Contralateral strength training attenuates muscle performance loss following anterior cruciate ligament (ACL) reconstruction; a randomised-controlled trial.

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ABSTRACT

Purpose: To investigate the effects of cross-education (CE) exercise on strength and performance at 10 and 24-weeks post anterior cruciate ligament (ACL) surgery.

Methods: Design*:* Randomised controlled trial. N=44 ACL-reconstruction patients, randomly-allocated into: CE: strength training of the non-operative limb, or CON: sham-exercise of upper limb stretching. Each patient underwent standardised ACL rehabilitation, plus 8 weeks of thrice weekly CE or CON, commencing at 2-weeks post-surgery. The primary outcome was quadriceps peak force (QPF) of the ACL-reconstructed limb at 10-weeks post-surgery. Secondary measures were hamstrings peak force (HPF), rate of force development (RFD) and International Knee Documentation Committee score (IKDC) at 10- and 24-weeks; QPF and hop for distance (HOP) at 24-weeks post-surgery

Results: CE significantly attenuated the decline in QPF of the ACL-reconstructed limb at 10-weeks compared to CON (16.6% decrease vs. 32.0%, respectively); that advantage was not retained at 24-weeks. A training effect was observed in the trained limb for HPF and QPF, which was retained at 24-weeks. No significant differences were observed for IKDC, HOP, RFD, or HPF of the reconstructed limb. Inter-limb symmetry (ILS) ranged from 0.78-0.89 and were not significantly different between groups.

Conclusion: High-intensity CE strength training attenuated the post-operative decline in QPF and should be considered in early phase ACL rehabilitation. ILS data showed good symmetry, but it masked significantly inferior performance between groups and should be used with caution.

Trial registration number: NCT02722876

KEYWORDS:

Cross-education; cross-transfer; rehabilitation; strength training.

ABBREVIATIONS

ACL: anterior cruciate ligament; CE: cross-education; CON: control; QPF: quadriceps peak force; HPF: hamstrings peak force; RFD: rate of force development; ILS: inter-limb symmetry; IKDC: international knee documentation

DECLARATIONS

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Availability of data and material: The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request

Code availability: Not Applicable

Ethics approval: The study was approved by the regional NHS research ethics committee

Consent to participate: Participants provided their written informed consent to participate in this study

Consent to publication: The Authors provide formal consent to publish.

INTRODUCTION

Anterior cruciate ligament (ACL) injury is a common and debilitating injury (Ardern et al. 2011) and without intervention often prevents return to play. Surgical reconstruction to restore mechanical rotational instability (Krause et al. 2018) is the preferred treatment option, where patients have ongoing symptoms of instability despite conservative treatment (Schmitt et al. 2012).

ACL reconstruction (ACLR) often results in significant and prolonged functional impairments, in particular asymmetry of quadriceps strength (Gokeler et al. 2014; Kuenze et al. 2015; Papandreou et al. 2013; Zult et al. 2018). A recent review reported persistent asymmetry of function in patients, including 23% (± 8%) side-to-side strength deficits at 6 months post- and 14% (± 5%) at 12-months post-ACLR (Lepley et al. 2015). Current evidence suggests that persistent quadriceps dysfunction (QD) contributes to the early-onset of osteoarthritis (Tourville et al. 2014) as well as deficits in functional performance and patient-reported outcomes (Schmitt et al. 2012). Minimising QD should therefore be a primary objective of ACL rehabilitation interventions, but due to post-operative pain and current practice that advocates minimal open kinetic chain isolation exercises (such as knee extensions) in the early ACLR period this is challenging to achieve.

The cross-education (CE) phenomenon describes the strength gain in the opposite (contralateral) untrained limb following unilateral contralateral resistance training. In healthy and athletic populations, recent meta analyses have reported the CE effect to represent an absolute gain of 8–12%, or around 50% relative to the improvement in the trained limb (Carroll et al. 2006; Manca et al. 2017). In orthopaedic populations, this magnitude of effect might offer the opportunity to attenuate post-operative deficits and accelerate the rehabilitation process, however, research has commenced only recently, yielding conflicting results.

