10;
- Plantiflexors strengthening with 2kg 3x10;
- Invertors strengthening with 2kg 3x10;
- Evertors strengthening with 2kg 3x10;
- Quadriceps strengthening with 2kg 3x10;
- Hamstrings strengthening with 2kg 3X10;
- Eccentric hamstring strengthening 1x10;
- CORE training: Bipedal bridge;
- CORE Training: Plank;
- Abdominal exercise progression;
- Gait training with parallel bar;
- Gait training up and down the ramp;
- Gait training climbing and descending the stairs;
- Proprioception according to the patient's evolution;
- Continue strengthening in a closed kinetic chain;
- Stretching quadriceps, hamstrings, abductors and adductors;
- Cryotherapy for 20 minutes (PRICE method).

13 rd and 14 th week

Objectives: To increase strength, endurance and proprioception of lower limbs. Start gym minimum load of 5kg with progression of load according to the patient's tolerance. Start walking on the treadmill.

- Punctual AsGa laser over the graft tendon and scan over it;
- US 1mHz pulsed in case of resorbable screw;
- Fascia release and thigh and leg massage;
- Multidirectional patellar mobilization;
- Fibular head mobilization;
- Start walking on the treadmill;
- Squat on the guided bar 3 x 10 with 6 kg in total;
- Leg press 3x10 with 20kg in total;
- Abductor chair 3x10;
- Adductor chair 3x10;
- Flexor chair 3x10;
- Extensor chair 3x10;
- Eccentric hamstring strengthening 1x10;
- Plantar arch strengthening 3x10;
- CORE exercises progression;
- Abdominal exercise progression;
- Gait training up and down the ramp;
- Gait training climbing and descending the stairs;
- Proprioception according to the patient's evolution;
- Start walking on the trampoline;
- Stretching quadriceps, hamstrings, abductors and adductors;
- Cryotherapy for 20 minutes (PRICE method).

15 th and 16 th week

Objectives: To increase strength, power and improve lower limb proprioception.

Continue gym, and start a unipodal exercises at the gym with 5 kg in the injured limb with progression of load according to the patient's tolerance.

- Punctual AsGa laser over the graft tendon and scan over it;
- US 1mHz pulsed in case of resorbable screw;
- Fascia release and thigh and leg massage;
- Multidirectional patellar mobilization;
- Fibular head mobilization;
- Start walking on the treadmill;
- Squat on the guided bar 3x10;
- Leg press 3x10;
- Abductor chair 3x10;
- Adductor chair 3x10;
- Flexor chair 3x10;
- Extensor chair 3x10;
- Eccentric hamstring strengthening 1x10;
- Plantar arch strengthening 3x10;
- CORE exercises progression;
- Abdominal exercise progression;
- Proprioception according to the patient's evolution;
- Start run training on the trampoline;
- Stretching quadriceps, hamstrings, abductors and adductors;
- Cryotherapy for 20 minutes (PRICE method).

17th to 40th week

Objectives: Bilateral knee joint rebalancing, improve lower limb proprioception with functional movements and improve muscle power.

- Multidirectional patellar and fibular head mobilization
- Start isokinetic training and agility training with light circuits and light run;
- Continue same gym strengthening exercises as the previous week's according to the patient's tolerance and load progression;
- CORE exercises progression;
- Abdominal exercise progression;

- Circuit and running training;
- Sport specific training;
- Proprioception according to the patient's evolution;
- Isokinetic training;
- Cryotherapy for 20 minutes (PRICE method);
- In the 19th and 20th week start the agility training;
- In the 21th and 22nd week start training with change of direction and abrupt stop.