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ORIGINAL ARTICLE

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Velocity specificity in early training of the knee extensors after anterior cruciate ligament reconstruction

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Abstract Resistance-training velocity specificity is known to occur in isotonic training of uninjured subjects and in isokinetic training of injured patients. Whether velocity specificity occurs with isotonic training in injured patients has not been tested, despite the common use of this exercise mode in patients. Thirty-two patients recovering from anterior cruciate ligament reconstruction (ACLR) surgery were tested at approximately 2 and 6 weeks after surgery. The isokinetic injured/uninjured strength ratios of the knee extensors were compared for the test velocities of $60° \cdot s^{-1}$ and $210° \cdot s^{-1}$, as assessed before and after a 4-week training period. Isotonic training of the knee extensors at $60° \cdot s^{-1}$ was applied in formal sessions three times per week. The isokinetic injured/uninjured strength ratios were compared for the two test velocities, and there was no indication that training velocity specificity occurred in these patients. Possible reasons for this finding, which contrasts with previous work, are discussed.

Key words Velocity · Specificity · Resistance training · Anterior cruciate ligament · Isotonics

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Introduction

The velocity specificity concept holds that resistance training at a specific velocity results in a greater increase in strength at that velocity than at other test velocities. If performance velocity is considered important, then it follows that resistance training velocity must be considered when designing an optimal training program. The question of whether or not there is carry-over to other velocities has been studied in great detail for isokinetic training (Fleck and Kraemer 1987; Morrissey et al. 1995; Sale and MacDougall 1981), but has been investigated in only two studies for resistance training, which is normally characterized by acceleration (e.g. weight lifting; Amiridis et al. 1997; Morrissey et al. 1998). In both of these studies the subjects were uninjured, young females and it was found that the greatest increases in strength occurred at the training velocity.

Almost all of the studies investigating velocity specificity in resistance training have used uninjured subjects. There are only two studies in the literature where velocity specificity in injured subjects has been investigated, and both of these studies used isokinetic training (Sherman et al. 1981; Thomee et al. 1987). It is not known whether velocity specificity occurs in injured individuals with the more commonly used training mode, isotonics. This is relevant because of the importance of resistance training in rehabilitation after orthopaedic injury and disease.

The purpose of this study was to investigate whether training velocity specificity occurs in weight-resisted dynamic exercise in the early period after anterior cruciate ligament reconstruction (ACLR) surgery. The results of this study are relevant to clinicians who design training programs to restore functional ability following injury.

Methods

Subjects

Potential subjects were identified for this study from post-ACLR in-patients. Subjects were deemed suitable for inclusion in the study if they had no prior history of pathology requiring medical attention to the contralateral lower limb. Within the first 2 weeks following surgery, subjects were approached and given a written and verbal explanation of the study, and then invited to volunteer for participation. Patients were accepted into the study if: (1) it was at least 2 weeks after their ACLR surgery, (2) their passive motion in the injured knee was near 90° flexion, and (3) they were able to walk without a walking aid. Patients were later excluded from this analysis if: (1) they had fewer than eight physiotherapy treatments sessions between the pre- and post-test sessions, (2) the pre- to post-test interval was outside the range of 27–34 days, (3) the surgery to pre-test interval was >19 days, and (4) the surgery to post-test interval was not within the range of 35–49 days.

Surgical procedures

Three orthopaedic surgeons contributed prospective subjects to participate in the study. Surgeon A (J.B.K.) performed ACLR using the technique described by Kennedy et al. (1980). This technique involves using a graft consisting of the ligament augmentation device (3 M, Minneapolis, Minn., USA) combined with a small film of the patellar tendon. The tendon graft remains anchored at the tip of the tibial tuberosity. It is threaded through a tibial bone tunnel and then passed through the joint with an over-the-top technique, and finally fixed with a lateral screw. Surgeons B (T.B.M.) and C (T.B.) performed arthroscopically assisted ACLR after harvesting a bone-patellar-tendon-bone graft from the central one-third of the extensor mechanism, via an anterior midline incision. The free graft is then inserted through tunnels in the tibia and femur, with fixation using interference screws or staples.