In the lower limb, three studies have investigated CE effects on performance in ACL populations (Harput et al. 2019; Papandreou et al. 2013; Zult et al. 2018). Whilst Papandreou et al. (2013) reported that CE training attenuated the loss of quadriceps strength in the injured limb (16% vs 37%, respectively), and self-perceived function at 9-weeks post-surgery. Zult et al. (2018) reported no short or longer-term effects of a CE intervention on self-perceived, HOP and quadriceps strength compared to standard care. The characteristics of the intervention likely plays a significant role in the efficacy of the cross-transfer effect, including intensity and type of muscle contractions, dose and inter-set rest periods. Current theory suggests that cross-education is neurally-driven, with higher intensity muscle contractions involving high proportions of fast twitch motor unit recruitment (Manca et al. 2017) and maximising stimulation of the corticomotor pathway that activates the unexercised limb (Hendy and Lamon, 2017). Thus studies that focus on lower intensity hypertrophic and muscle endurance responses (Zult et al. 2018), are unlikely to yield significant cross-transfer effects by comparison to maximal strength training (Papandreou et al. (2013).

More research is required to investigate the effects of CE on the function of other muscles, especially of the hamstring muscle group, which are integral to the dynamic protection of the ACL (Palmieri-Smith et al. 2019) and on the rate of force development capabilities (RFD). Given that most ACL injuries occur in a very limited time-frame (Krosshaug et al. 2007), restoration of the tempero-force characteristics of the dynamic knee stabilisers is also likely important to the minimising of injury risk. Research that shows lasting inferior early- and late-phase RFD performance in the ACL-reconstructed limb compared to health limb (Turpeinen et al. 2020) and the potential for contralateral improvements in RFD via CE exercise (Carr et al 2019), suggests the potential utility of a CE intervention on this index in an ACL population.

The aim of this study was, therefore, to investigate the immediate (10-weeks post surgery) and longer-term (24-weeks post surgery) CE effects on muscle performance and function following maximal strength training on the non-operative limb. These assessment points represent at 10-weeks: the earliest assessment point post the 8-week intervention and commensurate with a clinically-acceptable time for maximal open kinetic chain knee extensor contractions and at 24-weeks (6 months): historically the most common length of ACL rehabilitation programmes and the earliest permissible return to sport (van Grinsven et al. 2010); both time frames are standard in the literature.

METHODS:

Participants

Eligible patients provided written informed consent and were randomly-allocated to:

1.Cross-Education (CE): a standardised program of ACL rehabilitation used in current clinical practice (Appendix 1), plus 8-weeks of strength training on the non-operative limb; 2. Control (CON): the same ACL rehabilitation, plus sham exercise of time-matched bilateral upper limb flexibility. Participants were self-declared as recreationally active, exclusion criteria were: age <15 years and >60 years; co-morbidities (e.g. multi-ligament surgery); diagnosis of a systemic disease; symptomatic non-operative knee; any other reason that would lead to non-compliance.

This study was performed in line with the principles of the Declaration of Helsinki. The study was approved by the regional NHS research ethics committee and the research was conducted at UK NHS Hospital Trust (REC number 16/EM/0222). See Table 1 for participant characteristics.

Cross-Education Training

Strength training of the contralateral limb, commenced 2-weeks post-surgery and was performed 3 times per week for 8 weeks. Exercises comprised 3 sets of 3-5 repetitions maximum (RM) of: knee extensions; hamstrings curls and leg presses performed on commercially-available resistance machines with 1.5-2 minutes inter-set rest. Patients were familiarised and habituated to the exercise and weight selection during the first session and performance and load were monitored weekly. Verbal encouragement was provided during each supervised session and the same level of maximal effort was encouraged during independent training. The resistance was progressed when patients could lift >6 repetitions across 2 consecutive sets. Patients performed the CE exercise once per week in the physiotherapy gym, supervised by the trial physiotherapist and the remaining two sessions independently.

Control Stretching Exercise

The CON comprised a time-matched bilateral upper limb stretching programme comprising of 3 sets of 20-second standard static stretches of the pectoralis major, latissimus dorsi and triceps brachii muscles. An upper-limb 'exercise control' was used to minimise any effects of social approbation on outcomes resulting from additional attention from the trial physiotherapist. The upper limb was selected to avoid any carry-over effects on lower limb muscle performance. Adherence to CE and CON was monitored and recorded weekly by the trial physiotherapist.

Outcomes Assessment

Baseline measures were collected within 6 weeks pre surgery.

