Hip stress reduction after Chiari osteotomy

S. Herman¹, A. Jaklič², S. Herman³, A. Iglč⁴, V. Kralj-Iglič⁵
¹Clinical Department of Traumatology, University Medical Center, Ljubljana, Slovenia
²Institute of Metals & Technology, Ljubljana, Slovenia
³Department of Orthopaedic Surgery, University Medical Center, Ljubljana, Slovenia
⁴Laboratory of Applied Physics, Faculty of Electrical Engineering, Ljubljana, Slovenia
⁵Institute of Biophysics, Faculty of Medicine, Ljubljana, Slovenia

Abstract—A mathematical model was developed to study the effect of the Chiari osteotomy on the distribution of contact hip stress over the weight-bearing area. It was shown that Chiari osteotomy can increase the weight-bearing area directly (on the lateral side), owing to the additional area formed by the iliac crest fragment, and indirectly (on the medial side), owing to the shift of the stress pole in the medial direction. As a consequence, the contact hip stress is reduced after Chiari osteotomy. The indirect effect is important and often larger than the direct one. Using the proposed mathematical model and standard anteroposterior roentgenograms from archives, the average peak stress on the weight-bearing area, normalised with respect to the body weight ($P_{\text{peak}}/W_b$), was determined before and after Chiari osteotomy ($8310 \text{ m}^{-2}$ and $4480 \text{ m}^{-2}$, respectively) on a population of 29 dysplastic hips. The difference was statistically significant ($p < 0.006$). Based on the results presented, it can be concluded that the hip joint contact stress in dysplastic hips considerably decreases after Chiari osteotomy, indicating a favourable biomechanical effect of this operation.

Keywords—Chiari osteotomy, Hip joint, Contact stress, Mathematical modelling

1 Introduction

The Chiari osteotomy, introduced in the 1950s (Chiari, 1953), was recommended for dysplastic hips, with or without osteoarthritis, for congenital subluxations in young adults, for coxa magna in Perthes disease and for paralytic dislocations caused by muscular weakness and spasticity.

The osteotomy is made just above the hip joint capsule at the anterior inferior iliac spine and extends transversely and upwards to the greater sciatic notch. The larger fragment is moved medially as far as the bony contact will allow. The cut edge of the proximal side of the osteotomy forms an extended roof that is lined by the joint capsule. The capsule remains intact during the operation. The aim of the operation is to improve the acetabular roof, i.e. the covering of the femoral head. Preoperatively elevated contact hip joint stress, indicated as one of the reasons for the development of coxarthrosis (hadley et al., 1990; maxian et al., 1995; iglč et al., 2001), should consequently be reduced.

In general, the choice of whether a patient should undergo a surgical procedure on the hip is based on the clinical and biomechanical state of the patient's hip (pauwels, 1976; johnston et al., 1979; brand, 1997; brand et al., 2001). By 'biomechanical state', we mean a set of physical quantities such as forces and stresses acting in the hip (pauwels, 1976; kummer, 1991; brand, 1997). The biomechanical state of the hip involves more than the morphological and radiographical state of the hip described by parameters such as trabecular trajectories in the femoral head and neck (pauwels, 1976), the percentage of coverage of the femoral head (hefti, 1995) and various geometrical parameters of the hip and pelvis (wiberg, 1939; busse et al., 1972; kersnč et al., 1997; ganz et al., 1988).

The parameters determined in morphological and radiographic studies were actually introduced to represent the biomechanical state of the hip. To take into account the complex interactions that take place and to develop a more realistic description of the biomechanical state of the hip, mathematical models are used to determine forces and stresses in the hip (johnston et al., 1979; iglč et al., 1993a; hupp et al., 1999; daniel et al., 2001). It has been suggested that assessment of the forces and stresses in the hip using appropriate mathematical models could be used to improve the understanding of the processes leading to development of coxarthrosis, as well as to predict the optimum geometry of the hip after the operation (pauwels, 1976; kummer, 1991; brand, 1997).

