Muscle Stiffness and Biomechanical Stability

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HERE CAN BE significant confusion about the difference between the clinical and biomechanical concepts of stability. From a clinical perspective, a lack of stability is often discussed in the literature as a symptomatic response to some injurious event. The symptomatic response occurs as a result of excessive joint displacement that increases compression or tension of the surrounding joint structures, thus initiating a symptomatic response. From a biomechanical perspective, stability is a defined concept. Specifically, biomechanical stability is defined as the joint’s ability to maintain equilibrium in response to an external perturbation or load. One of the primary differences between clinical and biomechanical stability is that clinical stability refers to the symptoms following injury, whereas biomechanical stability refers to the ability of a joint to carry loads and remain in equilibrium.

A joint lacking biomechanical stability can be prone to musculoskeletal injury. If the joint is inherently unstable or unable to maintain equilibrium, an external perturbation will cause it to change in position, moving away from equilibrium (e.g., undergo translation, inversion, valgus). Excessive or uncontrolled changes in joint position might allow the passive stabilizing structures surrounding the joint to undergo excessive stress and strain, which might ultimately lead to injury. Therefore, maintaining biomechanical stability is a primary factor in minimizing the stress and strain placed on the passive stabilizing joint structures, thereby enhancing clinical stability and reducing injury risk.

Muscle Stiffness

Multiple factors ultimately influence the biomechanical stability of a joint, perhaps the most critical being the stiffness properties of the surrounding muscle and joint structures. It is believed that the stiffness properties of the surrounding muscle and soft-tissue structures at the time of perturbation are the first line of defense in maintaining joint stability, hence providing protection against injury. Stiffness is a term used in physics to describe the properties of deformable bodies in response to an external force perturbation; these bodies generate a resistive force and can store elastic energy. Specifically, stiffness is described as the force response to an imposed change in length of a tissue (Figure 1). This mechanical relationship is defined by $K = \Delta F/\Delta L$, where $K$ represents stiffness, $\Delta F$ is the change in muscle force, and $\Delta L$ represents the change in muscle length. It is important to note that muscle stiffness is different from muscle extensibility or flexibility, which refers to the available range of motion at a joint and does not take into consideration the amount of resistive force during muscle lengthening. The stiffness of inactive muscles (passive muscle stiffness) is likely influenced by muscle extensibility/flexibility. Research has shown,

![Figure 1](image)
however, that stiffness contributions from the passive soft-tissue structures alone are insufficient to maintain biomechanical stability after external perturbation. As such, muscle extensibility/flexibility is not likely to play a major role in determining the biomechanical stability of a joint.

The stiffness contribution from actively contracting muscles (active muscle stiffness) surrounding the joint is most important for maintaining biomechanical stability of the joint. The functional and physiologic relevance of active muscle stiffness is significant because it limits excessive joint motion and translation (i.e., maintains biomechanical stability) that might be transferred to ligamentous structures. Insufficient active muscle stiffness at the time of external perturbation might allow excessive muscle lengthening, which results in uncontrolled arthrokinematic motion and can increase ligament loading and injury risk.

Valid, reliable measurement of active muscle stiffness is highly desirable because of the influence of stiffness on the biomechanical stability of the joint system. The “transient oscillation” technique is a commonly reported experimental method used to quantify active muscle stiffness. This method involves measuring the transient rotational joint motion following an external perturbation, which appears as a damped oscillatory motion (Figure 2). To calculate active muscle stiffness, the following information must first be determined: damped frequency of oscillation, \( f_d \) (Figure 2; i.e., inverse of the time interval between the first two peaks of the oscillatory motion); coefficient of damping measured from the decay of the transient oscillatory motion, \( c \) (see McNair, Blackburn et al., and Wilson et al. for more detailed description of assessing coefficient of damping calculation); and mass of the limb segment, \( m \). Active muscle stiffness (\( K \)) can then be calculated using the following equation: \( K = 4\pi^2mf^2 + c^2/4m \).

One assumption made when assessing active muscle stiffness is that the muscles of interest are the primary muscles activated during testing. Coactivation of surrounding muscles can greatly influence active-stiffness measures. As such, muscle activation is typically continuously monitored via electromyography in order to ensure that only the muscles of interest are active.

The importance of active muscle stiffness in contributing to a joint’s biomechanical stability has led to research with significant clinical insight. It is well documented that women suffer a higher incidence of ACL injuries than men do. There is great interest in understanding factors that contribute to the gender bias in ACL injury. One potential explanation is differences in active muscle stiffness. Recent research has demonstrated active muscle stiffness of the quadriceps and hamstrings muscles to be significantly lower in women than in men at matched background-force levels of 0 kg, 10 kg, and 20% of maximal voluntary contraction. These findings are supported by those of Blackburn et al. Lower active muscle stiffness of the hamstrings and quadriceps in women might suggest reduced biomechanical stability of the knee joint. During functional tasks, external loading and perturbation are applied to the knee joint. Women demonstrating lower active muscle stiffness of the hamstrings and quadriceps might have greater arthrokinematic motion at the knee joint, which could increase ACL strain and place them at greater risk for ACL injury. It is not known whether lower active muscle stiffness actually predisposes one to injury. Thus, gender differences in active muscle stiffness and the greater incidence of ACL injuries in women require further study.

Active muscle stiffness might also play an important role in chronic joint instability. Repetitive damage to passive joint-stabilizing structures resulting from repeated episodes of “giving way” might be the re-