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Proprioception Following Anterior Cruciate Ligament Reconstruction

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Injury to the anterior cruciate ligament (ACL) is thought to disrupt joint afferent sensation and result in proprioceptive deficits. This investigation examined proprioception following ACL reconstruction. Using a proprioceptive testing device designed for this study, kinesthetic awareness was assessed by measuring the threshold to detect passive motion in 12 active patients, who were 11 to 26 months post-ACL reconstruction, using arthroscopic patellar tendon autograft ($n=6$) or allograft ($n=6$) techniques. Results revealed significantly decreased kinesthetic awareness in the ACL reconstructed knee versus the uninvolved knee at the near-terminal range of motion and enhanced kinesthetic awareness in the ACL reconstructed knee with the use of a neoprene orthotic. Kinesthesia was enhanced in the near-terminal range of motion for both the ACL reconstructed knee and the contralateral uninvolved knee. No significant between-group differences were observed with autograft and allograft techniques.

Proprioception is considered a specialized variation of the sensory modality of touch and encompasses the sensations of joint movement (kinesthesia) and joint position (joint position sense). Conscious proprioception is essential for proper joint function in sports, activities of daily living, and occupational tasks. Unconscious proprioception modulates muscle function and initiates reflex stabilization. Much effort has been dedicated to elucidating the mechanical function of knee articular structures and the corresponding mechanical deficits that occur secondary to disruption of these structures. Knee articular structures may also have a significant sensory function which plays a role in dynamic joint stability, acute and chronic injury, pathologic wearing, and rehabilitation training.

The extrinsic innervation of joints follows Hilton's law (34), which states that joints are innervated by articular branches of the nerves supplying the muscles that cross that joint. The afferent innervation of joints is based on peripheral recep-

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tors located in articular, muscular, and cutaneous structures. Articular receptors include nociceptive free nerve endings and proprioceptive mechanoreceptors. Ruffini endings, Pacinian corpuscles, and Golgi tendon organs are mechanoreceptors that have been morphohistologically identified in the anterior cruciate ligament (ACL) (24, 25, 29, 30), posterior cruciate ligament (PCL) (23), meniscus (28, 35), lateral collateral ligament (7), and infrapatellar fat pad (26).

Mechanoreceptors transduce some function of mechanical deformation into a frequency-modulated neural signal which is transmitted via cortical and reflex pathways. An increased stimulus of deformation is coded by an increased afferent discharge rate or an increased population of activated receptors. Grigg and Hoffman have correlated mechanoreceptor afferent discharge with strain energy density and have calibrated mechanoreceptors as in vivo load cells in the posterior capsule of the feline knee (15, 16). Receptors demonstrate different adaptive properties based on their response to a continuous stimulus.

Quick-adapting (QA) mechanoreceptors, such as the Pacinian corpuscle, decrease their discharge rate to extinction within milliseconds of the onset of a continuous stimulus. Slow-adapting (SA) mechanoreceptors, such as the Ruffini ending and the Golgi tendon organ, continue their discharge in response to a continuous stimulus. QA mechanoreceptors are very sensitive to changes in stimulation and are therefore thought to mediate the sensation of joint motion. Different populations of SA mechanoreceptors are maximally stimulated at specific joint angles, and thus a continuum of SA receptors is thought to mediate the sensation of joint position (5, 17, 21). In animal models these mechanoreceptors respond to active or passive motion with maximal stimulation occurring at the extremes of knee motion (13, 14, 22). Stimulation of these receptors results in reflex muscle contraction about the joint (4, 9, 20, 32).

The muscle spindle receptor is a complex, fusiform, SA receptor found within skeletal muscle. Via afferents and efferents to intrafusal muscle fibers, the muscle spindle receptor can measure muscle tension over a large range of extrafusal muscle length. There is considerable debate over the relative contribution of muscle receptors versus joint receptors to proprioception, with traditional views emphasizing joint mechanoreceptors and more contemporary views emphasizing muscle receptors (5, 6, 11, 12, 13, 33). Recent work suggests that muscle receptors and joint receptors are probably complementary components of an intricate afferent system in which each receptor modifies the function of the other (4, 10, 14).

