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The assessment of contact stress in the hip joint after operative treatment for severe slipped capital femoral epiphysis

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Abstract We determined contact stress on the articular surface of the hip joint in a group of patients who underwent operative treatment for severe slipped capital femoral epiphysis. Two different procedures were considered: the modified osteotomy of Dunn-Fish and the osteotomy of Imhäuser. In order to determine the stress distribution, a three-dimensional mathematical model was used taking into account the geometrical parameters of the pelvis and hip, which were measured from standard antero-posterior radiographs. We found that the Dunn-Fish procedure produced lower peak stress than the Imhäuser procedure.

Résumé Nous avons determiné la pression sur la surface articulaire de la hanche dans un groupe de patients operés pour épiphysiolyse femorale supérieure. Deux opérations ont été considereés: l'opération de Dunn-Fish modifieé et l'ostéotomie d'Imhäuser. Pour déterminer la distribution des pressions, un modèle mathématique tridimensionel a été employé, tenant compte des paramétres géometriques du bassin et de la hanche, obtenus à partir des clichés antéro-postérieurs. Nous avons trouvé que dans les hanches opérées par la procedure de Dunn-Fish modifiée les pics de pression sont inférieurs à ceux dans les hanches opérées par la technique d'Imhäuser.

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Introduction

Slipped capital femoral epiphysis (SCFE) is a disorder of early adolescence with separation between the epiphysis and the metaphysis of the femoral neck. The epiphysis remains in the acetabulum, while the femur rotates externally and posteriorly. Most authors recommend one of two approaches in the surgical treatment of severe SCFE, namely the osteotomy of the femoral neck described by Dunn and Fish [7, 8] and the intertrochanteric osteotomy described by Imhäuser [15] (Fig. 1).

In the Dunn-Fish procedure, a wedge, usually near the epiphyseal plate (Fig. 1A,B) is resected and in the Imhäuser procedure, a wedge is resected in the intertrochanteric region (Fig. 1A,C). In both cases the distance between the muscular insertions on to the greater trochanter and the centre of the femoral head is altered. The deformity caused by SCFE is corrected with the Dunn-Fish procedure whereas another compensatory deformity is produced by the Imhäuser procedure. Thus, the alteration of the geometry with respect to the normal hip joint is greater with the Imhäuser procedure than with the Dunn-Fish procedure.

The morphology of the hip and pelvis determines the contact stress within the weight bearing area of the hip joint. The significance of the distribution of contact stress within the hip joint as an important factor in the evaluation of the biomechanical status of the hip in different degenerative joint conditions has been described [10, 23, 24]. The prediction of optimal stress distribution produced by a certain surgical procedure may improve its success [2, 4, 12, 21]. The biomechanical effect of the different operative techniques in the treatment of SCFE may be estimated in terms of the postoperative value of the maximal contact stress on the weight bearing area (p_{max}) within the hip joint [12, 16]. The aim of this study was to compare the value of the peak contact stress (p_{max}) after the Dunn-Fish osteotomy with that after the Imhäuser osteotomy.

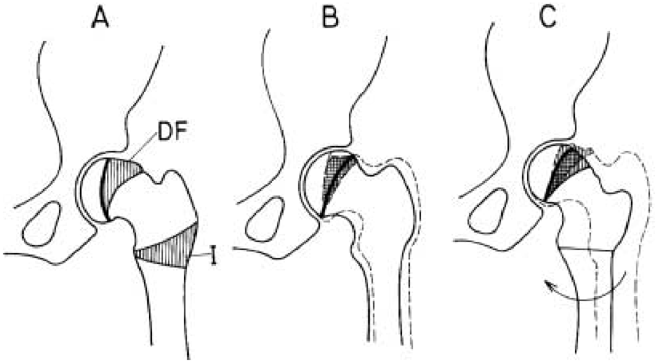

Fig. 1A–C Schematic presentation of the Dunn-Fish and of the Imhäuser operations. **A** *Shading* indicates the wedge on the femoral neck that is to be resected in the Dunn-Fish (*DF*) procedure (callus) and the wedge on the proximal femur that is to be resected in the Imhäuser (*I*) procedure. The geometry **B** after the Dunn-Fish procedure and the geometry **C** after the Imhäuser procedure are shown. *Thin lines* depict the situation before the operation. The *arrow* indicates derotation of the distal fragment