The primary outcome of QPF of the injured limb measured at 10-weeks post-surgery. Secondary outcomes were QPF and HOP at 24-weeks, hamstrings peak force (HPF), rate of force development (RFD) and IKDC, at 10- and 24 weeks. Isometric QPF, HPF and RFD were assessed using a custom-built dynamometer (Bailey et al. 2014).

QPF, HPF and RFD:

After a series of sub-maximal warm-up muscle activations, patients were instructed to flex or extend the knee joint as rapidly and forcefully as possible (approximately 3-s efforts) in response to an auditory signal (knee flexion angle 30°). Patients performed 5-10 maximal contractions, separated by a minimum of 30 seconds. The mean of the 2 best efforts was used to calculate all indices of performance. Verbal encouragement was provided throughout and the order of quadriceps and hamstrings testing was randomised. Peak force (N) was recorded as the highest force achieved in each contraction, indices of RFD ($N^{.s-1}$) were assessed across three 50ms epochs of the force-time curve, commencing at the onset of muscle force: 0-50ms; 50-100ms; 100-150ms.

HOP:

The hop for distance (HOP) was chosen as a secondary outcome to assess function. The patient hopped forward as far as possible along the line of a tape measure and landed on the same limb. Balance was maintained for 2 seconds to achieve successful hop. Three practice hops were offered and 3 measurable maximal trials per limb with a 30 second rest between hops were recorded and the average of the 3 hops was calculated for each leg. TheILS was recorded as the percentage difference between the two limbs.

IKDC:

The questionnaire was completed by the patient without any prompts or time restriction. The IKDC grades 18 statements, for symptoms, sports and activities of daily living. The scores range from 1 – 100, where 100 is optimal.

Sample Size and Allocation

The sample size was calculated using previously collected data from our laboratory on similar cohorts of ACL patients, which suggested a mean peak quadriceps force at 10 weeks of 400N, a standard deviation of 60N, and a correlation coefficient of 0.5 between baseline and 10 weeks peak force. Power calculations revealed that to detect a 50N (12.5%) between group difference in QPF at 10-weeks post-surgery (equivalent to a standardized effect size of 0.83) with 80% power, a sample size of 18 patients in each treatment group was required (Borm et al., 2007). 44 Patients were recruited to allow for a 20% attrition

Patients were allocated to treatment condition by the trial statistician using randomisation software that implemented the minimisation method (Pocock and Simon, 1975) to achieve balance between the two groups on a single stratifying variable (QPF). The software further used a biased coin when allocating the exercise, with the bias set as 0.7 in order to maintain allocation concealment (Barbáchano et al. 2018).

Statistical analysis

Quantile-Quantile (QQ) plots were made of all continuous data to check for deviations from normality. These plots included 95% confidence bands around the ideal line to assist judgement. All continuous data were summarised using means and standard deviations (SD), or if not normally distributed using medians and interquartile range. Outcomes were compared between the two groups using analysis of covariance (ANCOVA), with baseline scores as the covariate. In cases of seeming unbalance between the groups, differences adjusted for the unbalanced covariate were also determined. To assess differences in overall clinical outcomes (IKDC and HOP) between baseline and 6 months we used paired t-tests, whereas differences in clinical outcomes at 24 weeks were assessed using ANCOVA as explained above.

Statistical analyses were carried out using R version 3.6.1, using the package “nlme”.

Statistical significance was assumed where p-values <0.05.

RESULTS:

See figure 1 for flow diagram of patient recruitment. Adherence to the CON and CE conditions was 94% for both groups with a mean of 22.6 (± 2.5) sessions attended out of maximum 24.

No evidence was found to suggest continuous data was not normally distributed. The groups were evenly distributed across all variables apart from sex (**TABLE 1**), therefore sex-adjusted values were also calculated.

*** INSERT TABLE 1 NEAR HERE ***

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Muscle Strength

ACL surgery resulted in a 32% reduction in QPF of the injured limb from baseline to 10-weeks post-surgery in the CON group; this reduction was significantly attenuated in the CE condition to only 16.6% (baseline-adjusted difference 51N, 95%CI 18 to 85, p=0.004; gender and baseline-adjusted difference 42N, 95%CI 7 to 77) (**FIGURE 2**). This value was close to the 50N difference assumed in our sample size calculations. At 24-weeks post-surgery, group mean QPF scores in the CE group were 14% larger, albeit non-significant compared to the CON group.

