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IMPACT OF VIBRATION PLATFORM TRAINING ON POSTOPERATIVE ANTERIOR CRUCIATE LIGAMENT REHABILITATION. A SYSTEMATIC REVIEW

IMPACTO DEL ENTRENAMIENTO EN PLATAFORMAS VIBRATORIAS EN LA REHABILITACIÓN POST-QUIRÚRGICA DEL LIGAMENTO CRUZADO ANTERIOR. UNA REVISIÓN SISTEMÁTICA

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ABSTRACT

Keywords:
vibration platform, rehabilitation, anterior cruciate ligament, whole body vibration, strength.

The primary aim of the study was to review the available evidence on the effectiveness of whole-body vibration (WBV) training in comparison with conventional rehabilitation in the postoperative recovery of the anterior cruciate ligament (LCA). Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a systematic search was conducted in the databases PubMed, Cochrane, Scopus, Web of Science and Physiotherapy Evidence Database (PEDro) until July 2024. All randomized clinical trials in which intervention group performed WBV after ACL surgery were included. In order to check the methodological quality of the included studies, the CASPe scale, PEDro scale and the Cochrane bias assessment tool were used. Of the 470 records identified, 7 met the selection criteria. In general, despite there being a trend towards improvement (p>0,05) in strength with respect to the control group, no significant increases were observed. On the other hand, the studies found statistically significant (p<0,05) increases in balance and the Lysholm Scale compared to the control group. In conclusion, WBV therapy may constitute an effective strategy in the rehabilitation of patients with ACL reconstruction, showing positive results in knee musculature strength, balance, postural control an Lysholm Scale. In addition, WBV has been shown to be superior to conventional rehabilitation in increasing strength, balance and Lysholm Scale. However, there is no consensus on the effectiveness of both therapies on postural control and center of pressure oscillation. Future clinical trials are needed to substantiate the findings of this systematic review.

RESUMEN

Palabras clave:
plataforma vibratoria, rehabilitación, ligamento cruzado anterior, vibración a cuerpo entero, fuerza.

El objetivo de este estudio fue revisar la evidencia disponible sobre la efectividad del entrenamiento en plataformas de vibración de cuerpo entero (WBV) en comparación con la rehabilitación convencional en la recuperación postquirúrgica del ligamento cruzado anterior (LCA). Siguiendo las directrices "*Prefered Reporting Items for Systematic Review and Meta-anlisis*" (PRISMA) se realizó una búsqueda sistemática en las bases de datos PubMed, Cochrane, Scopus, Web of Science y "*Physiotherapy Evidence Database*" (PEDro) hasta julio de 2024. Se incluyeron todos los ensayos clínicos aleatorizados cuyo grupo intervención realizara WBV postcirugía de LCA. Se comprobó la calidad metodológica mediante la escala CASPe, PEDro y Cochrane. De los 470 registros identificados 7 cumplieron los criterios de selección. En general, a pesar de haber una tendencia a la mejora ($p>0,05$) de la fuerza respecto al grupo control, no se observaron aumentos significativos. Por otro lado, se encontraron incrementos significativos ($p<0,05$) del equilibrio y la Escala Lysholm de funcionalidad de la rodilla respecto al grupo control. En conclusión, la terapia de WBV puede constituir una estrategia efectiva en la rehabilitación de pacientes con reconstrucción de LCA, mostrando resultados positivos en la fuerza de la musculatura de la rodilla, el equilibrio, el control postural y la Escala de Lysholm. Además, la WBV ha demostrado ser superior a la rehabilitación convencional en el aumento de la fuerza, equilibrio y la Escala de Lysholm. Sin embargo, no hay consenso sobre la efectividad de ambas terapias en el control postural y la oscilación del centro de presiones.

Introduction

Anterior cruciate ligament (ACL) injuries represent a challenge in the setting of routine clinical practice in sports medicine and sports physiotherapy (Kakavas et al., 2020). These injuries are common in physically active people, with an approximate incidence of 250,000 injuries annually in the United States (Acevedo et al., 2014). They especially affect people who participate in high-intensity activities and sudden changes of direction (Kakavas et al., 2020). In 70% of cases the injury mechanism is indirect, being damaged during acceleration, deceleration and turning actions in which the foot remains fixed to the ground and the knee undergoes hyperextension, valgus and internal rotation, placing excessive stress on the ACL (Cimino et al., 2010; Kaeding et al., 2017; Letafatkar et al., 2019). ACL injury results in altered knee biomechanics leading to abnormal movement patterns and chronic instability (Lohmander et al., 2007). Over time this biomechanical alteration can lead to meniscal and articular cartilage lesions that will give rise to osteoarthritis after 15-20 years (Kaeding et al., 2017; Lohmander et al., 2007). To avoid these complications, 50% of patients undergo surgical ACL reconstruction to restore knee stability (Acevedo et al., 2014). However, post-surgical rehabilitation is essential to ensure a complete and effective recovery (Diermeier et al., 2021).

Traditionally, conventional physical therapy has been the mainstay of post-surgical ACL rehabilitation. This approach is aimed at restoring joint mobility and stability, strengthening the musculature, improving proprioception and reducing the risk of relapse (Seixas et al., 2020). Despite its good results, the search for other complementary physiotherapy procedures that can accelerate and optimize rehabilitation remains a priority in the research of this injury. In this context, vibration platforms that enable whole-body vibration (WBV) have emerged as a potentially effective tool in musculoskeletal rehabilitation (Van Heuvelen et al., 2021). WBV is an exercise modality in which subjects are exposed to mechanical vibrations by means of a platform, which can be vertical or lateral and alternating or tilting (Oroszi et al., 2020). It has been observed that WBV can improve fast muscle fiber activation and strength of the lower extremity musculature (Annino et al., 2017; Cardinale and Bosco, 2003; Zhang et al., 2021), being essential to recover the strength of the knee extensor musculature after ACL reconstruction (Sogut et al., 2022). Additionally, WBV appears to be beneficial in improving balance, proprioception and joint stability (Sierra-Guzman et al., 2018), particularly important effects for ACL recovery, given that stability and neuromuscular control are imperative for safe return to sporting activities (Kakavas et al., 2020). The properties of WBV are based on the fact that vibration provides a specific sensory stimulus that triggers neuromuscular and musculoskeletal responses, through the stretch reflex (Seixas et al., 2020). Thus, it has been reported that acute changes in motor output are related to an increase in muscle spindle sensitivity (Seixas et al., 2020).

