High contact hip stress is related to the development of hip pathology with increasing age

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Abstract

Background. High contact hip stress is believed to be one of the key biomechanical factors involved in the hip cartilage degeneration and osteoarthritis. Accordingly, with increasing age high contact hip stress is expected to cause elimination of subjects from the population of healthy hips, but its predictive value has not been evaluated so far. The objective of the paper is to investigate whether the exposure of healthy hips to estimated high contact hip stress is related to the development of hip pathology with increasing age.

Methods. A cross-sectional age- and gender-matched analysis of the peak contact hip stress calculated from pelvic geometry was made in 103 adult subjects with healthy hips. The peak contact hip stress was calculated from anterior–posterior pelvic radiographs of healthy hips by using a mathematical model of the human hip in the static one-legged stance.

Findings. In both female and male population, the average values of the peak contact hip stress normalized to the body weight are significantly higher and the values are also more dispersed in younger subjects when compared to older subjects.

Interpretation. The hip joints which remain healthy in the old age have lower average estimated peak contact hip stress. These results are consistent with the explanation that subjects with high estimated peak contact hip stress are more likely to develop hip disease in the course of life.

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1. Introduction

Biomechanical status of the hip depends on different factors, including congenital biomechanical predisposition, developmental changes in hip biomechanics and loading of the hip joint with different levels of physical activity in the course of life (Brand et al., 2001). In particular, the biomechanical inability of initially healthy hips to withstand long-term loading plays a decisive role in the development of pathologic processes in the hip joint with increasing age (Hadley et al., 1990). In this regard, high hip contact stress is believed to be one of the key biomechanical factors involved in cartilage degeneration and secondary hip osteoarthritis due to developmental dysplasia of the hip (Maxian et al., 1995) and due to avascular necrosis of the femoral head. It was found that hips with increased cumulative stress exposure have higher risk for avascular necrosis (Hadley et al., 1990) and the long-term clinical outcome of operative treatment in avascular necrosis of the femoral head is related to the postoperative reduction of the contact hip stress (Dolinar et al., 2003). The biomechanical analysis has also shown that with progression of the avascular necrosis the weight-bearing surface in the hip decreases and results in further increment of the peak contact hip stress (Dolinar et al., 2002). It has been shown that subjects with hip dysplasia on average have higher normalized peak stress than healthy subjects (Mavčič et al., 2002). Studies were performed where peak contact stress in the hip joint was compared

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between different groups of patients with developmental dysplasia of the hip (Vengust et al., 2001) and with slipped capital femoral epiphysis (Zupanc et al., 2001) in order to evaluate biomechanical outcomes of surgical procedures. Some authors have also considered the possibility of correlation between high contact hip stress and idiopathic osteoarthritis (Brinckmann et al., 1981; Brand et al., 2001). However, the predictive value of the peak contact hip stress as the risk factor for the development of pathologic processes in the population of healthy hips has not been evaluated so far.

The objective of the paper is to investigate whether the exposure of healthy hips to high contact hip stress is related to the development of hip pathology with increasing age. If high peak hip stress is indeed a risk factor for hip pathology and healthy subjects with high stresses are more likely to develop hip disease with increasing age, then only subjects with low peak stresses remain healthy in the old age. If, on the other hand, the hip contact stress has no influence on the development of hip pathology in the healthy population then the peak hip stress values are expected to remain approximately equally distributed at any age. The null hypothesis of our study states that the average values of the peak contact hip stress in different age groups of healthy adults are equal.

2. Methods

In the present study we analyzed the peak contact hip stress of 103 adult subjects with healthy hips from standard anterior–posterior pelvic radiographs. We used the database of digital pelvic contours of subjects with healthy hips that was created in previous studies (Kersnič et al., 1997; Mavčič et al., 2002). The 103 subjects were selected from among the group of adult patients who had had a radiograph of the pelvic region taken in the years 1988–1993 at the Department of Orthopaedic Surgery, University Medical Centre Ljubljana for reasons other than hip joint disease (e.g. lumbalgia). The analyzed radiographs were taken with the same radiographic machine. The inclusion criterion for participation in the study involved age over 18 at the time the radiograph was taken. The exclusion criteria for participation in the study included clinical or radiographic signs of hip pathology, insufficient technical quality of the radiograph and incomplete presentation of pelvis on the radiograph. In each selected subject we analyzed the left and the right hip as two individual hips and the subsequent analysis was made separately for females and males to allow for a gender-matched comparison. Accordingly, our sample consisted of 164 female and 42 male healthy hips. In the female group the subjects' age ranged from 18 to 86, median 54. In the male group the subjects' age ranged from 23 to 82,

median 54. In each gender group the subjects were further subdivided into two equally sized subgroups with regard to the median age—subjects under 54 years of age were thus assigned to the younger subgroup and subjects aged 54 or more to the older subgroup.

