International Orthopaedics (SICOT) (2010) 34:329–333
DOI 10.1007/s00264-009-0769-2

ORIGINAL PAPER

A computer model for evaluating the osteotomy parameters of Chiari pelvic osteotomy

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Received: 7 November 2008 / Revised: 23 February 2009 / Accepted: 24 February 2009 / Published online: 8 April 2009

Abstract This study was conducted to evaluate the effect of the various osteotomy parameters on the biomechanical aspects of the hip joint on a computerised model. The data of the radiographs and a three-dimensional (3D) CT scan of six patients with coverage deficient hip joint were used to construct a 3D computer model. Then Chiari type osteotomies were simulated using various heights, angles and fibrocartilage thicknesses. A new angle called the mid acetabular center edge (MACE) angle was defined in a mid coronal CT cut. The optimum displacement for obtaining the maximum coverage averaged 73%. The angle and height of the osteotomy had a significant effect on the MACE angle (*P* value<0.01). Our findings of these Chiari parameters may change the results of the osteotomy. The probability of adapting the proximal osteotomy segment to a deformed femoral head was explained by the model and a modified osteotomy "multiple height osteotomy" was proposed.

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Introduction

Chiari medial displacement osteotomy is a salvage procedure that cuts the cancellous bone of ilium and interposed hip joint capsule to deepen the deficient acetabulum. The major goals of this osteotomy are to delay osteoarthritis of the hip and, finally, total hip replacement. In spite of long-term follow-up studies, there are many controversies about the best way to do the osteotomy and its final outcome [1–7]. These different results may be due to varying surgical techniques and shapes of the osteotomy.

Although there are many articles about the biomechanics of normal and dysplastic hips, studies about biomechanical and geometrical changes after hip osteotomies seem to be lacking.

Our aim in this study was to evaluate the effect of the various osteotomy parameters on the biomechanical aspects of the hip joint after simulated Chiari osteotomy in a three-dimensional (3D) computer environment.

Materials and methods

Anteroposterior, false profile radiographs and three-dimensional (3D) CT scans of six patients with coverage deficient hip joints were taken. There were five dysplastic hips and one multiple epiphyseal dysplasia (MED) of the hip joint. For 3D computer modelling of the hip joint, digital CT images with DICOM (digital imaging and communications in medicine) files were converted to 3D STL (standard template library) files with Data Manager V2.8.2 software. The models were constructed and manipulated using SolidView V2006.1 software. Eight coronal cuts of the hip joint were obtained 5 mm apart from each

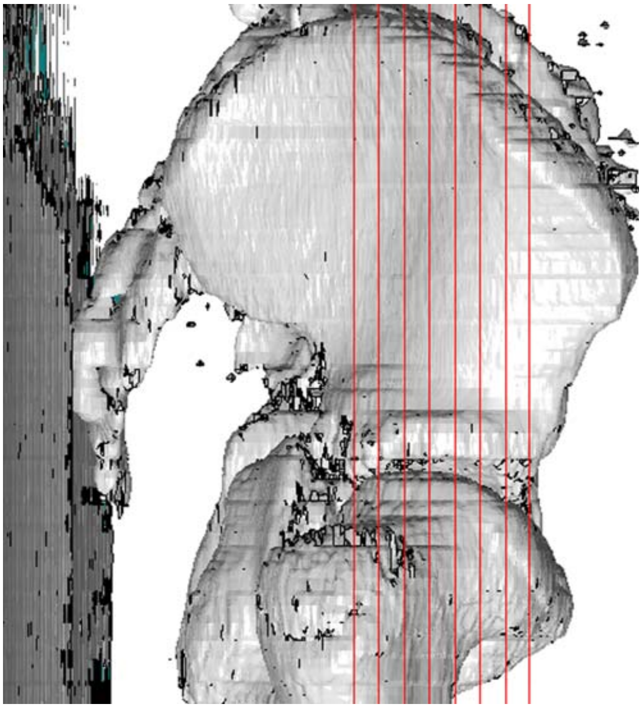

Fig. 1 Eight coronal cuts of the hip joint to determine the effect of the osteotomy in different parts of the acetabular roof

other (Fig. 1) to evaluate femoral head coverage in different areas of the acetabular roof.

