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Original article

Voluntary activation of quadriceps femoris in patients with unilateral anterior cruciate ligament rupture within 6 months of injury: A cross-sectional observational study

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ABSTRACT

Background: Deficits in quadriceps femoris strength and voluntary activation have been well documented in chronic anterior cruciate ligament (ACL) injuries, but less is known about the acute or early phase after injury.
Objectives: The aim of this study was to evaluate and compare the levels of quadriceps voluntary activation (VA) and strength in both limbs of participants with unilateral ACL ruptures (complete tears) within 6 months of injury.
Design: Cross-sectional observational study.
Method: Seventeen participants, 12 male, mean age 30 (17–45) years, performed maximal voluntary isometric contractions with the interpolated twitch technique.
Results: Mean (SD) peak VA was significantly lower in the injured limb 76.5 (15.0) % than the uninjured limb 85.9 (6.7) % ($p = 0.02$). Mean (SD) peak torque in the injured limb was significantly lower 162.7 (74.1) Nm than the uninjured limb 240.5 (81.0) Nm ($p < 0.01$).
Conclusions: This between-limb difference in VA has not previously been observed in patients within 6 months of ACL rupture. Our findings suggest that early rehabilitation programs for adults with ACL rupture should focus on reducing VA deficits to facilitate improvement of the quadriceps femoris muscle strength in the injured limb to comparable values of the uninjured limb.

1. Introduction

Ruptures of the anterior cruciate ligament (ACL) are common during sport and other recreational activity (Gianotti et al., 2009). Subsequent to an ACL rupture both quadriceps weakness (Hurley et al., 1992; Urbach et al., 1999; Keays et al., 2000; Chmielewski et al., 2004; Tsepis et al., 2006) and muscle fibre atrophy occur (Booth, 1982; Lieber et al., 1988). This can produce disability, prolong the rehabilitation process and delay return to sport and activities of daily living.

It has been widely reported that reflex inhibition of the musculature surrounding the knee joint exists following injury (Newham et al., 1989; Hurley et al., 1992) or simulated joint effusion (Spencer et al., 1984; Hopkins et al., 2002). This decrease in voluntary activation (VA), an inability to fully activate the muscle, has been termed arthrogenic muscle inhibition (AMI) (Hopkins and Ingersoll, 2000) or reflex inhibition (Stokes and Young, 1984). Iles et al. (1990) and Hopkins et al. (2001) concluded that joint effusion inhibits quadriceps alpha motor neurons due to excitation of slowly adapting Ruffini endings within the knee joint capsule and stimulation of the 1b inhibitory interneurons. Unless the AMI is reduced or suppressed this may limit rehabilitation (Hopkins and Ingersoll, 2000).

Several studies have investigated quadriceps strength in the injured and uninjured limbs of people with unilateral ACL injury, and have found significant strength deficits in the injured limb as would be expected (Urbach et al., 1999; Keays et al., 2000; Chmielewski et al., 2004; Tsepis et al., 2006). Likewise, it is known that quadriceps VA is lower in the injured limb than in

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healthy control participants (Urbach et al., 1999). But in studies which have compared the injured and uninjured limbs of unilateral ACL ruptured patients, most studies report bilateral deficits in VA, and only two studies have observed between-limb differences in VA to be statistically significant. Newham et al. (1989) examined VA in 11 males with ACL deficiency, at a mean of 11 months post injury. Mean (SD) quadriceps activation in the uninvolved limb was 94.2 ± 2.3% and the involved limb 74.7 ± 5.4%. Hurley et al. (1992) observed similar findings in 10 males with unilateral ACL rupture, mean time since injury 31 months. This is interesting because it could be logically presumed that the uninjured limb would exhibit lower levels of muscle inhibition, due to those reported differences in strength between limbs (Urbach et al., 1999; Chmielewski et al., 2004).

It is important to note that most ACL VA studies have focused on chronic injuries. Chronic ACL injury is often classed as over 6 months from injury, although it is noteworthy that there is variability in the literature in the use of acute/chronic descriptions, and these terms are often not defined (Flint et al., 2014). Nevertheless, there is a paucity of evidence regarding VA in the early stage of ACL injury, in the acute or subacute stages, 6 months or less from injury. Chmielewski et al. (2004) observed no significant difference in VA between the uninjured and injured limbs of 100 people with acute ACL rupture with a mean time since injury of 6 weeks (range 1–19 weeks). Mean VA in the uninjured limb was 92.8 ± 10.3 (range 54–100%) and in the injured limb 92.6 ± 10.4 (range 60–100%). Williams et al. (2005) observed similar findings in a cohort of 17 ACL deficient subjects at a mean time of 2 months since injury, reporting VA in the uninjured limb was 92 ± 6% and in the injured limb 90 ± 9%. This early stage of ACL injury is important as it is crucial during early rehabilitation that patients perform exercises that are effectively activating the quadriceps, in order to facilitate gains in strength and function following injury (Hart et al., 2010). In addition, early rehabilitation before ACL surgery is beneficial (Smith et al., 2014). An inability to fully activate the muscles of the injured limb could impact on the ability to regain strength and control. Better knowledge of VA in this early phase after ACL rupture could help improve the effectiveness of physiotherapeutic exercise.