Significant differences between treatment groups were also observed for QPF of the non-injured, trained limb. From pre- to 10-weeks post-surgery strength training resulted in an increase of QPF performance of 7% in the CE group and a 7% decrease in the CON group (baseline-adjusted difference 58N, 95%CI 28 to 87, p<0.001; gender and baseline-adjusted difference 49N, 95%CI 19 to 79) (**FIGURE 2**). This difference between groups was maintained at 24-weeks post-surgery (412.8N vs. 350.0N), representing a 17.7% between group difference (baseline-adjusted difference 54N, 95%CI 11 to 97, p=0.016; gender and baseline-adjusted difference 36N, 95%CI -8 to 80). Computation of individual inter-limb symmetry (ILS) (ratio of injured/uninjured QPF), revealed no statistical differences between groups at 24-weeks post ACLR (**TABLE 2**).

*** INSERT FIGURE 2 NEAR HERE ***

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Analyses of HPF data showed no between group-differences at 10-weeks post-surgery in either limb (baseline-adjusted difference -12N, 95%CI -56 to 31 (p=0.57) and 22N, 95% CI -2 to 46 (p=0.067); gender and baseline-adjusted difference -15N, 95%CI -59 to 29 and 23N, 95%CI -1 to 48, injured and non-injured side, respectively). At 24-weeks post-surgery HPF of the non-injured limb was significantly greater in the CE vs the CON group (baseline-adjusted difference 22N, 95%CI -23 to 66 (0.32) and 42N, 95% CI 4 to 79 (p=0.030); gender and baseline-adjusted difference 15N, 95%CI -29 to 59 and 39N, 95%CI 0 to 78, injured and non-injured side, respectively). Computation of individual ILS for HPF revealed no statistical differences between groups at 24-weeks post ACLR (**TABLE 2**).

Rate of Force Development

Analyses of RFD data showed a significant between-group difference at 10-weeks post-surgery in $QRFD_{0-50}$ for the non-injured limb that favoured the CON group (p=0.025) (**TABLE 3**). No differences in RFD values between groups for both limbs and muscle groups at all other time points were observed.

*** INSERT TABLE 3 NEAR HERE ***

IKDC and HOP

Significant improvements in IKDC (23%, p = 0.001) and HOP ILS(15%, p = 0.004) were observed from pre- to 24-weeks post with no significant differences between treatment groups (p=0.96 for both IKDC and HOPILS, see also **TABLE 2**).

DISCUSSION

This study aimed to investigate the immediate and longer-term effects of 8-weeks of CE strength training, in addition to standardised rehabilitation following ACL surgery on QPF. Secondarily, we sought to evaluate the effects of CE on HPF, RFD, IKDC and HOP over the same post-operative period.

Quadriceps Performance

Cross Education elicited a significant effect on QPF in the trained, non-injured limb; the significant 14% between group difference at 10-weeks remained at 24-weeks (**FIGURE 2**). The most important finding of this study however, is that this dose of CE exercise at a strength training prescription of 3-5RM over 24 sessions was effective in attenuating the decline in QPF of the injured limb (**FIGURE 2**).

The magnitude of decline in QPF associated with ACL reconstruction without CE is commensurate with previous studies. However the effects of CE on muscle force production in this patient population are equivocal. Papendreau et al. (2013) reported a 16% vs 37% deficit in QPF at 9-weeks post-surgery following CE (24 session of high-intensity eccentric muscle contractions) and standard care, respectively. Zult et al.(2018) observed no CE effect in the quadriceps with a hypertrophy-focussed intervention of 8-12RM over the same number of sessions. The specificity of the CE intervention, including intensity and type of muscle contractions, dose and inter-set rest periods likely play a role in the efficacy of the cross-transfer effect. Current theory suggests that cross-education is neurally-driven, with higher intensities involving high proportions of twitch motor unit recruitment (Manca et al. 2017) and maximising stimulation of the corticomotor pathway that activates the resting or unexercised limb (Hendy and Lamon, 2017). As such, maximal strength- (3-5RM), or high-intensity eccentric training are likely to be most effective.