Functionally, kinesthesia is assessed by measuring threshold to detection of passive motion (TTDPM), and joint position sense is assessed by measuring reproduction of passive positioning (RPP). In patients with unilateral joint involvement, the contralateral uninvolved knee serves as an internal control, and uninjured knees in a normative population serve as external controls. Using these measures in the knee, investigators have found proprioceptive deficits with aging (31), arthrosis (3), and ACL disruption (2). These processes damage articular structures containing mechanoreceptors and are thus hypothesized to result in partial deafferentation with resultant proprioceptive deficits. Proprioceptive enhancement was found to occur in ballet dancers (1) and also with the use of an elastic wrap (3), suggesting that training and bracing may have proprioceptive benefits.

For years, knee surgeons have postulated that the sensory loss associated with ACL injury may affect the results of ACL repair and reconstruction (2). Du Toit (8), Insall et al. (19), and Noyes et al. (27) have all advocated certain reconstructive techniques due in part to increased afferent preservation.

Although a proprioceptive deficit has been demonstrated following ACL disruption, functional assessment of proprioception after ACL reconstruction has not been studied. A proprioceptive deficit may detract from the functional result of ACL reconstruction and may predispose to reinjury. Bracing and wrapping are commonly thought to enhance proprioception; however, this has not been assessed quantitatively. The purposes of this study were to assess kinesthesia after ACL reconstruction and to elucidate any enhancement of kinesthetic awareness through the use of a neoprene sleeve.

Materials and Methods

Twelve subjects (8 females, 4 males) with a mean age of 23.2 ± 7.0 years who underwent arthroscopic patellar tendon ACL reconstruction using autograft ($n=6$) or allograft ($n=6$) techniques participated in this investigation. They were 11 to 26 months postreconstruction and all underwent similar postoperative rehabilitation programs. The subjects were active preinjury and postinjury, with a mean Tegner activity rating of 8.4 ± 1.5 at the time of testing. Exclusion criteria included contralateral knee pathology, involved knee PCL pathology, multiple surgical procedures in the involved knee, and patellofemoral joint dysfunction.

Proprioception was measured using a proprioception testing device (PTD) designed to assess kinesthetic awareness (Figure 1). The PTD measured the angular displacement of the knee prior to the subject being able to detect passive knee movement. The PTD moved the knee at a constant angular velocity of 0.5°/sec. A rotational transducer interfaced with a digital microprocessor counter provided angular displacement values. Test-retest reliability on the PTD has been established at $r=0.92$.

Testing was performed in a single session, with the test order of involved and uninvolved knee, starting position, and direction of movement being randomized and counterbalanced. Subjects were seated with a pneumatic compression boot on each foot, one of which was attached to the moving bar of the PTD. TTDPM of flexion and extension movements were measured from starting positions of 15° knee flexion (near-terminal range of motion) and 45° knee flexion (midrange of motion). TTDPM was measured for both the ACL reconstructed knee and the contralateral uninvolved knee. In addition, TTDPM was measured from a starting position of 45° knee flexion in the ACL reconstructed knee fitted with a commercially available neoprene sleeve (Pro Orthopedic Devices, Inc.). One-way analysis of variance with repeated measures was completed for involved/uninvolved TTDPM mean comparisons.

Results

Analysis of variance revealed significant kinesthetic deficits in the ACL reconstructed knee compared to the uninvolved knee, from a starting position of 15° and moving into both flexion, $F(1,10)=3.10$; $p<0.05$, and extension, $F(1,10)=7.39$; $p<0.01$ (Figure 2). There was no significant difference in TTDPM

