Two different techniques for the reconstruction of the anterior cruciate ligament. Which is better concerning postural control?

Dos técnicas diferentes para la reconstrucción del ligamento cruzado anterior. ¿Cuál es mejor para el control postural?

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Abstract

Introduction: Anterior cruciate ligament (ACL) tears are among the most common knee injuries. These injuries compromise stability and function, frequently requiring surgical reconstruction. Understanding how postural control of the lower limb is affected in patients undergoing ACL reconstruction (ACLR) with different techniques, under the same rehabilitation protocol, is essential for optimizing recovery and improving functional outcomes after physical therapy.
Objective: Compare the rehabilitation protocol effectiveness on postural control between the ACLR technique Bone-Tendon-Bone (BTB) and graft extracted from the semitendinosus and gracilis muscles (STG).
Methodology: Posturographic evaluation was performed 16 weeks after surgery with a 16-week standardized rehabilitation protocol in a BTB group (n=30, age=32,16±8,73 years, weight=78,03±9,53 kg, height=1,69±0,06 m) and another STG group (n=38; age=34,84±9,4 years; weight=76,47±9,27 kg; height=1,67±0,05 m).
Results: The investigation shows that there are no statistically significant differences in unilateral velocity ($p>0.05$) and unilateral area of the center of pressure ($p>0.05$) in subjects with ACLR using the BTB technique.
Discussion: Two ACLR techniques were compared under the same 16-week rehabilitation protocol, evaluating balance and postural stability. The results showed that the BTB technique presented less difference between the injured and healthy limbs, demonstrating better results than the STG graft. However, methodological limitations were identified, as well as the need to consider factors such as limb dominance in future research. Conclusions: The BTB reconstruction technique presents better postural control results in patients undergoing 16 weeks of physiotherapy.

Keywords

Anterior cruciate ligament; anterior cruciate ligament reconstruction; exercise therapy; physical therapy; postural balance.

Resumen

Introducción: Las roturas del ligamento cruzado anterior (LCA) se encuentran entre las lesiones de rodilla más comunes. Estas lesiones comprometen la estabilidad y la función y, a menudo, requieren una reconstrucción quirúrgica. Comprender el control postural de las extremidades inferiores en pacientes sometidos a reconstrucción del LCA (RLCA) con diferentes técnicas, bajo el mismo protocolo de rehabilitación, es esencial para optimizar la recuperación y mejorar los resultados funcionales después de la fisioterapia. Objetivo: Comparar la eficacia del protocolo de rehabilitación en el control postural entre la técnica de RLCA hueso-tendón-hueso (HTH) y el injerto tomado de los músculos semitendinoso y gracilis (STG).
Metodología: Se realizó una evaluación posturográfica 16 semanas después de la cirugía con un protocolo de rehabilitación estandarizado de 16 semanas en un grupo HTH (n=30, edad=32,16±8,73 años, peso=78,03±9,53 kg, altura=1,69±0,06 m) y otro grupo de STG (n=38; edad=34,84±9,4 años; peso=76,47±9,27 kg; altura=1,67±0,05 m).
Resultados: No se observan diferencias estadísticamente significativas en la velocidad unilateral ($p>0,05$) y el área unilateral del centro de presión ($p>0,05$) en sujetos con RLCA mediante la técnica HTH.
Discusión: Se compararon dos técnicas de RLCA bajo el mismo protocolo de rehabilitación de 16 semanas, evaluando el equilibrio y la estabilidad postural. Los resultados mostraron que la técnica HTH presentó menos diferencias entre las extremidades lesionadas y sanas, demostrando mejores resultados que el injerto STG. Sin embargo, se identificaron limitaciones metodológicas, así como la necesidad de considerar factores como la dominancia de las extremidades en futuras investigaciones.
Conclusiones: La técnica RLCA HTH presenta mejores resultados de control postural a 16 semanas de fisioterapia.

Palabras clave

Ligamento cruzado anterior; reconstrucción ligamento cruzado anterior; ejercicio terapéutico; terapia física; balance postural.