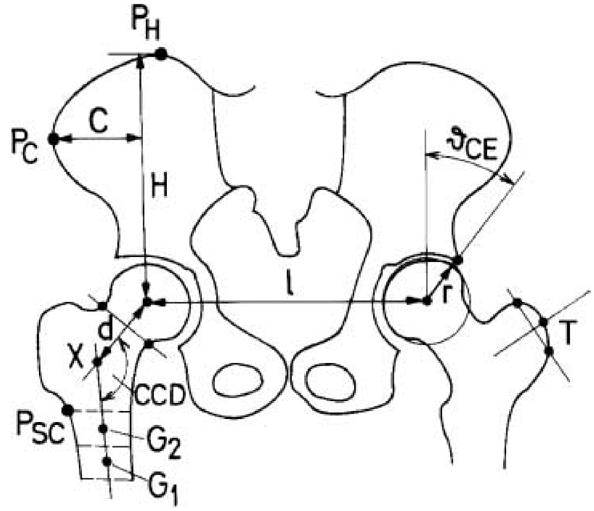

Fig. 2 Schematic presentation of geometrical parameters of hip and pelvis determined by the programme HIJOMO as described under Patients and methods. All the parameters should be taken at the operated side

Patients and methods

The medical records of 78 patients with moderate or severe SCFE who underwent surgical treatment with either the modified Dunn-Fish procedure or the Imhäuser procedure between 1970 and 1994 in the Department of Orthopaedic Surgery at Ljubljana were studied. The records included standard anteroposterior radiographs of the pelvis and both proximal femora. Patients were entered into the study if they fulfilled the following criteria: (a) the presence of a pre-operative slip greater than 50°, measured as the angle between the axis of the femoral shaft and the base of the capital epiphysis on frog-leg lateral views (according to Southwick [25]); (b) no radiographic evidence of aseptic necrosis of the femoral head or of degenerative arthritis of the hip joint; (c) available anteroposterior radiographs of the pelvis and proximal femora after removal of the internal fixation; (d) the absence of other operative procedures of the hips, and of neurological conditions.

In the group treated with the Dunn-Fish procedure there were initially 42 patients. Of these, 19 were boys and 23 were girls. The mean age at diagnosis was 13.1 years [9–16.4 years; standard deviation (SD)=1.7 years]. The mean time between the operation and removal of the fixation device was 2 years (0.6–4.3 years; SD=1 year). According to the Loder classification of SCFE [22], 29 hips were stable, 13 unstable, 16 acute, 6 acute on chronic and 20 chronic. According to the Boyer classification of SCFE [3], 40 were severe and 2 moderate. The mean displacement of the femoral epiphysis measured on frog-leg lateral radiographs was 61° (30°–90°; SD=9°). In this group we excluded 13 hips because they did not fulfill the criteria a–d as described above.

In the group treated with the Imhäuser procedure there were initially 36 patients. Of these, 19 were boys and 17 were girls. The mean age at diagnosis was 13.4 years (9.6–16.6 years; SD=1.3 years). The mean time between the operation and removal of the fixation device was 2.1 years (0.9–5.5 years; SD=1.1 years). According to the Loder classification 31 were stable, 5 unstable, 10 acute, 1 acute on chronic and 25 chronic. According to the Boyer classification 33 were severe and 3 moderate. The mean displacement of the femoral epiphysis measured on frog-leg lateral radiographs was 54° (40°–60°; SD=5°). We excluded eight hips from the study for not fulfilling our criteria. Thus our final study group comprised 29 hips treated by the modified Dunn-Fish procedure and 28 hips treated by the Imhäuser procedure. The follow-up time varied from 2 to 6 years.