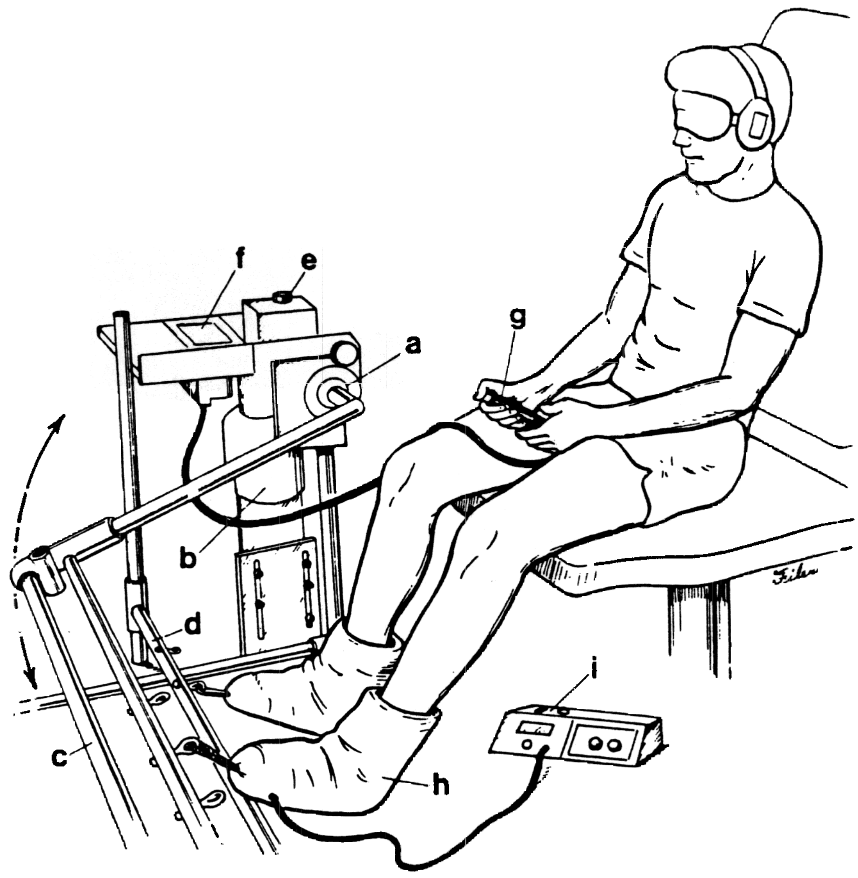

Figure 1 — Proprioceptive testing device: (a) rotational transducer; (b) motor; (c) moving arm; (d) stationary arm; (e) control panel; (f) digital microprocessor; (g) hand-held disengage switch; (h) pneumatic compression boot; and (i) pneumatic compression device. TTDPM is assessed by measuring the angular displacement until the subject senses motion in the knee.

between the ACL reconstructed knee and the contralateral uninvolved knee from a starting position of 45° and moving into either flexion or extension.

Kinesthetic awareness was significantly more sensitive from a starting position of 15° than from a starting position of 45° for both the ACL reconstructed knee and the uninvolved knee, moving into both flexion, $F(1,10)=3.56$; $p<0.05$, and extension, $F(1,10)=3.68$; $p<0.05$ (Figure 3). Kinesthetic awareness in the ACL reconstructed knee from the starting position of 45° was significantly enhanced with the use of the neoprene sleeve moving into both flexion, $F(1,10)=4.20$: $p<0.05$, and extension, $F(1,10)=7.56$; $p<0.01$ (Figure 4). Finally, there were no significant group differences between the autograft and allograft subjects for any of the test conditions.

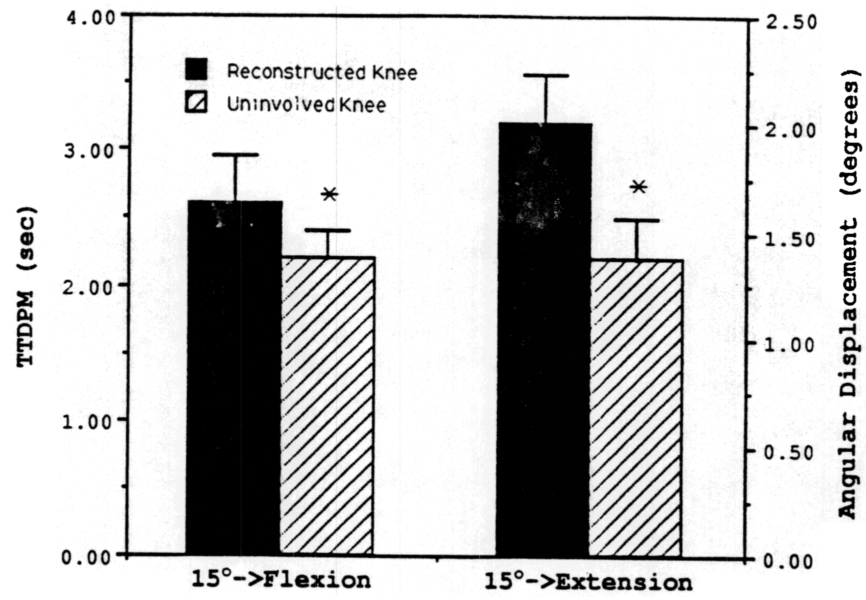

Figure 2 — Mean threshold to detection of passive motion (TTDPM) (time and angular displacement) for reconstructed versus uninvolved knee from a starting position of 15° flexion and moving into flexion and extension ($\pm SE$, $*p<0.05$).