Above the acetabular rim, the curved Chiari type osteotomy was simulated at different heights from the rim (1–5 mm) and different angles (10–30° with a 5° angle apart from each other). So, for each coronal cut, 25 different osteotomy parameters were tried.

Chiari pelvic osteotomy uses capsular fibrocartilage between new bony roof and the femoral head cartilage. The potential of the hip capsule to change its thickness may be different in every patient, so the fibrocartilage thickness after the osteotomy was assumed at 2, 4 and 6 mm. And for each thickness, a separate calculation was considered. So for each coronal cut 3×25=75 options were considered.

The distal fragment of the hip joint was displaced medially until the maximum coverage of the femoral head was obtained. The optimum displacement for maximum coverage averaged 73%. In one patient with a severe anterior exposure of the femoral head and a marked femoral anteversion, the femoral head coverage was not possible and the patient was excluded from the analysis.

The mid acetabular center edge angle (MACE angle) was defined and measured on a mid acetabular coronal cut. This angle may be different from the classic center edge (CE) angle of Wiberg which was also measured and averaged on AP hip radiograph by two senior orthopaedic surgeons and one radiologist.

By this computer simulation, the percentage of femoral head coverage, weight bearing (WB) contact area and MACE angle before and after each osteotomy were calculated (Table 1). The data was analysed with Spearman's correlations and ANOVA test (SPSS V14.1).

Results

Considering there were five patients available, 75×5=375 virtual osteotomies were simulated. Among these osteotomies, only 156 osteotomies (41%) increased weight bearing contact area of the hip joint. When the main parameters of the osteotomies were studied relating to these legitimate osteotomies, the height of the osteotomy was more important than angle of the osteotomy (mean height of legitimate osteotomies was 2.2 mm but for the others was 3.6 mm (*P* value<0.001). The angle of the osteotomies was not different between the two groups.

There was no significant correlation between plain X-ray CE angle (Wiberg CE Angle) with MACE angle and the primary WB contact area (*P* =0.95). Conversely, there was a high correlation between the primary WB contact area and primary MACE angle (*rho* =0.9, *P* <0.001). So MACE angle is a more reliable indicator of the deficient WB contact area. There was a negative correlation between the primary

Table 1 Hip geometric parameters before virtual osteotomy

Patient	Diagnosis	WB contact area (mm^2)	Femoral head uncoverage ratio	MACE angle	CE angle
1	DDH	1394.28	0.2762	24	32
2	DDH	676.52	0.4338	4	31
3	MED	893.52	0.4121	15	17
4	DDH	1239.48	0.1353	36	31
5	DDH	876.82	0.2651	14	28

WB weight bearing, *MACE* mid acetabular center edge, *CE* center edge, *DDH* developmental dysplasia of the hip, *MED* multiple epiphyseal dysplasia

WB contact area and the contact pressure on the hip joint (*rho* =−0.83, *P*<0.001).

In the simulated model, the angle of the osteotomies had a significant correlation with new MACE angle (*rho* =0.46, *P* =0.01), but there was no significant relation between osteotomy angle and secondary WB contact area.

Also the level of the osteotomy (distance from rim of acetabulum) had a significant negative correlation with secondary WB contact area but not with the MACE angle (*P*<0.001). Increasing the osteotomy level significantly decreased the area of new WB contact area (*rho* =−0.32, *P*<0.001) (Fig. 2). Conversely, increasing the osteotomy level, mildly increased the pressure on the hip joint (*rho*=0.25, *P*=0.004) (Fig. 3).

Increasing the assumed fibrocartilage thickness significantly increases the area of secondary WB contact area and decreases the contact pressure on the hip joint (*rho*=−0.42, *P* <0.001, *rho*=−0.24, *P*<0.001).

With a higher primary WB contact area (less dysplastic hip joint), the new WB contact area and new MACE angle will be greater after simulated Chiari osteotomy (*P*<0.001).

There was no entry of the osteotomy line to the sacroiliac joint even in a 30-degree angle osteotomy.

Discussion

The ideal Chiari osteotomy was described as making an angle of 10º upwards, immediately above the hip joint capsule and displaced by 50% of the pelvic width [8]. Sticking to the technical details of the operation has been considered by most of the reports to be the guarantee to successful outcome [9–11].