Understanding the effects and application of vibration platforms in ACL rehabilitation could have a significant impact on clinical practice and improve patient outcomes, offering faster and more effective recovery. In addition, it could result in a lower incidence of lesion recurrence, better quality of life and reduced costs associated with prolonged treatment. Therefore, the objective of this research was to systematically review the available scientific evidence on the effectiveness of WBV treatment on strength and neuromuscular parameters in physically active adults in post-surgical ACL rehabilitation. In a complementary manner, the effectiveness of WBV compared to traditional rehabilitation in post-surgical ACL rehabilitation was reviewed.

Method

Search strategy

For the selection of studies, a structured search was carried out using the electronic databases Medline (PubMed), Cochrane, Scopus, Physiotherapy Evidence Database (PEDro) and Web of Science until July 2024. The search was conducted following the methodological guidelines "Preferred Reporting Item Guidelines for Systematic Reviews and Meta-Analyses" (PRISMA) (Page et al., 2021) and the PICOS question model as follows: P (population): physically active adults (≥18 years) undergoing surgery after sustaining an ACL injury. I (intervention): WBV during the postoperative recovery period. C (comparison): conventional rehabilitation or placebo treatment. O (results): strength parameters (peak torque, electromyographic amplitude, isometric and isokinetic strength, peak power and rate of torque development) and neuromuscular parameters (balance, postural control and oscillation of the center of pressures). S (study design): randomized clinical trials.

The search strategy contained a combination of Medical Subject Headings (MeSH) and free words for related key concepts including: ("Anterior Cruciate Ligament" OR "Anterior Cruciate Ligament Reconstruction" OR "Anterior Cruciate Ligament Injuries") AND ("Whole Body Vibration" OR "Whole Body Vibration Training" OR "Whole Body Vibration Exercise" OR "Whole Body Vibration Therapy"). Two authors independently searched the 5 databases and a third reviewer resolved disagreements. All the studies obtained were compared in order to narrow down the search as much as possible and avoid repetition of studies. In addition, the bibliographic references of the included studies and part of the excluded studies were reviewed in order to identify relevant titles that might have been overlooked by the search strategy.

Selection Criteria

The following inclusion criteria were established for the selection of articles: 1) physically active patients (≥18 years) undergoing surgery following ACL injury; 2) treatment with WBV during postoperative rehabilitation; 3) comparison with a group receiving conventional rehabilitation (no vibration) or placebo treatment; 4) original records (meta-analyses, reviews and editorials will not be considered); 5) accurate WBV protocol information (time of use, frequency, vibration etc.); 6) report primary or secondary results related to strength parameters (peak torque, electromyographic amplitude, isometric and isokinetic force, peak power and rate of torque development) and/or neuromuscular parameters (balance, postural control and center of pressures oscillation); 7) score higher than six on the Spanish Critical Appraisal Skills Programme (CASPe) questionnaire (Cabello, 2021) and the PEDro scale (Moseley et al., 2020); 8) publications in Spanish, English, Italian, French and Portuguese.

No criteria were applied regarding the sex of the participants, the duration of the intervention or the age of the studies.

Data Extraction and Synthesis

The following information was extracted from each trial included in the review: Surname of the first author, year of publication, country where the study was carried out, design, sample size, sex, age, height, body weight, losses, intervention in the control group (CG) and in the intervention group (IG), parameters evaluated and results obtained. Two researchers performed the data extraction process using a spreadsheet. In case of disagreements, a third reviewer participated in the process.

Evaluation of Methodological Quality

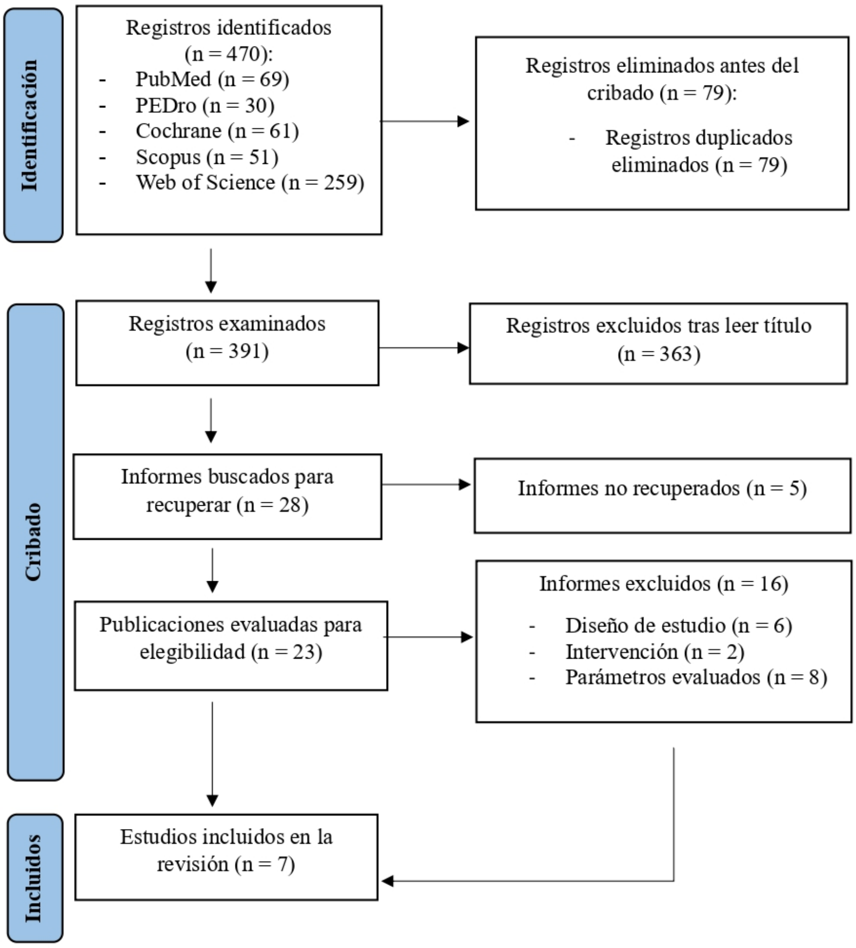
The selected articles were critically read to assess their methodological quality using the PEDro (Moseley et al., 2020) and CASPe (Cabello, 2021) scales. Additionally, the risk of bias was assessed using the Cochrane tool (Higgins et al., 2011).