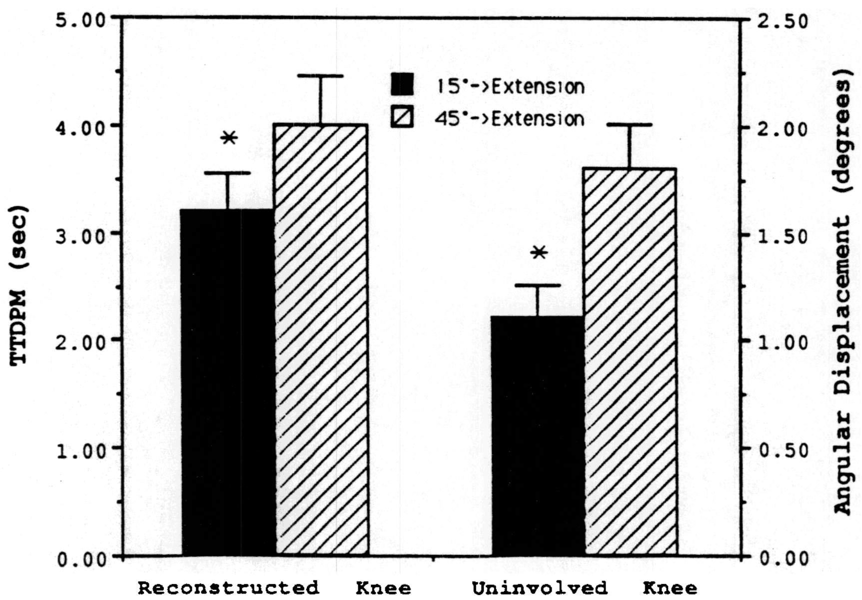

Figure 3 — Mean threshold to detection of passive motion (TTDPM) (time and angular displacement) for reconstructed versus uninvolved knee from starting positions of 15° and 45° and moving into flexion and extension ($\pm SE$, $*p<0.05$).

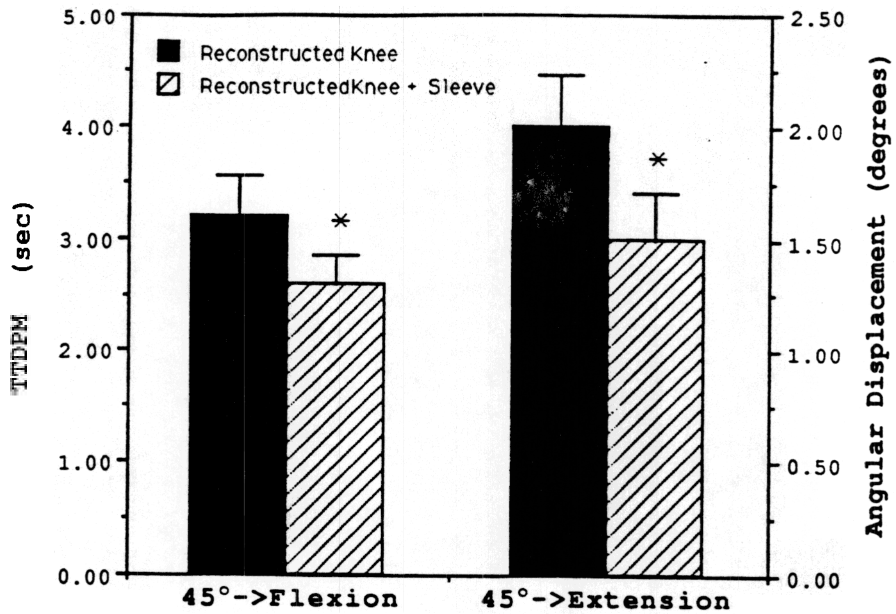

Figure 4 — Mean threshold to detection of passive motion (TTDPM) (time and angular displacement) for reconstructed knee and reconstructed knee with neoprene sleeve from a starting position of 45° flexion and moving into flexion and extension (±*SE*, **p*<0.05).