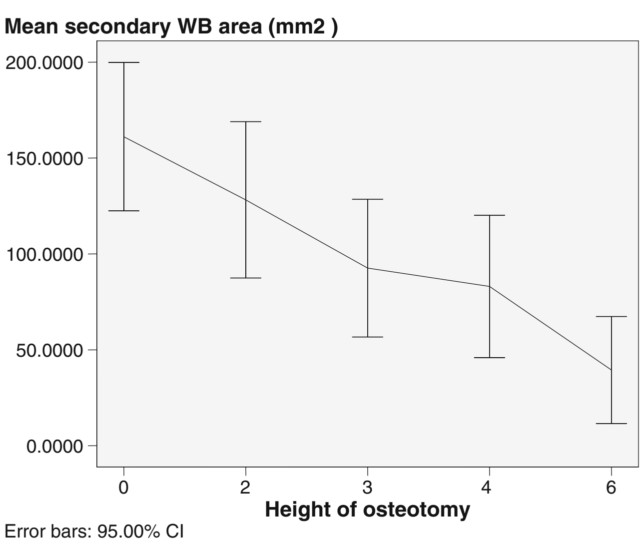

Fig. 2 Increasing the height of the osteotomy from the acetabular rim will decrease the weight bearing contact area of the joint

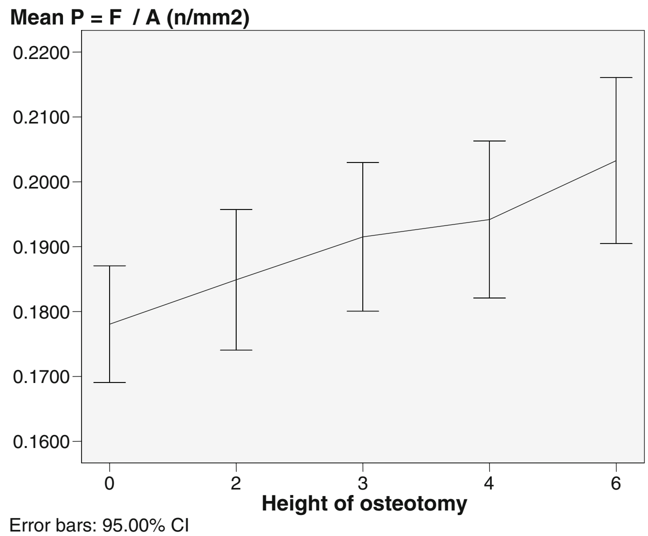

Fig. 3 Increasing the height of the osteotomy will increase the contact pressure of the hip joint

Results in children, related to the study of an anatomical model of the pelvis, demonstrate that the Chiari osteotomy is unable to give much coverage to the anterior part of the femoral head [12]. Interestingly in our study, one patient had a severe anterior exposure of the femoral head, whereby the femoral head coverage was not possible with these simulated cuts and the patient was excluded from the analysis. On the other hand, among 375 osteotomies, only

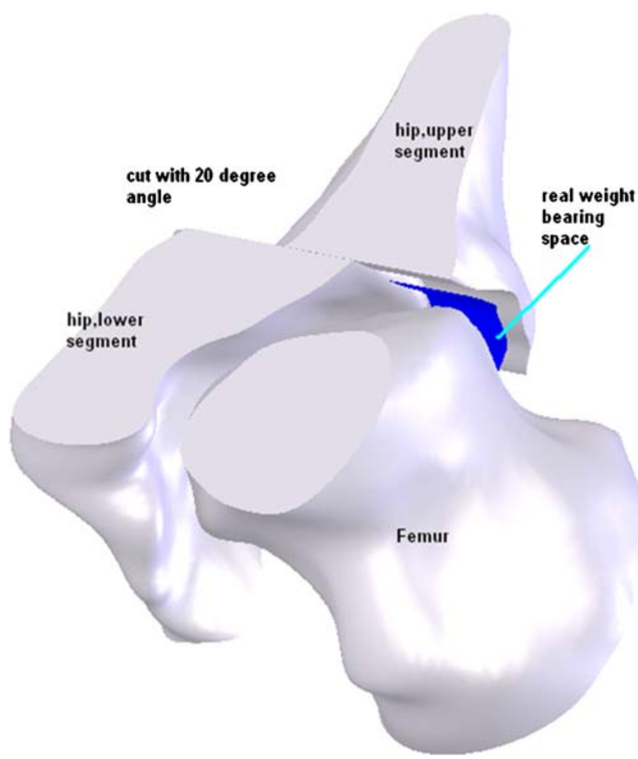

Fig. 4 A "multiple height curved osteotomy" could cover a deformed femoral head without impingement

156 osteotomies resulted in an increase of the weight bearing contact area (41%). To have a legitimate Chiari osteotomy, the height of the osteotomy was the most important factor (mean height 2.2 mm, $P<0.001$).

