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Claire Coulondre, MSc[1,2,3;] Robin Souron, PhD[4,5]; Alexandre Rambaud, PhD[4]; Etienne Dalmais, MD[1,2,3]; Loïc Espeit, MSc[4]; Thomas Neri, PhD[4,6]; Alban Pinaroli, MD[7]; Gilles Estour, MD[7]; Guillaume Y Millet, PhD[4,8]; Thomas Rupp, PhD[1]; Léonard Feasson, PhD[4,9]; Pascal Edouard, PhD[4,9]; Thomas Lapole, PhD[4]

[1] Inter-university Laboratory of Human Movement Biology (LIBM), University of Savoie Mont Blanc, EA 7424, 73000 Chambéry, France

[2] Centre d'Evaluation et de Prévention ARTicualire (CEPART), 73490 Challes-les-Eaux

[3] Centre d'Orthopédie et de Traumatologie du Sport, 73000 Bassens

[4] Univ Lyon, UJM-Saint-Etienne, Inter-university Laboratory of Human Movement Biology, EA 7424, F-42023, Saint-Etienne, France

[5] Laboratory of Impact of Physical Activity on Health (IAPS), UR n°201723207F, University of Toulon, France

[6] Department of Orthopaedic Surgery, University Hospital of Saint Etienne, Faculty of medicine, Saint-Etienne, France

[7] Médipôle de Savoie, 73190 Challes-les-Eaux

[8] Institut Universitaire de France (IUF)

[9] Department of Clinical and Exercise Physiology, Sports Medicine and Myology Units, Regional Institute of Medicine and Sports Engineering (IRMIS), University Hospital of Saint-Etienne, Faculty of medicine, Saint-Etienne, France

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Corresponding author:

Thomas LAPOLE

Laboratoire Interuniversitaire de Biologie de la Motricité

Bâtiment IRMIS

10 rue de la Marandière

42270 Saint Priest en Jarez

04 77 42 18 91; thomas.lapole@univ-st-etienne.fr

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ABSTRACT

Background. After anterior cruciate ligament reconstruction (ACLR), quadriceps strength must be maximized as early as possible.

Objectives. We tested whether local vibration training (LVT) during the early post-ACLR period (i.e., ~10 weeks) could improve strength recovery.

Methods. This was a multicentric, open, parallel-group, randomized controlled trial. Thirty individuals attending ACLR were randomized by use of a dedicated Web application to 2 groups: vibration (standardized rehabilitation plus LVT, n=16) or control (standardized rehabilitation alone, n=14). Experimenters, physiotherapists and participants were not blinded. Both groups received 24 sessions of standardized rehabilitation over ~10 weeks. In addition, the vibration group received 1 hr of vibration applied to the relaxed quadriceps of the injured leg at the end of each rehabilitation session. The primary outcome — maximal isometric strength of both injured and non-injured legs (i.e., allowing for limb asymmetry measurement) — was evaluated before ACLR (PRE) and after the 10-week rehabilitation (POST).

Results. Seven participants were lost to follow-up, so data for 23 participants were used in the complete-case analysis. For the injured leg, the mean (SD) decrease in maximal strength from PRE to POST was significantly lower for the vibration than control group (n=11, -16% [10] vs n=12, -30% [11]; p=0.0045, Cohen's d effect size = 1.33). Mean PRE–POST change in limb symmetry was lower for the vibration than control group (-19% [11] vs -29% [13]) but not significantly (p=0.051, Cohen's d effect size = 0.85).

Conclusion. LVT improved strength recovery after ACLR. This feasibility study suggests that LVT applied to relaxed muscles is a promising modality of vibration therapy that could be implemented early in ACLR.

Trial registration. ClinicalTrials.gov: NCT02929004

Keywords: local vibration; strength; rehabilitation; anterior cruciate ligament reconstruction

Introduction

After anterior cruciate ligament reconstruction (ACLR), the ultimate goal of rehabilitation is to restore function of the lower limbs to pre-injury levels [1]. However, patients present large quadriceps strength deficits in the first weeks after ACLR [2, 3]. For instance, limb asymmetry (i.e., difference in maximal isometric strength between the injured and non-injured leg) has been reported as 36% and 19% at 5 and 12 weeks after ACLR, before returning to the pre-surgery level 26 weeks after ACLR [3]. Quadriceps weakness may even persist up to 2 years after ACLR [2]. This weakness may increase both the delay and quality of a return to sport/play [4] and risk of second ipsi- or contralateral ACL injury [5]. It may also contribute to patella-femoral pain [6], altered gait pattern [7] and running biomechanics [8], which altogether impair the rehabilitation process and prevent a return to work as well as sports. The risk of developing knee joint osteoarthritis is increased owing to quadriceps strength loss [9]. Therefore, quadriceps strength should be maximized as early as possible after ACLR [10].

Quadriceps weakness after ACLR can be explained in part by muscle wasting [11], but quadriceps activation failure also substantially contributes to the functional impairment [2, 12]. Quadriceps activation failure refers to the inability to fully recruit motor units and/or at a sufficient discharge rate, mainly because of altered corticospinal excitability [12, 13] and/or

arthrogenic muscle inhibition, defined as neural inhibition arising from alterations in spinal reflex pathways due to factors such as swelling and inflammation [14]. Therefore, reactivating quadriceps is the first aim of early rehabilitation [1]. However, the immediate post-surgery context (e.g., graft healing, pain, meniscal sutures) prevents the optimal use of strength training. Hence, practical guidelines currently recommend quadriceps isometric exercises during the first week post-surgery, associated or not with cryotherapy to reduce pain and arthrogenic muscle inhibition [1]. In the following weeks, neuromuscular electrostimulation is also recommended [1, 15]. When quadriceps are reactivated and when graft healing and potential complications no longer exist, neuromuscular training and strength exercises can be implemented to further strengthen the quadriceps [1]. These guidelines clearly emphasize the need to enhance quadriceps neural drive as soon and as efficiently as possible after surgery, despite the aforementioned post-surgery issues.