To accurately assess VA it is necessary to determine whether the motor neuron pool is sufficiently excited during a voluntary contraction to evoke all the force the muscle is capable of producing (Herbert and Gandevia, 1999). If compliance is obtained and maximal effort is made but maximal muscle strength is not achieved, it is likely that there is an underlying physiological reason as the cause, for example AMI (Hart et al., 2010). The twitch interpolation technique can be used to estimate the level of neural drive to a muscle. An electrical impulse is delivered in a controlled manner to a voluntarily contracting muscle (whilst recording force/torque output) and if a twitch-like increment in the force/torque produced by the muscle is observed then maximal force/torque is not being generated voluntarily (Gandevia et al., 1998). The size of this twitch can be used to estimate the level of neural drive to the muscles (when compared to the force/torque generated from the same twitch in a resting muscle), and hence recruitment of the motor neuron pool. It can therefore be said that this interpolated twitch "is an index of the completeness of muscle activation" (Oskouei et al., 2003).

The variation of levels of VA reported in the previous ACL studies may be the result of methodological differences in the elicitation and measurement of the stimulated twitch. The methodologies described in several studies are questionable in terms of the level of stimulation delivered to the quadriceps. This level has often been under 100 mA which can be inadequate (Behm et al., 1996; Hart et al., 2010).

So it can be seen that some important aspects remain unclear. To the authors' knowledge, there is little research evaluating levels of VA and strength in patients within six months of ACL rupture. Furthermore, there is marked variation in the levels of muscle inhibition reported in studies, and this could be due to methodological differences and particularly inadequate stimulation. Therefore, the aim of this study was to evaluate and compare quadriceps VA and maximal voluntary strength in both limbs of people with unilateral ACL ruptures within six months of injury using an adequate level of stimulation. It was hypothesised that both VA and quadriceps strength would be lower in the injured limb than the uninjured limb.

2. Methods

This was a cross sectional observational study. The primary outcome measures were the level of quadriceps VA and torque from both legs.

2.1. Participants

Approval was gained from the Teesside University School of Health and Social Care Research Ethics Committee, the South Tees Local Research Ethics Committee and the South Tees Hospitals Research Approval Board. Patients with a unilateral ACL rupture (i.e. complete tear) within 6 months of injury were recruited via an acute hospital orthopaedic outpatients clinic. All subjects were diagnosed with an ACL rupture by a consultant orthopaedic surgeon or Extended Scope Practitioner Physiotherapist, and diagnosis confirmed by MRI scan. To be included, participants had to be over the age of 16 years (or skeletally mature as determined by closure of epiphyses on plain X-ray) and they were excluded if they had bilateral injuries; previous injury or surgery to the same knee within the previous 2 years; underlying rheumatological, neurological, cardiovascular or degenerative/congenital condition affecting the lower limbs; history of steroid use (performance enhancing or medication); or were pregnant. Before taking part, each participant read an information sheet about the study and gave informed consent.

The study was time-limited as part of a PhD studentship and so recruitment was set for a fixed period of nine months. In this respect, as an exploratory study, no *a priori* sample size was set, but it was hoped to recruit approximately 20 participants in this within-subjects study to give an adequate degree of precision in estimates made from the results. Twelve male and five female participants were recruited to the study, mean (SD) age 30.2 (9.5) years and mean (SD) time since injury 83 (59) days. Full demographic data are presented in Table 1. No participants had any previous surgery to the injured knee.

2.2. Procedures

All participants gave standard demographic data and completed the Lysholm score (Tegner and Lysholm, 1985) and the International

Table 1
Demographic data of study participants (n = 17).

	Mean (SD)	Range	
		Lower	Upper
Age (years)	30.2 (9.5)	17	45
Height (cm)	176.8 (10.1)	155	195
Time since injury (days)	83 (59)	16	172
IKDC subjective knee score	48.3 (15.4)	25.3	73.6
Lysholm score	54.2 (21.2)	30	91

SD standard deviation.