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Proprioception of the Ankle and Knee

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Summary

Proprioception and accompanying neuromuscular feedback mechanisms provide an important component for the establishment and maintenance of functional joint stability. Neuromuscular control and joint stabilisation is mediated primarily by the central nervous system. Multisite sensory input, originating from the somatosensory, visual and vestibular systems, is received and processed by the brain and spinal cord. The culmination of gathered and processed information results in conscious awareness of joint position and motion, unconscious joint stabilisation through protective spinal-mediated reflexes and the maintenance of posture and balance. Clinical research aimed at determining the effects of articular musculoskeletal injury, surgery and rehabilitation, on joint proprioception, neuromuscular control and balance has focused on the knee and ankle joints. Such studies have demonstrated alterations in proprioception subsequent to capsuloligamentous injury, partial restoration of proprioceptive acuity following ligamentous reconstruction, and have suggested beneficial proprioceptive changes resulting from comprehensive rehabilitation programmes.

Athletically induced capsuloligamentous injuries to the knee may cause long term disability. In addition to mechanical disruption of articular structures following injury, the loss of proprioception may have a profound effect on neuromuscular control and the activities of daily living. It appears that neurological feedback mechanisms originating in articular and musculotendinous structures provide an important component for the maintenance of functional joint stability.[1-4] The purpose of this review is to outline the concept of proprioception as it relates to neuromuscular control and articular function. The influence of injury, surgical reconstruction and rehabilitation on proprioception will also be examined with specific emphasis on techniques used to re-establish this sensory modality.

1. Overview of Proprioception

Muscular activity and joint motion, performed either consciously or subconsciously, are the products of multisite sensory input which is received and processed by the brain and spinal cord. The perception and execution of musculoskeletal control and movement are mediated primarily by the central nervous system (CNS). The CNS receives input from 3 main subsystems: the somatosensory system; the vestibular system; and the visual system (see fig. 1).[5]

The somatosensory system, often referred to as proprioception, functions to detect sensory stimuli such as touch, pain, pressure and movements such as joint displacement.[5] This system receives input from the peripheral articular and musculotendinous receptors concerning changes in muscle length and

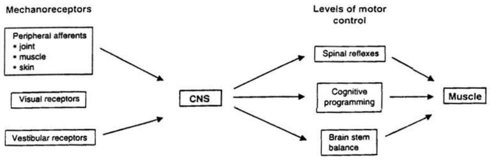

Fig. 1. Neuromuscular control pathways (reproduced from Lephart & Henry,[17] with permission).

tension, in addition to information regarding joint position and motion. Afferent nerves, also referred to as mechanoreceptors, are located within the skin, in the musculotendinous unit and within the bone, joint ligaments, and joint capsule.[3,5,6]

Cutaneous afferents contribute minimally to joint proprioception, while the contribution of muscle spindle receptors and joint receptors is much greater. Mechanoreceptors originating in the joint capsule, bone and ligaments serve as range limit detectors, sensors of joint compression, and potentially provide for extreme range joint protection by signaling the presence of noxious intense stimuli.[7] There are 2 types of articular mechanoreceptors, quick-adapting (QA) and slow-adapting (SA), which vary based upon their response to a continuous stimulus. Whereas the QA receptors decrease their discharge near the onset of a continuous stimulus, the SA receptors' response is to continue their discharge.[8] The sensation of joint motion is thought to be mediated by QA mechanoreceptors, while SA receptors may play more of a role in joint position sense and sensation of changes in joint position.[9] In the knee joint, mechanoreceptors, specifically those which respond to joint acceleration and deceleration, have been identified in both the joint capsule and ligamentous insertions. Information, originating from these specialised neural mechanoreceptors, is converted to frequency-modulated neural signals which result in the conduction of an action potential to the CNS.[10-12]

Muscle receptors provide a necessary complementary neural contribution in addition to the information of joint sensibility from the articular receptors. Muscle spindle afferents respond as a function of muscle length to contribute to joint proprioception. These SA receptors, located within skeletal muscle, maintain a symbiotic relationship with articular receptors to result in sensations of joint motion, joint acceleration and joint position, in addition to sensations of pain.[13-15]

The second subsystem supplying the CNS with sensory input is the vestibular system. The vestibular system receives information from the vestibules and semicircular canals of the ear, which can be used in 3 different ways in order to maintain body posture. This information can be used to maintain body posture by controlling eye musculature so as to maintain visual focus when the head changes position, to maintain upright posture and for conscious awareness of body and joint position, and motion.[11]

The visual system, the third subsystem contributing to CNS sensory input, also contributes to the maintenance of balance. This system provides the body with visual cues for use as reference points in orientating the body in space. It is generally agreed that, under normal conditions, the somatosensory and visual subsystems are the primary mediators of balance and postural awareness.