In the last decade, vibration therapy has gained popularity. It consists in delivering vibration using whole-body vibration (WBV) platforms [16, 17] or directly to muscles or tendons by using local vibration (LV) [18]. In the context of ACLR, a single session of WBV or LV while patients maintain a squat position has been reported to acutely improve quadriceps strength when applied 50 months post-surgery, likely by reducing arthrogenic muscle inhibition [19]. However, similar results were not observed when WBV was applied at a mean of 17 weeks post-ACLR [20]. Moreover, when applied chronically as a training intervention, several weeks of WBV improved muscle strength when the intervention was started at least 1 month after ACLR but not during the second week of rehabilitation [17]. Three consecutive days of LV applied to isometrically contracted quadriceps 1 month after surgery also improved quadriceps strength when evaluated 9 months later [21].

Although the aforementioned studies provided promising results for ACLR rehabilitation, they may not be applicable in the early period after ACLR when the quadriceps

is not yet reactivated [1]. An alternative could be to apply LV directly over the relaxed quadriceps by using a small and portable device [18]. When using appropriate LV characteristics (e.g., frequency or amplitude), repetitive small changes in muscle length strongly activate afferents originating from muscle spindles (i.e., mechanoreceptors sensitive to muscle stretch [22]), projecting their excitatory synaptic inputs to the spinal cord and cortical areas [18]. As a result, prolonged LV exposure at rest (i.e., 20 to 60 min) has been found to induce acute neural modulations in healthy individuals [18, 23, 24]. When chronically used (i.e., LV training [LVT]), prolonged LV exposure can in turn trigger long-term adaptations [18]. Accordingly, we recently demonstrated that 4 weeks of LVT applied over the relaxed quadriceps significantly increased muscle strength in healthy individuals, and the improved neural drive mainly accounted for the gains [25]. These results, combined with the simplicity (a key parameter in clinical settings) of using LVT [18], suggest that this technique may be promising in terms of promoting neuromuscular reconditioning during the early rehabilitation period after ACLR.

This study aimed to test whether adding LVT to standardized rehabilitation during the early post-ACLR period (i.e., ~10 weeks) could improve quadriceps strength recovery as compared with standardized rehabilitation alone.

Materials and methods

Study design

This was a multicentric, open, parallel-group, randomized controlled trial including individuals who underwent ACLR between December 2016 and January 2020. This study conformed to standards from the latest revision of the Declaration of Helsinki and was approved by the Committee for the Protection of Persons (CPP Sud-est I, no.: 2016-34). The University Hospital of Saint-Etienne (France) was the sponsor of this study (ClinicalTrials.gov: NCT02929004).

375

376 ***Population and procedure***

377 Eligible participants were 18 to 50 years old, had unilateral ACL tear and were awaiting surgery
378 for unilateral ACLR (with hamstring or patellar tendon autograft). They were identified from
379 contacts with 5 primary (i.e., physiotherapy clinics) and 4 tertiary (i.e., orthopedic departments)
380 healthcare centres of our network in Saint-Etienne and Chambéry, France. Exclusion criteria
381 were previous ACLR, taking neuro-active substances, acute or chronic neurological disorders,
382 or being a professional athlete.

383 Participants first visited the laboratory within 15 days before surgery for an initial
384 inclusion dedicated to the assessment for eligibility, medical checking, provision of written
385 informed consent, and familiarization with the experimental procedures before performing
386 baseline measurements (PRE).

387 Immediately after surgery and before the beginning of rehabilitation, we used the
388 REDCap Web application (https://redcap-ex.chu-st-etienne.fr/redcap/) to randomly assign
389 participants to the control (i.e., standard rehabilitation) or vibration group (i.e., standardized
390 rehabilitation plus LVT). Experimenters, physiotherapists and participants were not blinded.
391 Participants had to attend a second visit to the laboratory after 24 sessions of rehabilitation
392 performed within 8 to 11 weeks (depending on schedule possibilities) post-surgery (POST).
393 Figure 1 illustrates the flow of participants in the study.

394

395 ***Standard rehabilitation protocol***

396 Both groups performed a standardized post-ACLR rehabilitation. Each participant was
397 supervised by their own physiotherapist who agreed to apply the protocol that had previously
398 been sent. The rehabilitation protocol used was similar to the one presented in S1 Appendix of
399 [26]. Briefly, participants had to follow 2 to 3 rehabilitation sessions per week, with at least 1

day of rest in between, for a total of 24 sessions within 8 to 11 weeks of rehabilitation. In the first phase, rehabilitation focused on early motion and basic movement retraining (e.g., achieving full knee extension, minimizing swelling, regaining quadriceps activity and control). The second phase began approximately 3 weeks after surgery (i.e., when patients presented a closed wound, minimal effusion, knee extension close to 0° and flexion close to 90°, normal mobility of the patellofemoral joint, and reactivated quadriceps). This phase was dedicated to basic strength and proprioception (e.g., restoring proper body alignment and control, building lower extremity and core body strength, improving proprioception).

Intervention: local vibration

In addition to the standardized rehabilitation, the vibration group performed the vibration program, which consisted of 1-hr vibration sessions at the end of each rehabilitation session to avoid any potential influence of vibration-induced fatigue on the rehabilitation protocol [24]. The vibrating device (VB 115, Techno Concept, Mane, France) was applied locally and strapped with elastic Velcro fasteners directly on the rectus femoris muscle (i.e., 40% of the muscle length from the upper edge of the patella to the anterior superior iliac spine) of the injured leg [25] (Fig. 2). The participant was seated on a chair during the entire vibration session, with a knee angle as close as possible to 90°. Considering that small vibration amplitudes and frequencies up to 80 to 120 Hz are highly effective for stimulating muscle spindle afferents [18], vibration characteristics were set at 100-Hz frequency and 1-mm amplitude as in our previous studies [25, 27].