The peak stress estimation in healthy hips was based on a previously developed analytical three-dimensional biomechanical model (Iglič et al., 1993; Ipavec et al., 1999; Mavčič et al., 2002). The model can be used to estimate the resultant hip force and the stress distribution in the hip joint from an anterior–posterior pelvic radiograph, whereby the computed biomechanical parameters correspond to the static one-legged stance. The one-legged stance is considered to be the representative position for slow gait as the most frequent activity in everyday life (McLeish and Charnley, 1970). The model takes into account the fact that in the one-legged stance the pelvis is slightly inclined and the hip centres are not leveled. Errors in determination of the peak contact hip stress derive from unknown magnifications of radiographs and from errors in the determination of the geometrical parameters due to different distances of the selected points from the plane of the radiographic film. Within the validity of the model, the error in estimating the peak contact hip stress amounts to approximately 10% (Mavčič et al., 2002). The pelvic bone contours were put into digital form and the following radiographic parameters were measured (Mavčič et al., 2002): the interhip distance l, the pelvic height H, the pelvic width laterally from the femoral head centre C, the coordinates of the insertion point of abductors on the greater trochanter (point coordinates T_x, T_z) in the frontal plane, the radius of the femoral head r and the Wiberg centre-edge angle ϑ_{CE}. The three-dimensional reference coordinates of the muscle attachment points were taken from the paper of Dostal and Andrews (1981) and they were adjusted by linear scaling with regard to the radiographic pelvic parameters (l, C, H, T_x, T_z) for each individual hip. The solution of the vector equations for the equilibria of forces and torques yielded the three components of the resultant hip force $\boldsymbol{R}$ and the tensions in the abductor muscles. From known values of the femoral head radius r, the Wiberg centre-edge angle ϑ_{CE}, the magnitude of the resultant hip force $\boldsymbol{R}$ and the inclination of the resultant hip force with respect to the vertical ϑ_R, the peak stress on the weight-bearing surface was computed for every individual hip (Ipavec et al., 1999). In this paper we report the results of the peak contact hip stress normalized to the body weight of each subject (p_{max}/W_B), since due to the retrospective nature of the study the data on patients' body weights were not available in most cases. Nevertheless, by using p_{max}/W_B it is possible to emphasize the influence of pelvic geometry on hip pathology without other confounding factors (body weight, physical activity, profession). The normalized

stress p_{max}/W_B has already been acknowledged as the relevant biomechanical parameter in previous studies (Brinckmann et al., 1981).

For each gender the average values of the normalized peak stress in the younger subgroup and the older subgroup were compared with the two-tailed Student t-test for unequal variances. The trend line for the dependence between the peak contact hip stress and the age was computed with linear regression.

3. Results

Fig. 1 shows the dependence between the normalized peak hip stress p_{max}/W_B and the subjects' age for female hips and Fig. 2 shows the results for male hips. It can be seen that the values of p_{max}/W_B are on average lower and
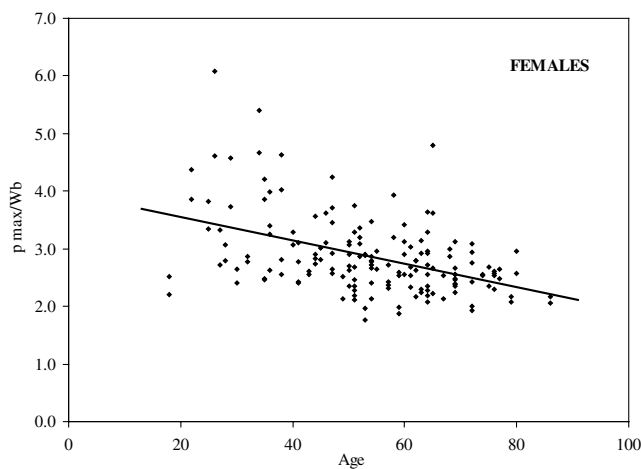

Fig. 1. Dependence between the normalized peak contact hip stress p_{max}/W_B and the subjects' age for 164 female healthy hips; the corresponding trend line is depicted.
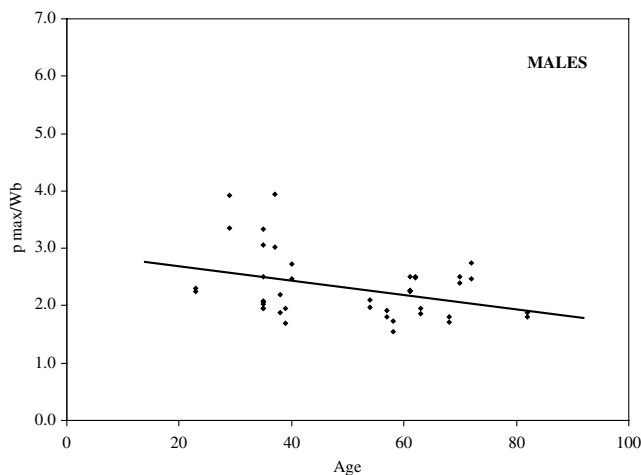

Fig. 2. Dependence between the normalized peak contact hip stress p_{max}/W_B and the subjects' age for 42 male healthy hips; the corresponding trend line is depicted.