Introduction

Anterior cruciate ligament (ACL) injuries are among the most prevalent and extensively studied conditions in sports medicine (Akpinar et al., 2018). In the United States alone, approximately 120,000 athletes are affected annually (Frank & Jackson, 1997; Majewski et al., 2006), contributing to an overall incidence of around 200,000 cases per year (Spindler & Wright, 2008; Armitano-Lago et al., 2020). Epidemiological data from other countries reveal considerable variation in ACL reconstruction (ACLR) rates. For instance, Australia and Norway report annual incidences between 34 and 52 cases per 100,000 inhabitants (Lopes et al., 2016). Similarly, in Europe, the incidence ranges from 21.70 to 33.60 per 100,000 inhabitants over a 14-year follow-up period (Longo et al., 2021). In the U.S., a study in New York State reported an increase in ACLR procedures from 6,178 in 1997 to 7,507 in 2006 (Lyman et al., 2009), reflecting a rising trend in surgical intervention.

Mechanistically, ACL injuries are commonly caused by anterior translation and excessive internal rotation of the tibia during dynamic movements. These biomechanical disruptions compromise proprioception, joint stability, muscle strength, and overall functional performance (Akpinar et al., 2018; Denti et al., 2000; Friedrich et al., 2008; Hewett et al., 2013; Hirjaková et al., 2016; Howells et al., 2011). Proprioception, defined as the sensory modality responsible for detecting joint position and motion (Héroux et al., 2022), encompasses static position awareness, motion and acceleration sensing, and efferent motor activity that regulates reflex responses and muscular coordination (Blum et al., 2021). This function is primarily mediated by mechanoreceptors located in the ACL, playing a crucial role in maintaining knee joint stability (Greiner et al., 2023).

Disruption of proprioceptive pathways following ACL injury leads to increased nociceptive input, neuromuscular dysfunction, delayed muscle activation, and altered motor responses, all of which contribute to biomechanical imbalances and increased loading on the injured limb (Andernord et al., 2014; Hirjaková et al., 2016). These changes highlight the essential role of proprioception in rehabilitation and recovery. While mechanical stabilization is a fundamental goal of ACL reconstruction, accumulating evidence underscores the importance of proprioceptive feedback in restoring functional knee stability and optimizing postoperative outcomes (Grueva-Pancheva et al., 2021).

According to Hirjaková et al. (2016), the main purposes of ACLR are; Recover joint stability, kinematics and prevent degenerative changes in the joint in the long term. The type of treatment depends fundamentally on the age, degree of instability, level of activity of the patient, and their functional, work, and sports expectations.

In this regard, the most widely used techniques for the ACLR are: The graft with patellar tendon commonly known as Bone-Tendon-Bone (BTB), this technique provides a resistance of 168% over the normal ACL, while the technique with a graft extracted from the semitendinosus and gracilis muscles (STG) has less comorbidity than the BTB technique, and finally allografts of the patellar tendon, Achilles tendon or long tendons such as the anterior or posterior tibial (Ayala-Mejías et al., 2014). The STG technique showed faster in the rehabilitation process than the BTB technique (Cirstoiu et al., 2011), where key points are; that postoperative pain is greatly reduced (Aglietti et al., 1994), good knee mobility is obtained very rapidly, approximately 60 degrees after the first 72 hours, and the active mobilization of the patient is early (Cirstoiu et al., 2011).

Early-stage rehabilitation is critical to post-ACLR success. Without high-quality rehabilitation in the early stages, patients often fail to overcome critical aspects of dysfunction, limiting knee function and hindering optimal transition to later stages of rehabilitation. At this early stage, it is crucial to address six main dimensions: (i) pain and swelling; (ii) knee joint range of motion; (iii) arthrogenic muscle inhibition and muscle strength; (iv) quality of movement and neuromuscular control during daily activities; (v) psychosocial, cultural and environmental factors; and (vi) preservation of physical fitness (Buckthorpe et al.,2024). These are possible goals to achieve in a period to 4-6 months or 9-12 months in more conservative rehabilitation process. Although it is clear that rehabilitation after ACLR includes a series of activities or limitations, those activities to rehabilitation process are cold therapy, immediate versus delayed motion, immediate versus delayed weightbearing, closed versus open kinetic chain exercises, bracing, home versus clinic-based rehabilitation, neuromuscular electrical stimulation versus voluntary muscle contraction, specific exercise programs (Beynnon et al., 2005). On the other hand, none activities showed specific training to balance how key elements in this process.

