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PEAK HIP-JOINT CONTACT STRESS IN MALE AND FEMALE POPULATIONS

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ABSTRACT

Increased contact hip-joint stress could be one of the reasons for the higher incidence of coxarthrosis in the female population. Therefore, in this work, the normalized peak contact stress in the articular surface of the hip joint was determined for 33 male and 113 female healthy hips. Stress was determined by the mathematical model describing one-legged stance, where hip geometry was taken into account for each individual. The hip geometry was determined from standard anteroposterior radiographs using the computer aided system. Our results show that the peak contact stress normalized with respect to the body weight is considerably higher (cca 20%) in the female population than in the male population. The difference is statistically significant ($P < 0.00005$) and is mainly attributed to the smaller radius of the articular surface in the female population. The results are in favor of the hypothesis that the increased hip joint contact stress in the female population could contribute to greater incidence of arthrosis in the female population relative to the male population.

INTRODUCTION

It was indicated that an excessive contact stress may accelerate the degenerative processes in the hip.[5, 18] It is therefore important to study the distribution of the contact stress to explore the pathomechanics of the degenerative joint diseases,[2, 3, 17, 19] as well as to predict an optimal stress distribution after certain operative interventions[1, 7, 9, 17] and to design the rehabilitation procedures.[16] Increased contact stress in the joint articular surface can result from a too small hip-joint weight-bearing area, from a too high resultant hip-joint force and a too vertical resultant hip-joint force.[2, 3, 13, 17, 19] The direction and magnitude of the resultant hip-joint force depends among others on the femoral and pelvic geometries.[2, 10, 12, 14, 19] Figure 1 shows schematically the stress distribution and the resultant hip-joint

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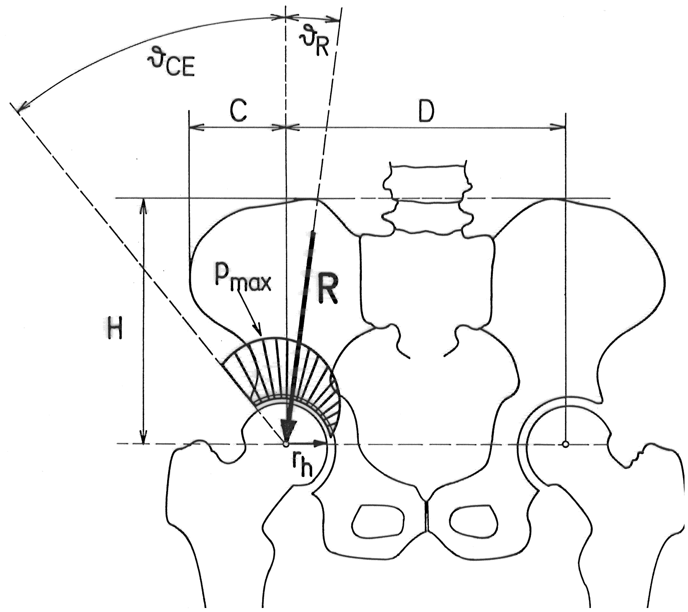

Fig. 1 Schematic presentation of the stress distribution in the hip-joint articular surface, of the resultant hip-joint force *R* and of some geometrical parameters that are important in determination of the resultant hip force and the corresponding stress distribution. The arrow points to the position of the peak stress p_{max}.

force. Some geometrical parameters that are important for determination of the resultant hip force. The corresponding stress distribution is also depicted.

In the previous work,[15] we proposed that higher contact hip-joint stress could be one of the reasons for higher incidence of coxarthrosis in the female population. The study[15] was performed by using standard AP radiographs from the archive. Only the radiographs that displayed no anomalies in the femoral and pelvic shapes, were taken into account. It was shown[15] that in the female population, the femoral head radius was significantly smaller while the distance between the inner acetabular rims was significantly larger than in the male population. Both these features cause an increase of the contact stress in the hip-joint articular surface.[9, 11] However, the quantitive values of stress have not been determined. In this work, we present an improved and more precise study of the difference between the female and the male hip and pelvis , which also includes the calculation of the normalized peak stress on the weight-bearing area.

METHODS

The standard anteroposterior radiographs were taken from the medical records of the University Medical Centre, Ljubljana. The radiographs of the subjects having degenerations or anomalies in the hip and pelvic shapes were excluded. Also, the radiographs of the subjects for which greater trochanter as well as the complete pelvis were not visible were excluded from the study. Thus, the final analysis of the femoral and pelvic geometrical parameters was performed for 113 adult female and 33 adult male hips. A magnification rate of 10% was used.

The normalized peak stress on the weight-bearing area was calculated by the mathematical model.[9, 13] The model gives the distribution of stress over the weight–bearing area. It was shown that for hips with normal values of the center-edge angle of Wiberg, the stress distribution attains the highest value p_{max} [13]

$$p_{max} = R\zeta / r^2 \quad (1)$$

where R is the magnitude of the resultant hip-joint force, r is the radius of the hip-joint articular surface and ζ is the numerical factor that depends on the inclination of the resultant hip force with respect to the saggital plane (ϑ_R) and on the center-edge angle (ϑ_{CE}) (Fig. 1). The model for determination of the stress distribution [9, 13] therefore requires as an input data the magnitude and the direction of the resultant hip force, the center-edge angle and the radius of the hip-joint articular surface. The radius of the articular surface is represented in this work by the radius of the femoral head r_h.