Discussion

The use of TTDPM as a measure of kinesthesia has been established by previous studies. Slow, passive motion was used in this investigation, as this is thought to maximally stimulate slow-adapting joint mechanoreceptors while minimally stimulating muscle receptors (2). Although we were primarily focusing on joint receptors in joint injury, muscle receptors are an integral component of a complex afferent system and may also play a role in kinesthetic awareness of slow, passive motion. In addition to reflex pathways, joint mechanoreceptors have been shown to have cortical pathways that account for conscious appreciation of joint movement and position. Our finding of enhanced kinesthetic awareness in the near-terminal range of motion is commensurate with neurophysiological studies that have shown maximal response of joint mechanoreceptors at the extremes of motion (13, 14, 22).

It has been shown that a proprioceptive deficit exists after ACL disruption (2), and we have found that a deficit continues after reconstruction. Knee articular structures, including the ACL, posses mechanoreceptors, and damage to these structures can result in partial deafferentation. Barrack and Skinner (2) found a longer TTDPM in the ACL-disrupted knee compared to the contralateral uninvolved knee when tested at 30–40° of knee flexion.

In this study we found a longer TTDPM in the ACL reconstructed knee compared to the contralateral uninvolved knee when tested at 15° knee flexion, and no significant difference when tested at 45° knee flexion. Thus, kinesthesia in the midrange of motion may have returned following ACL reconstruction. However, kinesthesia is more sensitive in the near-terminal range of motion, hence any difference between the involved and uninvolved knee would be more apparent. The TTDPM of the uninvolved knee in this study was similar to the TTDPM in a previously studied normative, uninjured population (18).

No differences in proprioception were detected between the autograft and allograft subjects in this study. Unfortunately, the design of this study did not allow us to compare other ACL reconstructive techniques or follow any proprioceptive return over a time course after repair. Theoretically, operative techniques can restore proprioception directly through reinnervation of damaged structures, or indirectly through restoration of appropriate tension in capsuloligamentous structures. Acute ACL repair may facilitate regeneration along with maintaining anatomic relationships. The extent of reinnervation in the reconstructed ligament and its relationship to revascularization needs to be addressed. Prosthetic grafts, vascularized grafts, free grafts, and allografts all may have different reinnervation potential.

Bracing and wrapping have been thought to serve a sensory function in addition to a mechanical function. Barrett and co-workers found that an elastic bandage enhanced joint position sense in patients with osteoarthritic knees and in patients after total knee arthroplasty (3). We found enhancement of kinesthesia with the use of a commercially available neoprene sleeve (Pro Orthopedic Devices, Inc.). Proprioception is mediated by afferent input from articular, muscular, and cutaneous structures. The neoprene sleeve could have augmented afferent input by providing increased cutaneous stimulation.

Proprioception may play a protective role in acute injury through reflex muscular splinting. The protective reflex arc initiated by mechanoreceptors and muscle spindle receptors occurs much more quickly than the reflex arc initiated by nociceptors (70–100 m/sec vs. 1 m/sec). Thus, proprioception may play a more significant role than pain sensation in preventing injury in the acute setting.

Proprioceptive deficits, however, probably play more of a role in the etiology of chronic injuries and reinjury. Initial knee injury results in partial deafferentation and sensory deficits which can predispose to further injury (24). Proprioceptive deficits may also contribute to the etiology of degenerative joint disease through pathologic wearing of a joint with poor sensation. It is unclear whether the proprioceptive deficits that accompany degenerative joint disease are a result of the underlying pathologic process or contribute to the etiology of the pathologic process.

Methods to improve proprioception after ACL injury or ACL reconstruction could improve knee function and decrease the risk of reinjury. Afferent input is altered after joint injury and may remain altered after joint reconstruction. However, proprioceptive rehabilitation may allow the patient to retrain sensation of joint movement and position to this altered afferent input pattern. Proprioceptive training has become an integral aspect of ankle rehabilitation. Proprioceptive training regimens for the knee need to be developed and tested.

Summary

The results of this study reveal that a kinesthetic deficit exists in the ACL reconstructed knee at the near-terminal range of motion and that the use of a neoprene sleeve enhances kinesthetic awareness. We have also shown that kinesthesia is more sensitive in the near-terminal range of motion in both the reconstructed knee and the uninvolved knee. Finally, we found no differences in kinesthetic awareness between the allograft and autograft groups. The results of this study help to elucidate the sensory function of the ACL and the proprioceptive deficits that occur after ACL injury and reconstruction.

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