

# Effect of Age and Osteoarthritis on Knee Proprioception

a report by

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Proprioception is defined as the afferent information arising from the internal peripheral areas of the body that contribute to postural control, joint stability, and several conscious sensations. It has several submodalities:

- joint position sense (the appreciation and interpretation of information concerning joint position and orientation in space);
- active and passive kinesthesia (the ability to appreciate and interpret joint motions); and
- the sense of heaviness (the ability to appreciate and interpret force applied to or generated within a joint).<sup>1</sup>

Proprioceptive information from afferent sensory organs (mechanoreceptors) reaches the central nervous system (CNS), where it is processed and integrated with other signals to regulate neuromuscular control and properly maintain joint stability.<sup>2</sup> Proprioception plays a vital role in maintenance of joint stability of the knee via the sensorimotor system. Any processes that effect proprioception or processing of afferent information will have a significant impact on functional joint stability (see *Figure 1*).<sup>2,3</sup> Two of these processes include aging and osteoarthritis (OA). The purpose of this article is to describe proprioception and its role in achieving joint stability, discuss the effect of age and OA on knee proprioception, and evaluate the effects of surgical and non-surgical interventions on knee proprioception.

## Proprioception and Its Role in the Sensorimotor System

There are numerous types of afferent sensory organs (mechanoreceptors) found in the various knee joint structures: Ruffini endings, Pacinian corpuscles, Golgi tendon organ (GTO)-like endings, free nerve endings, muscle spindles, and GTOs. The signals from the Ruffini endings may contain information about static joint position, intra-articular pressure, and the amplitude and velocity of joint rotations.<sup>4</sup> Pacinian corpuscles function as pure dynamic mechanoreceptors.<sup>5</sup> GTO-like endings are active toward the end range of joint motion.<sup>6</sup> Free nerve endings become active when the articular tissue is subjected to damaging mechanical deformations.<sup>7</sup> Muscle spindles are oriented in parallel with the skeletal muscle fibers encoding the event of muscle stretch and the rate of passive elongation.<sup>8</sup> In contrast, GTOs are aligned in series within the musculotendinous junctions encoding the stretch on the tendon generated by the total force of a given muscle during contraction.<sup>8</sup>

## Role of Proprioception in the Sensorimotor System

Muscle spindles and GTOs play an important role in regulating muscle tone and joint stiffness, especially during dynamic tasks.<sup>9</sup> As the main contributor to leg stiffness, muscle stiffness is defined as the ratio of change in force per change in length and consists of two components: an intrinsic and a reflex-

mediated component.<sup>10</sup> The intrinsic component is dependent on the viscoelastic properties of the muscle and the number of actomyosin bonds, while the reflex-mediated component is dependent on the excitability of the alpha motor neuron pool.<sup>3,11,12</sup> The gamma-muscle spindle system can change the sensitivity and threshold of the alpha motor neuron pools, regulating the amount of intrinsic muscle stiffness; it is influenced by the mechanoreceptors and integrates with descending and reflex input.<sup>3,13</sup> Increased muscle stiffness can have two advantages: increased resistance against sudden joint displacement and enhanced time to transmit loads to muscle spindles, quickly initiating reflexive activity.<sup>14,15</sup> The regulation of muscle stiffness through the gamma-muscle spindle system is an essential role of proprioception and, along with integration in the CNS, it contributes to elicit appropriate neuromuscular control and achieve joint stability.<sup>3,11,12</sup>

Neuromuscular control is defined as the unconscious activation of dynamic restraints occurring in preparation for, and in response to, joint motion and loading for the purpose of maintaining and restoring functional joint stability.<sup>1</sup> Humans use a combination of feedforward and feedback neuromuscular control. Feedback control uses information about the current state of a person and the external environment to modify muscle activity. Feedforward control does not require peripheral receptors, instead modifying muscle activity by anticipating the external environment.<sup>9</sup>

There are two fundamentally different ways in which the CNS uses sensory feedback. First, the afferent feedback, a part of normal movement, is integrated with motor commands in the activation of muscles. This feedback is anticipated by the CNS and built in to the motor program's controlling movement.<sup>16</sup> Second, the reflex-mediated component is generated when an unexpected change occurs in the sensory feedback. These reflexes constitute error signals, which aim to correct the ongoing movements and avoid falling. Although the reflex signals are not sufficient to correct the movement, the error signals inform the higher structures of the brain about the disturbance and help the brain to adjust the motor programs (motor learning), in addition to the regulation of stiffness via the gamma-muscle spindle.<sup>16,17</sup>

Feedforward control achieves joint stability through both short-range stiffness and muscle pre-activation. Activated muscles can provide resistance against sudden stretch or joint perturbation. Since the muscles are already active at the time of perturbation, the time to reach peak force is very short (less than 50ms) and provides a substantial response to the perturbation.<sup>18,19</sup> This fast production of force—short-range stiffness—is considered to be the first line of defense.<sup>20,21</sup> Muscle pre-activation (onset time and amplitude) is modified depending on the external environment. For example, during a drop-landing

task from a tall box when potential injurious forces are greater, a person has earlier onset of quadriceps and greater activation prior to foot contact compared with a small box drop-landing.<sup>22</sup> Thus, the muscles surrounding a joint adequately anticipate musculoskeletal needs and achieve joint stability.