Results

Selection of Studies

The literature search resulted in a total of 470 studies, 69 from Medline (PubMed), 30 from PEDro, 61 from Cochrane, 51 from Scopus and 259 from Web of Science. After eliminating duplicates (n=79), the title and abstract of the remaining 391 studies were analyzed and 363 were eliminated because they did not meet the selection criteria. In a second phase, 28 full-text studies were evaluated, 21 were discarded for not having access to the full text (n=5), not being clinical trials (n=6), not treating ACL injury with WBV (n=2) and not evaluating strength or neuromuscular parameters (n=8). Likewise, the bibliographic references of the included articles and part of the excluded articles were reviewed with the aim of finding additional relevant studies, but there were no results. Therefore, a total of 7 articles (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003) that met all the established selection criteria were included (Figure 1).

Figure 1
Flow chart illustrating the process of identification and selection of studies included in this review, following the guidelines established by "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) (Page et al., 2021)



Evaluation of Methodological Quality

Table 1 shows the scores obtained in the CASPe questionnaire. All studies scored equal to or greater than 9 (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003). Only Costantino et al. (2018) obtained the maximum score. The main shortcomings in terms of methodological quality have been found in blinding items (Berschin et al., 2014; Blackburn et al., 2021; Salvarani et al., 2003), similar groups at baseline (da Costa et al., 2019; Salvarani et al., 2003), large treatment effect (Berschin et al., 2014; da Costa et al., 2019; Pamukoff et al., 2016, 2017) and applicability to your environment or local population (Pamukoff et al., 2016, 2017).

Regarding the PEDro methodological quality questionnaire, all selected articles scored 6 or higher (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003). The highest score was obtained by the study of Costantino et al. (2018) with 11 points, in contrast to Salvarani et al. (2003) who scored the lowest, with 6 points. All studies met the items of randomization, minimum 85% follow-up, intention-to-treat data analysis, statistical comparison between groups, and point and variability measures (Table 2).

Table 1

Methodological quality of the articles included in the systematic review according to the CASPe questionnaire

FIRST AUTHOR, YEAR OF PUBLICATION AND COUNTRY	ITEMS											Total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Berschin et al. (2014), Germany	YES	YES	YES	NO	YES	YES	NO	95% CI $p < 0,05$	YES	YES	YES	9
Costantino et al. (2018), Italy	YES	YES	YES	YES	YES	YES	YES	95% CI $p < 0,05$	YES	YES	YES	11
da Costa et al. (2019), Brazil	YES	YES	YES	YES	NO	YES	NO	95% CI $p < 0,05$	YES	YES	YES	9
Pamukoff et al. (2017), USA	YES	YES	YES	YES	YES	YES	NO	95% CI $p < 0,05$	NO	YES	YES	9
Pamukoff et al. (2016), USA	YES	YES	YES	YES	YES	YES	NO	95% CI $p < 0,05$	NO	YES	YES	9
Salvarani et al. (2003), Italy	YES	YES	YES	NO	NO	YES	YES	95% CI $p < 0,05$	YES	YES	YES	9
Blackburn et al. (2021), USA	YES	YES	YES	NO	YES	YES	YES	95% IC $p < 0,05$	YES	YES	YES	10

Note. CI=Confidence Interval. CASPe questionnaire items: 1=Clearly defined question; 2=Random assignment; 3=Patients considered until the end; 4=Blinding; 5=Similar groups at baseline; 6=Equally treated groups; 7=Large treatment effect; 8=Precision of effect; 9=Applicability to your local environment or population; 10=All outcomes considered; 11=Benefits justify risks and costs.

Table 2

Methodological quality of the articles included in the systematic review according to the PEDro questionnaire

FIRST AUTHOR, YEAR OF PUBLICATION AND COUNTRY	ITEMS											Total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Berschin et al. (2014), Germany	YES	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	8
Costantino et al. (2018), Italy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	11
da Costa et al. (2019), Brazil	YES	YES	YES	NO	YES	NO	NO	YES	YES	YES	YES	8
Pamukoff et al. (2017), USA	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES	9
Pamukoff et al. (2016), USA	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES	9
Salvarani et al. (2003), Italy	NO	YES	YES	NO	NO	NO	NO	YES	YES	YES	YES	6
Blackburn et al. (2021), USA	YES	YES	NO	YES	NO	NO	NO	YES	YES	YES	YES	7

Note. Items of the PEDro scale: 1=Choice criteria; 2=Random assignment; 3=Hidden assignment; 4=Similarity of groups at baseline; 5=Participant blinding; 6=Therapist blinding; 7=Evaluator blinding;

8=Minimum 85% follow-up; 9=Analysis of data by intention-to-treat; 10=Statistical comparison between groups; 11=Spot and variability measures.

Bias Risk Assessment

To assess the risk of bias of the selected studies, the Cochrane bias assessment tool (Higgins et al., 2011) was used and is shown in Table 3 and Figure 2. All 7 studies showed low risk on the items of random sequence generation, incomplete follow-up, selective reporting of results, and other biases (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003). However, consistent with what was found in the PEDro and CASPe scales, the risk of participant and rater blinding bias was high in 5 (Berschin et al., 2014; Blackburn et al., 2021; Pamukoff et al., 2016, 2017; Salvarani et al., 2003) and 4 studies respectively (Berschin et al., 2014; Blackburn et al., 2021; da Costa et al., 2019; Salvarani et al., 2003).

