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Influence of the pelvic shape on the biomechanical status of the hip

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Summary

A simple static three-dimensional mathematical model of an adult human hip in one-legged position is used in order to estimate the resultant force of the hip muscles and the contact force in the hip joint for different pelvic shapes. The variation of pelvic shape was simulated by changing the components of the radius vectors of the muscle origins on the crista iliaca and by changing the interhip distance. It is concluded that the magnitudes of the hip muscle resultant force and the hip joint contact force are minimal for the high, laterally inclined pelvis with small interhip distance and maximal for the shallow, steep pelvis with great interhip distance.

Relevance

It is proposed that shallow and steep pelvic shape with great interhip distance is unfavourable regarding the development of osteoarthrosis in the hip joint because of the greater magnitude of the hip joint contact force.

Key words: Pelvic shape, joint force, muscle force, biomechanics, osteoarthrosis

Introduction

It is commonly agreed that a too high joint contact pressure can encourage an already existing osteoarthrotic process in the hip joint[1]. The average hip joint contact pressure depends on the magnitude of the hip joint contact force and the size of the hip joint contact area; therefore these two factors are equally important for osteoarthrosis development[1,2].

In the past the influence of the femoral geometry on the hip joint contact force was mainly studied[3], while this work deals with the dependence of the hip joint contact force on the pelvic geometry. In this way the role of the pelvic shape as an etiological factor for osteoarthrosis development and its progression could be elucidated.

The aim of this work is to determine theoretically the pelvic shape corresponding to the maximal hip joint contact force, which bears a higher risk of the development of osteoarthrosis in the hip joint. Therefore a simple static three-dimensional mathematical model of the adult human hip in one-legged stance is used to calculate the hip joint contact force $\vec{R}$ for different pelvic shapes.

Method

The model is defined by means of the pelvic force and moment equilibrium equations[2]:

$$\sum_i \vec{F}_i - \vec{R} + (\vec{W}_B - \vec{W}_L) = \vec{O}, \tag{1}$$

$$\sum_i (\vec{r}_i \times \vec{F}_i) + \vec{a} \times (\vec{W}_B - \vec{W}_L) = \vec{O}, \tag{2}$$

where index i runs over all hip muscles forces $\vec{F}_i$ included in the model, $\vec{W}_B$ is the body weight force, $\vec{W}_L$ is the weight force of the supporting limb, $\vec{r}_i$ is the radius vector of the i-th muscle force $\vec{F}_i$ application point drawn from the origin of the coordinate system to the muscle origin point on the pelvis, and parameter $\vec{a}$ (which can be calculated using the approximative expression[2]) is the moment arm of force $(\vec{W}_B - \vec{W}_L)$.

The muscles piriformis, gluteus medius, gluteus minimus, rectus femoris, and tensor fasciae latae are

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included in the model. Since gluteus medius and gluteus minimus are attached to the pelvis over a rather large area, each of these two muscles is divided into three segments. These segments of gluteus medius and glutus minimus and the remaining three muscles are classified in three groups according to their positions[2]: anterior (a), middle (m) and posterior (p).

It is assumed that the force of an individual muscle $\vec{F}_i$ points in the direction of the vector $\vec{s}_i$ connecting the radius vector of the muscle origin point on the pelvis and the corresponding radius vector of the muscle insertion point on the femur. The force of the individual muscle $\vec{F}_i$ is proposed to be proportional to its relative cross-sectional area A_i and its average tension σ_i:

$$\vec{F}_i = \sigma_i \cdot A_i \cdot \vec{s}_i, \qquad (3)$$

where the values of A_i are taken from Iglič et al.[2]. The model assumes that average tensions of individual muscles are equal in the single muscle group (a,m,p). This presumption enables us to include in the model a number of muscles which exceeds the number of the model force and moment equilibrium equations.

The variation of pelvic configuration is simulated by changing the reference components of the muscle origin point radius vectors on the crista iliaca, taken from Dostal and Andrews[4], in the mediolateral direction (δz) and in the superioinferior direction (δx) respectively and by changing the reference interhip half distance (8.45 cm) for δl.