The current study is only the second to examine the longer-term effects of CE training in patients after ACLR. Zult et al. (2018) reported no CE effects on QPF at any time period following a hypertrophy-focused intervention. The between-group difference of 30N (14%) observed at 24-weeks post-surgery in the current study was below our target difference of 50N and thus the advantage conveyed by CE observed at 10-weeks post-surgery was not significantly retained (**FIGURE 2**). The current study purposely recruited a sample of patients representative of a typical clinical population to explore the CE effect in a realistic NHS clinical setting in contrast to prior studies that have used more homogenous groups (Harput et al. 2019; Papandreou et al. 2009; Papandreou et al. 2013). Whilst it's not possible to conclude, contributing factors to the loss of the CE advantage at this time point could include inter-patient variability in resistance training habits and experience.

On balance, the CE group demonstrated enhanced recovery of QPF for both limbs, without significantly impacting the ILS. At 10-weeks post-surgery this may represent the physiologic adaptations subsequent to the CE intervention. Thereafter, the mechanisms of differential performance between groups potentially represent a combination of the carry-over effect of the CE exercise coupled with behavioural changes once the CE was removed and patients became more independent in their rehabilitation.

Hamstrings Performance

The CE intervention did not influence HPF performance of the injured limb, despite the appearance of an accelerated recovery (**FIGURE 2**). The reason for the differential findings of CE effect between muscle groups is unclear; the dose of open kinetic chain exercise during the CE intervention was the same for hamstrings and quadriceps. However, it is conceivable that the leg-press exercise is more quadriceps dominant (Escamilla et al 2001) and thus the dose was dissimilar. Given that the cross-education effect is muscle specific (Andrushko et al 2018) and that dose may play a role in determining the extent of adaptation (Papandreou et al 2013) the dose in the present study may have been insufficient to elicit detectable change of 50N in this ACLR population. Indeed, significant group mean differences were only seen in HPF on the non-injured, trained leg at 24-weeks post-surgery, representing a 37.5% higher peak force compared to the CON group (**FIGURE 2**).

Inter-Limb Symmetry: QPF and HOP

A ILS of 85–90% or greater for QPF and HOP is a commonly-published return to sport (RTS) criteria (e.g. Adams et al 2012; Wellsandt et al. 2017). The QPF ILS ranged from 0.8 - 0.89 (80%-89%) at 24-weeks (**TABLE 2**). In isolation these ILS scores might add confidence to RTS decisions in the current patient cohort. However, as others have also warned (Wellsandt et al 2017), ratio data might over-estimate physical capabilities. Despite the ILS of 0.89 for HPF in the CON group vs 0.8 in the CE, the absolute HPF in the CON group was inferior, and the QPF failed to return to baseline levels (**FIGURE 2**). External stresses and strains of sport are likely to remain unchanged, thus patients' performance capabilities whether absolute or relative to body mass, are important to consider when estimating injury risk or deciding on return to sport.

The HOP ILS ranged from 78%-81% at 24-weeks, which is similar to that reported by Zult et al. (2018). This range would suggest return to sport is not advisable and continued rehabilitation is required.

Rate of Force Development

To our knowledge, this is the first study to investigate RFD following a CE intervention in a clinical population. In young healthy participants, Carr et al. (2019) investigated the time-course of adaptation of neuromuscular parameters, A 32% increase in late phase RFD and a 95% increase in early phase RDF were observed at 2 and 3-weeks, in the untrained arm respectively. Despite the appearance of a CE effect in preserving RFD_{50} in the quadriceps of the injured limb at 10-weeks post (**TABLE 3**), this was not significant once adjusted for baseline values.

Our RFD data does not demonstrate a clear pattern of differential recovery between the groups for either muscle group. In the current study, the 10-weeks post ACLR assessment point represented the first time patients maximally activated the knee . This delay of maximal activation, and residual physical symptoms such as swelling, and cognitive factors such as hesitancy and self-doubt about perceived abilities, are likely to have contributed to the large degree of intra- and inter-participant variability in responses. Furthermore, the current intervention was strength-focused; patients were instructed to focus on the production of maximal force during the CE intervention, not to achieve the 'explosive' speed of muscle activation integral to the development of RFD abilities (Buckthorpe and Roi, 2006; Hannah et al. 2012).