Information gathered by the somatosensory, vestibular and visual systems is processed at 3 distinct levels of motor control: the spinal level; the brain stem; and the higher brain centres. The spinal level provides for dynamic muscular stabilisation and synchronisation of muscle activation patterns based upon spinal reflexes as well as activity received from higher levels of the CNS. The brain stem processes information from the 3 CNS subsystems via the cerebellum nuclei for the maintenance of posture and balance. The higher brain centres, such as the motor cortex, basal ganglia and cerebellum, are responsible for cognitive programming of musculoskeletal motion. The culmination of gathered and processed information results in conscious awareness of joint position and joint motion sensibility that contribute to motor programming, unconscious joint stabilisation through protective spinal-mediated reflexes and the maintenance of posture and balance.[5,16-18]

2. Assessment of Motor Pathways

Proprioceptive acuity in the knee and ankle have been the focus of a number of investigations. Since the proper functioning of these 2 joints is critical to the integrity of the lower kinematic chain, alterations in proprioceptive awareness may have profound effects on performance. The measurement of the various pathways that mediate motor control (cortical level processing, brain stem activities and spinal mediated reflexes) have provided insight into the effects of injury, surgical reconstruction and rehabilitation on articular pathology (see fig. 2).

Assessment of joint proprioception is divided into 2 components: kinaesthesia and joint position sensibility. Kinaesthesia is assessed by measuring the threshold to detection of passive motion, while joint position sense is assessed by measuring the reproduction of passive positioning and the reproduction of active positioning (see fig. 3).[17,19,20] In order to minimise the contribution of musculotendinous mechanoreceptors (muscle spindles and Golgi tendon organs) in providing the CNS with information regarding limb position and movement, the threshold to detection of passive movement and reproduction of passive positioning are conducted at a slow angular velocity (0.5 to 2 degrees per second).[17] The passive nature of this assessment procedure is thought to selectively stimulate Ruffini or Golgi type mechanoreceptors in the joint.

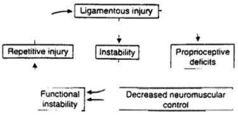

Fig. 2. Functional stability paradigm depicting the progression of functional instability due to the interaction between mechanical instability and decreased neuromuscular control (reproduced from Lephart & Henry,[17] with permission).

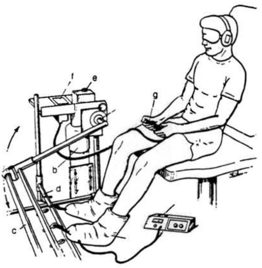

Fig. 3. Proprioception testing of the knee joint: (a) rotational transducer; (b) motor; (c) moving arm; (d) stationary arm; (e) control panel; (f) digital microprocessor; (g) hand-held disengage switch; (h) pneumatic compression boot; and (i) pneumatic compression device. Threshold to detect passive motion (TTDPM) is assessed by measuring the angular displacement until the patient senses motion in the knee (reproduced from Lephart et al.,[12] with permission).

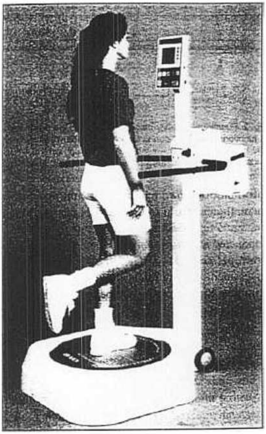

Fig. 4. Instrumented stableometry unit, Biodex Stability System [Biodex Medical Systems Inc., Shirley (NY)].

Postural sway and balance are evaluated to determine the combination of peripheral, vestibular, and visual contributions to neuromuscular control (see fig. 4). Balance stabilometry provides a specialised mode of assessment for the overall contribution of these various neural afferent signals to maintain upright standing posture.[21]

The assessment of the spinal reflex pathway is conducted to determine the latency of muscular activation to involuntary perturbations. Electromyographic analysis has been utilised extensively to examine the role of this neuromuscular pathway during movements that place functional loads on the ankle and knee joint. A resulting insufficiency of synergistic muscular action maintaining joint congruency and integrity may predispose an individual to chronic joint instability that may contribute to articular degeneration.

As indicated earlier, articular integrity of the knee and ankle are critical for optimal functioning of the lower extremity. A thorough understanding of the clinical research aimed at determining the effects of injury, surgical reconstruction and rehabilitation on joint proprioception, neuromuscular control and balance are important for the development of scientific based treatment options.

2.1 Knee Proprioception

Injury to capsuloligamentous structures, in addition to osteoarthritic changes, has resulted in articular deafferentation, thereby contributing to alterations in kinaesthesia and joint position sense. Reductions in kinaesthesia have been detected by Barrack and Skinner[1] as a result of increasing age and disruption of the anterior cruciate ligament. Decrements in joint position sensibility have also been found to be further exacerbated by osteoarthritic changes.[2] It is important to note that reductions in proprioceptive acuity may contribute to further degenerative changes in the joint, as the spinal reflexive pathway may be impaired.[22]

Disruptions in the afferent pathway which are mediated partly by articular mechanoreceptors may contribute significantly to an insidious pattern of microtrauma and re-injury (see fig. 2). Reductions in reflex muscular stabilisation resulting from anterior cruciate ligament (ACL) deficiency, as observed by Beard et al.,[23] demonstrate how this reflex arc may be inhibited. Reflex activation of the hamstring muscles appeared to be diminished following the application of an anterior shear force to the lower leg in the closed kinematic chain position.[23] Solomonow et al.[24] demonstrated that reflex activity of the hamstring muscles following a direct stress placed on the ACL is a critical factor for dynamic knee stabilisation.