The hypothesis was proposed that increasing the coverage of the femoral head in places where it is deficient should decrease the contact stress in the hip joint (ganz et al., 1988; millis et al., 1995; murphy et al., 1999). However, relatively few works addressing changes in the biomechanical state of the hip in a quantitative manner (iglč et al., 1993a; hupp et al., 1999; kummer et al., 1991; zupec et al., 2001; vengust et al., 2001) are available to provide a test of this hypothesis.

In the case of the Chiari osteotomy, postoperative changes in the muscle forces (del p et al., 1990; iglč et al., 1993c) and a postoperative change in the resultant hip joint force

Correspondence should be addressed to Dr Veronika Kralj-Iglič; email: vera.kralj-iglic@bihlz.mf.uni-lj.si
Paper received 17 July 2001 and in final form 20 February 2002
MBEC online number: 20023680
© IFMBE: 2002
(IGLić et al., 1993c; ANTOLiČ et al., 1996) have been predicted. However, a mathematical estimation of the hip contact stress before and after the Chiari osteotomy has not yet been reported to our knowledge. Therefore the specific aim of the present work was to construct a mathematical model for estimating the contact stress distribution and the weight-bearing area in the dysplastic hip joint before and after the Chiari osteotomy, where the additional coverage of the femoral head by the *ala osis illi* (CHIARI, 1953) was to be taken into account.

Using the proposed mathematical model for determination of the contact stress distribution, a mathematical model for calculation of the resultant hip joint force in a one-legged stance (IGLić et al., 1993b; DANIEL et al., 2001) and standard anteroposterior roentgenographs from the archives, the hip joint contact stress distribution was determined before and after the Chiari osteotomy on a population of dysplastic hips.

2 Material and methods

2.1 Mathematical model of stress distribution in the hip joint after Chiari osteotomy

In the model, the femoral head is represented by a fraction of a sphere, and the acetabulum is represented by half of a spherical shell, called the acetabular contact hemisphere. An articular surface is imagined, its radius *r* being the average of the radii of the femoral head and the acetabulum. The shear stresses in the hip joint due to friction are neglected because of the small value of the frictional coefficient of the hip joint articular surface (EBERHARDT et al., 1991; McCUTCHEON, 1962; LIPSHITZ and GLIMCHER, 1979), so that only the normal stress is considered. We refer to the normal stress as the hip joint stress.

When the hip is not loaded, the sphere of the femoral head and the sphere of the acetabulum are considered to be concentric. Upon loading, the centres of both spheres no longer coincide, and the femoral head moves towards the acetabulum, thereby squeezing the intermittent cartilage (BRINCKMANN et al., 1981). The point of closest approach of the two spheres is called the pole of the stress distribution. It is taken that stress in the hip joint articular surface is proportional to strain within the cartilage. Consequently, stress at the chosen point on the articular surface is described as (BRINCKMANN et al., 1981; IGLić et al., 1993b)

\[ p = p_0 \cos \gamma \]

where \( p \) is the value of stress at the pole, and \( \gamma \) is the angle between the radius vectors to the pole and the radius vector to the chosen point. In the spherical co-ordinate system, the co-ordinates of the pole are the azimuthal angle \( \Phi \) and the polar angle \( \Theta \). The angle \( \Phi \) is taken to be positive in the lateral direction. Considering the resultant hip force to be known, the distribution of stress on the hip joint articular surface can be calculated, taking into account the relationship between the contact stress and the resultant hip joint force \( R \).

\[
\int p_0 \cos \gamma \, dA = R
\]

where \( dA \) is the area element. The integration is performed over the weight-bearing area \( A \). The lateral border of the weight-bearing area is defined by the lateral coverage of the femoral head. On the medial side, the border is defined by the condition that stress vanishes. This means that the medial border is an angle of \( \pi/2 \) away from the pole (IAPAVC et al., 1999). The resultant hip joint force can, in general, be expressed by its magnitude and direction.

