

Received: 2006.XX.XX
Accepted: 2006.XX.XX
Published: 2007.XX.XX

Hip joint contact stress as an additional parameter for determining hip dysplasia in adults: Comparison with severin's classification

Authors' Contribution:

- A** Study Design
- B** Data Collection
- C** Statistical Analysis
- D** Data Interpretation
- E** Manuscript Preparation
- F** Literature Search
- G** Funds Collection

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Source of support: Slovenian Research Agency, project No. J3-6198-0381-06

Summary

Background:

The hip's biomechanical state affects its future development. Therefore, a relevant biomechanical evaluation would be of use in assessing hip dysplasia. Recently, a noninvasive method was developed to determine stress on the weight-bearing area of the hip. The biomechanical assessment was compared with Severin's radiographic classification.

Material/Methods:

Standard anteroposterior radiographs, taken prior to surgery, of 35 adult patients who were treated for hip dysplasia were analyzed. The AP radiographs of 59 hips were classified into groups 1–3 according to Severin's classification. The geometrical and biomechanical parameters of the hips within each of Severin's groups were compared.

Results:

The differences between the mean peak stress on the weight-bearing area of the hip and the peak stress normalized to body weight of both the first and second groups compared with the third group were highly statistically significant. All three of Severin's groups had stress readings ranging from 2 to 4 MPa.

Conclusions:

This study shows that, in general, the biomechanical results corresponded to the results obtained by Severin's evaluation; however, when assessing an individual hip, important differences may be present. Since all of Severin's groups had a stress reading ranging from 2 to 4 MPa, it would be useful to determine the hip's stress distribution when determining treatment.

Key words:

hip • dysplasia • hip stress • severin • coxarthrosis • radiograph

Full-text PDF:

<http://www.medscimonit.com/fulltxt.php?IDMAN=9497>

Word count:

XXXX

Tables:

1

Figures:

2

References:

30

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BACKGROUND

Hip joint osteoarthritis is a common disabling condition in the population [1]. There are many factors that contribute to hip osteoarthritis [2]. It has been found that increased hip joint stress in dysplastic hips can be responsible for the development of coxarthrosis [3–6]. Surgery is thought to establish a more favorable distribution of stress in the hip joint and thereby slows down or prevents the development of coxarthrosis [7–9]. Therefore, an objective measurement is required in order to decide whether or not a particular hip requires surgery. Furthermore, it is important to determine which geometry would yield the most favorable long-term effect [3]. A method for determining hip stress in individual patients would thus help guide treatment; however, no such method has been developed as yet for use in clinical practice. The most commonly used methods for evaluating dysplastic hips are radiographic methods that consider mainly the shape of the pelvis and the proximal femur. These methods are based on clinical experience and are also believed to reflect hip stresses. According to Severin [11], hips can be classified into six groups based on the center-edge angle of Wiberg (∂_{CE}), the age of the patients, and the degree of (in)congruence between the femoral head and the acetabulum. The center-edge angle of Wiberg evaluates the degree of lateral coverage of the femoral head; it is formed by the line that runs parallel to the longitudinal body axis and by the line that connects the center of the femoral head and the edge of the acetabular roof [12]. Severin's groups 1, 2, and 4 are further divided into subgroups a and b. Group 1a consists of hips that have a normally shaped femoral head and an acetabulum in which ∂_{CE} is larger than 25° . Group 2a consists of hips that have a moderately deformed femoral head or neck or an acetabulum in which ∂_{CE} is larger than 25° . Group 1b consists of hips that have a normally shaped femoral head and acetabulum in which ∂_{CE} is from 20° to 25° . Group 2b consists of hips that have a moderately deformed femoral head or neck or an acetabulum in which ∂_{CE} is from 20° to 25° . Group 3 consists of hips in which ∂_{CE} is smaller than 20° . Group 4a consists of moderately subluxated hips with ∂_{CE} positive or equal to zero. Group 4b consists of moderately subluxated hips with a negative ∂_{CE} . Group 5 consists of hips in which the femoral head articulates with a secondary acetabulum in the upper part of the original acetabulum, while group 6 consists of dislocated hips [11].