Training

Subjects were asked to attend outpatient physical therapy sessions three times per week for the 4-week training period of the study. Subjects exercised their knee extensors either in the open kinetic chain (OKC), using either ankle weights or on various machines designed for isolated resistance of this muscle group, or in the closed kinetic chain (CKC), using a leg-press machine (horizontal leg press, Technogym UK, Bracknell, UK). For subjects training using the OKC exercise, the attending therapist decided whether to use ankle weights or the knee extensor exercise machine, and was urged to use machines as early as possible. For both types of training, three sets of the 20-repetition maximum (20RM) repetitions were used in each session. The weight used in the 20RM was determined through trial and error by the attending therapist, and was altered whenever the therapist felt it appropriate. The target training range of movement (ROM) was 90°–0° knee flexion, but was less than this if the patient indicated knee pain or lacked the necessary passive ROM. To control velocity, subjects used Right Weigh (Baltimore Therapeutic Equipment, Baltimore, USA) timing feedback devices. These machines, used only when exercise was performed on the weight machines, give immediate feedback to the subjects about the timing of their weight lifting relative to target times, as they train and for the duration of the lifting (concentric) and lowering (eccentric) phases of a repetition. The target time settings used, denoted as level 3 on the machine, were 1.5 s for the lifting phase and 3.0 s for the lowering phase of a training repetition, with a 1.0-s interval between phases. These represent average angular velocities of $60° \cdot s^{-1}$ for the lifting phase and $30° \cdot s^{-1}$ for the lowering phase.

Testing

Isokinetic knee muscle strength testing was performed using the Lido isokinetic system (Lido Multi-Joint II, Loredan Biomedical, California, USA). Testing was performed with the subject sitting with their hips flexed to approximately 80°. Stabilization straps were placed across the subject's hips and chest, and the subject gained further stabilization by gripping a metal bar at each side of the test chair near their hip joints. Since the pain-free ROM of the injured leg determined the ROM used for testing, this leg was tested first. The ROM was determined by fixing the injured leg to the isokinetic actuator and then using the computer to move the knee slowly through flexion and extension until the patient either reported knee pain or achieved 90° of flexion and 0° extension. If the patient reported knee pain before reaching 90° of flexion or 0° extension, the angle at which this pain first appeared was noted, and testing was performed 10° short of this angle. The abbreviated ROM used on the injured leg was also used on the uninjured leg. The ROM was determined in the pre-test session and maintained in the post-test session.

Test velocities were $60° \cdot s^{-1}$ and $210° \cdot s^{-1}$, with the slower velocity tested first. Prior to the start of the subject's efforts the machine weighed the leg by moving the subject passively through the ROM. This was done so that the machine could correct for the torque caused by the weight of the lower leg and fixation assembly. Two warm-up maximal contractions were performed at each test velocity for both muscle groups tested, followed by a 30-s interval, before five maximal effort test repetitions were performed. Prior to each concentric contraction, subjects were instructed to "Push..." (for knee extensors) or "Pull..." (for knee flexors), "...as hard as you can until the machine comes to a stop", and this was done without verbal encouragement during contractions.

Data analysis

The isokinetic knee extensor gravity-corrected torque and knee-angle data were downloaded from the Lido to an ASCII file for further processing (Matlab, The MathWorks, Natick, Mass., USA). Knee angle was differentiated over time and a window of interest was defined by a threshold joint angular velocity of $30° \cdot s^{-1}$. This avoided high-frequency torque transients and decreased the acceleration and deceleration phases at the ends of the range of motion. Each window was isolated and interpolated to a curve of 100 points within the total arc of motion. The maximum torque achieved by each subject within their five repetitions was recorded for statistical analysis. The peak torque generated by the injured leg at each speed was divided by the peak torque of the uninjured leg at the same speed for pre- and post-tests. This yielded the following injured/uninjured (I/U) ratios, which were converted to percentages: $(I/U)_{1,60}$, $(I/U)_{2,60}$, $(I/U)_{1,210}$ and $(I/U)_{2,210}$, where the subscript 1 indicates before rehabilitation, subscript 2 represents after rehabilitation, and subscripts 60 and 210 indicate the test velocity.