In this work, we consider the one-legged stance where the resultant hip force lies in the \( y = 0 \) (frontal) plane (see Fig. 1). Therefore the resultant hip force can be described by only two parameters \( R = (-R \sin \Theta, 0, R \cos \Theta) \), where \( R \) is the magnitude of the resultant hip force, and \( \Theta \) determines the angular displacement of the resultant hip force from the vertical axis, as defined in Fig. 1. The angle \( \Theta \) is taken to be positive for the inclination of \( R \) that is presented schematically in Fig. 1. In the following, the co-ordinate system is rotated, so that \( \sin \Theta = 0 \) and \( \Theta = 0 \) (IAPAVC et al., 1999). In the rotated system, the resultant hip force is

\[
R = (-R \sin \Theta, 0, R \cos \Theta)
\]

(2)

To express the integrals of (1), we have, in the previous works (IGLić et al., 1993a; IAPAVC et al., 1999), used spherical co-ordinates. Here, we introduce a somewhat different choice of co-ordinates that proves to be more convenient for the modelling of the additional acetabular roof (Fig. 1). The chosen co-ordinates are \( x = r \cos \beta \sin \phi, y = r \sin \beta \) and \( z = r \cos \beta \cos \phi \), where \( r \) is the radius of the articular sphere, and the angles \( \beta \) and \( \phi \) are depicted in Fig. 1. The angle \( \phi \) is considered to be positive in the lateral direction and negative in the medial direction (Fig. 1). The area element is

\[
dA = r^2 \cos \beta \sin \phi \, d\beta \sin \phi \, d\phi \, d\beta
\]

(3)

and

\[
\cos \gamma = \cos \beta \cos \phi
\]

(4)
Using expressions (1), (3) and (4), the components of the force \( \mathbf{R} \) are

\[
R_x = \rho_0 r^2 \int_0^{\varphi} \cos \varphi \sin \varphi \, d\varphi
\]

(5)

\[
R_y = \rho_0 r^2 \int_0^{\varphi} \cos \varphi \sin \varphi \, d\varphi
\]

(6)

\[
R_z = \rho_0 r^2 \int_0^{\varphi} \cos \varphi \sin \varphi \, d\varphi
\]

(7)

The integration is performed over the weight bearing area. The weight-bearing area is divided into two parts (Fig. 1). The first part is formed by the \textit{ala ossis ilii} segment. For simplicity, we assume that the roof is symmetric with respect to the \( y = 0 \) plane and that the pole lies on the lateral side of the acetabular contact hemisphere. This can be expected for the one-legged stance position of the body. Therefore the integration bounds are \( \theta \in (-\theta_0, \theta_0) \) and \( \varphi \in (\theta_\text{CE1} - \Theta, \theta_\text{CE2} - \Theta) \). The angles \( \theta_\text{CE1} \) and \( \theta_\text{CE2} \) and \( \Theta \) are taken to be positive in the lateral direction. The meaning of the angles \( \theta_0, \theta_\text{CE1} \) and \( \theta_\text{CE2} \) can be deduced from Fig. 1. The second part is formed by the acetabular shell. The integration bounds are \( \theta \in (-\pi/2, \pi/2) \) and \( \varphi \in (-\pi/2, \theta_\text{CE1} - \Theta) \). After some calculation, we obtain

\[
R_x = -\rho_0 r^2 g
\]

(8)

\[
R_y = 0
\]

(9)

\[
R_z = \rho_0 r^2 h
\]

(10)

where

\[
g = \frac{2}{3} \cos^2(\theta_\text{CE1} - \Theta) + \left( \sin \theta_0 - \frac{\sin^3 \theta_0}{3} \right)
\]

\[
\times (\cos^2(\theta_\text{CE2} - \Theta) - \cos^2(\theta_\text{CE1} - \Theta))
\]

(11)

\[
h = \frac{2(\theta_\text{CE1} - \Theta + \pi/2 + \sin(2(\theta_\text{CE1} - \Theta))/2)}{\sin(2(\theta_\text{CE1} - \Theta))}
\]

(12)

Using the expressions for the components of the resultant hip force (2) and (8) and (10)–(12), the co-ordinate of the stress pole \( \Theta \) is determined from the non-linear algebraic equation

\[
tg(\theta_R + \Theta) - \frac{g}{h} = 0
\]

(13)