Primary and secondary outcomes

PRE and POST measurements consisted of strength and functional measurements. Participants were instructed to avoid the consumption of caffeine on the day of the experiment and avoid

425 performing any strenuous exercise for 48 hr before testing. Strength measurements were first
426 performed on the non-injured, then injured leg. Participants were seated upright in a custom-
427 built chair with both knee and hips at 90° flexion. Knee extensor isometric strength was
428 assessed by using a calibrated force transducer (Omega Engineering, Stamford, CT), which was
429 attached above the participant's malleoli. During contraction, participants were instructed to
430 pull against the strain gauge (i.e., knee extension) and were provided with real-time feedback
431 of their strength on a screen. Movements of the upper body were minimized by using belts
432 across the thorax and waist. After a standardized warm-up consisting of 10 isometric
433 contractions of the knee extensors at increasing intensities until reaching 90% of the perceived
434 maximal strength followed by a 3-min rest, participants were asked to perform two 5-sec
435 maximal voluntary contractions (MVCs) separated by 60 sec of rest. If the difference between
436 the two MVCs was > 5%, participants performed a third MVC. During MVCs, participants
437 were instructed to extend their knee (in isometric condition) "as hard as possible" and were
438 verbally encouraged.

439 After a 3-min rest, participants performed a series of 5 explosive isometric contractions
440 (~0.5 sec) separated by 30 sec of rest to determine the rate of force development (RFD).
441 Participants were instructed to isometrically extend their knee "as fast as possible," and strong
442 verbal encouragement was provided. The trial was repeated again if 1) countermovement was
443 detected (i.e., a quick flexion before the knee extension was determined from a force drop of 2
444 N below the baseline) or 2) the force reached < 70% of the maximal strength previously
445 recorded [28].

446 The primary outcome of the study was the maximal isometric strength defined as the
447 highest strength occurring during 500 ms. The limb symmetry index (LSI) was calculated to
448 compare quadriceps maximal isometric strength between the injured and non-injured leg (i.e.,
449 $LSI_{Strength}$):

$$LSI\ (\%) = \left(\frac{injured\ leg}{non - injured\ leg}\right) \times 100$$

The secondary outcome was the RFD, defined as the average slope over 100 ms (Δforce/Δtime, Nm/s) [29] from the onset of the contraction. The onset of the force development was defined automatically as the point at which force exceeded 3 SDs over the average resting baseline [30]. The mean of the 5 impulsive contractions was retained for analysis. LSI was also calculated for RFD (i.e., LSI_{RFD}).

Functional performance was also measured as a secondary outcome and included the Timed Up and Go test (TUG) and the Six-Minute Walk Test (6MWT). We initially aimed to investigate the level of voluntary activation by using transcranial magnetic stimulation during MVC [25], but as another secondary outcome, this test was finally not included owing to the inability of our second recruiting centre to perform such testing.

Sample size calculation

As the primary outcome of the present study, quadriceps strength was used for sample size calculation with G*Power v3.1. Considering one of our recent studies that investigated the effect of LVT on dorsiflexion isometric maximal strength of healthy individuals [27], a between-group effect size of 1.09 for PRE–POST changes in quadriceps strength was expected and initially used for calculating the required sample size. The calculated sample size was 38 (i.e., 19 per group) to achieve a power of 0.90 at an alpha level of 0.05. Because of a disappointing recruitment rate, we revised the sample size calculation by considering a more recent study that investigated the effect of LVT on quadriceps strength of healthy individuals. The calculated sample size was 22 (i.e., 11 per group) based on an effect size of 1.3 with a power of 0.80 at an alpha level of 0.05. Considering a potential 30% withdrawal, we included 30 individuals.

475 ***Statistical analysis***

476 Data are presented as mean ± standard deviation (SD) for continuous variables and number (%)
477 for categorical variables. Statistical tests were performed with Statistica (StatSoft Inc., Tulsa,
478 OK). All variables were normally distributed (Kolmogorov-Smirnov normality test). For
479 ANCOVA analyses, homogeneity of variance was verified by the Levene test. $P<0.05$ was
480 considered statistically significant. The comparability of between-group characteristics was
481 tested by unpaired Student t test for continuous variables and chi-square test for categorical
482 variables. Complete-case analyses were used for both primary and secondary outcomes.

483 To analyse maximal isometric strength and RFD values, a mixed model ANCOVA was
484 used with "leg" (non-injured vs injured) and "time" (PRE vs POST) as within-subject variables,
485 group (control vs vibration) as a between-subject variable, and baseline scores (i.e., PRE values)
486 as covariates. For LSI and functional measurements, a mixed model ANCOVA was used with
487 "time" (PRE vs POST) as a within-subject variable, "group" (control vs vibration) as a between-
488 subject variable, and PRE values as covariates. Post-hoc analyses were performed with
489 Bonferroni testing when ANCOVAs identified significant differences. Estimated effect size
490 was reported as partial eta square ($p\eta^2$) (with $p\eta^2 \geq 0.07$ and ≥ 0.14 used as moderate and large
491 effects, respectively [31]).

492 Moreover, besides ANCOVAs performed on raw values, we further calculated for each
493 parameter the mean PRE–POST changes with 95% confidence intervals to compare the
494 magnitude of recovery between groups by using ANCOVA (with "group" as a between-subject
495 variable and baseline scores as covariates):

496 $$PRE - POST\ change\ (\%) = \left(\frac{POST - PRE}{PRE}\right) \times 100$$

497 For PRE–POST changes, Cohen's d effect size with 95% confidence intervals were calculated
498 (with values of d = 0.2, 0.5 and 0.8 considered small, medium and large effects, respectively)
499 [31].