An analysis of variance (ANOVA) was performed to study the effects of training group (OKC and CKC) and test speed ($60° \cdot s^{-1}$ and $210° \cdot s^{-1}$) on the I/U percentages. Post-hoc investigations using *t*-tests were used to explore significant differences in the percentages. The final analysis investigated the effects of test speed on the absolute change in the I/U percentage from test 1 to test 2 ($(I/U)_{2,60}$–$(I/U)_{1,60}$; $(I/U)_{2,210}$–$(I/U)_{1,210}$).

Results

Thirty-two subjects (8 females, 24 males) were included in the study. Their mean (SD) body mass, height and age were 75 (12) kg, 176 (10) cm and 29 (9) years, respec-

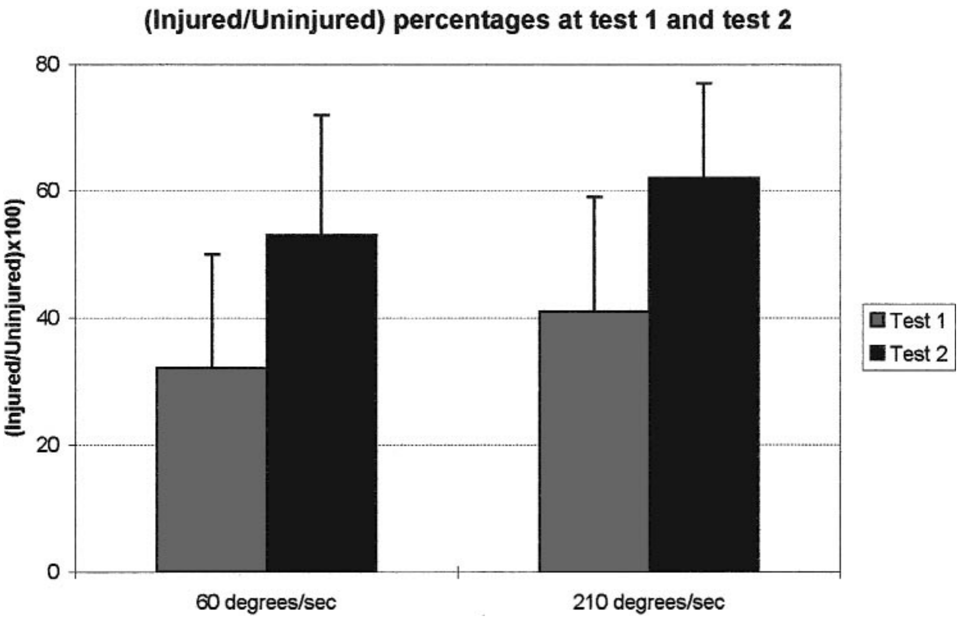

Fig. 1 Means and standard deviations of the injured/uninjured (I/U) percentages at test 1 (pre-test, *grey bar*) and test 2 (post-test, *black bar*) for both test velocities ($60° \cdot s^{-1}$ and $210° \cdot s^{-1}$)

Table 1 Means (SD) of the knee extensor isokinetic maximum peak torques generated in the injured and uninjured legs (n = 32)

Leg and condition	Test velocity	
	$60° \cdot s^{-1}$	$210° \cdot s^{-1}$
Injured knee, pre-rehabilitation	57 (37)	54 (27)
Injured knee, post-rehabilitation	100 (49)	85 (31)
Uninjured knee, pre-rehabilitation	182 (45)	134 (34)
Uninjured knee, post-rehabilitation	187 (50)	137 (37)

tively. Seventeen of the subjects were in the CKC training group and fifteen were in the OKC training group.