Previous studies found that in dysplastic conditions where ∂_{CE} is small or negative, hip joint contact stress is higher than in hips with a larger ∂_{CE} ; however, stress can also be higher due to a higher or a too vertical resultant hip joint force [13–15]. The direction and magnitude of the resultant hip joint force \mathbf{R} depends, among other factors, on the femoral and pelvic geometry [3,16]. It has been suggested that a computer model could be useful for guiding clinical decision-making to determine optimal treatment [15,17–20]. The influence of both the ∂_{CE} and \mathbf{R} are expressed by the contact stress distribution. Some recent studies indicate that the distribution of the contact stress is the most important biomechanical parameter for predicting successful hip development [20,21].

Over the last 10 years, our group has developed a relatively simple and validated method for determining contact stress

distribution that uses data obtained from standard anteroposterior radiographs [22–24]. This method is based on a mathematical model of the resultant hip force in the one-legged stance [16] and on the mathematical model of the hip stress [14] (a detailed description of both models is given in [23]). It was found that the most important factor that determines hip stress is ∂_{CE} [14]; however, body weight and other geometrical parameters of the hip and pelvis also influence hip stress distribution [24]. Furthermore, the method has been proven to be clinically relevant for evaluating the long-term clinical status of hips after osteotomies for aseptic necrosis of the femoral head [25] and after Bernese osteotomy [26]. This method has also been used to analyze the effect of the Salter innominate osteotomy [27] as well as the Imhauser and Dunn-Fish operations for severe slipped capital femoral epiphysis [28].

To determine whether and to what extent the parameters according to Severin's classification reflect the biomechanical state of the hip, the results of both evaluations should be compared. In this study, we determined the peak stress in the hip joint weight-bearing area and the peak stress normalized to body weight for non-subluxated hips that had been evaluated according to Severin's radiographic method. Thus we studied the extent to which our method reflects the clinical experience embodied in Severin's classification and the extent that Severin's classification reflects the biomechanical state of the hip.

MATERIAL AND METHODS

We retrospectively analyzed standard anteroposterior radiographs of the hip and pelvis of 35 consecutive adult patients (30 female, 5 male) who had been treated in the Department of Orthopedic Surgery, University Medical Center, Ljubljana, from 1980 to 1989 due to unilateral/bilateral residual hip dysplasia. Twenty-seven patients underwent unilateral and 8 patients bilateral total hip replacement. All radiographs that were analyzed were taken prior to surgery using the same protocol and with the patient in the supine position. The patients' mean age at the time the radiographs were taken was 32 years (range: 18–50 years). Both hips (70 hips) were analyzed in all patients. The mathematical model used to calculate hip stress [14] assumes that the femoral head and the acetabulum are congruent in the unloaded state. However, this assumption is clearly not fulfilled in subluxated and dislocated hips; therefore, the 11 subluxated or dislocated hips were excluded from the study (groups 4a, 4b, 5 and 6). Thus the final sample consisted of 59 congruent hips. Based on Severin's classification, there were 9 hips in group 1, 11 in group 2, and 39 in group 3. Hips in groups 1 and 2 were not divided into subgroups a and b.

Peak contact stress in the weight bearing area of the hip (p_{max}) was calculated using a computer program, HIPSTRESS [22,23]. The program consists of two procedures: one for determining the hip-joint contact stress distribution and the other for determining the resultant hip joint force \mathbf{R} . The input data for the program HIPSTRESS are the magnitude and the direction of the resultant hip joint force, the radius (r) of the hip joint articular surface, and ∂_{CE} . The resultant hip joint force is determined based on geometrical parameters: the interhip distance (l), the pelvic height (H), the pelvic width (C), the coordinates (z , x) of the effective points

Table 1. Geometrical parameters of Severin's three groups and body weight.

