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Stress distribution on the hip joint articular surface during gait

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Abstract. The magnitude and the direction of the resultant hip joint force are different in different body positions during gait. Therefore the stress distribution in the hip joint articular surface also changes. The aim of this work is to study how the stress distribution changes if the magnitude and the direction of the hip joint force is changed during gait. For this purpose a three-dimensional mathematical model is developed. We calculated the values of the peak stress and the location of the pole on the articular surface (where the stress is maximal) in the successive phases of the walking cycle. The values of the peak stress range from 0.8 MPa in the one limb stance phase to 2.6 MPa in the heel strike phase.

Key words: gait, hip joint, resultant hip joint force, stress distribution, articular surface.

Introduction

During gait the upper part of the body and the swinging leg are supported alternately by each hip. The period is divided into successive phases [1]. We analysed the right single support period of the gait between 12^{th} and 23^{th} phase (Figure 1). The magnitude and the direction of the resultant hip joint force of these phases were taken from Maquet [4]. Using these data, the stress distribution on the articular surface of the hip joint were calculated for each phase of the walking cycle.

Method

To calculate stress distribution on the hip joint articular surface we generalised our previously developed three-dimensional model of an adult human hip in which the resultant hip joint force $\vec{R}$ was confined to lie in the frontal plane of the body [3] to the situation in which $\vec{R}$ may attain an arbitrary direction. In the model, the femoral head is represented by a sphere and the acetabulum is represented by a fraction of spherical shell separated by a soft intermediate layer. If the hip is unloaded, the femoral head sphere and the acetabular spherical shell are concentric, while if the hip is loaded, the femoral head sphere is displaced relative to the acetabular spherical shell. A hip joint articular surface sphere is constructed (Figure 2). The radius of the hip joint articular surface sphere (r) is taken to be the mean of the radii of femoral head sphere and the acetabular shell. The articular stress integrated over the stress bearing area (S) yields the resultant hip joint force $\vec{R}$,

$$\vec{R} = \int_S p \, d\vec{S}, \tag{1}$$

where

$$d\vec{S} = (sin\vartheta \, cos\varphi, \ sin\vartheta \, sin\varphi, \ cos\vartheta) \, r^2 \, sin\vartheta \, d\vartheta \, d\varphi, \tag{2}$$

r, ϑ, φ are the coordinates of a particular point on the hip joint articular surface sphere, and p is stress at a particular point on this sphere. It is assumed that stress p is cosine function of the angle between the stress pole and the chosen point on the articular surface [2],

$$p = p_0 cos\gamma, \tag{3}$$

where p_0 is the value of p at the pole and γ is the angle between a particular point on the surface and the pole. Knowing the components of the resultant hip joint force, the value of stress at the pole p_0 and the coordinates of the pole Θ, Φ (Figure 2) are determined by solving the three equations for the

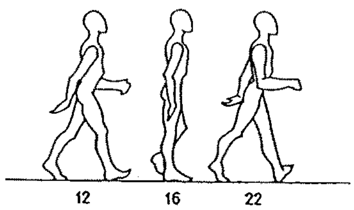

Figure 1: Three positions of the body during the right single support period of the gait between 12^{th} and 23^{th} phase according to Braune and Fischer: position in the 12^{th} phase (heel strike), position in the 16^{th} phase (one limb stance) and position in the 23^{th} phase (toe off).

components of force $\vec{R}$ (1). The integration of stress is performed over the stress bearing area shown in Figure 2. The lateral border is determined by the intersection of plane which is inclined for the angle ϑ_{CE} regarding to $x = 0$ plane.

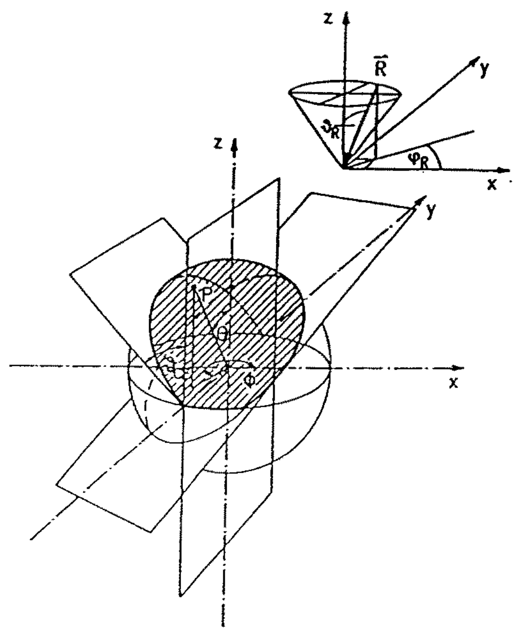

Figure 2: Schematic three dimensional representation of the hip joint articular surface and the stress bearing area (shaded). The pole of stress distribution $P(\Theta, \Phi)$ is marked. Upper right: the resultant hip joint force vector $\vec{R}$. The force $\vec{R}$ is inclined for ϑ_R with respect to z - axis and rotated with respect to x-axis counterclockwise for φ_R in the $z = 0$ plane.

Results

The values of peak stress and the location of the pole on the articular surface were calculated for successive phases of the gait. The minimum of the peak stress is attained between 16^{th} and 18^{th} phase (Figure 3). The coordinate of the pole Θ exhibits a minimum between 16^{th} and 18^{th} phase while the coordinate Φ increases monotonously attaining the value of 180^o between 16^{th} and 18^{th} phase of gait.

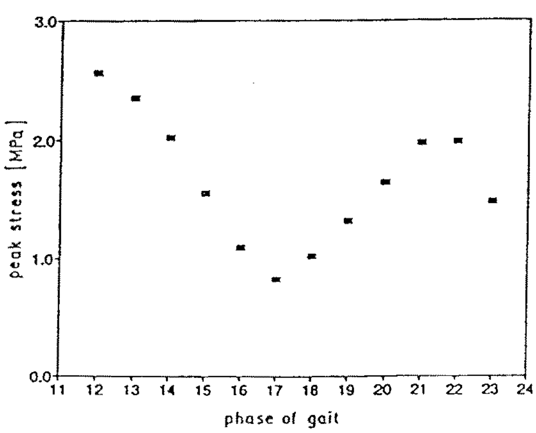

Figure 3: Calculated values of the peak stress in successive phases of the walking cycle for body weight $W = 590\ N$, the articular sphere radius $r = 2.5\ cm$ and lateral coverage $\vartheta_{CE} = 25^o$

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