The value of stress at the pole \( \rho_0 \), can then be obtained from (6):

\[
\rho_0 = R \cos(\theta_R + \Theta)r^2
\]

\[
\left( \frac{2(\theta_\text{CE1} - \Theta + \pi/2 + \frac{1}{2}\sin(2(\theta_\text{CE1} - \Theta)))}{3}
\right.
\]

\[
+ \left( \sin \theta_0 - \frac{\sin^3 \theta_0}{3} \right)
\]

\[
\times (\theta_\text{CE2} - \theta_\text{CE1} + \sin(2(\theta_\text{CE2} - \Theta)))
\]

\[
\left. - \frac{\sin(2(\theta_\text{CE1} - \Theta))}{2} \right)
\]

(14)

The unique solution of the non-linear equation (13) was found numerically using the Newton iterative method. The value of \( \theta_0 \) (Fig. 1) was estimated to be between 10° and 40°, according to the thickness of the \textit{ala ossis ilii} at the cut. If we take \( \theta_0 = 0 \), we recover the equations of the model (IPAVEC et al., 1999) for the centre-edge angle \( \theta_\text{CE} = \theta_\text{CE2} \). And, for \( \theta_0 = 90^\circ \), we recover the equations of the model (IPAVEC et al., 1999) for \( \theta_\text{CE} = \theta_\text{CE1} \).

We describe the hip joint stress by its maximum value on the weight-bearing area \( p_{\text{max}} \). If the pole of the stress distribution lies within this area, \( p_{\text{max}} \) is equal to \( p_0 \). If the pole lies outside the weight-bearing area, the value of maximum stress is taken at the point closest to the pole (EBRINKMANN et al., 1981; IPAVEC et al., 1999).

To determine the stress distribution in a non-operated hip, the magnitude and the direction of the resultant hip joint force, the radius of the articular sphere and the Wiberg angle should be known, whereas, to determine the stress distribution after the Chiarai osteotomy, the magnitude and the direction of the resultant hip force, the radius of the articular sphere and both centre-edge angles should be known.

2.2 Determination of hip stress from standard anteroposterior radiograph

As stated above, the model for determination of hip stress distribution requires as input the magnitude and the direction of the resultant hip joint force, as well as the radius of the articular sphere and the centre-edge angles. The radius of the articular sphere \( r \) and the centre-edge angles before and after the operation (\( \theta_\text{CE1} \) and \( \theta_\text{CE2} \), respectively) were determined from the standard anteroposterior roentgenograph (Fig. 2). The radius of the articular sphere was estimated by the radius of the femoral head.

The resultant hip joint force was determined using a three-dimensional mathematical model of an adult human hip in a one-legged stance (IGLIČ et al., 1993b; DANIEL et al., 2001). It was found that, in the one-legged stance, the resultant hip force lies almost in the frontal plane of the body (IGLIČ et al., 1993b). The model for determination of the resultant hip force requires an input additional geometrical parameters of the pelvis and the proximal femur (Fig. 2): the inter-hip distance \( l \), the pelvic width \( H \), the pelvis width \( C \), the vertical and horizontal co-ordinates of the effective muscle attachment point on the greater trochanter \( \gamma_T \) and \( h_T \), respectively, and the body weight \( W_B \).

The geometrical parameters were obtained from digitised profiles of the roentgenographs using the HUOMO program (ZUPANC et al., 2001; KERSNIC et al., 1997). The HUOMO program was adjusted for the purpose of this work by also considering the centre-edge angle after Chiarai osteotomy (\( \theta_\text{CE} \)).
In non-operated hips, stress distribution was determined by the HIPSTRESS program, as described in detail elsewhere (Daniel et al., 2001; Zupanc et al., 2001; Vengust et al., 2001).

2.3 Roentgenographs

Standard anteroposterior roentgenographs of adult patients who underwent Chiari pelvic osteotomy at the Department of Orthopaedic Surgery in Ljubljana, in the period from 1980 to 1990, were taken from the archive. The roentgenographs of 29 female patients were considered in this study. The average age at the time of operation was 31.9 years (range 18–51 years). The average time duration between the operation and the control, when the second roentgenograph was taken, was 2.7 years.

For comparison, 29 roentgenographs of healthy female hips were taken from the archive of the Clinical Department of Traumatology in Ljubljana. These roentgenographs were made within the standard procedure for treatment of injured patients. The average age of the patients was 31.0 years (range 18–51).