Figure 2

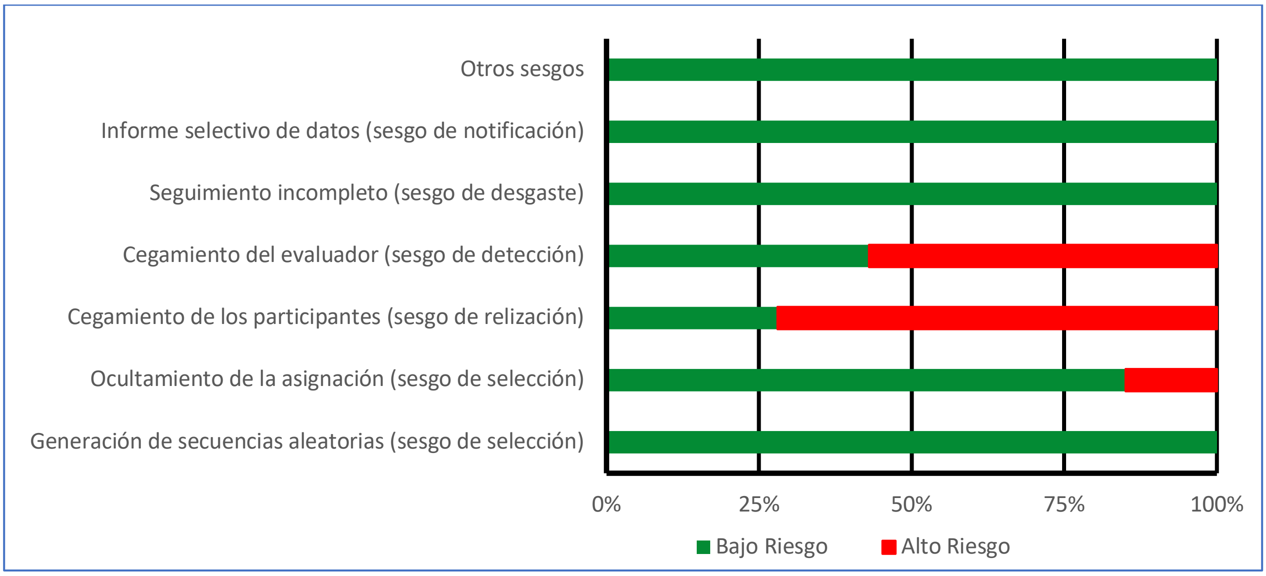
Bias assessment of the articles included in the systematic review according to the Cochrane tool

FIRST AUTHOR, YEAR OF PUBLICATION AND COUNTRY	1	2	3	4	5	6	7
Berschin et al. (2014), Germany	+	+	-	-	+	+	+
Costantino et al. (2018), Italy	+	+	+	+	+	+	+
da Costa et al. (2019), Brazil	+	+	+	-	+	+	+
Pamukoff et al. (2017), USA	+	+	-	+	+	+	+
Pamukoff et al. (2016), USA	+	+	-	+	+	+	+
Salvarani et al. (2003), Italy	+	+	-	-	+	+	+
Blackburn et al. (2021), USA	+	-	-	-	+	+	+

Note. "+": low-risk bias; "-": high risk of bias; "?": uncertainty about the potential for bias or lack of information about it; T: total number of items completed per study. Cochrane tool items: 1=random sequence generation; 2=allocation concealment; 3=participant blinding; 4=evaluator blinding; 5=incomplete follow-up; 6=selective reporting of results; 7=Other biases.

Figure 3

Problems encountered in the risk of bias assessed with the Cochrane tool



Characteristics of Participants and Interventions

A total of 207 participants (111 ♂ y 96 ♀) between 20 and 30 years of age were recruited at the beginning of the study. Only one participant was not evaluated at the end of the study because he did not complete the intervention (Costantino et al., 2018). The participants were physical persons the participants were physically active people who sustained an ACL injury and underwent surgery with an autograft of the ACL tendon (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; Pamukoff et al., 2016, 2017; Salvarani et al., 2003), hamstring (Blackburn et al., 2021; Pamukoff et al., 2016, 2017) or allograft (Blackburn et al., 2021; Pamukoff et al., 2016, 2017). All studies included both women and men, except Costantino et al. (2018) which evaluated only females and da Costa et al. (2019) that studied only men (Table 4).

All studies compared the effect of conventional physical therapy procedures in isolation with the effect of conventional physical therapy combined with WBV (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003). Conventional physical therapy procedures included methods such as passive kinesitherapy, transcutaneous electrical nerve stimulation (TENS), stretching, strengthening of knee and hip flexors and extensors, proprioception and aerobic exercise. In a complementary manner, Pamukoff et al. (2016,2017) and Blackburn et al. (2021) compared with a third group that received localized vibration in the quadricipital tendon area. The duration of the intervention ranged from 11 weeks (Berschin et al., 2014) to 1 week (Blackburn et al., 2021). The weekly frequency ranged from 5 sessions (Salvarani et al., 2003) to 1 session (Blackburn et al., 2021) with a duration of 40 (Berschin et al., 2014) to 10 minutes (Salvarani et al., 2003). Vibration frequencies of 26 Hz (Costantino et al., 2018), 30 Hz (Berschin et al., 2014; Blackburn et al., 2021; Pamukoff et al., 2016, 2017; Salvarani et al., 2003) and 50 Hz (da Costa et al., 2019) were used. The position chosen for vibration was standing (Berschin et al., 2014; Blackburn et al., 2021) and isometric squat (Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003) (Table 5).

Evaluation of Results

The results obtained after the interventions are shown in Table 4.