The resultant hip force was calculated by the mathematical model of the one-legged stance [10–12] that requires as an input the distance, between the two femoral head centers (D), the coordinates of the attachment points of the muscles that act on the pelvis in the one-legged stance, the height of the pelvis (H), the horizontal distance between the most lateral point on the crista iliaca and the femoral head center (C) (Fig. 1) and the body weight (W_B). The reference values of the model muscle attachment points were taken from Dostal and Andrews.[4] The resultant hip force is proportional to the body weight W_B, [10] therefore, the normalized peak stress (p_{max} / W_B) can be written as

$$P_{max} / W_B = \xi / r^2 \quad (2)$$

where the numerical factor ξ depends on the shape of the pelvis and the proximal femur, including the center-edge angle. The effect of the radius of the articular surface r is distinguished from the other effects [Eq. (2)].

To determine the geometrical parameters from the X-ray image, we used the computer-aided system. [8, 15] The system uses digitized profiles and some characteristic points of standard antero-posterior X-ray radiographs of both proximal femurs and pelvis as an input. The curves that represent the head of the femoral head were fitted by the circles using the least-squares method.[8]

The geometrical parameters and the normalized peak stress in the hip joint were determined for each hip. The results concerning the female and the male populations were then analyzed using descriptive statistical methods. The probability P describing statistical significance of the difference between the mean values was determined. When determining the statistical significance of the difference, the system yields the probability P up to four decimal values. When all four values were found to be zero ($P = 0.0000$), we report in the text that $P < 0.00005$.

RESULTS AND DISCUSSION

Figure 2 shows the distribution of the normalized peak stress in the hip joint (p_{max} / W_B) in the female and male populations. The mean value of p_{max} / W_B was found to be larger in the female population (4.045 kPa / N) than in the male population (3.214 kPa / N). The difference (cca 20%) is statistically significant ($P < 0.00005$). As the body weight in the female population is expected to be smaller than in the male population, the difference in p_{max} between the female and male populations would be even larger than in p_{max} / W_B.

Further, we can also distinguish the effect of the radius of the articular surface from the effects of the shapes of the pelvis and the proximal femur. First, we consider the effects of the shapes of the pelvis and the proximal femur which are given in the factor ξ [Eq. (2)]. This is obtained by comparing the quantities $p_{max} r^2 / W_B = \xi$ of the two populations. The calculated difference between the mean values of the factor ξ for the female and male populations is not statistically significant.

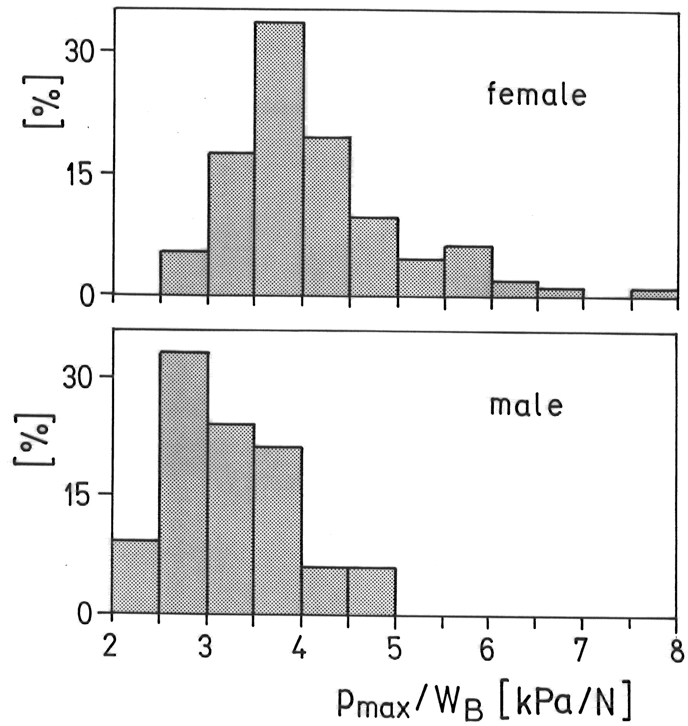

Fig. 2 Histogram of the normalized peak stress in the articular surface of the hip joint (p_{max} / *W*B) in the female and male populations.

Therefore, the most important effect is attributed to the radius of the articular surface. The mean value of the radius of the articular surface is lower in the female population (2.39 cm) than in the male population (2.66 cm). The difference (cca 15%) is statistically significant ($P < 0.00005$). To determine the effect of the femoral head radius on the peak stress, we compared the quantity $p_{max} / W_B \xi = 1 / r^2$. It was found that the mean value of $1 / r^2$ in the female population (0.176 cm^{-2}) is higher than in the male population (0.140 cm^{-2}). The difference (cca 20%) is statistically significant ($P < 0.00005$).

In conclusion, our results show that the contact stress is considerably and significantly higher in the female population relative to the male population. Since it was indicated that etiologic factors associated with hip arthrosis depend on the sex,[20] our results are in favor of the hypothesis that the greater incidence of arthrosis in female population relative to the male population might be related to the increased hip-joint contact stress in the female population. [15] We found that some of the parameters that according to the model[13] influence the peak stress, significantly differ in the two populations. The body weight has an opposite effect to that of the radius of the articular surface. The body weight is more favorable (lower) in the female population while the radius is smaller in the female population, which is unfavorable. As the effect of the body weight is the parameter that can be to some extent regulated in healthy subjects by avoiding overweight, [6] the female population would take advantage of the factor that is in favor of by keeping the peak stress as low as possible.

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