However, the ACL injury can negatively influence postural control, generating mechanical instability of the joint and deficits in sensory-motor control of the lower extremity (Di Stasi et al., 2013). This influence on postural control can lead to an increased risk of a new injury, resulting in a pathological cycle and therefore a sensory defect in motor and postural control that is not yet understood (Fulton et al., 2014; Paterno et al., 2010). This is because different central motor sensory systems are involved in neuromuscular stability and any alteration in it requires a more specific study (Finley et al., 2012). Postural control assessment is commonly used through posturography test in force platforms for quantitative analysis of balance, through variables that integrative different systems how the nervous, sensory, and motor systems. The variables used in the posturography test are those that have relation assessment center of pressure (CoP) so much in velocity, displacement, and area of CoP, the velocity of CoP shows what fast were the CoP displacements and considered the measure with the highest reliability among trials, while the area of CoP estimates the dispersion of the CoP data during the task, but this variable has lowest reliability among trials. On the other hand, the displacement of CoP is the displacement of the resultant vector of the ground reaction force of the center of gravity (Duarte & Freitas, 2010).

Currently, there is a lack of evidence-based data describing the alteration in postural control before and after ACL reconstruction, and the importance of the ACL on proprioceptive control and joint stability is unknown (Bartels et al., 2016, 2018; Paterno et al., 2010).

Palm et al. (2013) describe a 21% increase in stability 608 days after anterior cruciate ligament reconstruction (ACLR) and 14% after 3 months after ACLR, with the difficulty that they do not use the same measurement methodology (Palm et al., 2015).

In other hand, a study conducted by Armitano-Lago et al., 2020 in 16 subjects with ACLR greater than two years after surgery compared to a control group undergoing neuromotor evaluations, which included measures of reaction time (both sitting and postural), walking ability, balance, range of movement of the ankle, proprioception, knee joint laxity, patellar tendon reflex latency, and quadriceps strength showed main finding was that the ACLR group showed a slower reaction than the control group under postural feedback conditions. This slowing occurred regardless of the limb (affected or unaffected) used for stepping. These results suggest that the impact of an ACLR is not limited to mechanical aspects or the joint itself, but is intensified under challenging postural movement conditions, affecting the ability of individuals with ACLR to respond quickly. (Armitano-Lago et al., 2020)

Based on what has been described, we hypothesize that patients undergoing ACLR with the BTB technique have better postural control than patients undergoing ACLR with the STG technique after a rehabilitation protocol. In this way, the objective of this study is to compare the rehabilitation protocol effectiveness on postural control between the surgical reconstruction technique BTB and STG.