Force

The changes produced in strength were evaluated by the 7 studies (Berschin et al., 2014; Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017; Salvarani et al., 2003). Isometric (Berschin et al., 2014; Blackburn et al., 2021; da Costa et al., 2019; Pamukoff et al., 2016; Salvarani et al., 2003) and isokinetic (Berschin et al., 2014; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017) strength was analyzed. All 7 studies reported increases in strength over baseline being significant ($p<0.05$) in 4 of them (Berschin et al., 2014; Costantino et al., 2018; Pamukoff et al., 2016; Salvarani et al., 2003). While 5 studies found improvements over GC (Blackburn et al., 2021; Costantino et al., 2018; Pamukoff et al., 2016, 2017; Salvarani et al., 2003) being significant ($p<0.05$) only in 2 of them (Constantino et al., 2018; Pamukoff et al., 2016).

Isokinetic strength of knee extensor muscles increased with respect to baseline in all 5 studies that evaluated it (Berschin et al., 2014; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016, 2017) being statistically significant ($p<0.05$) in 3 of them (Berschin et al., 2014; Costantino et al., 2018; Pamukoff et al., 2016). However, only Costantino et al. (2018) and Pamukoff et al. (2016) reported significant improvements ($p<0.05$) over the GC. On the other hand, all studies that evaluated isometric strength of knee extensors found increases from baseline except da Costa et al. (2019). Regarding GC, only 3 studies reported improvements (Blackburn et al., 2021; Pamukoff et al., 2016; Salvarani et al., 2003) being significant ($p<0.05$) those found by Pamukoff et al. (2016).

Knee flexor strength was evaluated by 4 studies (Berschin et al., 2014; Costantino et al., 2018; Pamukoff et al., 2016; Salvarani et al., 2003). Three reported significant improvements ($p<0.05$) while Pamukoff et al. (2016) found no change from the baseline. Regarding CG, Costantino et al. (2018) and Salvarani et al. (2003) reported increases ($p<0.05$) in isokinetic and isometric strength respectively, while Berschin et al. (2014) and Pamukoff et al. (2016) reported no changes.

Neuromuscular parameters

Only 2 of the 7 studies (Berschin et al., 2014; da Costa et al., 2019) assessed neuromuscular parameters. Berschin et al. (2014) reported significant ($p<0.05$) increases in equilibrium relative to baseline and CG. Da Costa et al. (2019) found non-significant ($p>0.05$) improvements in center-of-pressure oscillation relative to baseline that did not extend to CG.

Other parameters

Berschin et al. (2014) evaluated the effect of WBV on ROM, anterior drawer and Lysholm Scale. They found non-significant improvements ($p>0.05$) with respect to baseline and found no changes with respect to the CG in ROM and anterior drawer. However, they reported significant improvements ($p<0.05$) over baseline and CG on the Lysholm Scale assessing knee functionality.

Table 3

Summary of selected studies

FIRST AUTHOR, YEAR OF PUBLICATION AND COUNTRY	TYPE OF STUDY	PARTICIPANTS (SAMPLE SIZE AND CHARACTERISTICS)	INTERVENTION	PARAMETERS EVALUATED	RESULTS
Berschin et al. (2014), Germany	Randomized clinical trial	n_i =40 (29 ♂ y 11 ♀), Qx: autograft with patellar T **GC**: n_i= 20 (15 ♂ y 5 ♀); 0 losses → n_f=20 Age (mean ± SD): 28 ± 6.8 years BMI (mean ± SD): 24,3 ± 2,8 Kg/m^2 Days from injury to surgery (mean ± SD): 90.7 ± 47.9 days **GI$_{WBV}$**: n_i= 20 (14 ♂ y 6 ♀); 0 losses → n_f=20 Age (mean ± SD): 27 ± 4.2 years BMI (mean ± SD): 23,2 ± 3,4 Kg/m^2 Days from injury to Qx (mean ± SD): 82.4 ± 39.2 days	**GC**: Rehabilitation protocol after ACL Qx (Exercise program to strengthen the hip and knee muscles. Balance and proprioception work). **GI$_{WBV}$**: WBV standing and squats	**Flexor and extensor strength**: - Isokinetics - Isometric **Neuromuscular**: - Balance **Clinicians**: - Active ROM - Front drawer - Lachman - Lysholm Scale	**GI$_{WBV}$**: changes from the beginning ↑* Isokinetic and isometric strength ↑* Balance ↑ Active ROM ↑ Front drawer ↑* Lysholm **GI$_{WBV}$ vs GC** ↔ Isokinetic and isometric strength ↑* Balance ↔ Active ROM ↔ Front drawer ↔ Lysholm
Costantino et al. (2018), Italy	Randomized clinical trial	n_i = 39 (39 ♀), Qx: patellar T. autograft **GC**: n_i= 19 (19 ♀); 0 losses → n_f=19 Age (mean ± SD): 25.42 ± 2.39 years BMI (mean ± SD): 20,06 ± 1,80 Kg/m^2	**GC**: Rehabilitation protocol after ACL Qx (passive kinesitherapy, TENS, stretching, flexor and extensor strengthening exercises, proprioception, e.g. aerobic). Placebo treatment on vibration platform off.	**Isokinetic strength flexors and extensors**: - Peak torque - Maximum power	**GI$_{WBV}$**: changes from the beginning ↑* Flexor isokinetic strength (peak torque and maximum power) ↑* Isokinetic force extensors (peak torque and peak power)