Measuring technique The computer programme HIPSTRESS [11] was used to calculate the contact stress distribution within the hip joint. The geometrical parameters were determined directly from the standard antero-posterior (AP) radiographs. The HIP-STRESS programme consists of two procedures: one for the determination of the hip joint contact stress distribution [12, 16] and the other for the determination of the resultant hip joint force **R** [13, 14]. The procedure for the measurement of the hip joint contact stress distribution [11, 12, 16] requires as input data the magnitude and direction of the resultant hip force **R**, the radius of the articular surface of the hip joint (r) and the centre-edge angle of Wiberg (ϑ_{CE}; Fig. 2). The force R was calculated by the programme based on a three-dimensional mathematical model of the hip joint in the one-legged stance [13, 14]. This programme requires as an input the distance between the centres of the two femoral heads (l), the co-ordinates of the effective points of muscle insertion on to the greater trochanter, with respect to the centre of the femoral head (point T), the height of the pelvis (H), the horizontal distance between the most lateral point on the iliac crest and the centre of the femoral head (C), and the body weight (W_B). The reference values of the model muscle attachment points [6] are rescaled in order to adjust for the configuration of the hip and pelvis of the individual patient [1]. Thus the values of l, H and C and the position of point T from AP radiographs for each patient are recorded.

The values of the geometrical parameters, l, H, C, point T, r and ϑ_{CE}, were measured from the AP radiograph by using the computer programme HIJOMO as described in detail elsewhere [17, 19]. We digitised the profile of both proximal femora and acetabulae and the characteristic points: the highest and most lateral point of the iliac crest (P_H and P_C, respectively), and the point determining the symmetric region of the femoral canal (P_{SC}; Fig. 2). Fitting the appropriate part of the profile of the proximal femur and using the least squares method we measured the radius of the femoral head. The effective muscle insertion into the greater trochanter (T; Fig. 2). was obtained from the intersection of the profile of the greater trochanter and the symmetral to the line connecting its highest and most lateral points. The capitatocolodiaphyseal angle was obtained by determining the directions of the femoral canal and of the neck. The length of the digitised profile of the proximal femur below the point P_{SC} was divided into two parts. The "gravity centres" of the profiles of both parts were calculated (marked in Fig. 2 by G_1 and G_2, respectively). The line connecting these two centres determines the direction of the femoral canal. The direction of the neck was determined by the least distance between both sides of the profile of the neck. The length of the femoral neck is the distance between the centre of the femoral head and the point X (Fig. 2). A mean magnification of 1.1 of the X-ray pictures was taken into account.

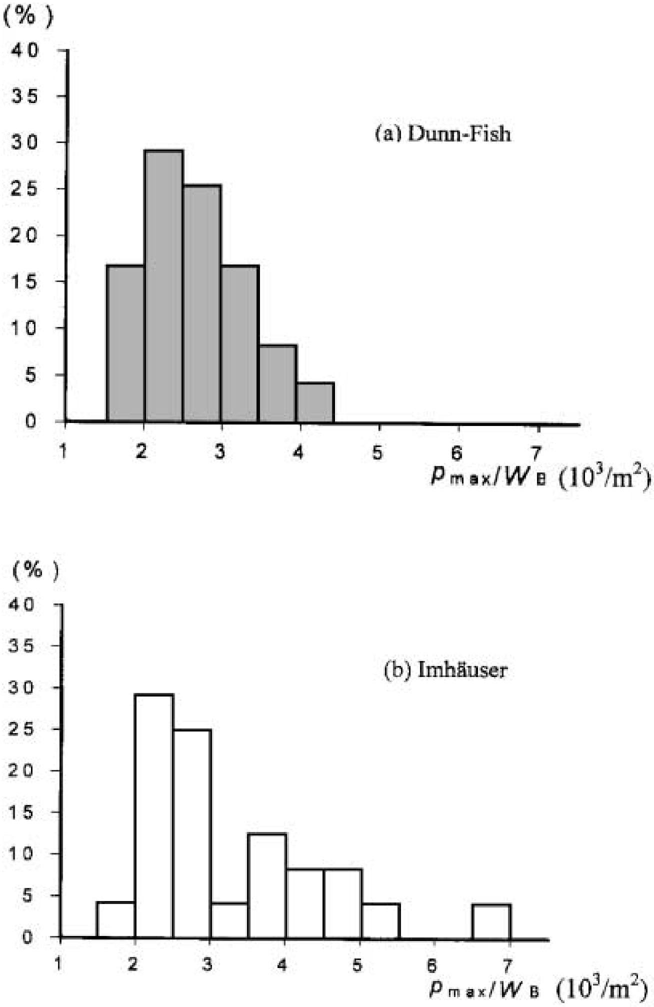

Fig. 3 Peak stress in the weight bearing surface normalised with respect to the body weight p_{max}/W_B **a** after the modified Dunn-Fish procedure and **b** after the Imhäuser procedure

We determined the contact peak stress normalised with respect to the body weight p_{max}/W_B. The normalised peak stress p_{max}/W_B and some geometrical parameters of the hip were analysed using statistical methods. The *t*-test and the Mann-Whitney test were used to compare the parameters in the two groups.