Method

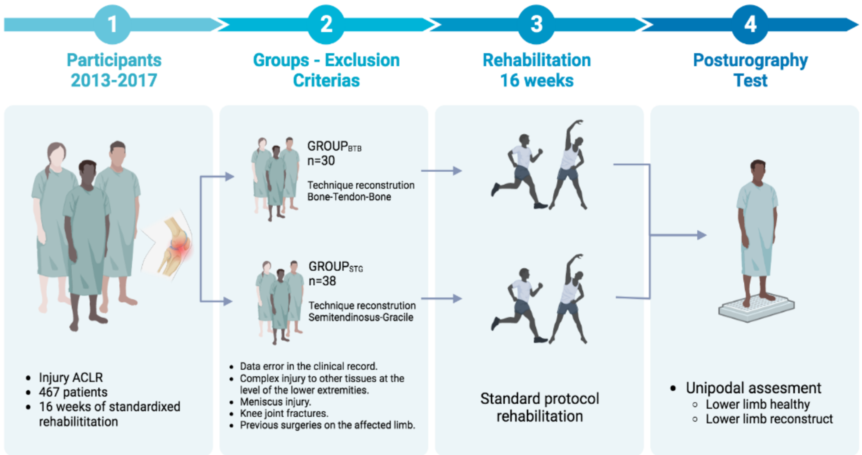
Participants

The type of sample is non-probabilistic, where the sample size was defined for convenience and was given by all patients undergoing ACLR at the Hospital del Trabajador de Santiago during the years 2013-2017, which add up to a total of 467 patients, All patients underwent the post-ACLR rehabilitation protocol, which consists of several phases, depending on the weeks of post-operative (PO) evolution: i) Immediate PO: from the first PO day until hospital discharge, with the objectives of pain management, quadriceps muscle activation, recovering passive range of motion for knee extension. ii) Initial outpatient: from admission to outpatient rehabilitation until the second PO week, with the objectives of regaining motor control of the lower extremity, improving voluntary quadriceps muscle activity, and regaining active range of motion in extension and 90° of active flexion. iii) Intermediate outpatient: from the third week to the eighth PO week, with the objectives of recovering active flexion range of motion 130°, re-education of gait, and re-adaptation to physical effort. iv) Advanced outpatient: from the ninth to the twelfth PO week, with goals of improving muscle flexibility, full range of motion recovery, intensive muscle strengthening, and progressive reintegration to activities. v) Final outpatient: from the thirteenth to the sixteenth PO week, with the objectives of optimizing muscle performance, agility activities, dexterity, and proprioceptive training. All these activities were performed by highly trained physical therapists from the lower extremity team and subsequent evaluation by posturography, where exclusion criterias are; data error in the clinical record, complex injury to other tissues at the level of the lower extremities, meniscus injury, knee joint fractures, previous surgeries on the affected limb, where all patients were in active employment prior to their injury. The final participants, after applicated exclusion criterial, in the study was 68 patients: a) groupBTB [n=30, age=32,16±8,73 years, weight=78,03±9,53 kg, height=1,69±0,06 m] are patients who underwent reconstruction of the anterior cruciate ligament using the Bone-Tendon-Bone technique (BTB), and b) groupSTG [n=38; age=34,84±9,4 years; weight=76,47±9,27 kg; height=1,67±0,05 m] are patients who underwent the Semitendinosus-Gracile (STG) reconstruction technique. The benefits and risks associated with this research were explained before signing the institutionally approved informed consent form. The research protocol was approved by the Ethics Committee of the Hospital del Trabajador de Santiago Nº 14/2019, in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Procedure

This study is observational, cohort retrospective, and analytical where to control for confounding bias and the effects of confounding variables, we used the matching of the surgery they underwent. Data collection was done directly from the patient's clinical record, using the number registered in evaluation forms upon admission to post-surgery rehabilitation treatment. From where the differentiation data of the operative protocol was obtained to distinguish the ACLR method, it was later reviewed if there was any type of complex lesion in the affected lower extremity and if the clinical record was complete and without errors, a process in which It was possible to determine that the final number of participants in the study (n=68). The patients (n=30) who underwent reconstruction of the anterior cruciate ligament using the BTB technique and the patients (n=38) who underwent the STG reconstruction technique. The patients are assessment with posturography after of 16 weeks of treatment in which the fundamental objectives were: a) recover range of joint movement, b) muscle strengthening, c) muscle flexibility, d) gait re-education, e) aerobic training and balance, and d) balance training throughout the rehabilitation process (Figure 1).

Figure 1. Process diagram.



ACLR: anterior cruzado ligament reconstructs; $GROUP_{BTB}$: Group of reconstruct technique bone-tendon-bone: $GROUP_{STG}$: Group of reconstruct technique semitendinosus-gracile.

Measure - Posturography Test

The Posturography test is performed barefoot, the person evaluated climbs onto the platform in unipodal support with the lower extremity healthy, the contralateral lower extremity with the hip and knee joint in 90° flexion, once on top they are asked to keep their eyes fixed on the front at one point for

30 seconds, and then repeat the procedure with the operated lower extremity, keeping his/her arms crossed over the chest (Di Fabio, 1995; Miner et al., 2022; Tjernström et al. 2015). Sensitivity and specificity of platform posturography for identifying patients with vestibular dysfunction. The equipment of posturography was on HurLabs Balance Trainer BT3® platform [dimension 2,36x22,83x19,69 in; non-linearity +/-0,02%; sensitivity 2mV/V +/-0,25%] (2006), Kokkola, Finland. The variables are expressed in speed (mm/s) and excursion area (mm2) of the CoP with a sample frequency of 400 Hz, evaluation carried out by the person in charge of the biomechanics unit.

Statistical analysis

The normality of data distribution was confirmed using the Kolmogorov-Smirnov test and a histogram plot (Martínez González et al., 2001). After the determination of both groups, a Shapiro-Wilk test (N<50) per group was performed, maintaining the abnormal behavior. Data are reported as means, medians, standard deviations (SD) and quartiles of variable de CoP [speed and area CoP] to each group of reconstruct technical [groupBTB and groupSTG], where the data behaved abnormally and considering that the study variables were dependent characteristics. The Wilcoxon signed rank test was used to compared health limb vs injury limb in each group [groupBTB and groupSTG] and compared; health limb groupBTB vs health limb groupSTG and injury limb groupBTB vs injury limb groupSTG was used U de Mann Whitney (U) and effect size with probability of superiority (PSest), where values will be qualitatively categorized as no effect (PSest ≤ 0,0), little effect (PSest ≥ 0,56), medium effect (PSest ≥ 0,64) and big effect (PSest ≥ 0,71) (Grissom, 1994; Luis, 2016). The statistical tests will be carried out using the SPSS statistic® software.