In all roentgenographs, an average magnification of 110% was taken into account. The data were analysed by descriptive statistical methods. The distributions of all the variables were normal, and therefore average values of the respective groups could be compared.

3 Results

The effect of the Chiari osteotomy on the distribution of the contact hip stress was studied theoretically using the developed mathematical model, in which the additional coverage of the femoral head by the *ala ossis ilii* could be taken into account.

Fig. 3 shows the calculated peak stress on the weight-bearing area $p_{\text{max}}$ for different centre–edge angles $\theta_{\text{CE}}$ after the operation. For comparison, we show the peak stress on the intact hip joint with the corresponding centre–edge angle $\theta_{\text{CE}} = \theta_{\text{CEI}}$. It can be seen that the peak stress is considerably reduced, owing to the Chiari osteotomy, the effect being more significant for larger $\theta_{\text{CEI}}$. However, the peak stress is still higher than the corresponding peak stress in the intact hip.

Fig. 4 shows the contact stress distribution for different centre–edge angles $\theta_{\text{CEI}}$ after the operation. For comparison, we also show the contact stress distribution on the intact hip joint with the corresponding centre–edge angle $\theta_{\text{CE}}$. The position of the pole is indicated (see black dot). It can be seen that the contact stress considerably decreases after the Chiari osteotomy; however, it is still higher than the corresponding contact stress in the intact hip, with $\theta_{\text{CE}} = \theta_{\text{CEI}}$. The effect is more significant for larger values of $\theta_{\text{CEI}}$, i.e. for a larger additional acetabular roof formed by the *ala ossis ilii* segment (see also Fig. 1).

Fig. 5 shows the size of the weight-bearing area $A$ for different centre–edge angles $\theta_{\text{CEI}}$ after the operation. The individual contributions, i.e. the contribution of the *ala ossis ilii* osteotomy segment $A_{\text{roof}}$ and the contribution of the acetabulum $A_{\text{acei}}$, are
also given. It can be seen that the operation significantly increases the weight-bearing area in the medial region of the acetabulum. This indirect contribution to the increase in the weight-bearing area is several times larger (for example, four times at $\theta_{\text{CE2}} = 20^\circ$) than the direct one $A_{\text{roof}}$ and, for larger $\theta_{\text{CE2}}$, exceeds even the size of the weight-bearing area before the operation.

The effect of the width of the additional femoral roof on the average peak stress $p_{\text{max}}$. The value of $\theta_r = 90^\circ$ is the limit of the intact hip ($A_{\text{roof}} = A_{\text{CE2}}$).

By using the methods described above, we determined the relevant geometrical parameters, the magnitude and the inclination of the resultant hip force, the peak stress and the weight-bearing area for 29 hips that underwent the Chiari operation. We also determined the corresponding quantities for 29 healthy hips. As there were no data on the weight of the patients, we present the peak stress normalised by the body weight. The results are shown in Table 1. The normalised resultant hip force $R/W_B$ on average is $3.14$ (SD = 0.26) before the operation, $3.18$ (SD = 0.39) after the operation and $2.71$ (SD = 0.17) in normal hips. There is no statistically significant difference between the values of $R/W_B$ before and after the operation ($p = 0.64$), whereas the differences between the group of normal hips and both groups of operated hips (before and after the operation) are statistically significant ($p < 0.005$).

Analysis of the roentgenographs showed that the Chiari osteotomy considerably and statistically significantly decreases

The normalised peak stress $p_{\text{max}}/W_B$. However, the average normalised peak stress after the operation is higher than the average normalised peak stress in the population of normal hips. The normalised peak stress $p_{\text{max}}/W_B$, on average, is $8310$ m$^{-2}$ (SD = 4021 m$^{-2}$) before the operation, $4480$ m$^{-2}$ (SD = 2575 m$^{-2}$) after the operation and $3540$ m$^{-2}$ (SD = 845 m$^{-2}$) in normal hips (Table 1). The difference between the groups before and after the operation is statistically significant ($p < 0.005$), whereas the difference between the group after the operation and the group of normal hips is not statistically significant ($p = 0.7$).

