

HIP STABILITY: MECHANICAL CONTRIBUTIONS OF INDIVIDUAL MUSCLES

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INTRODUCTION

The hip is a joint that is subjected to high forces during both dynamic and static activities. In the physiological range, translational hip stability is provided by: 1) muscle, 2) the acetabular cup, 3) ligaments. However, in this range, muscles are almost exclusively responsible for rotational stability. Little is known about the potential contributions of individual muscles to the rotational stability of the hip. Recently, a method has been developed to allow for such a calculation with knowledge of the muscle line of action and force generating potential [3]. The purpose of this study was to determine the individual hip muscle contributions to rotational stability about the flexion/extension and abduction/adduction axes in a neutral and flexed posture.

METHODS

The biomechanical model of Delp et al [2] was used to characterize the joint rotational and translational characteristics and the muscle lines of action of 19 muscles crossing the hip (with a total of 27 separate fascicles). Stability analyses were performed about the: 1) flexion/extension and 2) abduction/adduction axes in the: 1) neutral standing posture and 2) with the knee and hip both flexed to 90 degrees.

The model of Potvin and Brown [3] was used to calculate individual muscle contributions to joint stability for each of the four axis/posture combinations. The minimum potential energy (V) approach was used to calculate stability. This method assumes that a system is stable if its total V is at a minimum. In other words, the second derivative of the system V must be positive definite [1]. For a particular muscle, V was calculated as the elastic energy stored in the muscle plus the work done by the muscle for small rotations:

$$U(m) = F \Delta \ell + \frac{1}{2} k \Delta \ell^2 \quad (1)$$

where: $U(m)$ = potential energy stored in the muscle, F = muscle force (N), k = muscle stiffness (N/m), r = muscle moment arm (m), ℓ = muscle length (m) defined from the origin (A) to insertion (B). A and B can also be used to define nodes on either side of a joint and are expressed relative to the hip coordinates. The change in length was a function of the rotation (θ). For the hip joint, the anatomical axes were: abduction/adduction (x), internal/external rotation (y) and flexion/extension (z).

The stability contribution of a muscle about the z axis (S_z), is calculated as the second derivative of $U(m)$ with respect to a small rotation angle ($d\theta$) using a Taylor Series expansion, differentiating twice with respect to θ , and simplifying. A further substitution of $k=qF/\ell$ [1] was made yielding equation (2). For muscles without nodes, $L = \ell$. Otherwise ℓ is the distance between nodes and L is the total muscle length. All analyses were run with maximal muscle forces, after correcting for the active and passive force length effects.

$$S(m)_z = F \left[\frac{A_x B_x + A_y B_y - r_z^2}{\ell} + \frac{q r_z^2}{L} \right] \quad (2)$$

RESULTS AND DISCUSSION

Flexion/Extension axis: In the neutral posture, the semimembranosus (SM) was found to be the dominant hip stabilizer about the flexion/extension axis, with values 68% and 132% higher than the next highest muscles; biceps femoris long head and rectus femoris (RF), respectively. These muscles have the highest force potential in this posture and each are oriented in such a way as to optimize their geometric potential to contribute to joint stiffness (termed "geometric stability" or S_G and related to having large moment arms and/or short lengths). The stability values were found to be much lower when the knee and hip were both flexed to 90°, with the largest contributors being: RF and SM (due to high force potential) and adductor magnus 3 (due to its moderate force and high S_G). It should be noted that the SM was observed to have values in the flexed posture that were only 33% of that in the neutral posture. In addition, all three hip adductor muscles were found to have greatly enhanced flexion/extension stabilizing potential in the flexed, compared to the neutral, posture. While somewhat unrealistic (because the resulting net moment is not zero), the total maximum stability potential was approximated by setting each muscle force to 100% of maximum and summing across muscles. For the flexion/extension axis, the total stability in the neutral posture was 2.6 times higher than that in the flexed posture.

Abd/Adduction axis: In the neutral posture, the dominant stabilizers were gluteus medius 1 (due to high force and S_G) adductor magnus 1 (due to very high S_G) and adductor longus (due to moderate force and high S_G). However, in the flexed posture, the gluteus medius 1 and adductor magnus 1 dropped to 8% and 22% of their neutral values and the adductor longus increased somewhat to be the dominant stabilizer (due to a very high S_G), followed by the adductor magnus 3 and the psoas. Overall, the neutral posture was found to have a maximum abd/adduction stabilizing potential 4.4 times higher than the flexed posture.

CONCLUSIONS

This study demonstrates the utility of a simple stability equation for accurately dissecting the individual muscle contributions to hip stability. It is anticipated that this work will lead to a better understanding of the factors that lead to hip instability and injury.

REFERENCES

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