Results

Table 1 show information regarding the descriptive statistics of the sample according to the area of CoP and velocity of CoP variables for the healthy and injured lower extremity. The Kolmogorov-Smirnov and Shapiro Wilk test showed that almost all variables in this study are abnormal[p<0.05], except for the variable of speed of the healthy lower limb for BTB, which showed normal behavior results. The Wilcoxon test signed ranges where the oscillation area of the CoP was compared between health limb vs injury limb in GroupBTB [p=0,797] did not show significative differences; however, the health limb vs injury in GroupSTG [p=0,001] showed significate differences. To comparative velocity of the CoP between the health limb vs injury in GroupBTB [p=0,813] did not showed significative differences, and another GroupSTG between the health limb vs injury [p=0,009] showed significate differences. The oscillation area of the CoP and velocity of the CoP to injuries limbs between GroupBTB vs. GroupSTG are not significative differences [p=0,088; U=708; PSest=0,62 and p=0,436; U=633; PSest=0,55] respectively, while the oscillation area of the CoP and velocity of the CoP to healthy limbs between GroupBTB vs. GroupSTG neither showed significative differences [p=0,630; U=531; PSest=0,46 and p=0,537; U=520; PSest=0,45] respectively. In addition, a superiority probability analysis was performed for CoP velocity and CoP area between the healthy and injured limbs in both groups ($Group_{BTB}$-$Group_{STG}$), showing two-tailed p values of 0.198 for CoP velocity of the injured lower limb, 0.659 for CoP velocity of the healthy lower limb, 0.478 for CoP area of the injured lower limb, and 0.851 for CoP area of the healthy lower limb.

Table 1. Descriptive statistical and differences between groups and limbs.

	$Group_{BTB}$ [n=30]		$Group_{STG}$ [n=38]		Δ Groups [$Group_{BTB}$ - $Group_{STG}$]		SE diff		CI 95% differences		p two-tailed	
Variables	Healthy limb	Injury limb	Healthy limb	Injury limb	Healthy limb	Injury limb	Healthy limb	Injury limb	Healthy limb	Injury limb	Healthy limb	Injury limb
Speed of CoP (mm/s)					Speed of CoP (mm/s)							
Mean ± SD	15,30 ± 3,86	16,12 ± 5,36	14,87 ± 3,75	18,26 ± 7,75								
95% CI	13,86 – 16,75	14,12 – 18,13	13,64 – 16,11	15,72 – 20,82	0,43	-2,14	0,9734	1,66606	(-1,48;2,34)	(-5,39;1,11)	0,659	0,198
Median	14,66	14,99	14,14[a]	16,2								
Q_1-Q_3	12,64 - 17,81	12,96 - 16,53	12,05 - 16,81	12,05 - 23,21								
Area of CoP (mm^2)					Area of CoP (mm^2)							

Mean ± SD	453,32 ± 206,36	543,92 ± 504,17	443,49 ± 203,15	624,79 ± 366,47								
95% CI	376,32 – 530,43	355,66 – 732,18	376,72 – 510,27	504,34 – 745,25	9,83	-80,87	52,0382	114,0308	(-92,16; 111,82)	(-304,37 ; 142,63)	0,851	0,478
Median	430,71	370,13	399,71[a]	530,52								
Q_1-Q_3	312,81 - 524,77	329,64 - 512,10	283,28 - 518,56	361,85 - 827,98								

CoP: center of pressure – SD: standard deviation – 95% CI: 95% Confidence Interval for mean - Q_1: quartile 25 – Q_3: quartile 75 - $Group_{BTB}$: Group bone-tendon-tone technique - $Group_{STG}$: group semitendinosus-gracile technique - [a] Differences between healthy limb vs injury limb intra-group [$Group_{BTB}$ and $Group_{STG}$] [b] Differences between group to healthy limb vs healthy limb, and injury limb vs injury limb [$Group_{BTB}$ and $Group_{STG}$]- SE diff: Standard Error of Differences -CI: Confidence Interval.