		GI$_{WBV}$: n_i= 20 (20 ♀); 1 loss → n_f=19 Age (mean ± SD): 25.47 ± 2.01 years BMI (mean ± SD): 20,29 ± 1,28 Kg/m^2	**GI$_{WBV}$**: Rehabilitation protocol after Qx of ACL + WBV in squat position and monopodal squat (25º of flexion).		**GI$_{WBV}$ vs GC** ↑* Flexor isokinetic strength (peak torque and maximum power) ↑* Isokinetic force extensors (peak torque and peak power)
da Costa et al. (2019), Brazil	Randomized blinded clinical trial	n_i =44 (44 ♂), Qx: not specified **GC**: n_i= 22 (22 ♂); 0 losses → n_f=22 Age (mean ± SD): 26.8 ± 6.83 years BMI (mean ± SD): 26,5 ± 2,96 Kg/m^2 Postoperative time (mean ± SD): 17 ± 1.26 weeks **GI$_{WBV}$**: n_i= 22 (22 ♂); 0 losses → n_f=22 Age (mean ± SD): 28 ± 5.52 years BMI (mean ± SD): 27,1 ± 4,49 Kg/m^2 Postoperative time (mean ± SD): 16.8 ± 1.55 weeks	**GC**: Placebo treatment on vibration platform off. **GI$_{WBV}$**: WBV in monopod squat position (40º flexion).	**Isokinetic strength extensors**: - Peak torque - Total labor **Isometric strength extensors**: - EMG (vastus lateralis and medialis) **Neuromuscular**: - Oscillation of the center of pressures (A-P and lateral)	**GI$_{WBV}$**: changes from the beginning ↑ Isokinetic force extensors (peak torque and total work) ↔ Isometric strength extensors ↑ A-P center of pressure oscillation ↔ Lateral center of pressure oscillation **GI$_{WBV}$ vs GC** ↔ Isokinetic extensor strength (peak torque and total work) ↔ Isometric strength extensors ↔ Oscillation of the center of pressures A-P ↔ Lateral center of pressure oscillation

Pamukoff et al. (2017), USA	Single-blind randomized clinical trial	n_i=20 (6 ♂ y 14 ♀), Qx: 16 autograft with patellar T., 3 autograft with hamstring T. and 1 allograft; 0 losses → n_f=20 Age (mean ± SD): 21.1 ± 0.5 years Height (mean ± SD): 168.4 ± 4.2 cm Weight (mean ± SD): 68.3 ± 6.5 kg Postoperative time (mean ± SD): 50.6 ± 9.3 months The 20 patients were randomly assigned to the 3 groups (GI_{WBV}, GI_{LV} and GC); after the intervention, a week's rest was allowed and the 20 patients were reassigned to another group and the process was repeated a third time.	**GC**: Isometric squat (60º of flexion) without any vibration **GI_{WBV}**: WBV in squat position (60º of flexion) **GI_{LV}**: Local antero-posterior vibration in the quadricipital tendon in squat position (60º of flexion)	**Isokinetic strength extensors**: - Early RTD - Late RTD **Electromechanical delay**: time difference between the onset of EMG activity and the onset of torque - Vasto lateral - Vast middle - Anterior rectus	**GI_{WBV}**: changes from the beginning ↑* early RTD ↑ Electromechanical delay lateral and medial vastus ↔ Late RTD, electromechanical delay, straight anterior rectum **GI_{WBV} vs GC** ↑ Early RTD ↑ Electromechanical delay lateral and medial vastus ↔ Late RTD, electromechanical delay, straight anterior rectum
Pamukoff et al. (2016), USA	Single-blind randomized clinical trial	n_i=20 (6 ♂ y 14 ♀), Qx: 16 autograft with patellar t., 3 autograft with hamstring t. and 1 allograft; 0 losses → n_f=20 Age (mean ± SD): 21.1 ± 1.2 years Height (mean ± SD): 168.4 ± 9.5 cm Weight (mean ± SD): 68.3 ± 14.9 Kg Postoperative time (mean ± SD): 50.6 ± 21.3 months The 20 patients were randomly assigned to one of the 3 groups (GI_{WBV}, GI_{LV} and GC) after the intervention a week of rest was left and the 20 patients were again assigned to another group and the process was repeated a third time.	**GC**: Isometric squat (60º of flexion) without any vibration **GI_{WBV}**: WBV in squat position (60º of flexion) **GI_{LV}**: Local antero-posterior vibration in the quadricipital tendon in squat position (60º of flexion)	**Isokinetic extensor strength**: - Peak torque - RTD **Isometric strength extensors**: - Maximum EMG amplitude - CAR (Central Activation Ratio) **Isometric flexor strength**: - EMG amplitude -	**GI_{WBV}**: changes from the beginning ↑* peak torque, EMG amplitude extensors, CAR ↔ RTD, flexor EMG amplitude **GI_{WBV} vs GC** ↑* Peak torque, EMG extensor amplitude, CAR ↔ RTD, flexor EMG amplitude
Salvarani et al. (2003), Italy	Randomized clinical trial	n_i =20 (17 ♂, 3 ♀), Qx: autograft with patellar T.	**GC**:	**Isometric strength extensors and flexors**	**GI_{WBV}**: changes from the beginning

		GC: n_i= 10; 0 losses → n_f=10 Age (mean ± SD): 26.8 ± 5.2 years Height (mean ± SD): 175.2 ± 8.3 cm Weight (mean ± SD): 73.2 ± 7.9 kg Postoperative time: 1 month **GI$_{WBV}$**: n_i= 10; 0 losses → n_f=10 Age (mean ± SD): 29.7 ± 7.8 years Height (mean ± SD): 174.1 ± 7.7 cm Weight (mean ± SD): 72 ± 7.6 kg Postoperative time: 1 month	Rehabilitation protocol after ACL Qx (passive kinesitherapy, electrostimulation, stretching, cryotherapy, isometric, isotonic and isokinetic exercises, proprioception). Isometric squat (25º of flexion) without any vibration **GI$_{WBV}$**: Rehabilitation protocol after Qx of ACL + WBV in squat position (25º of flexion).	(EMG vastus medialis, biceps femoris and soleus): - Peak strength - Medium strength - Force during the middle of the first second	↑* Peak strength ↑* Average strength ↑* Force during the middle of the first second **GI$_{WBV}$ vs GC** ↑* Peak strength ↑ Average strength ↑ Force during the middle of the first second
Blackburn et al. (2021), USA	Randomized crossover clinical trial	n_i =24 (9 ♂ y 15 ♀), Qx: 16 autograft with patellar T., 3 autograft with hamstring T. and 1 allograft; 0 losses → n_f =20 Age (mean ± SD): 22 ± 4 years Postoperative time (mean ± SD): 50 ± 41 months The 24 patients were randomly assigned to one of the 3 groups (GI$_{WBV}$, GI$_{LV}$ and GC) after the intervention a week of rest was left and the 20 patients were reassigned to another group and the process was repeated a third time	**GC**: Standing upright with slight flexion without any vibration **GI$_{WBV}$**: WBV in standing position with slight flexion **GI$_{LV}$**: Local anteroposterior vibration in the quadricipital tendon in standing with slight flexion	**Isometric extensor strength** (dynamometry): - Peak torque - RTD - Maximum EMG amplitude (vastus lateralis and medialis)	**GI$_{WBV}$**: changes from the beginning ↑* Peak torque ↑RTD, vastus medialis EMG amplitude ↔Vastus lateralis EMG amplitude **GI$_{WBV}$ vs GC** ↑* Peak torque ↑ RTD, vastus medialis EMG amplitude ↔ vastus lateralis EMG amplitude