IKDC

Our results are similar to Zult et al. (2018), where CE provided no significant influence on a subjectively measured outcome, (Huston Clinic Knee Score), but differ from Papandreou et al. (2009), where significant improvements were found in self-perceived outcome (Lysholm) at 9-weeks post-surgery. Different scoring systems offer different insights into self-perceived abilities and as such cannot be directly compared. The IKDC is a reliable and frequently-used inventory in ACLR-specific literature and scores of >88% have been suggested as a criteria to help guide return to sport. The IKDC score at 24-weeks post-surgery ranged from 79%-81% in our study, which in isolation would suggest the need for further rehabilitation

Limitations.

Whilst clear instructions were given to patients to keep their injured leg relaxed throughout the CE exercises, in the absence of muscle EMG we were unable to confirm that no muscle activity was present. Given the configuration of the unilateral resistance exercises, however, any muscle activity would likely have been minimal and unlikely to contribute substantively to the effects observed.

CONCLUSION:

These data show that post-operative high-intensity strength training in the non-operative limb attenuated the post-operative decline in QPF in the operative limb at 10-weeks post-surgery, and was associated with a profile of ‘restored to baseline’ levels of muscle strength across both limbs and muscle groups at 24 weeks. This is the first study to document the CE effect in a heterogenous ACL-injured population and the current data adds to the evidence that strength-focussed CE should be incorporated into early phase ACL rehabilitation to minimise post-operative QD. Furthermore, these data clearly show a discrepancy in ILS may lead to an overestimation of physical capabilities if judged by QPF alone. Therefore, absolute strength scores and a battery of subjective and physical measures must be taken into account during clinical decision making to more accurately judge performance capabilities.

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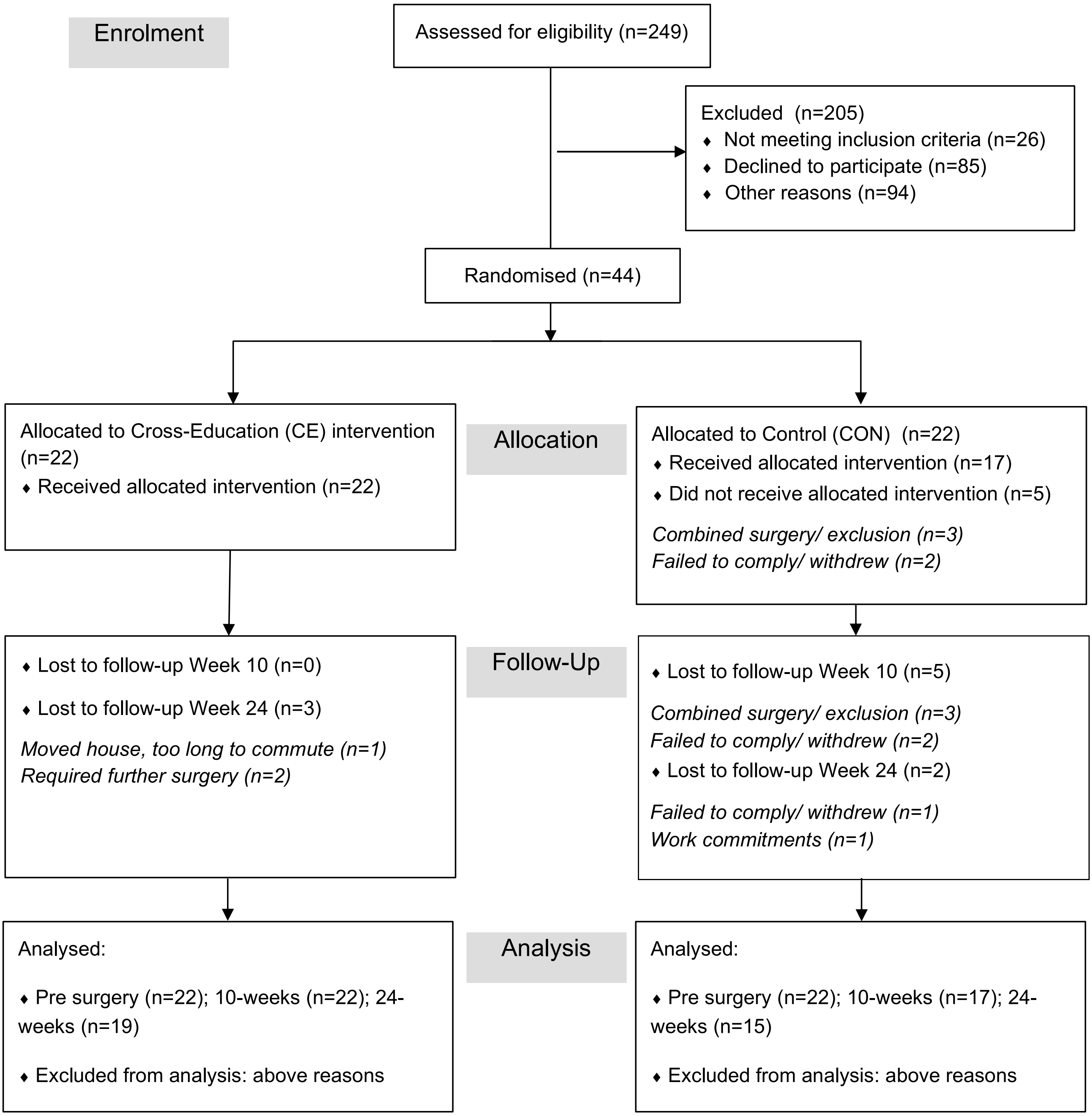
Figure Legends

