Clinical Biomechanics 30 (2015) 738–747

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Combination of eccentric exercise and neuromuscular electrical stimulation to improve biomechanical limb symmetry after anterior cruciate ligament reconstruction

Lindsey K. Lepley [a,c], Edward M. Wojtys [b], Riann M. Palmieri-Smith [b,c,*]

[a] Department of Rehabilitation, University of Kentucky, Lexington, KY, USA
[b] Department of Orthopedic Surgery, University of Michigan, Ann Arbor, MI, USA
[c] School of Kinesiology, University of Michigan, Ann Arbor, MI, USA

ARTICLE INFO

Article history:
Received 1 December 2014
Accepted 21 April 2015

Keywords:
ACL
Knee
Rehabilitation
Strength testing
Biomechanics

ABSTRACT

Background: We have previously reported that an eccentrically-based rehabilitation protocol post-ACLr induced greater quadriceps activation and strength than a neuromuscular electrical stimulation (NMES) intervention and was just as effective as a combined NMES and eccentric intervention. However, the effect an eccentrically-based intervention has on restoring normal knee mechanics during a single-legged landing task remains unknown.
Methods: Thirty-six individuals post-injury were placed into four treatment groups: NMES and eccentrics, eccentrics-only, NMES-only, standard of care, and healthy controls participated. NMES and eccentrics received a combined NMES and eccentric protocol post-reconstruction (each treatment 2× per week for 6 weeks), whereas groups NMES-only and eccentric-only received only the NMES or eccentric therapy, respectively. To evaluate knee mechanics limb symmetry, the area under the curve for knee flexion angle and extension moment was derived and then normalized to the contralateral limb. Quadriceps strength was evaluated using the quadriceps index.
Findings: Compared to healthy, reduced sagittal plane knee limb symmetry was found for groups NMES-only, ECC-only and standard of care for knee extension moment ($P < 0.05$). No difference was detected between healthy and NMES and eccentrics ($P > 0.06$). No difference between groups was detected for knee flexion angle limb symmetry ($P > 0.05$). Greater knee flexion angles and moments over stance were related to quadriceps strength.
Interpretation: The NMES and eccentrics group was found to restore biomechanical limb symmetry that was most closely related to healthy individuals following ACL reconstruction. Greater knee flexion angles and moments over stance were related to quadriceps strength.

1. Introduction

The restoration of quadriceps muscle strength following anterior cruciate ligament (ACL) reconstruction is a major challenge for patients and rehabilitation specialists. Often, despite clinicians' best efforts, quadriceps weakness persists long after the rehabilitation period has ended (Keays et al., 2010; Palmieri-Smith et al., 2008; Tourville et al., 2014). This persistent weakness can cause significant alterations in daily life, as it can lead to altered movement patterns (Lewek et al., 2002; Snyder-Mackler et al., 1991) that are associated with decreased functional performance and possibly re-injury (Schmitt et al., 2012). Accordingly, rehabilitation approaches that target, and combat, quadriceps weakness may be able to reduce the biomechanical alterations that are associated with the lingering strength deficits.

Previous work has found that quadriceps strength post-ACL reconstruction is significantly related to alterations in sagittal plane knee motion (Lewek et al., 2002; Snyder-Mackler et al., 1991). Specifically, during walking and jogging tasks, patients that exhibited greater post-operative quadriceps strength demonstrated movement patterns that were indistinguishable from individuals that are non-injured (Lewek et al., 2002) and their non-injured limb (Snyder-Mackler et al., 1991). Wherein patients with quadriceps strength deficits displayed reduced knee flexion angles (Lewek et al., 2002; Snyder-Mackler et al., 1991) and extension moments during activity (Lewek et al., 2002). Thus, it seems that if clinicians can identify and implement therapeutic interventions that are capable of improving the recovery of quadriceps strength, they can positively influence sagittal plane knee mechanics, which should help to improve functional performance and possibly reduce the occurrence of re-injury (Oberländer et al., 2013).

* Corresponding author at: 4745G Central Campus Recreational Building, 401 Washtenaw Ave., Ann Arbor, MI 48109.
E-mail address: riannp@umich.edu (R.M. Palmieri-Smith).