Knee extensor maximum peak torque values are presented in Table 1. The knee extensor I/U ratios for each test session and speed are presented in Fig. 1. The ANOVA indicated that training group had no significant effect ($P < 0.05$) on I/U percentages at each test session, or on their absolute change from session 1 to session 2. Isokinetic testing speed and test session both had an effect on the I/U percentage. Post-hoc analysis indicated that these percentages were significantly greater at test 2 than test 1 at both speeds ($P < 0.001$), and that the percentage was greater at $210° \cdot s^{-1}$ than $60° \cdot s^{-1}$ at both test sessions ($P < 0.001$). The absolute improvement in the (I/U) percentages was not affected by the testing speed, with the mean (SD) improvement being 22 (15)% and 22 (17)% at $60° \cdot s^{-1}$ and $210° \cdot s^{-1}$, respectively.

Discussion

The primary and most obvious conclusion from this study, and the one likely to be taken by clinicians, is that velocity specificity in isotonic training of injured subjects does not exist or, if it does, it is not measurable with isokinetic testing. These results conflict with the only other studies where isotonic training velocity specificity has been investigated (Amiridis et al. 1997; Morrissey et al. 1998). Of these two studies, the latter is the more appropriate for comparison with the present study. There are differences between the present study and the work of Morrissey et al. (1998) that may explain the contrasting results. In the previous study, training was of a homogenous group (age, gender) of uninjured subjects using squat lifting exercise (closed kinetic chain) who trained their knee extensors over a longer period than that used in this study. The analysis of injured subjects in the present study made the collection of maximal muscle performance difficult due to the influence of pain during the testing. In general, this pain was greater at the pre-test and in the $60° \cdot s^{-1}$ testing (unpublished data). This confounding factor of pain may have hidden any true velocity specificity that occurred. It is also possible that 4 weeks of training three times per week was insufficient to generate detectable and significant velocity specificity.

Morrissey et al. (1998) found that training velocity specificity in the knee extensors can be detected when training occurs in the CKC but testing occurs in the OKC. Analysis was included in the present study to assess whether treatment group (OKC vs CKC) affected velocity specificity. No significant treatment group effect was found, giving further evidence for the absence of training velocity specificity when the kinetic chain used in testing matches the training kinetic chain type.

Only two studies have been carried out where velocity specificity was investigated in injured subjects (Sherman et al. 1981; Thomee et al. 1987). In these studies, isokinetic training was used to investigate specificity changes in patients recovering from open menisectomy and ACLR surgery, respectively. In the study of Thomee et al. (1987), training was initiated 6 months after ACLR in 16 subjects, with some of the subjects training their knee flexors and extensors at $60^\circ \cdot s^{-1}$ and the rest of the subjects training at $180^\circ \cdot s^{-1}$. Isokinetic testing was performed at 0, 30, 60, 120, 180 and $300^\circ \cdot s^{-1}$. Speed specificity was noted, as evidenced by greater increases in the muscle strength of the knee extensors at $300^\circ \cdot s^{-1}$ in the fast-training group (82% increase) as compared to the slow-training group (38% increase). The fast-training group also exhibited a significantly greater increase in strength at $300^\circ \cdot s^{-1}$ as compared to $30^\circ \cdot s^{-1}$. Thus, at least in patients recovering from ACLR, resistance-training velocity specificity appears to occur only in the later phase of rehabilitation using isokinetic exercise, possibly because of the greater pain experienced in the early period of rehabilitation, which confounds the results. The inclusion of another treatment group in the present study with training at $210^\circ \cdot s^{-1}$ would have allowed a more complete analysis of training velocity specificity in the early period after ACLR. It is possible that velocity specificity may be exhibited at this faster concentric training velocity because the decreased force inherent in higher concentric velocities may cause less pain and allow the patient to work at a higher percent of their maximum effort.

The next step in this line of research is to continue to investigate whether resistance-training velocity specificity occurs in injured subjects with different diagnoses and using different forms of resistance training. More importantly, the training velocities need to be compared for their effectiveness in restoring function to injured subjects. We know of no studies in which this question has been broached, with all previous investigations analysing relative training effectiveness in uninjured subjects (Morrissey et al. 1998; Palmieri 1987; Smith and Melton 1981; Van Oteghen 1973; Young and Bilby 1993).

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