Table 1
Minimum peak contact hip stress, maximum peak contact hip stress, mean peak contact hip stress and the standard deviation of the peak contact hip stress normalized to the body weight in the four age- and gender-matched sample groups

Sample group	No. of hips	Minimum stress (kPa/N)	Maximum stress (kPa/N)	Mean stress (kPa/N)	Standard deviation (kPa/N)
Females					
Younger (<54 years)	82	1.8	6.1	3.1	0.8
Older (≥54 years)	82	1.9	4.8	2.6	0.5
Males					
Younger (<54 years)	21	1.7	4.0	2.5	0.7
Older (≥54 years)	21	1.6	2.8	2.1	0.3

less dispersed with increasing age. The trend lines decrease with age; the standardized beta coefficient for linear regression equals −0.46 ($R^2 = 0.21$; $P < 0.001$) for female subjects and −0.36 ($R^2 = 0.13$; $P = 0.019$) for male subjects. The comparison between the subgroups of younger and older subjects for each gender is presented in Table 1, where the minimum, the maximum and the average value of p_{max}/W_B for each subgroup is shown with the corresponding standard deviation. It can be seen that in both females and males, older subjects have lower average normalized peak stress and smaller standard deviation of values than younger subjects. The difference in the average normalized peak contact hip stress between younger females and older females is statistically significant ($P < 0.001$) and the difference between younger males and older males is also statistically significant ($P = 0.026$). In addition, the comparison between the age-matched subgroups of male and female subjects has been made. It has been found that females have higher average normalized peak stress than males, both in the younger ($P = 0.002$) and in the older subgroup ($P < 0.001$).

4. Discussion

Our study has shown significant differences in the normalized peak contact hip stress between different age groups of healthy adult hips. In each gender older subjects have significantly lower average peak stress and smaller standard deviation of values than younger subjects. While the value of peak stress decreases with age and the dispersion of values is smaller, the minimum value is more or less constant. Such observations are consistent with the explanation that the age differences in p_{max}/W_B are due to the elimination of subjects with high peak contact hip stress from the population of healthy hips. Our results indicate that only the hip joints of the subjects with low peak contact hip stress remain

healthy in the old age. In addition, female subjects in the analyzed sample of healthy hips have higher average normalized peak stress than male subjects in both age groups. Similar findings were reported in previous studies where biomechanical parameters in females were found to be less favorable than in males (Iglič et al., 2001) and the incidence of hip osteoarthritis in females was higher (Tepper and Hochberg, 1993). Some authors have argued that not only the amplitude of the hip stress but also the duration of exposure to higher hip stress should be considered (Hadley et al., 1990) and the clinical data have shown that age is an independent risk factor for hip osteoarthritis (Hootman et al., 2003). The results of our study are in agreement with such observations and they show that the long-term detrimental effect of high peak stress manifests mostly in the older population.

The major limitation of our study is the relatively simple biomechanical model that enables evaluation of peak stress in one static body position only. Therefore, the model does not allow for comparison of kinetic and kinematic parameters between younger and older subjects that have been studied with the laboratory measurements (Luepongsak et al., 2002). Nevertheless, dynamic differences in gait patterns between younger and older subjects are by some authors considered to be mostly attributable to reduced walking speed (Kerrigan et al., 1998). Physical activity and work load of each individual subject is another possible confounding factor that was not taken into account in the present study. There exist conflicting reports on the correlation between various physical activities and the development of hip pathology. Some studies have shown that very high work loads cause increased risk for hip osteoarthritis (Vingard et al., 1997), but other studies have found no relationship between physical activity and osteoarthritis (Rogers et al., 2002). By taking into consideration that most adult body-weight values lie between 500 and 1500 N, we can conclude that the results of the estimated peak contact hip stress in this study (range of the normalized values 1.6–6.1 kPa/N) lie within an order of magnitude of the peak contact hip stress measured with cadaveric specimens in vitro (8.8 MPa) and with an instrumented partial hip endoprosthesis in vivo (6.7 MPa) (Brown and Shaw, 1983; Hodge et al., 1986). The results also correspond to the estimations of the peak contact hip stress with the finite element models (Brand et al., 2001).

The differentiation of exact causes of hip pathology in subjects with high contact hip stress is beyond the scope of the present cross-sectional study. According to epidemiological studies, the majority of cases with hip pathology over 50 years of age are attributable to idiopathic hip osteoarthritis (Gabriel, 2001). Therefore, the findings indicate indirectly that high hip contact stress could be a risk factor for the development of idiopathic osteoarthritis in healthy hips. In order to get a decisive answer on the role of stress distribution in the hip, a larger subject pool, a prospective longitudinal cohort analysis of healthy population and an epidemiological analysis of the incidence of hip osteoarthritis as well as other causes of hip pathology within the cohort would be necessary.

5. Conclusions

The estimated peak contact hip stress in older healthy adult human hips is on average lower and less dispersed than in younger healthy adult human hips. This finding is consistent with the explanation that subjects with high estimated peak contact hip stress are more likely to develop hip disease in the course of life and are therefore eliminated from the population of healthy hips.

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