http://dx.doi.org/10.1016/j.clinbiomech.2015.04.011
0268-0033/

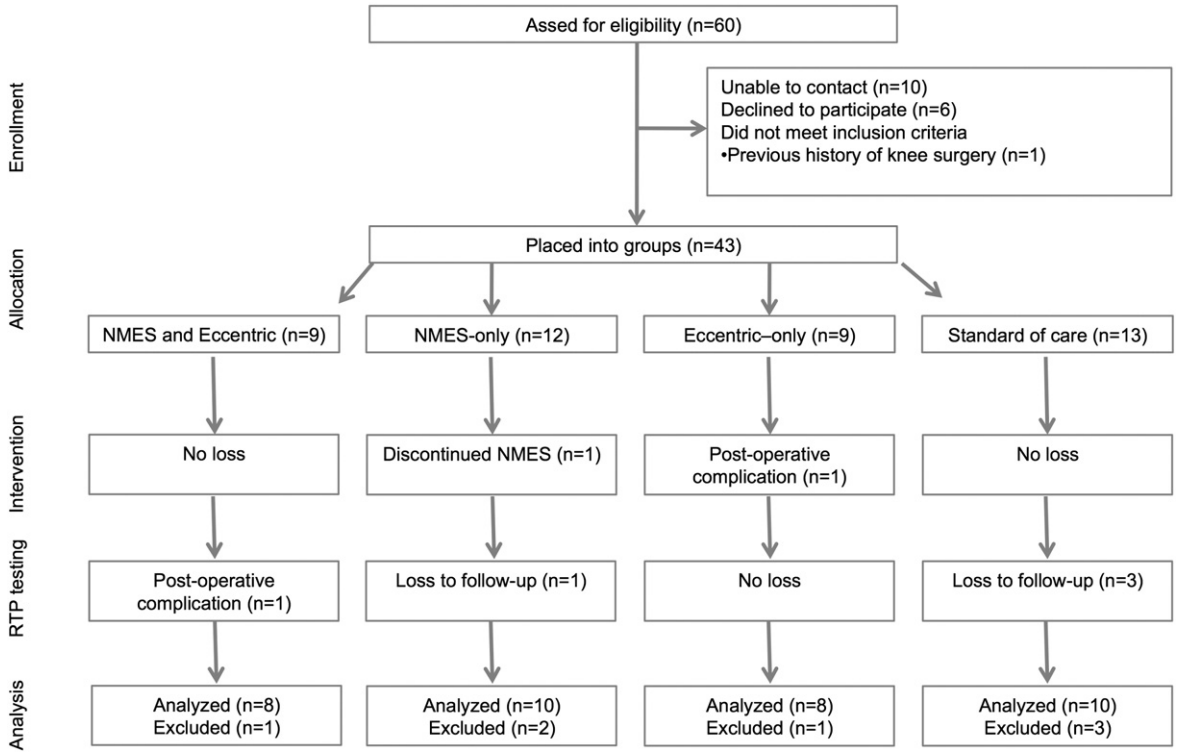

Fig. 1. Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) diagram. NMES = neuromuscular electrical stimulation, RTP = return-to-play.

In our own work, we have previously demonstrated that the application of a combined neuromuscular electrical stimulation (NMES) and eccentric exercise intervention is one such therapeutic approach that can induce significant and clinically meaningful gains in quadriceps strength post-ACL reconstruction (Lepley et al., 2015). This 12-week post-operative combined NMES and eccentric exercise intervention (6 weeks of NMES and followed by 6 week of eccentric exercise) was compared to the standard of care post-ACL reconstruction, and the separate application of just the NMES or eccentric exercise therapy. In general, our previous work indicated that eccentric exercise was likely the driving factor behind strength gains, as patients that were exposed to eccentrics recovered quadriceps strength better than those that were not. Additionally, the combined effect of NMES and eccentrics was not found to be superior to isolated eccentrics exercise post-surgery. Further, patients that received the eccentric intervention were able to demonstrate strength that was similar to non-injured matched healthy controls at a time when they were returned back into participation.

With the above in mind, the motivation behind this study was to examine the capability of the combined NMES and eccentric exercise intervention to improve sagittal plane knee symmetry after ACL reconstruction. We chose to specifically investigate the sagittal plane, as alterations in this plane are consistently observed following ACL reconstruction (Hart et al., 2010; Lewek et al., 2002; Snyder-Mackler et al., 1991), and the sagittal plane is where the quadriceps muscle has the most influence (Herzog et al., 2003; Hurley, 1999). Though our previous work indicates that eccentric exercise is effective at restoring muscle strength(Lepley et al., 2015) knowing if these improvements in strength translate to better movement profiles during functional tasks is equally important. Moreover, understanding the benefit of our therapeutic approach to improve knee symmetry will help to provide preliminary evidence of therapies that can positively influence movement after ACL reconstruction that in part, will help to justify the necessity of this intervention to be examined using a large randomized controlled trial. As such, the purpose of this study was to evaluate the effects of our combined NMES and eccentric exercise intervention on sagittal plane knee mechanics post-ACL reconstruction during a dynamic landing task. We hypothesized that compared with the standard of care and the NMES-only intervention; an eccentrically-based rehabilitation program, which was found to reinstitute normative quadriceps function in our previous work (Lepley et al., 2015), would result in a greater measure of sagittal plane knee limb symmetry, wherein these patients would demonstrate knee flexion angles and moments that more closely resemble their contralateral non-injured limb during dynamic activity. Furthermore, we hypothesized that greater quadriceps strength limb symmetry would be positively associated with greater biomechanical limb symmetry.

2. Methods

2.1. Participants

This study sample consisted of the same patients and participants that participated in our previous study (Lepley et al., 2015) (Fig. 1, Table 1). Prior to the recruitment of participants, this trial was prospectively registered in a public registry (NCT01555567). *A priori* power analysis determined that six participants per group would be needed based off previous work examining the effectiveness of NMES to improve quadriceps function after ACL reconstruction (projected effect size 3.66 for quadriceps strength, α-level 0.05, 1-β 0.80) (Wigerstad-Lossing et al., 1988).

Briefly, individuals that were scheduled for ACL reconstruction at the University of Michigan were invited to participate. Of the 36 patients with ACL reconstruction that elected to participate, 13 females and 23 males were placed into intervention groups. The average age of all patients with ACL reconstruction was 21.4 $\pm$ 5.2 years of age. Thirty-one patients received bone-patellar-tendon autografts and five received semitendinosus and gracilis autografts. Participants were eligible for enrollment if they met the following criteria: 1) were between 14–30 years of age, 2) were planning to undergo rehabilitation at our orthopedic clinic, 3) had an acute ACL injury (defined as reporting to a physician within 48 h post-injury), 4) had no previous history of surgery to either