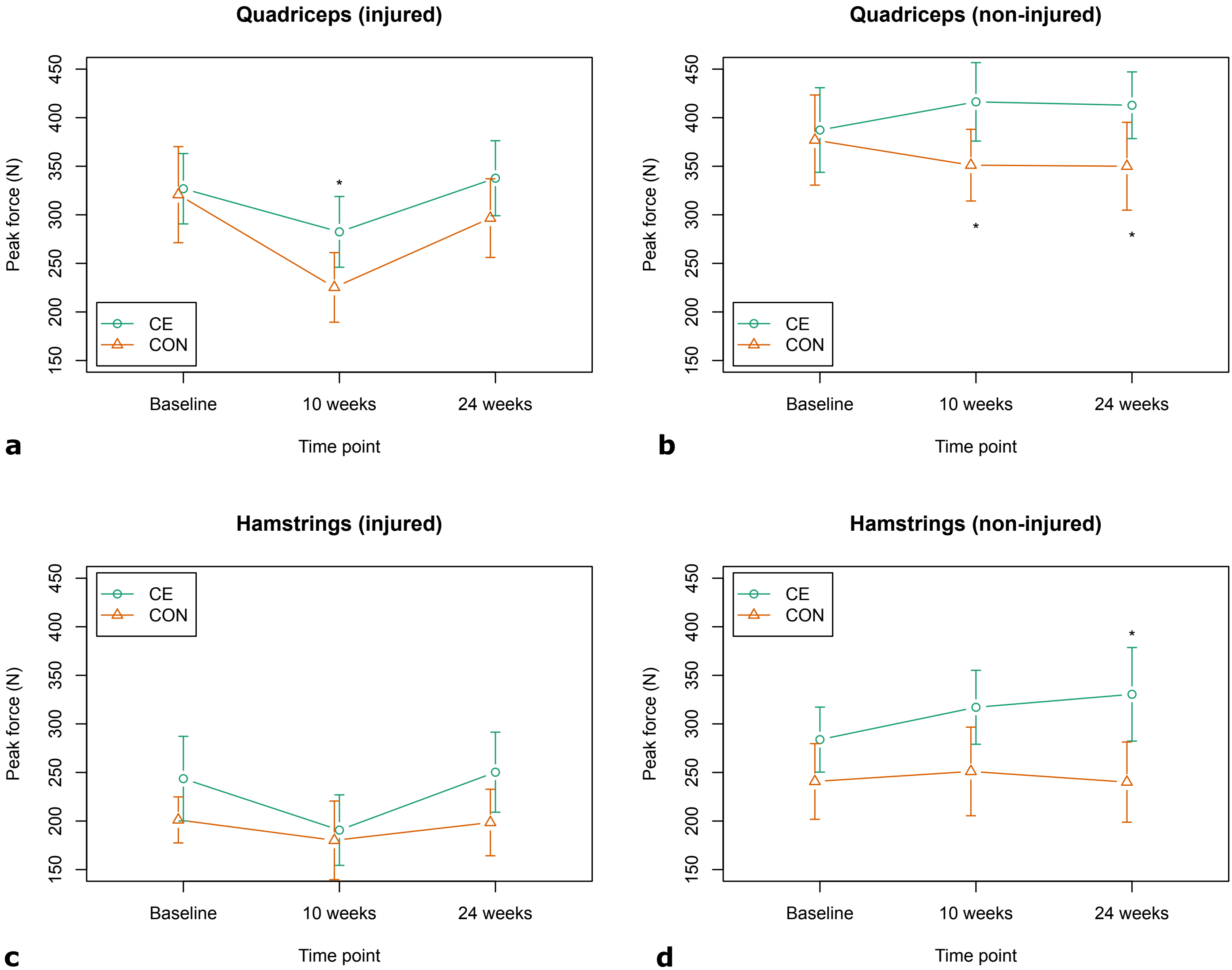
FIGURE 1. Flow diagram of patient recruitment