The size of the weight-bearing area is $12.63$ cm$^2$ (SD = 5.00 cm$^2$) before the operation, $20.31$ cm$^2$ (SD = 6.69 cm$^2$) after the operation and $19.40$ cm$^2$ (SD = 3.65 cm$^2$) in normal hips. The difference between the groups before and after the operation is statistically significant ($p < 0.005$), whereas the difference between the group after the operation and the group of normal hips is not statistically significant ($p = 0.5$).

### 4 Discussion
The hypothesis was tested that increasing the operative coverage of the femoral head where it is deficient should decrease the contact stress in the hip joint. By calculating the contact stress distribution of the hip before and after the Chiari osteotomy, in the present work, we provide evidence in favour of this hypothesis. Favorable clinical results have also been reported (MIGAUT et al., 1995; NISHINA et al., 1990; OSEBOLD et al., 1997; REYNOLDS, 1986; WINDHAUSER et al., 1991) in accordance with this hypothesis.

Our theoretical results presented in Figs 4 and 5 indicate that the Chiari osteotomy increases the weight-bearing area directly, owing to additional coverage by the ala nasis ili, and indirectly, owing to an increase in the weight-bearing area on the medial side. The indirect effect occurs owing to the shift of the stress pole in the medial direction. The increase in the weight-bearing area due to the shift of the stress pole in the medial direction is represented in Fig. 5 by the difference between $A_{\text{roof}}$ and the initial $A$ (broken line).

It can be seen in Fig. 6 that the wider roof reduces the stress more effectively; however, the effect exhibits saturation, so that values of $\theta_r$ higher than about $30^\circ$ bring no significant additional improvement. This is owing to low values of stress at the edge of the weight-bearing area far from the pole.

The indirect effect of the Chiari osteotomy in increasing the weight-bearing area is even more important than the direct effect, as it causes the relief of stress at those parts of the weight-bearing area where the stress is the highest before the operation (Fig. 4). Besides lowering values of the stress in these regions of the weight-bearing area, the gradient of contact stress on the lateral border is also decreased. This may be of
importance as the contact stress gradients are related to fluid flow in the articular cartilage and may therefore directly influence tissue remodelling ( BRAND, 1997).

Hipel et al. (1999) estimated the weight-bearing area for dysplastic hips and for normal hips. The weight-bearing area was obtained as a portion of the sphere that lies within the edges defined by the digitalisation of the acetabular rim and the acetabular notch. A three-dimensional reconstruction of the acetabulum and femur was obtained from computed tomographic data. They found that the average weight-bearing area was about 13 cm² in dysplastic hips, which is in agreement with our results, and about 18 cm² in normal hips, which is smaller than our value (Table 1). However, in our sample of normal hips, the average centre–edge angle was somewhat larger (35°) than in the sample of Hipp et al. (32°), and this can be considered to be the reason for the differences observed between the values of the weight-bearing area of normal hips.

We took into account that the size of the weight-bearing area at a given body position is consistently related to the stress distribution and is not simply a morphological parameter. The stress distribution and the size of the weight-bearing area are different in different body positions and activities. In this work, we analysed (Figs 3–6) the peak stress and the size of the weight-bearing area for a given magnitude and direction of the resultant hip force. The analysis could be further upgraded by considering that the magnitude and the direction of the resultant hip force change with time, for example during gait ( BRAND et al., 1994; PEDERSEN et al., 1997; IPAVEC et al., 1999). However, during gait, the effective centre–edge angle, if measured in the laboratory co-ordinate system, changes owing to swinging of the pelvis. For reasons of simplicity, the contact stress distribution was therefore calculated in the pelvic co-ordinate system, where the contact stress distribution represents the loading of the acetabulum (IPAVEC et al., 1999).

For the purpose of this study, we adjusted the HIJOMO computer program for determination of the geometrical parameters (Zupanc et al., 2001; Keršnik et al., 1997) by determining an additional centre–edge angle. There are still unresolved problems with the precision of the determination of the radius of the femoral head. The program fits the profile of the femoral head by a circle using the least squares method. However, the heads of dysplastic hips can deviate considerably from the spherical. It seems that the radius of the articular sphere is somewhat underestimated, as the head of the dysplastic hip is flattened, and therefore, in effect, the distance to the centre of rotation is increased.