Results

Among 30 participants initially included in the study, 7 were lost to follow-up, so 23 were included in the complete-case analysis: 12 randomly assigned to the control group and 11 to the vibration group (Fig. 1 and Table 1). No adverse effects of the vibration program were reported.

Primary outcome

We found a significant leg × time × group interaction for maximal strength ($F_{(1,19)}$=4.56; p=0.046; $p\eta^2$=0.19). PRE and POST values did not differ for the non-injured leg for both the vibration (p=1) and control (p=1) groups, but values for the injured leg were significantly decreased from PRE to POST for the vibration (p=0.009) and control (p<0.001) groups (Table 2). Mean PRE–POST changes (Fig. 3A) did not differ between groups for the non-injured leg (p=0.37) but were significantly lower for the vibration than control group for the injured leg (p=0.0049).

When considering $LSI_{Strength}$, we found a significant interaction between group and time ($F_{(1,20)}$=5.74; p=0.026; pn^2=0.22). $LSI_{Strength}$ was significantly decreased from PRE to POST for both the vibration (p<0.001) and control groups (p<0.001). The between-group difference in mean PRE-POST changes were not significant (p=0.051; Fig. 4A).

Secondary outcomes

RFD for 1 participant of the control group was not recorded because of the inability of the person to avoid countermovement before explosive knee contractions (i.e., n=11 in both groups for this parameter). We found no leg × time interaction ($F_{(1,18)}$=1.67; p=0.21; pn^2=0.085) nor further interaction with the group factor ($F_{(1,18)}$=3.33; p=0.085; pn^2=0.16) (Table 2).

Accordingly, the vibration and control groups did not significantly differ in mean changes in RFD for the non-injured leg (p=0.32; Fig. 3B) or the injured leg (p=0.10; Fig. 3B).

We found a significant group × time interaction for LSI_{RFD} ($F_{(1,19)}$=4.42; p=0.049; pn^2=0.19). LSI_{RFD} was significantly decreased from PRE to POST in the control group (p<0.001) but not vibration group (p=0.13). The groups did not significantly differ in mean PRE-POST LSI_{RFD} changes (p=0.095; Fig. 4B).

Regarding functional measures (Table 2), we found no significant time ($F_{(1,19)}$=1.33; p=0.26; pn^2=0.19) or group × time interaction ($F_{(1,19)}$=0.77; p=0.39; pn^2=0.13) for TUG performance, nor time ($F_{(1,19)}$=0.037; p=0.85; pn^2=0.054) or group × time interaction ($F_{(1,19)}$=0.89; p=0.36; pn^2=0.15) for 6MWT performance. The groups did not significantly differ in mean PRE–POST changes in the TUG and 6MWT (p=0.37 and 0.36, respectively).

Discussion

To the best of our knowledge, this was the first study to examine the effect of LVT on quadriceps strength during early ACLR rehabilitation. The main finding of this randomized controlled trial was that adding LVT to a standardized rehabilitation early (~10 weeks) after surgery improved the strength recovery of the injured leg. This observation was evidenced by the significant attenuation of maximal isometric strength reduction from PRE to POST (primary outcome) in the vibration versus control group. However, the groups did not differ in recovery of RFD or TUG and 6MWT performance (secondary outcomes).

Individuals with ACLR are well known to experience quadriceps muscle weakness in the injured leg after surgery [2]. Accordingly, we observed a residual decrease in maximal isometric quadriceps strength in the present study ~10 weeks after ACLR, which was associated with an increased inter-limb asymmetry (i.e., decreased $LSI_{Strength}$). Thus, reduced strength capacities can be attributed to alterations within the quadriceps muscle (i.e., muscle atrophy

550 and alteration in contractile function [11]), and/or voluntary activation failure (i.e., reduced
551 neural drive via diminished excitability of spinal-reflexive and/or corticospinal pathways [2,
552 12]). Cross-sectional studies reported altered explosive contraction capacities in individuals
553 several months after ACLR as compared with controls [32], but we did not find any conclusive
554 difference in RFD between PRE and POST measurements.

555 Our results show that adding LVT to the standardized rehabilitation attenuated the
556 reduced strength capacity. Indeed, the participants who followed the LVT lost almost twice as
557 less (-16 vs -30%; large effect size) maximal isometric strength of their injured leg than their
558 counterparts who did not use LVT. Despite the large effect size, there was no significant effect
559 on LSI (p=0.051; see below). Nonetheless, this observation agrees with previous findings
560 showing force improvement in healthy individuals after a training intervention with similar
561 vibration characteristics [25, 27, 33-35]. Specifically, for the quadriceps muscles, LVT was
562 reported to induce a 14% strength increase in postmenopausal women after 26 weeks of training
563 with 5 sessions per week [35] or a 12% gain after 12 sessions over 4 weeks [25]. After 4 and
564 12 weeks of LVT, quadriceps maximal strength increased by 30% in healthy individuals [36]
565 and 63% in those with sarcopenia [37], respectively. However, these 2 studies, contrary to the
566 previous cited LVT studies, did not include a control condition, which prevents from conclusive
567 interpretation of their results. Altogether, growing evidence suggests that LVT may improve
568 strength capacity, and the present study supports this concept in the context of early ACLR
569 rehabilitation. However, the effect of LVT on RFD is less clear. RFD was not altered from PRE
570 to POST, but LSI_{RFD} was significantly reduced in the control group only, without any group
571 difference in PRE–POST changes.

572 The main strength of the study is showing the effectiveness of LVT to improve strength
573 recovery in the early rehabilitation phase after ACLR. Although it would have been interesting
574 to report indicators of self-reported function, the included sample was relevant because it well

represented the average population that physiotherapists have to supervise during post-ACLR rehabilitation [38]. The primary outcome was meaningful and relevant in clinical practice. For instance, minimizing quadriceps strength loss during the first months post-ACLR can predict improved running biomechanics [39]. Yet, we found no functional changes when considering TUG and 6MWT performance, but these tests are not sensitive in the context of ACLR (i.e., no changes were observed in the control group).

