

## The role of proprioception in the treatment of sports injuries

S. M. Lephart and F. H. Fu

Orthopaedic Surgery and Division of Sports Medicine, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

**SUMMARY.** The recent appreciation of the neural mechanism of articular structures has elicited considerable attention to the role of proprioception following joint injury. This is especially true following sport related injuries due to the role proprioception plays in performance of skilled movements and with reflex joint stabilization during running and throwing. Recent research in the area of proprioception has provided a basis for substantiating proprioceptive deficits with joint injury and the necessity for integrating specific activities into the rehabilitation program for the athlete. This paper will review these recent developments and provide additional information relative to the potential effect surgery has on enhancing this neurosensory mechanism. Although these recent developments provide a basis for understanding proprioception there is still a wealth of information that is not understood relative to this complex mechanism.

### INTRODUCTION

Ligaments play a major role in normal joint kinematics, providing mechanical restraint to abnormal joint movement when a stress is placed on the joint. Following injury to these tissues there is an inherent loss of mechanical stability to the joint resulting in aberrations to normal kinematics. Management of these sport-related injuries focuses on restoring joint kinematics either through surgical reconstruction, or by enhancing muscular reflex compensatory stabilization through rehabilitation. By restoring joint stability either mechanically or substituting with secondary stabilizers it is speculated that sport activities can be resumed, recurrent injury will be minimized, and progressive joint degeneration can be avoided.

Kennedy<sup>1</sup> observed that in addition to their mechanical restraining function, articular ligaments provide important neurological feedback that directly regulates muscular reflex stabilization about the joint. The neuromuscular controlling mechanism is mediated by articular mechanoreceptors and provides the individual with the *proprioceptive* sensations of kinesthesia and joint position sense. The neurological feedback for the control of muscular actions serves to protect against excessive strain on passive joint restraints and provides a prophylactic mechanism to recurrent injury. Following joint injury, disruption to these articular mechanoreceptors inhibits normal neuromuscular reflex joint stabilization and contrib-

utes to repetitive injuries and the progressive decline of the joint (Fig. 1). Therefore, ligament injury not only results in the loss of the mechanical stability of the joint but also diminishes the capacity for secondary stabilizers (muscles) to provide joint stability through reflex contraction. This proprioception mechanism has recently received considerable attention relative to the treatment of sports injuries.

### PROPRIOCEPTION TERMINOLOGY

The terminology related to joint sensation is often misunderstood and used inappropriately, which has led to confusion and a lack of appreciation for these mechanisms during rehabilitation. Articular sensations are described as *proprioception* and *kines-thesia*.<sup>2</sup> There is considerable discrepancy in the

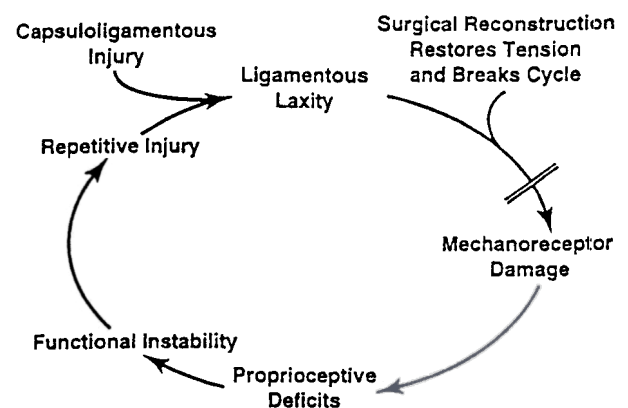


Fig. 1—Feedback mechanism for joint mechanoreceptors.

definitions of these two terms as related to their physiological functions. Mountcastle & Willis<sup>3</sup> define proprioception as the conscious awareness of limb position, while they define kinesthesia as the awareness of joint motion. On the other hand, Bastian<sup>4</sup> defines the kinesthetic mechanism, as a complex of sensations including those in which movement is not featured, while Sherrington<sup>5</sup> describes the proprioceptive sense as including vestibular sensations and inputs from muscles and joints that are not necessarily perceived. For the purpose of this paper, we will define proprioception as a specialized variation of the sensory modality of touch that 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 elucidate the mechanical function of articular structures and the corresponding mechanical deficits which occur secondary to disruption of these structures. Articular structures also have a significant sensory function which plays a role in dynamic joint stability, acute and chronic injury, pathologic wearing, and rehabilitation training.