Although this biomechanical study was inspired by the Chiari osteotomy, the main result regarding the augmentation of the weight-bearing area due to the shift of the stress pole can be generalized to any hip osteotomy that affects the stress distribution. It is shown in this work that a small increase in the weight-bearing area in the region of high stress can cause a considerable shift of the stress pole and therefore a change in stress distribution. This causes an increase in the weight-bearing area that can be several times larger than the direct increase in the weight-bearing area.

There may be an additional effect of the Chiari osteotomy due to the medial or lateral shift of the femoral head center (JOHNSON et al., 1979; IGLIĆ et al., 1993c; Delp et al., 1990). It was suggested (ANTOLIĆ et al., 1996) that it is favourable if the femoral head center is moved medially and, in this way, the resultant hip force (JOHNSON et al., 1979; SIKAR et al., 1992; IGLIĆ et al., 1993c) and the hip contact stress (Ilić et al., 1993a) can be substantially reduced. The present clinical study indicates that there is no change, on average, in the magnitude of the resultant hip force after the operation. This is in agreement with previous measurements, where no average shift of the interhip distance could be found (ANTOLIĆ et al., 1996).

The Chiari osteotomy can also cause a shift of some muscle attachment points. Therefore the length of the muscles and the maximum available muscle forces can change after the operation (Delp et al., 1990; IGLIĆ et al., 1993c).

During the stance phase of slow gait, the accelerations are not significant (McLEISH and CHARNELEY, 1970), and the vertical floor reaction force is nearly constant for a period (Charneley and Pusso, 1968). Therefore the one-legged stance is important, not only in its own right, but also owing to its resemblance to the stance phase of slow gait (McLEISH and CHARNELEY, 1970). In addition, it was also indicated that the peak hip stress during the midstance phase of gait is related linearly to peak hip stresses in all phases of gait, as well as to some other activities such as abduction, external rotation and flexion (Hipp et al., 1999). Therefore, in the present clinical study, the distribution of the contact hip stress was calculated in the static one-legged stance, which is considered to be a representative body position. For this body position, the geometrical parameters required as input data for the mathematical models described can be estimated from standard anteroposterior roentgenographs (Daniel et al., 1999), which can be taken from the archives. No additional measurements on patients are therefore required.

5 Conclusions

In this paper, the effect of the Chiari osteotomy on the distribution of the contact hip stress was studied using a mathematical model. It was shown that the Chiari osteotomy can substantially increase the weight-bearing area and, consequently, decrease the contact stress in the hip joint. Based on the present theoretical study, it was concluded that the Chiari osteotomy can increase the weight-bearing area directly, owing to the additional area formed by the acetabulum segment, and indirectly, owing to the shift of the stress pole in the medial direction. The indirect effect is important and usually larger than the direct one. Using the proposed mathematical model and standard anteroposterior roentgenographs from the archives, it was also shown on a population of 29 dysplastic hips that the contact stress considerably decreases after the Chiari osteotomy.

In conclusion, our results indicate that the redistribution of stress after Chiari osteotomy can yield biomechanically favourable effects, so that the biomechanical state of the hip approaches the situation in the normal hip. From this point of view, the Chiari hip osteotomy is a successful operation and should be considered as a possibility for preserving the patient’s own hip as long as possible (Brand, 1997; Mills et al., 1995).

Acknowledgments—The authors are indebted to L. Zaletel-Kragelj for performing the statistical analysis and to D. Tomasević for the graphics used for presenting the results in Fig. 4. The software HIPSTRESS can be obtained from the authors free of charge.

References


Author's biography

SLĘCZKO HERMAN joined the Department of Orthopaedic Surgery and finished his specialist training in 1970. He obtained his PhD in 1977 and became a Professor of Orthopaedic Surgery in 1983. From 1980 to 1997 he was the head of the University Department of Orthopaedic Surgery in Ljubljana. Since 1996 he has been head of the chair of Orthopaedics at the University of Ljubljana. His special fields of interest are prosthesis hip and knee replacement and biomechanics.