Our study involved a relatively small sample size, lower than the initial sample size reported in ClinicalTrials.gov. Although we report a between-group effect size of 1.33 for PRE–POST changes in quadriceps strength of the injured leg, reaching an *a posteriori* power of 0.86, this may have prevented some results to be significant (e.g., $LSI_{Strength}$). Including more participants would have better revealed surgery-induced alterations in RFD as well as the potential effects of LVT. Studies with larger sample sizes are also needed to allow for generalisation (e.g., by considering graft type and/or sex as covariates in the analyses). Another limitation of the present study may be the lack of blinding, and further studies should try to propose a control sham condition. Finally, our experimental design did not allow for determining the exact mechanisms involved in the LVT-induced preservation in strength capacities, and one can only be speculative. Because neural adaptations were proposed as the main explanation for strength gains after LVT in healthy individuals [18], further investigations are needed to determine whether adding LVT to standardized rehabilitation can prevent the deleterious effects that arthrogenic muscle inhibition [14] and/or altered corticospinal excitability [12, 13] may have on neural drive after ACLR. Potential effects of LVT on muscle atrophy also need to be considered [40].

Conclusions

The present study reports that LVT can improve strength recovery after ACLR. Importantly, no adverse effects were reported, so this technique can provide a high risk/benefit ratio in that it requests no help from a clinician and can even be used as a self-rehabilitation technique at home. Despite some limitations and that the study can be considered only a feasibility study, the present results suggest that LVT on relaxed muscles is a promising modality of vibration therapy and could be implemented in the early period of ACLR rehabilitation in addition to standardized rehabilitation.

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Legends

Fig. 1. Flow of participants in the study (Consolidated Standards of Reporting Trials [CONSORT]).

Fig. 2. The vibrating device used for local vibration training.

Fig. 3. Mean and individual PRE–POST changes in maximal isometric strength (A) and rate of force development (RFD) (B) for the non-injured and injured legs for control and vibration groups. Data are mean (SD). * P<0.05. PRE, before anterior cruciate ligament reconstruction; POST, and after 10-week rehabilitation.

Fig. 4. Mean and individual PRE–POST changes in limb symmetry index for strength ($LSI_{Strength}$) (A) and LSI for rate of force development (LSI_{RFD}) (B) for control and vibration groups. Data are mean (SD). PRE, before anterior cruciate ligament reconstruction; POST, and after 10-week rehabilitation.