## Effect of Age on Proprioception

A decline in muscle mass and strength is one prominent characteristic of natural aging. Strength loss can limit the activities of daily living and mobility, increase the chance of falling, and possibly even cause a loss of mechanoreceptors that can further decrease proprioception and balance.<sup>23–26</sup> Peripheral neuropathy is also common in the elderly and has been identified as another risk factor for falls, leading to long-term disabilities or, ultimately, mortality.<sup>27,28</sup> In the joint stability paradigm (see Figure 1), age-related factors will lead to the loss of mechanoreceptors and diminish proprioception. Because deficiencies in neuromuscular control contribute to functional joint instability, repetitive micro-trauma can occur at the joint during gait or other functional activities. This repetitive micro-trauma, unfortunately, is a precursor for OA.<sup>29</sup>

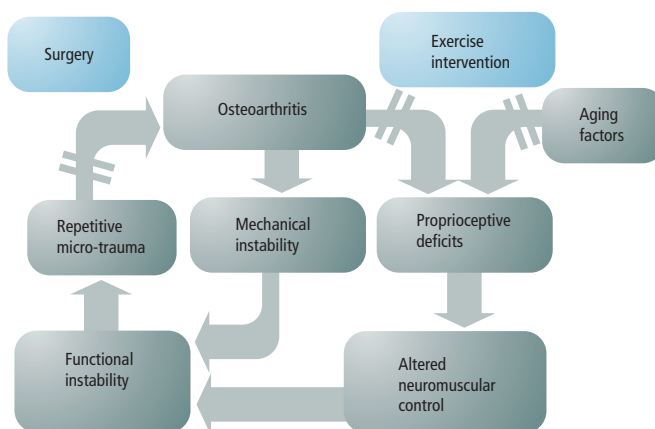
## Effect of Osteoarthritis on Proprioception

Knee OA is one of the most common musculoskeletal diseases in individuals over age 65.<sup>30</sup> Quadriceps weakness is common among individuals with OA regardless of the severity of OA or amount of muscle atrophy, suggesting that this muscle weakness is due to the failure of the nervous system to fully activate available muscle fibers.<sup>31</sup> Proprioception has shown to decrease further in osteoarthritic knees compared with age-matched healthy knees. Interestingly, the proprioception deficits were not related to the severity of OA, and decreased proprioception was present in the contralateral limb of individuals with OA, suggesting a deterioration of the sensorimotor system.<sup>32,33</sup> In the joint stability paradigm (see Figure 1), the arrow to proprioception deficits and altered neuromuscular control may be the main pathway leading to functional joint instability. Recent evidence supports that the loss of muscle strength and development of OA are the results of muscle dysfunction due to long-term reduction of physical activity and loss of mechanoreceptors rather than a ‘wear and tear’ of the articular cartilage as, age-matched individuals with regular exercise demonstrate better strength, function, balance, and proprioception.<sup>34</sup>

## Surgical or Non-surgical Interventions on Proprioception

Surgical interventions are widely used and accepted as a treatment of severe OA. Patient satisfaction, rating of pain, and activities of daily living were all fair or excellent after surgical interventions; however, proprioception was not fully restored after surgical interventions.<sup>35,36</sup> Proprioception may take some time to recover from surgical interventions, even in healthy

**Figure 1: Joint Stability Paradigm—Effects of Age-related Factors, Osteoarthritis, and Exercise Intervention on Proprioception**



individuals, suggesting the importance of post-operation rehabilitation and physical activity in restoring proprioceptive functions.<sup>37</sup> Additional sensory input from cutaneous and tactile afferents with the application of a brace or tape may aid in the recovery process.<sup>38</sup>

Proprioception and neuromuscular function have shown improvement in healthy individuals as a result of long-term physical exercise.<sup>39,40</sup> Since they are both modifiable factors, consistent and regular physical exercise can be used as a preventive or non-operative intervention to enhance proprioceptive functions, reverse the age-related strength loss, and achieve joint stability (see Figure 1). Several studies have reported on the effectiveness of such intervention programs in individuals with OA.<sup>41,42</sup> Exercise interventions can prevent or slow down the progression of OA, minimize pain, and potentially reverse the aging process. The positive effects of exercise interventions incorporating balance tasks are widely accepted for keeping the elderly population active and preventing falls.<sup>43</sup>

## Conclusions

This paper emphasizes the vital role of proprioception in the sensorimotor system and its importance in achieving joint stability. Proprioception deficits are commonly found in the elderly and individuals with OA, and these deficits have been shown to be accentuated by age-related factors and the disease processes of OA. Fortunately, proprioception has been shown to improve through both consistent physical exercise and post-surgical rehabilitation. A restoration of proprioception should, therefore, be incorporated as a part of comprehensive care of the elderly and individuals with OA. ■

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