Results

We compared p_{max}/W_B after the Imhäuser procedure with that after the modified Dunn-Fish procedure. The respective histograms are shown in Fig. 3. The mean p_{max}/W_B after the Imhäuser procedure is 3277 m^2 (1975–6581 m^2) while the mean p_{max}/W_B after the Dunn-Fish procedure is 2699 m^2 (1682–4346 m^2). The standard deviation in the Imhäuser group is 1179 while the standard deviation in the Dunn-Fish group is 683. There are thus considerable differences in the mean values as well as in the variances. The *P*-value that gives statistical significance by the *t*-test assuming unequal variances is 0.024. As the distribution in the Imhäuser group deviates from the normal we also performed the nonparametric test. The median value p_{max}/W_B in the Imhäuser group (2991 m^2) is higher than that in the Dunn-Fish group (2597 m^2). The *P*-value that gives statistical significance by the Mann-Whitney test is 0.079. This would be expected for a test with smaller power than the *t*-test. However, the assumption of equal distributions (except for the location) for the Mann-Whitney test is in our case also not met.

The average length of the femoral neck after both osteotomies was smaller than in the contralateral hip. In the Dunn-Fish group the mean length on the operated side was 16 mm (1–26 mm; SD=5 mm) and 27 mm (11–36 mm; SD=6 mm) on the contralateral side. In the Imhäuser group, the mean length on the operated side was 20 mm (7–36 mm; SD=7 mm) and 26 mm (10–48 mm; SD=8 mm) on the contralateral side. In the analysed postoperative cases treated by the Imhäuser procedure we found that the mean capitatocolodiaphyseal (CCD) angle of the femoral neck (144°; 124°–171°; SD=10°) was higher than on the contralateral side (138°; 113°–154°; SD=10°).

Discussion

The determination of hip stress is limited by the precision of the measurements of the geometrical parameters. Assuming that the femoral head centres are levelled, we could not say from the X-rays, for example, how far the highest point on the iliac crest lies posteriorly, as determined by the rotation of the pelvis. However, in determining the peak stress, not all the parameters are equally important, as the functional relations between them are non-linear. Within the validity of the model we estimated that there would be up to 10% error due to lack of three-dimensional information from the radiographs. Furthermore, as there was no length standard present whilst taking the X-rays (e.g. a metal sphere of a known radius), an error is introduced with different magnifications for each patient. In another study X-rays of the normal hips taken with the length standard have been considered [26]. It was found that the magnification may vary from 1.1 to 1.3. However, distribution of the magnification was normal. Thus, when considering the two groups, the magnification would not affect the relative difference between the mean or median values, but would rather increase the noise and cause the statistical significance of the difference between the groups to be smaller. Thus, in our opinion, our results indicate that the Dunn-Fisher group exhibits lower stress than the Imhäuser group.

Direct measurement of the contact stress distribution within the hip joint during gait and in other activities has so far only been performed in a single subject with an implanted partial endoprosthesis which included a stress measuring device [20]. For non-operated hips, external laboratory measurements in combination with simulations or mathematical models can produce global predictions of stress distribution during gait [5, 16]. However, in clinical practice, simpler mathematical models [9, 12] may also be useful for estimating stress distributions; and such methods could be suitable for the routine planning of surgical treatment. However, the effect of the postoperative change of femoral and pelvic geometry should be considered [12, 13, 14, 18, 21, 24].

Although our results indicate that the modified Dunn-Fish procedure yields a more favourable biomechanical outcome (lower p_{max}/W_B), this is only one of many aspects relevant to the result. Both operative procedures are technically demanding and the outcome is determined by surgical technique. Nevertheless, as we have shown, the geometrical parameters of the pelvis and femur should be considered, and this may be especially important in patients who are overweight or whose hips are dysplastic.

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