Partial restoration of kinesthetic awareness following ACL reconstruction has been demonstrated by Barrett.[25] This restoration, however, was found to occur in the mid range of motion for the knee (45° flexion) and not at the terminal range (15° flexion).[25] Lephart et al.[12] found similar results in patients following either arthroscopically assisted patellar-tendon autograft or allograft ACL reconstruction. Although these findings suggest that kinesthetic awareness may have returned in the mid range of motion following ACL reconstruction, the evaluation of kinaesthesia in the near terminal range may be more sensitive.

The restoration of joint position sensibility and neuromuscular control should be a vital concern in any comprehensive rehabilitation programme. Although minimal research exists regarding the efficacy of rehabilitation on knee proprioception, preliminary evidence suggests that the inclusion of a proprioceptive component may be beneficial. It has been demonstrated that individuals with either ACL deficiency or surgical reconstruction had improved balance ability and knee joint position sense following training.[26]

2.2 Ankle Proprioception

The role of partial deafferentiation of articular mechanoreceptors following joint injury was first suggested by Freeman and Wyke.[27] This effect has been suggested as a key factor contributing to chronic ankle instability. Freeman and Wyke[27] observed a decrease in the ability to maintain single leg stance in the sprained ankle as compared to the contralateral uninjured ankle. The effect of unilateral ankle sprains on cortical measures of proprioception, as detected by passive joint position sense to movement, was investigated by Garn and Newton.[28] Kinaesthetic acuity appeared to be diminished in the injured as compared with the uninjured ankle. Glenncross and Thornton[29] also reported deficits in the ability to reproduce passive ankle positioning in patients demonstrating unilateral ankle injury.

In addition to a reduction in sensory afferent input for articular mechanoreceptors, diminished postural reflex responses have also been reported following injury. Konradson et al.[30] found a prolonged peroneal reaction time in response to a sudden inversion stress in individuals demonstrating chronic ankle instability. Increases in postural sway were observed by Cornwall and Murrall[31] among individuals with acute ankle sprains as compared with an uninjured control group. Contrary to these findings, however, Tropp and Odenrick[32] found no increases in postural sway in a group of soccer players with previous ankle sprains as compared with a group of uninjured soccer players.

Although little evidence currently exists regarding the role of surgical reconstruction on the sensory afferent and efferent motor responses to involuntary perterbations, preliminary research suggests a beneficial role of rehabilitation activities. It has been demonstrated recently that balance training enhances the ability to maintain upright standing posture in individuals with a previous history of ankle sprains.[33] It was also found that improvements in balance performance following a 4-week training period appeared to be greater in individuals with previously reported ankle sprains as compared with uninjured participants.[33] The maintenance of functional joint stability of the ankle is suggested to be dependant upon dynamic neuromuscular control of excessive motion and would therefore, benefit from proprioceptive training techniques.

3. Clinical Application

Once proprioceptive deficiencies have been identified, subsequent to either an acute or chronic musculoskeletal injury, a rehabilitation programme should be developed and implemented. A rehabilitation programme to address proprioceptive deficits should integrate all subsystems of proprioception in addition to the 3 levels of motor control.

Higher brain centre–promoting activities are initiated on the cognitive level, such as consciously performing end range joint positioning activities, and through repetitive execution stimulate the conversion of conscious to unconscious motor programming. This transition from conscious to unconscious motor programming is performed in the lower extremity through dynamic balance rehabilitation activities. Initially, patients concentrate on the rehabilitation task being performed in order to facilitiate and maximise sensory input. As the patient progresses, the activities incorporate cognitive or psychomotor aspects, which ultimately aid in converting conscious joint stabilisation and control to unconscious motor programming.[4,18]

To enhance motor function at the brain stem level, balance and postural maintenance activities should be employed. These equilibrium-promoting activities should be performed both with and without visual system input, be implemented following a standardised progression, and be specific to the type of activities and skills the patient will require. The initiation of balance activities assumes the patient is able to bear weight on the lower extremity. Once implemented, these activities should follow the progression from static balance activities to dynamic skill activities. For static balance activites, patients should progress from bilateral to unilateral activities, from activities with the eyes open to those with the eyes closed and from those performed on a stable surface to those performed on an unstable surface.[4,11,18]

To address the spinal level of motor contol, rehabilitation activities which produce sudden changes in joint position should be included to promote unconscious reflex joint stabilisation. Activities such as training on unstable platforms and plyometric exercises encourage joint muscular co-contractions and reactive dynamic muscular stabilisation and therefore address neuromuscular training at the spinal level of motor control.[6,18]

The influence of proprioception in mediating neuromuscular control has been demonstrated to have profound effects in the injured and surgically repaired joint. Although there is not yet a consensus regarding the role of proprioceptively mediated rehabilitation activities in regaining neuromuscular control, preliminary evidence suggests that such activities may influence the return to participation for the injured athlete.

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