Note. ↑: increase; ↑*: significant increase; ↔: no difference between groups; ♂: male; ♀: female; A-P: anterior-posterior; EMG: electromyography CG: control group; GILV: intervention group with local vibration;GIWBV: full-body vibration intervention group; BMI: body mass index; kg/m2: kilograms divided by meters squared; ACL: anterior cruciate ligament; nf: final sample size; ni: final sample size; ni: final sample sizeñnf: final sample size; ni: initial sample size; Qx: surgeryí; ROM: range of motion; RTD: rate of torque development; SD: standard deviation; t: tendon; TENS: transcutaneous electrical nerve stimulation; tt: treatment.

Table 4
Characteristics of interventions on vibrating platforms

Author, year and country	Exercises	Specific vibration parameters	Volume and intensity	Frequency (days/week)	Time (minutes/session)	Duration (weeks)	Supervision
Berschin et al. (2014), Germany	Sem 2-4: Isometric standing Sem 5-7: Isometric standing Sem 8-11: Squats (load 10% RM)	Sem 2-4: 10-15 Hz Sem 5-7: 30 Hz Sem 8-11: 30 Hz Breadth: 5-9 mm	Sem 2-4: 2-6 reps of 1 min Sem 5-7: 5 reps of 1.5-2 min Sem 8-11: 5-7 reps of 2 min	3-4	40	11	Yes
Costantino et al. (2018), Italy	Isometric squat with 25° of knee flexion Monopodal isometric squat with 25° of knee flexion	Frequency: 26 Hz Breadth: 4mm	6 reps of 1 min 1 min rest between reps and 2 min between exercises	3	Not specified	8	Yes
da Costa et al. (2019), Brazil	Monopodal isometric squat with 40° knee flexion	Frequency: 50 Hz Breadth: 4 mm	10 reps of 30 sec 30 sec rest	Not specified	Not specified	Not specified	Yes
Pamukoff et al. (2017), USA	Isometric squat with 60° knee flexion	Frequency: 30Hz Acceleration: 2g	6 reps of 60 sec 2 min rest between reps	Not specified	20	Not specified	Yes
Pamukoff et al. (2016), USA	Isometric squat with 60° knee flexion	Frequency: 30Hz Acceleration: 2g	6 reps of 60 sec 2 min rest between reps	Not specified	20	Not specified	Yes
Salvarani, et al. (2003), Italy	Isometric squat with 25° of knee flexion	Frequency: 30Hz	5 reps of 60 sec 1 min rest between reps	5	10	2	Yes
Blackburn et al. (2021), USA	Standing upright with slight knee flexion	Frequency: 30Hz Acceleration: 2g	6 reps of 60 sec 2 min rest between reps	1-3 (3 sessions in total with a break of 2-7 days)	20	1-3	Yes

Note: g: acceleration of gravity (9.8m/s2); Hz: hertz; min: minutes; mm: millimeters; RM: repetition maximum; sec: seconds; wk: week.

Discussion and Conclusions

The objective of this systematic review was to critically evaluate the comparative efficacy of vibration platform-based training (GIWBV) with respect to a standard exercise protocol (CG) in improving strength and neuromuscular parameters in physically active adults in post-surgical ACL rehabilitation. Seven studies met the selection criteria and were included in the review. Overall, despite observing a trend towards improvement ($p>0.05$) in strength in participants who used the vibration platforms with respect to the CG, no statistically significant increases were observed (Blackburn et al., 2021; Pamukoff et al., 2017; Salvarani et al., 2003). In relation to balance and the Lysholm Scale of knee functionality, statistically significant ($p<0.05$) increases have been reported with respect to CG (Berschin et al., 2014).

Force Parameters

Strength is one of the main functional abilities that are compromised in patients undergoing ACL reconstruction, so its restoration is a necessity during the rehabilitation process. Gaining strength is essential to improve knee stability, control movements, facilitate return to sporting activity and prevent secondary injuries. It is a key component in the recovery, readaptation process and helps patients regain optimal function and performance for return to sporting activity (Buckthorpe et al., 2019).

Isokinetic dynamometry is considered the gold standard test to objectively assess muscle strength as it allows the measurement of muscle strength at different angles of movement and contraction velocities (Stark et al., 2011). This test provides detailed information about a muscle's ability to generate force in a controlled and precise manner. Isokinetic dynamometry is particularly useful for assessing muscle asymmetry, identifying strength deficits, and monitoring progress in the rehabilitation of muscle and joint injuries (Montejo et al., 2019). In fact, all the articles included in this review evaluated different strength parameters in general. Four studies assessed peak torque or "peak torque" in English (Blackburn et al., 2021; Costantino et al., 2018; da Costa et al., 2019; Pamukoff et al., 2016), i.e., the value of force or torque produced by a muscle or muscle group during a maximal muscle contraction. Torque strength is a key measure in strength assessment and is especially relevant in injury rehabilitation and in assessing progress during a strength training program (Buckthorpe et al., 2019; Simpson et al., 2019). In the study by Costantino et al. (2018) subjects experienced a significant increase in both knee flexors and extensors in this parameter relative to the CG. Similar results were obtained by Pamukoff et al. (2017) and Blackburn et al. (2021), studies in which there was also a non-significant increase in peak torque of the extensor muscles. However, da Costa et al. (2019) obtained no differences with respect to GC, also in extensors, after a WBV session. Variations in the frequency application protocol, from 26 Hz to 50 Hz and the time at which the WBV intervention was applied to the patients, as well as the interindividual response of the subjects could explain the divergence of the results obtained in the different studies.