	∂_{ce} (degrees)	r (cm)	H (cm)	C (cm)	x (cm)	z (cm)	L (cm)	Wb (kg)
Severin's group 1 n=9	25 min 21 max 29	2.6 min 2.4 max 3.1	15 min 13.6 max 16	5.1 min 3.8 max 6.1	1 min -0.7 max 6.2	6.2 min 5 max 7.1	20.8 min 19.3 max 22.8	66 min 54 max 79
Severin's group 2 n=11	24 min 20 max 30	2.7 min 2.4 max 3	14.4 min 11.5 max 15.4	5.4 min 4.5 max 6.5	1.6 min 2.5 max 3	5.8 min 5 max 6.7	21 min 18.4 max 22.6	70 min 56 max 91
Severin's group 3 n=39	12 min 0 max 19	2.6 min 2.4 max 3.1	14.7 min 11.4 max 16	4.7 min 3.2 max 6.3	1.5 min -0.7 max 3	5.6 min 4.5 max 7.5	20.6 min 18.4 max 22.5	67 min 54 max 82

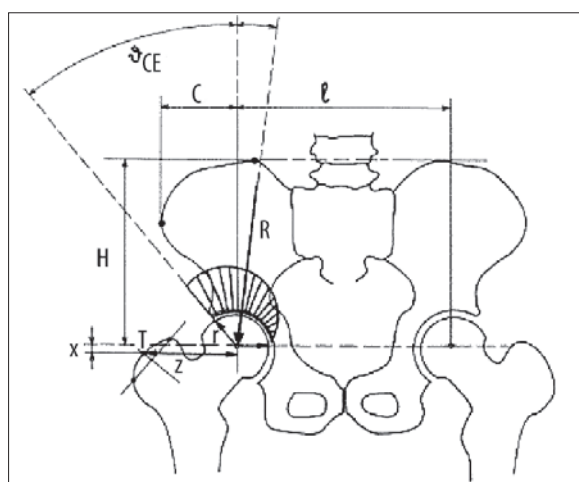


Figure 1. The geometrical parameters used for determining the resultant hip joint force (**R**) include: interhip distance (**l**), pelvic height (**H**), pelvic width (**C**), and coordinates of the muscle attachment point (**T**) on the greater trochanter (**z** and **x**), and the center-edge angle of Wiberg (l_{ce}).

(**T**) of muscle insertion on the greater trochanter, and the body weight (**Wb**) [24] (Figure 1). The geometrical parameters are assessed on standard anteroposterior radiographs using the computer-aided system HIJOMO [29]. An average magnification rate of 10% was taken into account.

Figure 1: The stress distribution is presented by the maximal value of p_{max} and also by the peak stress calculated with respect to the body weight (p_{max}/Wb), which reflects the effect of hip geometry.

Students' *t*-test was used to compare differences in p_{max} and p_{max}/Wb between Severin's groups 1, 2, and 3. A power analysis was performed, and a two-sided *p* of 0.05 was set as the level of significance.

RESULTS

Table 1 shows the mean geometrical parameter values and body weights in Severin's groups 1, 2, and 3.

Table 1: The values of ∂_{ce} and the geometrical parameter *z* were higher in Severin's group 1 than in Severin's group

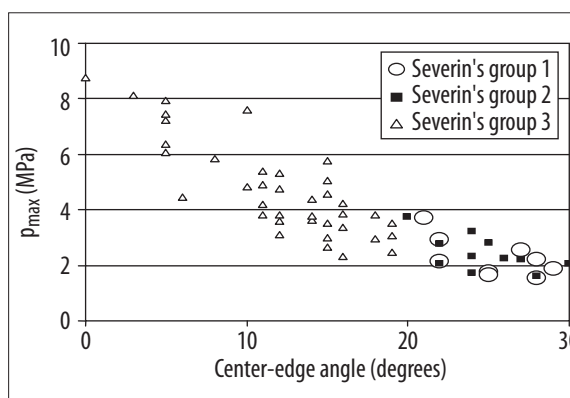


Figure 2. Dependence of p_{max} on l_{ce} for hips in all three Severin's groups. The values of Severin's group 1 are indicated with empty circles, Severin's group 2 with full squares, and Severin's group 3 with empty triangles.

3 ($p < 0.0001$ and $p = 0.02$, respectively). Higher values of ∂_{ce} ($p < 0.0001$), geometrical parameter *C* ($p = 0.006$), and geometrical parameter *r* ($p = 0.04$) were found in Severin's groups 2 than in Severin's group 3. None of the geometrical parameters were statistically significantly different between Severin's groups 1 and 2. However, the number of subjects in these groups was small; thus, type II error is possible. Body weight was not statistically different among the three Severin's groups.