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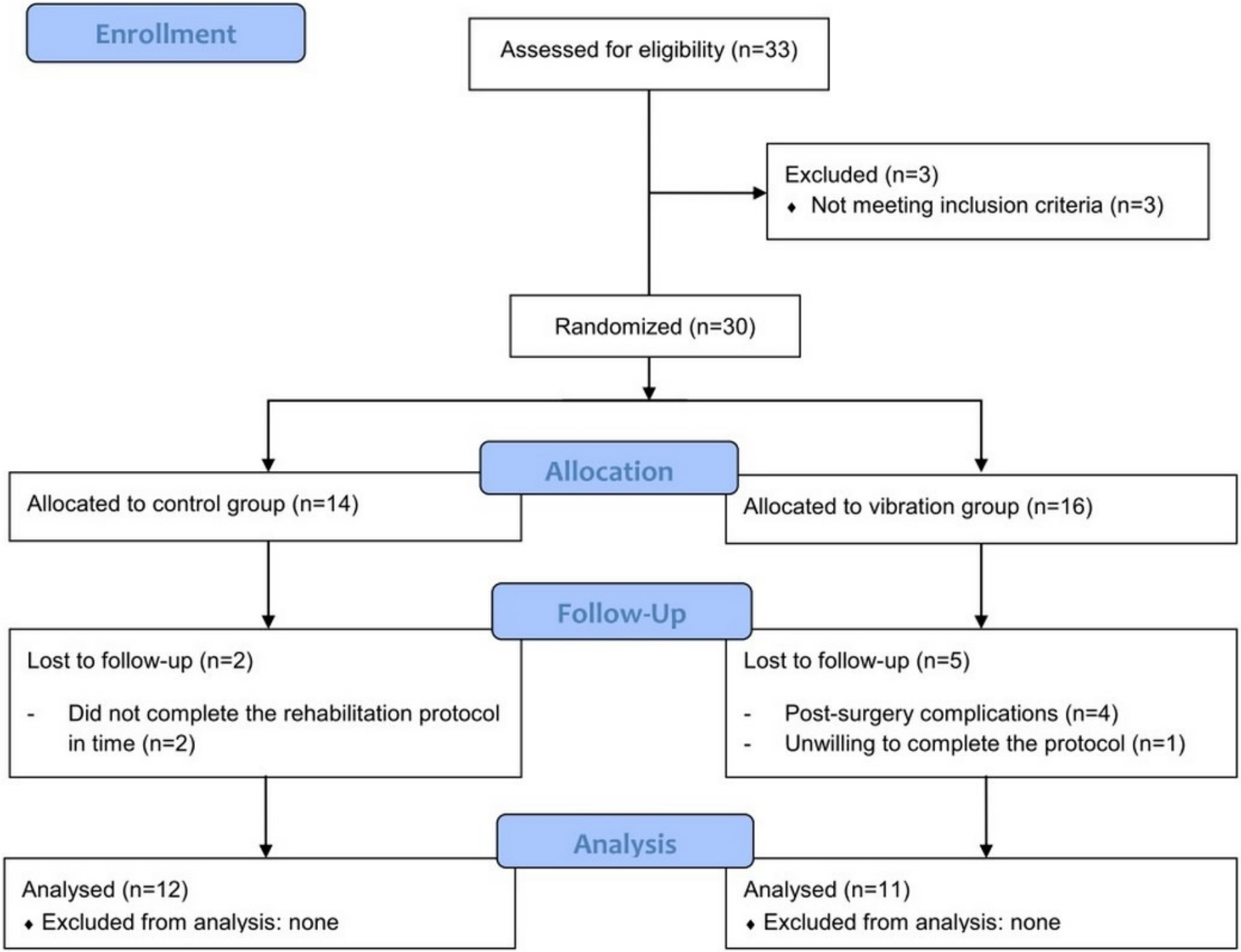
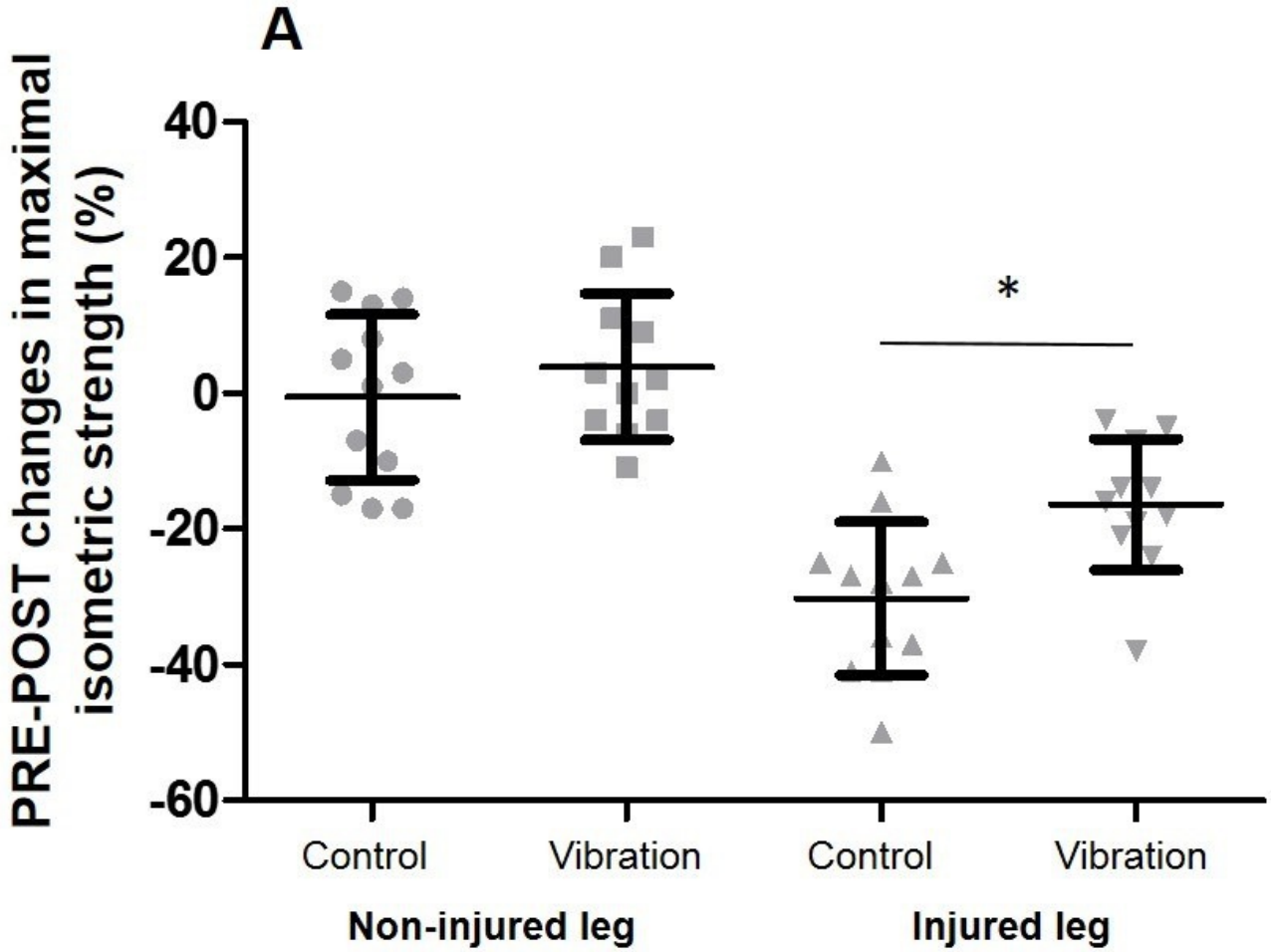