## PERIPHERAL NEURAL RECEPTORS

Peripheral afferents (mechanoreceptors) have histomorphologically been identified in articular structures of the shoulder,<sup>6</sup> knee<sup>7</sup> and ankle<sup>8</sup> joints of humans. 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 a rise in the population of activated receptors. Grigg & 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.<sup>9,10</sup> 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.<sup>11</sup> Slow-adapting (SA) mechanoreceptors, such as the Ruffini ending, Ruffini corpuscles, and the Golgi tendon-like 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 and change in joint position.<sup>12</sup> In animal models, these mechanoreceptors respond to active or passive motion with maximal stimulation occurring at the extremes of knee motion.<sup>13,14</sup> Stimulation of these receptors results in reflex muscle contraction about the joint.<sup>15,16</sup> In addition to the joint receptors, the muscle spindle receptors are a complex, fusiform, SA receptors 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 to proprioception of muscle receptors versus joint receptors, with traditional views emphasizing joint mechanoreceptors and more contemporary views emphasizing muscle receptors.<sup>13</sup> Recent work suggests that joint receptors and muscle receptors are probably complementary components of an intricate afferent system in which each receptor modifies the function of the other.<sup>14,15</sup> With the identification of these receptor types in most joints, and the knowledge of their function,<sup>9,10,13</sup> it appears that the ligamentous, cartilaginous, and muscular structures of joints contain the neural components necessary for the sensation of motion (rapidly adapting receptors, e.g. Pacinian corpuscles), joint position and acceleration (slowly adapting receptors, e.g. Ruffini endings and Ruffini corpuscles), and pain (free-nerve endings). This would, therefore, support the contemporary view that both joint and muscle receptors contribute to the sensory appreciation of joint position.

## EFFECTS OF INJURY ON PROPRIOCEPTION

Functionally, kinesthesia is assessed by measuring threshold to detection of passive motion (TTDPM)<sup>17-20</sup> while joint position sense is assessed by measuring reproduction of passive positioning (RPP)<sup>21</sup> and reproduction of active positioning (RAP).<sup>21</sup> TTDPM, when tested at slow angular velocity (0.5–2.5°/s), is thought to selectively stimulate Ruffini or Golgi-type mechanoreceptors, and because the test is performed passively, it is believed to maximally stimulate joint receptors while minimally stimulating muscle receptors. In shutting down muscle activity, TTDPM is often chosen to assess afferent activity following ligament pathology. RAP, although usually performed at slow speed, stimulates both joint and muscle receptors and provides a more functional assessment of the afferent pathways. Neither TTDPM, RPP, nor RAP provides an assessment of the unconscious reflex arc believed to provide dynamic joint stability. The assessment of reflex capabilities is usually performed using EMG interpretation of firing patterns of those muscles crossing the respective joint.<sup>22</sup> In patients with unilateral joint

tested at 15° knee flexion and no significant difference when tested at 45° knee flexion.<sup>18</sup> Thus, kinesthesia in the mid-range 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 uninjured knee would be more apparent.

For years, knee surgeons have postulated that the sensory loss associated with ACL injury may affect the results of ACL repair and reconstruction.<sup>17</sup> 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 & co-workers<sup>25</sup> found that an elastic bandage enhanced joint position sense in patients with osteoarthritic knees, as well as in patients after total knee arthroplasty. We found enhancement of kinesthesia with the use of a commercially available neoprene sleeve (Pro Orthopedic Devices, Inc, Tucson, Arizona).<sup>18</sup> 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 knee 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/s vs 1 m/s).<sup>26</sup> 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 differentiation and sensory deficits which can predispose to further injury.<sup>1</sup> 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.

It is clear that joint effusion, particularly in the knee, contributes to a decreased mechanoreceptor afference, resulting in the inhibition of muscular contractions. In the knee, this inhibition is mediated by slowly adapting mechanoreceptors and appears to

provide long-term quadriceps shut down, particularly in the vastus medialis.<sup>26</sup> A 30–50% inhibition of the reflex-evoked quadriceps contraction can be observed with 60 cm<sup>3</sup> of intra-articular effusion.<sup>1</sup> This muscular inhibition severely disrupts neuromuscular training during rehabilitation and provides a fundamental basis for relief of joint effusions, from a neurological basis. Any proprioceptive deficits resulting from chronic joint effusion may contribute to the inability to provide neuromuscular joint control and therefore result in joint degeneration.

A proprioceptive deficit may detract from the functional result of knee surgery, may inhibit complete rehabilitation, and may predispose the athlete to reinjury. Thus, it is clear, based on the results of these studies, that any comprehensive rehabilitation program designed to return athletes to preinjury levels of activity following knee injuries should include an extensive proprioception element.