Electromyography is a procedure used to measure and analyze the bioelectrical activity of muscles through the use of electrodes placed on the surface of the skin or through intramuscular electrodes. This test allows the detection and recording of muscle action potentials, providing information on muscle activation, coordination and function (Gila et al., 2009). This parameter was evaluated in four studies. Salvarani et al. (2003), Pamukoff et al. (2017) and Blackburn et al. (2021) reported an increase in electromyographic amplitude with respect to CG, while da Costa et al. (2019) reported no differences between groups.

The main difference between these studies (Blackburn et al., 2021; da Costa et al., 2019; Pamukoff et al., 2016; Salvarani et al., 2003) is the time elapsed from ligament reconstruction to intervention, being much shorter in the study by da Costa et al. (2019) (between 15 and 19 weeks), which in the studies of Pamukoff et al. (2016) and Blackburn et al. (2021) ranges from nine to 91 months.

Finally, other parameters such as maximum flexor and extensor power, evaluated by Costantino et al. (2018) found significant ($p<0.05$) increases compared to GC. The rate of torque development was evaluated in three of the selected studies, with improvements obtained by Pamukoff et al. (2017) and Blackburn et al. (2021) especially the rate of early torque development in extensor muscles. However, no significant differences were obtained in the study by Pamukoff et al. (2016).

All these improvements can be explained by the muscular response to vibration, when performing automatic contractions and stretching. The mechanical stimulus generated by the vibrating platform produces a stretch and contraction reflex in the muscles 30 to 60 times per second, resulting in a continuous muscle contraction (Alguacil et al., 2009). The sinusoidal oscillatory movements generated by the vibrating platform are transmitted to the whole body, which increases the gravitational load on the neuromuscular system. This causes the muscles to work to overcome the force of gravity. Upon contact with the vibrating platform, the mechanical stimulus of vibration is transmitted throughout the body, activating various skin and muscle sensory receptors, including muscle spindles. Muscle spindles detect changes in muscle stretch length and velocity and Golgi tendon organs that respond to tension and load on tendons (Albasini et al., 2010; Cardinale and Bosco, 2003; Seixas et al., 2020).

A tonic vibratory reflex is then triggered, which is responsible for muscle contraction and relaxation and involves an automatic response in the muscles, which contract and relax in synchrony with the vibration. This in turn triggers a number of neuromuscular responses, including stimulation of motor units, improvement of muscle coordination and modulation of muscle activation. These responses contribute to muscle strengthening and conditioning, as well as improved stability and balance (Albasini et al., 2010; Alguacil et al., 2009; Cardinale and Bosco, 2003; Seixas et al., 2020).

In other research, no increase in quadriceps strength has been obtained (Pistone et al., 2016; Rowe et al., 2022). In turn, research on athletes aimed at evaluating WBV programs also showed no improvement over conventional strength training (Fernández-Rio et al., 2010).

Neuromuscular Parameters

For balance and postural control (Berschin et al., 2014) and center of pressures oscillation (da Costa et al., 2019) discrepant results were obtained. In terms of balance, a significant improvement was obtained ($p<0.05$). On the other hand, in the oscillation of the center of pressures, the results remained similar with respect to the CG. This difference may be due to the clear variation in frequencies used in both studies, since in Berschin et al. (2014) started treatment at 10 Hz and ascended to 30 Hz; while da Costa et al. (2019) maintained a frequency of 50 Hz throughout the intervention.

Previous studies (Fu et al., 2013; Moezy et al., 2008) observed significant improvements in overall stability and anteroposterior and mediolateral indices. However, the recent meta-analysis by Rowe et al. (2022) states that this type of therapy does not improve anteroposterior stability, but it can improve overall and mediolateral stability.

Improvements in balance and postural control could be attributed to the oscillatory movements provided by the vibration platforms. These mechanical vibrations generate multiple and repetitive instability situations, which stimulates the motor learning process. The application of mechanical vibrations leads to the adaptation of neuromuscular reflexes, resulting in a more efficient control of vibration processes from a mechanical point of view. As individuals are regularly exposed to mechanical vibrations, their peripheral and central nervous and muscular systems adapt and learn to respond more efficiently to maintain balance and stabilize the body (Alguacil et al., 2009).

Limitations

Within the included studies, limitations were found in terms of study design, heterogeneity of WBV protocols, variability in CGs, and cohort characteristics. All of which makes it difficult to compare studies and interpret the effects of WBV, which is why meta-analysis has not been possible. In addition, the included trials had small sample sizes and heterogeneous samples, and in some cases, detailed demographic data were not provided.

In view of these limitations, caution is advised when interpreting the results. Moreover, despite the popularity of WBV as a therapeutic modality, in view of the insufficient scientific evidence currently available in this regard, its efficacy is not yet sufficiently demonstrated due to the lack of standardized protocols (Wang et al., 2020). The approach of protocols customized to individual needs could prove useful in the rehabilitation of musculoskeletal disorders, as well as improve sports performance (Bonanni et al., 2022).

Further research in this area is suggested to gain a more robust understanding of the potential effects and benefits of WBV.

Conclusions

WBV therapy, through the use of vibratory platforms, may constitute an effective strategy in the rehabilitation of patients with ACL reconstruction. WBV has demonstrated positive results in knee musculature strength, balance, postural control and the Lysholm Knee Functionality Scale. In addition, WBV has been shown to be superior to conventional rehabilitation in increasing strength, balance and Lysholm Scale. However, there is no consensus on the effectiveness of both therapies on postural control and center of pressure oscillation. Future clinical trials are needed to support the findings of this systematic review.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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