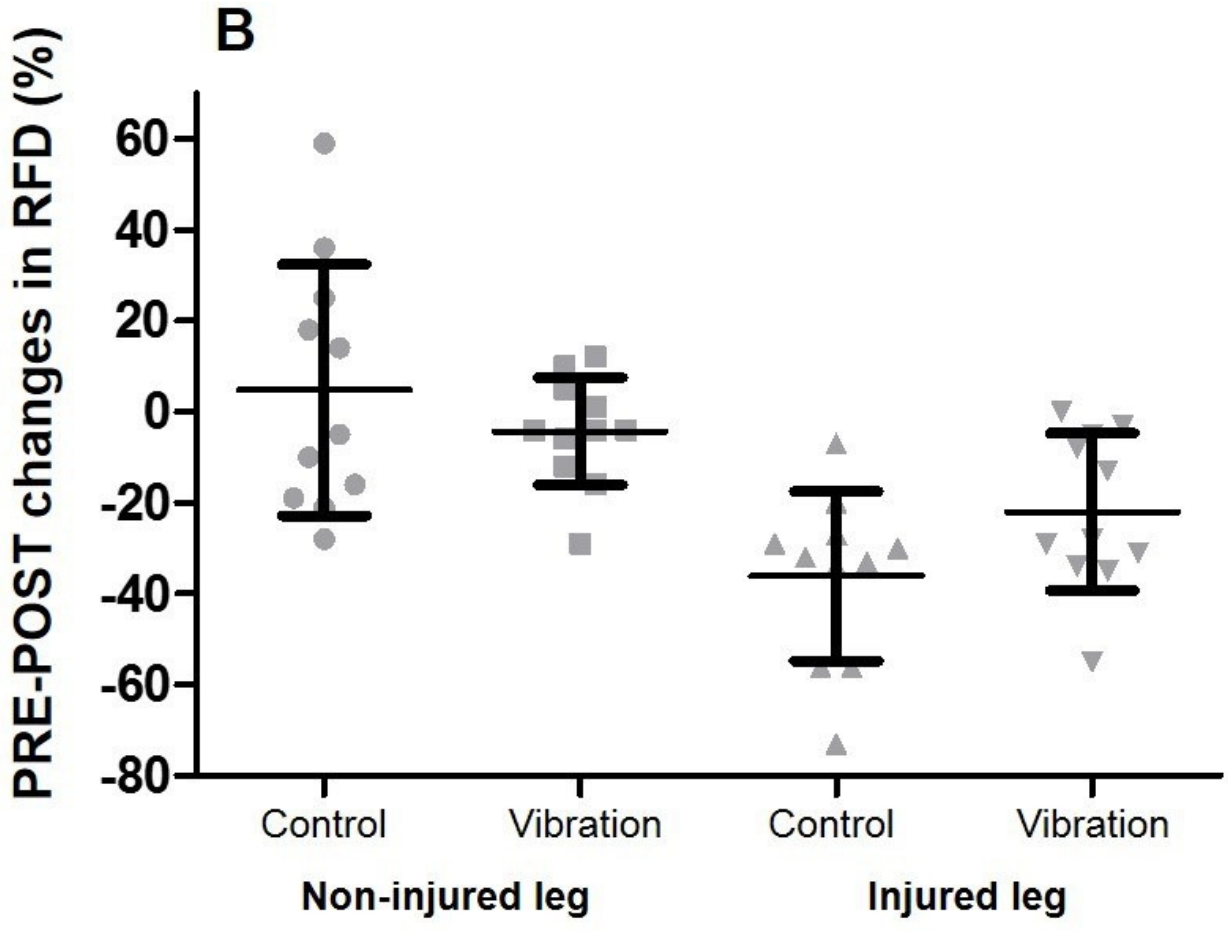
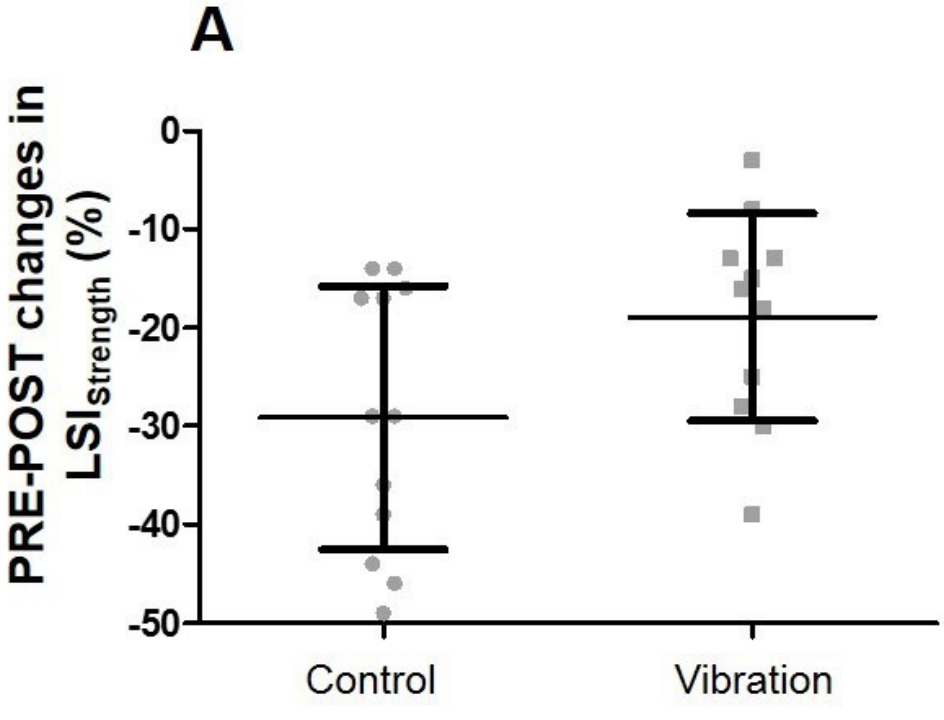
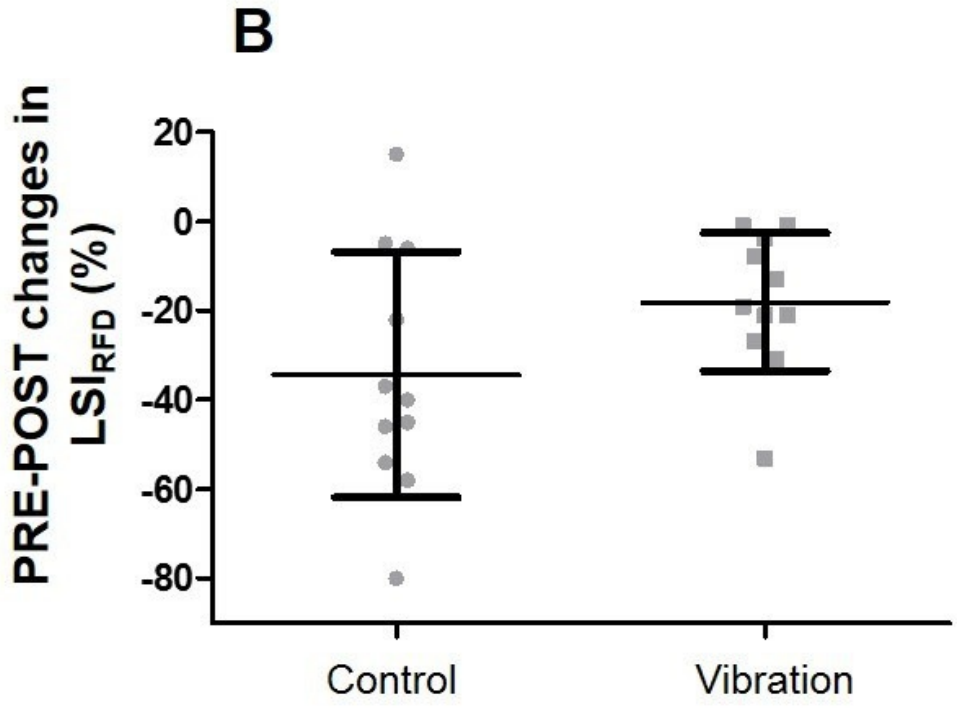