In this study a new term "mid acetabular CE (MACE) angle" was defined very similar to the Wiberg CE angle but in a mid coronal CT cut. There was no significant correlation between standard CE angle of Wiberg and this new CE angle. This difference is due to the fact that classic Wiberg CE angle is measured on an AP hip X-ray which is not a real indicator of the hip coverage as a whole and it may change according to patient position, but MACE angle is measured directly on a mid coronal CT cut, which means an average of AP hip coverage. In contrast to the Wiberg CE angle, there was a high correlation between the primary WB contact area and primary MACE angle ($rho=0.9$, $P<0.001$).

The level of the osteotomy and the amount of displacement are the most important factors that influence the prognosis [13–15]. The level of the osteotomy line was classified by Azuma et al. [16], which involves four zones on the anteroposterior radiograph and four zones on the lateral radiograph. According to Matsuno et al. [17], the average clinical result was good in 74 (84%) of the 88 patients in whom the osteotomy was at the level of less than 10 mm from the acetabular rim. This may be due to the negative effect of the level of the osteotomy on the new WB contact area according to our simulated surgery ($P <$ 0.001). Also, the results will be different than shown in this study even in the Azuma zones I and II (height less than 10 mm). The osteotomies with height less than 3 mm are more crucial than the other factors.

A computer simulated model of the osteotomy revealed that increasing osteotomy level causes higher pressure on the WB area, probably due to lesser new shelf area, which is the cause of the poor results.

According to this 3D model, the final thickness of fibrocartilage interposed tissue after the osteotomy is essential to increase the congruency of new shelf area; thus, determining this thickness may be important in final clinical results. Høgh and Macnicol [18] and Calvert et al. [19] confirmed that better function was achieved if the hip was operated upon when the patient was younger. The potential power of the interposed capsular tissue to convert to a thick fibrocartilage tissue may be a reasonable explanation of their results. Iliescu et al. [20] also showed this favourable effect after the osteotomy. They stated that this new and larger contact zone, over time, is due to the recovery and remodelling of the bone tissue. According to a study by Nakano et al. [21], labrectomy with Chiari osteotomy may adversely affect long-term results possibly due to a reduction in the volume of the interposed soft tissues. In the simulated model, the angle of the osteotomy had a significant effect on new MACE angle ($P=0.01$) but there was no significant relation between osteotomy angle and secondary WB contact area. This means that false increase of the CE angle in a high-angled osteotomy produces a large hole in the weight bearing area and possibly a femoroacetabular impingement (FAI) syndrome.

Colton reported that displacing a Chiari osteotomy more than 50% can cause substantial problems with bone healing [22]. In this study, the distal fragment of hip joint was displaced medially until the maximum coverage of the femoral head was obtained. The optimum displacement for obtaining the maximum coverage averaged 73%. More than this amount of displacement will not cover the hip joint and would also have the problem of the bone healing.

For one patient with MED, the curved type Chiari osteotomy was changed minimally to better cover the femoral head and to prevent FAI syndrome. The probability of abutting the proximal osteotomy segment to the deformed femoral head during medial displacement is high, especially in low-level osteotomies. A "multiple height osteotomy" is a simple solution to this problem. It is better that the height in the mid coronal area is above the anterior and posterior margins of the acetabulum (Fig. 4).

Conclusion

Computer modelling of the hip joint can determine the level and angle of the osteotomy and amount of the medial displacement of the lower segment to decrease the probability of unexpected contacts of bone and cartilage, to reduce high pressure on the hip joint and to increase the effective WB area. Computer modelling of the Chiari osteotomy revealed that the height of the osteotomy is the most important factor to produce better results. Precise evaluation of the femoral head deformity is mandatory to change the shape of the osteotomy. A standard osteotomy in such cases will lead to FAI syndrome and poor results.

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