The peak stress was calculated for the three Severin's groups. In the first group (Severin's groups 1a and 1b), the mean p_{max} was 2.3 (range: 1.5–3.7) MPa, while in the second group (Severin's groups 2a and 2b) the mean p_{max} was 2.4 (range: 1.6–3.7) MPa; the difference between these two mean values was not statistically significant ($p = 0.6$). However, the number of hips in the two groups was small; thus, type II error is possible. The mean p_{max} was 4.9 (range: 2.3–10) MPa in the third group (Severin's group 3). There was a highly statistically significant difference between the mean p_{max} of the first and second groups compared to the third group ($p < 0.001$).

p_{max}/Wb was determined for the three Severin's groups. The mean p_{max}/Wb was 3512 (range: 2128–5559) m^{-2} in the first group, 3543 (range: 2505–5074) m^{-2} in the second group, and 7243 (range: 3129–13493) m^{-2} in the third group. The

difference in the mean values between the first two groups was not statistically significant ($p=0.9$). However, the number of hips in the groups was small, giving rise to a possible type II error. In contrast, the differences between the mean p_{\max}/Wb of the first and second groups compared with the third group were highly statistically significant ($p<0.001$).

Figure 2 shows the dependence of p_{\max} on ∂_{CE} for hips from all three Severin's groups.

Figure 2: An overlap of the Severin's groups in the range from 2 to 4 MPa can be seen. This interval included 5 of 9 (56%) hips from Severin's group 1, 9 of 11 (82%) hips from Severin's group 2, and 18 of 39 (46%) hips from Severin's group 3.

DISCUSSION

Our results show that Severin's group 1 hips have significantly smaller p_{\max} and p_{\max}/Wb values compared with Severin's group 3 hips. Severin's group 2 hips also have significantly smaller p_{\max} and p_{\max}/Wb compared with Severin's group 3 hips. These results support the presence of a correlation between Severin's classification and the biomechanical analyses. Our results also show that the Severin's groups 1 and 2 hips have p_{\max} and p_{\max}/Wb values that are not statistically significantly different. The geometrical parameters of these two groups were also not statistically significantly different. However, the number of hips in Severin's groups 1 and 2 was small; therefore, type II error is possible when comparing these two groups. It is possible to distinguish between Severin's groups 1 and 2 on the basis of descriptive data, but these data are subjective, and their interpretation depends on the experience of the examiner. In general, higher peak stress is seen in the higher Severin's groups. Therefore, on a population level, our method appears to reflect the clinical experience embodied in Severin's classification, and Severin's classification reflects the biomechanical state of the hip.

However, when decisions need to be made for particular patients, it is not so straightforward. There is considerable overlap of p_{\max} values among the three Severin's groups. Figure 2 shows that the interval of p_{\max} between 2 and 4 MPa includes hips of all three of Severin's groups. This means that in hips grouped according to p_{\max} , some of the Severin's group 3 hips would have lower p_{\max} values than some of the hips that are considered to be normal based on Severin's classification. The overlap is due to the effect of geometrical hip and pelvis parameters other than ∂_{CE} . It has been reported that a large femoral head, a small inter-hip distance, and a laterally extensive greater trochanter are favorable with respect to peak stress [24]; they may, therefore, partly compensate for the effect of a smaller ∂_{CE} . We found that there were differences between Severin's groups 1 and 3 in the lateralization of the greater trochanter. While with very small ∂_{CE} (such as for example 5°) the compensation by other parameters is rather small, there is a region of ∂_{CE} between 15° and 25° where the effect of the other geometrical parameters may be sufficient to make a distinction between healthy and diseased hips [15].

The mathematical model used in this study does not account for deviations in the shape of the femoral neck, head,

and acetabulum that distinguish Severin's groups 1b and 2b from the corresponding groups 1a and 2a. Also, in its present form the model cannot be used to describe subluxated and dislocated hips. Previous studies suggest that after acetabular osteotomy, dysplastic hips undergo morphologic changes with acetabular subchondral bone formation and spontaneous enlargement of the acetabulum [30]. These changes may be the result of changes in the stress distribution and weight-bearing area, as predicted by our model.

CONCLUSIONS

While on a population level the biomechanical results are correlated with Severin's classification, important differences may be found when assessing individual hips. In the range of ∂_{CE} between 15° and 25° , the stress distribution should be determined to help determine optimal management.

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