#### Ankle proprioception research

Freeman et al<sup>8</sup> were the first to postulate that chronic ankle instability was due, in part, to partial differentiation of articular mechanoreceptors with joint injury. They subjectively observed decreased stability in one-legged stance in the sprained ankle versus the contralateral uninjured ankle. Konradsen et al<sup>27</sup> studied the reaction of subjects with chronic ankle instability to sudden inversion using EMG and joint motion analysis. They found a prolonged peroneal reaction time in these patients versus age-matched controls, suggestive of a partial differentiation of reflex stabilization. Garn & Newton<sup>28</sup> studied the ability of a subject to properly sense a passive movement or no movement state in the dorsiflexion-plantarflexion plane, and found decreased kinesthetic awareness in the involved ankle of subjects with unilateral ankle sprains. Glenncross & Thornton<sup>29</sup> reported deficits in active replication of passive ankle/foot positioning in the dorsiflexion-plantarflexion plane, while testing the sprained ankle versus the contralateral uninjured ankle.

Subsequent to these early studies on ankle proprioception many other studies have demonstrated that proprioceptive deficits play a role in functional stability of the ankle joint. Gross<sup>30</sup> most recently reported that decrease in sensory input from joint receptors can lead to abnormal body positioning and diminished postural reflex responses leading to an increased probability of reinjury.

The results of studies using stabilometric techniques (force plate, opto-electronic joint analysis) to assess postural sway and balance in patients with chronic ankle instability has been equivocal. Tropp et al<sup>31</sup> found no increase in postural sway when comparing a group of soccer players with histories of ankle sprains to a control group of uninjured soccer players.

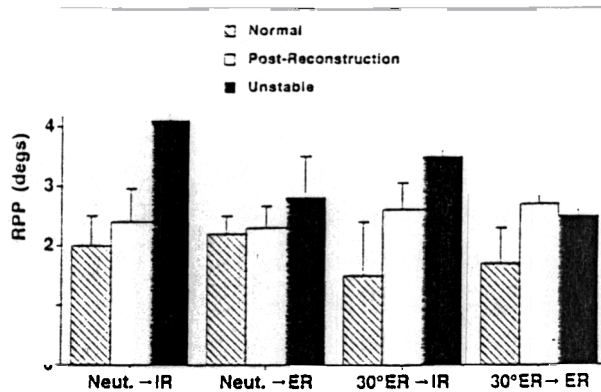


Fig. 3—Shoulder proprioception: mean error values for reproduction of passive positioning for normal, unstable and surgical groups.

tightens the capsule, 'retensions' the soft tissue and most likely facilitated proprioception function.

Rehabilitation considerations may also be related to enhanced proprioception following shoulder capsulolabral reconstruction. Although in our studies the instability group underwent similar rehabilitation activities as the surgery group, mechanical stabilization following surgery could have provided for more effective neuromuscular retaining and hence pro-



Fig. 4—Lower extremity kinesthetic training on an unstable platform to retrain reflex muscular stabilization.



Fig. 5—Joint repositioning exercise at end ranges of motion

moted enhanced function of this mechanism. The rehabilitation program for these patients emphasized proprioceptive input to recognize joint position as well as learning correct movement patterns and techniques apart from development of strength and endurance. These exercises included matching and rematching joint position, weight bearing through the upper extremity, and open kinetic chain exercises. The later stages of the rehabilitation focused on activities that promoted proprioceptively mediated reflex joint stabilization. Although this reflex arc has not been demonstrated in the shoulder, similar neuromuscular mechanisms in the knee have been identified reproducibly and believed to play a key role in joint arthrokinematics.

## PROPRIOCEPTION REHABILITATION

Developing a sports rehabilitation program that incorporates proprioceptively mediated muscular control of joints necessitates an appreciation for the central nervous system's (CNS) influence on motor activities. Joint afferents contribute to CNS function at three distinct levels of motor control.<sup>33</sup> At the spinal level, reflexes subserve movement patterns that are received from higher levels of the nervous system. This provides for reflex splinting during conditions of abnormal stress about the joint and has significant implications for rehabilitation.<sup>18</sup> The muscle spindles play a major role in the control of muscular movement by adjusting activity in the lower motor neurons. Partial differentiation of joint afferent receptors has also been shown to alter the musculature's ability to provide co-contraction joint stabilization by antagonistic and synergistic muscles, thus resulting in the potential for reinjury.<sup>1</sup>

The second level of motor control is at the brain