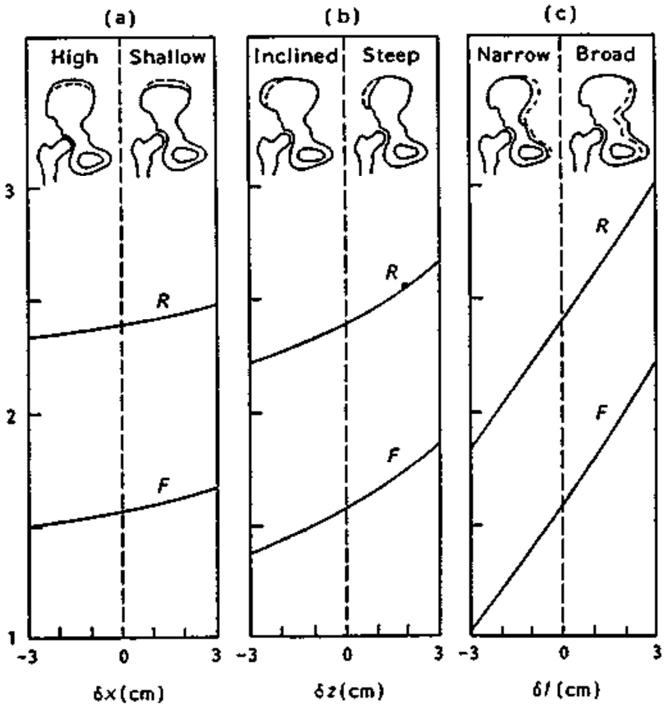

Figure 1. (a),(b): Calculated magnitudes of the hip muscle resultant force $\vec{F}$ (F) and the hip joint contact force $\vec{R}$ (R) as functions of the simulated crista iliaca shift in the superior ($\delta x < 0$), inferior ($\delta x > 0$), medial ($\delta z > 0$) and lateral ($\delta z < 0$) directions. (c): Calculated R and F as function of the simulated change of the interhip half distance (δl). Six major characteristic pelvic shapes are schematically presented in the figure: high ($\delta x < 0$), shallow ($\delta x > 0$), inclined ($\delta z < 0$), steep ($\delta z > 0$), broad ($\delta l > 0$), and narrow ($\delta l < 0$) pelvic shape. The reference pelvic shape is denoted by the dotted line. All the calculated values of R and F are normalized with respect to the magnitude of the body weight force (W_B).

Results

The results are interpreted in the view of the hip joint contact force $\vec{R}$ and the hip muscles resultant force $\vec{F} = \sum \vec{F}_i$ dependencies on the different simulated pelvic configurations (Figure 1). It can be seen from Figure 1 that the magnitudes of the hip joint contact force and the hip muscle resultant force have minimal values for the high, laterally inclined pelvis with small interhip distance, while both forces have maximal values for the shallow and steep pelvis with great interhip distance.

Discussion and conclusions

Until now the influence of the femoral shape on the hip joint contact force[3] has received much more attention than the influence of the pelvic shape. The present study suggests and proves that the pelvic shape is important too as a factor determining the magnitude of the hip joint contact force. Namely, according to our study the magnitude of the hip joint contact force varies as a function of the pelvic shape up to 55% relative to the value for the reference pelvic shape ($R = 3.7\ W_B$ for $\delta x = \delta z = \delta l = 3$ cm, while $R = 2.4\ W_B$ for $\delta x = \delta z = \delta l = 0$). In comparison, the magnitude of the hip joint contact force varies as a function of the femoral shape (femoral neck angle, anteversion–retroversion, position of the greater trochanter) up to 25% relative to the value for the reference femoral shape[3].

It is concluded that a shallow and steep pelvic shape with great interhip distance is unfavourable regarding osteoarthrotic development in the hip joint because of the high magnitude of the hip joint contact force.

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