FIGURE 2. Effects of CE and CON on peak force performance of the quadriceps injured (a); non-injured (b) and hamstrings injured (c); non-injured (d) limbs. Group mean ± SD.

* CE Significantly from CON $p<0.05$

Flow Diagram of Recruitment





Quadriceps (injured)
Quadriceps (non-injured)
Hamstrings (injured)
Hamstrings (non-injured)
Peak force (N)
150
200
250
300
350
400
450
Baseline
10 weeks
24 weeks
Time point
CE
CON
*
a
b
c
d

Table 1. Participant characteristics (mean (± SD).

Participant Characteristics	CE N = 22	CON N = 22
Male (N)	15	10
Age (yrs)	33.3 (10.0)	30.4 (9.4)
Height (cm)	174.8 (9.4)	172.1 (9.5)
Mass (kg)	80.6 (11.8)	82.6 (18.2)
Time since injury (months)	8.3 (8.4)	8.3 (7.4)
Dominant limb L	3	3
Injured Limb L	13	10
Graft:		
BTB	12	11
HT	10	10
QT	0	1
Revision Reconstruction BTB	2	3

CE: Cross Education; CON: Control; BTB: Bone-patella tendon-bone graft; HT: Hamstrings tendon graft; QT: Quadriceps tendon graft

Table 2. Inter-limb symmetry (ILS) of Quadriceps and Hamstrings Peak Force (mean (±SD) [95% CI]) at 24-weeks post surgery.

	Control (CON)	**Intervention (CE)**	**Difference (baseline adjusted)**	**p-value**
ILS				
Quadriceps (ratio I/NI)	0.86 (0.17)	0.86 (0.19)	-0.05 [-0.13, 0.03]	0.23
Hamstring (ratio I/NI)	0.89 (0.38)	0.80 (0.34)	-0.08 [-0.30, 0.14]	0.47

NI: Non-injured limb; I: Injured limb

Table 3. Rate of Force Development (RFD) $N^{.s-1}$ of quadriceps and hamstrings (mean (±SD) [95% CI]) at 10-weeks post surgery.

RFD (ms epochs)	**Muscle Group**	**Control (CON)**	**Intervention (CE)**	**Difference (baseline adjusted)**	**p-value**
RFD_{0-50}	Hams (NI)	935 (677)	1031 (506)	22 [-290, 335]	0.89
	Quads (NI)	1841 (891)	1471 (765)	-477 [-891, -63]	0.025
	Hams (I)	664 (419)	672 (386)	-59 [-309, 192]	0.64
	Quads (I)	844 (424)	1136 (647)	363 [-4, 730]	0.052
RFD_{50-100}	Hams (NI)	1518 (899)	1805 (842)	207 [-308, 721]	0.42
	Quads (NI)	1841 (891)	1599 (774)	-336 [-831, 159]	0.18
	Hams (I)	949 (527)	1066 (613)	-24 [-381, 334]	0.89
	Quads (I)	1701 (822)	1994 (793)	-9 [-485, 467]	0.97
$RFD_{100-150}$	Hams (NI)	1445 (737)	1806 (855)	178 [-265, 621]	0.42
	Quads (NI)	1611 (792)	1710 (753)	62 [-423, 546]	0.80
	Hams (I)	887 (582)	914 (568)	-24 [-421, 374]	0.90
	Quads (I)	*1192 (583)*	*1165 (580)*	*-155 [-512, 203]*	*0.39*

Hams: Hamstrings; Quads: Quadriceps: I: Injured limb; NI: Non-injured limb