Discussion

The different reconstruction techniques of the anterior cruciate ligament, the post-surgery, and the rehabilitation process are a challenge because ACL surgery and physical therapy treatment have the main goal of restoring normal knee kinematics and functional stability in the shortest possible time (Ambrosi et al., 2023). The rehabilitation protocol is essential to returning the knee to its healthy state. Fast balance recuperation is key for correct joint functionality since damage to the anterior cruciate ligament injury affects knee balance and proprioception (Emami Meibodi et al., 2022).

To the authors' knowledge, this is the first study that has measured balance between the two surgical reconstruction techniques anterior crucial ligament, more did in, with the same rehabilitation protocol of 16-week. The main results indicated that the surgical reconstruction bone-tendon-bone technique not showed the difference between the injured limb and the healthy limb, showing that this rehabilitation protocol had good results in the surgical reconstruction bone-tendon-bone technique after therapy 16-week.

Some explaining for the results are possible methods of anterior crucial ligament reconstruction of bone-tendon-bone because Herbawi et al. (2022) and Hurley et al. (2022) demonstrated that this is a stronger and more stable graft with fewer soft tissue incisions compared to hamstring grafts. (Herbawi et al., 2022; Hurley et al., 2022). The rehabilitation protocol with interventions with visual feedback can enhance the static and dynamic balance and improve position sense, which is the final step in this protocol for both groups. (Emami Meibodi et al., 2022), where the bone-tendon-bone technique has many advantages; creating bone tunnels in targeted positions safely and easily reduces bone loss and low risk of technical failure, but the rehabilitation process's main importance is its short surgical time (Hayashi et al., 2017).

The comparison between healthy and injured extremities for area and speed of CoM in group semitendinosus-gracile technique showed differences; according to these results obtained (Mohammadi et al., 2012) showed that eight months after the ACLR in elite athletes, there were postural asymmetries compared to the control group, demonstrating greater displacement, speed and oscillation area of the center of pressure in the injured limb compared to the contralateral one (Zouita Ben Moussa et al., 2009). Direct connections between the neurological structures of the ACL, the spinal cord, and the supraspinal areas mainly explain this. Therefore, the lesion can decrease afferent information, according to Mohammadi et al. (2012).

A systematic review and meta-analysis reported that people with ACL injury decrease their postural stability by up to 30% between a posturographic evaluation before surgery and six weeks after surgery (Lehmann et al., 2017) due to damage to the sensitive joint mechanoreceptors. to joint deformation, changes in position and movement carried out mainly in the knee, causing a deficit in sensorimotor control (Konishi, 2011). These changes in sensorimotor control can lead to a disturbance in sensory input, contributing to afferent and efferent alterations in joint stability, which translates into greater instability (Lehmann et al., 2017).

In this work, the results showed information very close to that reported in the literature, where significant differences are seen in the comparison between the healthy and injured limb, where a greater excursion of the center of pressure of approximately one is reported for the area of the injured limb 50% of the cases compared to the injured extremity, a similar situation is described for speed with a 15% difference, where the oscillation speed of the center of pressure is higher on average for the injured lower extremity. Although the treatment protocol and the evaluation are standardized, one of the limitations of this study is that said interventions were carried out by different professionals and not under the author's supervision. This could generate differences regarding the techniques, forms of treatment, and the accuracy of their application cannot be verified. Another limitation is not taking into account the dominance of the subjects. Such dominance could also alter performance and performance in the evaluation (Bartels et al., 2019). A similar study carried out by Muehlbauer et al. (2014) showed that regardless of the sensory condition of the limb, there are no significant statistical differences between the dominant and non-dominant leg, being able to use one or the other leg interchangeably during the static balance test other limbs in healthy young adults. Due to this discrepancy, it would be interesting to determine the implication that dominance in the extremities may have in patients with ACLR for the evaluation in the posturography (Muehlbauer et al., 2014). For future research, it would be important to consider the variables mentioned above in order to minimize the bias that could occur with the differences in the forms of application of evaluations, treatments, and to consider the clinical implications that these could have.

Conclusions

Based on the results obtained, the bone-tendon-bone reconstruction technique presents better postural control results in patients undergoing 16 weeks of physical therapy treatment with emphasis on; recovering joint range of motion, muscle strengthening, muscle flexibility, gait re-education, aerobic and balance training, and balance training throughout the rehabilitation process.

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