Enrollment
Assessed for eligibility (n=33)
Excluded (n=3)
♦ Not meeting inclusion criteria (n=3)
Randomized (n=30)
Allocation
Allocated to control group (n=14)
Allocated to vibration group (n=16)
Follow-Up
Lost to follow-up (n=2)
- Did not complete the rehabilitation protocol in time (n=2)
Lost to follow-up (n=5)
- Post-surgery complications (n=4)
- Unwilling to complete the protocol (n=1)
Analysis
Analysed (n=12)
♦ Excluded from analysis: none
Analysed (n=11)
♦ Excluded from analysis: none


A
PRE-POST changes in maximal isometric strength (%)
40
20
0
-20
-40
-60
*
Control
Vibration
Control
Vibration
Non-injured leg
Injured leg


B
PRE-POST changes in RFD (%)
60
40
20
0
-20
-40
-60
-80
Control
Vibration
Control
Vibration
Non-injured leg
Injured leg


A
PRE-POST changes in LSI Strength (%)
0
-10
-20
-30
-40
-50
Control
Vibration


B
PRE-POST changes in LSI RFD (%)
20
0
-20
-40
-60
-80
Control
Vibration

275 Table 1. Characteristics of participant groups.

	Control group (n=12)	Vibration group (n=11)	*P*-value (Group effect)
Age (years)	29 (9)	30 (10)	0.86
Sex (male / female)	7 / 5	6 / 5	0.86
Mass (kg)	75 (18)	74 (20)	0.88
Height (cm)	176 (12)	172 (9)	0.37
Body mass index (kg/m²)	23.7 (3)	24.7 (6)	0.64
Pre-injury activity physical activity level (Tegner)	7.4 (1.9)	6.7 (2.3)	0.44
Leg dominance (left / right)	1 / 11	2 / 9	0.48
Injured leg (left / right)	4 / 8	4 / 7	0.88
Graft type (hamstring tendon / bone-patellar tendon-bone)	9 / 3	10 / 1	0.32
Concomitant meniscal repair	5	3	0.26

Concomitant anterolateral ligament reconstruction	5	4	0.41
Time between pre-tests and surgery (days)	5.4 (3.9)	4.4 (3.1)	0.48
Time between surgery and post-tests (days)	70.6 (6.4)	74.0 (5.5)	0.19

Data are mean (SD) or number.

Table 2. Maximal isometric strength, rate of force development (RFD), limb symmetry index (LSI) and functional performance [Timed Get Up and Go test (TUG) and Six-Minute Walk Test (6MWT)] for control and vibration groups before surgery (PRE) and after the intervention (POST).

	Control group		**Vibration group**		**Effect size (Cohen's d [95% CI])**		
	PRE	POST	PRE	POST	PRE to POST Control	PRE to POST Vibration	Difference in recovery between groups
Maximal isometric strength (N)							
Non-injured leg	712 (215)	706 (240)	616 (219)	629 (197)	0.03 [-0.20 to 0.26]	0.06 [-0.12 to 0.24]	0.38 [-0.44 to 1.21]
Injured leg	567 (216)	398 (160)*	555 (230)	468 (219)*	0.89 [0.44 to 1.33]	0.39 [0.16 to 0.61]	1.33 [0.43 to 2.24]
$LSI_{Strentgh}$ (%)	80 (18)	56 (15)*	90 (16)	72 (12)*	1.42 [0.67 to 2.14]	1.26 [0.50 to 1.98]	0.85 [-0.0035 to 1.71]
RFD (N/s)							
Non-injured leg	3060 (1087)	3113 (1255)	3083 (1129)	3060 (1087)	0.05 [-0.32 to 0.41]	0.15 [-0.03 to 0.33]	0.43 [-0.41 to 1.28]
Injured leg	2522 (906)	1659 (867)	2799 (1172)	2522 (906)	0.97 [0.46 to 1.47]	0.48 [0.16 to 0.79]	0.79 [-0.073 to 1.66]
LSI_{RFD} (%)	85 (22)	54 (23)*	90 (11)	85 (22)	1.40 [0.39 to 2.36]	0.96 [0.35 to 1.56]	0.73 [-0.13 to 1.59]
Functional measures							
TUG (s)	6.98 (0.77)	7.54 (0.88)	6.92 (1.46)	7.24 (1.52)	0.67 [0.04 to 1.28]	0.21 [-0.01 to 0.43]	0.39 [-0.46 to 1.23]
6MWT (m)	590 (71)	570 (69)	547 (89)	551 (109)	0.29 [-0.11 to 0.36]	0.03 [-0.30 to 0.36]	0.40 [-0.45 to 1.24]

Data are mean (SD) unless indicated.

* indicates significantly different from PRE