Effect of Dega Osteotomy on the Biomechanics of the Hip Analyzed with the Method of Finite Element Analysis

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Introduction: Hip osteotomies are performed in the treatment of developmental hip dysplasia for anatomical reconstruction of the deformity. Dega osteotomy is an acetabuloplasty indicated in childhood treatment. In this study we performed a finite element analysis of the hip in order to clarify the effect of the Dega osteotomy on biomechanics of the dysplasic hip.

Material and methods: We used the CT data from two children: one with normal hip for reference, and one with dysplasia of the left hip. After the reconstruction of the geometrical models for normal, dysplasic, and post-Dega osteotomy hips, we made a finite element analysis for each model, using hexahedral elements.

Results: In our postoperative model the intrarticular pressure decreased from 5.7 MPa in the dysplasic model to 3.5 MPa. The acetabular contact area in the post-osteotomy model increased two times compared to the dysplasic model.

Conclusions: The positive effects of the Dega osteotomy on the biomechanics of the dysplasic hip is proved in the size and shape of the postoperative contact areas, which are almost the size and shape of the normal hip.

Keywords: hip biomechanics, developmental hip dysplasia, finite element analysis, Dega osteotomy

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Introduction

Developmental hip dysplasia is an abnormal condition in which the hip joint architecture results in the decreased supportive property of the joint, which can lead to secondary osteoarthritis of the hip. Hip osteotomies are performed for the anatomical improvement of the joint. Several surgical procedures have been described in order to improve the coverage of the femoral head. The reconstruction osteotomies are directional acetabular osteotomies (complete cuts of the pelvic bones and redirecting the acetabulum – Steel, Tönnis, LeCoeur, Salter) or acetabular reshaping osteotomies (incomplete cuts by hinging on different parts of the triradiate cartilage – Pemberton, Dega) [1–5].

The indications of the type of osteotomy are determined by the severity of the dysplasia and the age of the patient. Evaluation of the results of hip osteotomies takes years of postoperative follow-up, clinical and radiological evaluation of the treated patient. With mathematical model construction and finite element analysis of the reconstructed complex structure we can have immediate results from the behavior of the analyzed structure. In the field of medicine the finite element method was first applied in hip prosthesis design, and biomechanical study of the bone structure [6].

Dega osteotomy is one of the acetabular reconstructive surgeries performed in the treatment of acetabular dysplasia in patients with developmental dysplasia of the hip under 12 years of age [7]. It is an acetabuloplasty that changes the shape and the dimensions of the acetabulum in order to restore the normal connection between the acetabulum and the femoral head. The purpose of this study is to determine the effect of Dega osteotomy on the biomechanics of the hip with the help of finite element analysis, compared to the normal hip biomechanics.

Materials and methods

Because the accuracy of analysis of biomechanical responses depends on structural geometry and material properties, it is important to develop a model that is as close to biological conditions as possible. Subject-specific finite element models of bones derived from computer tomography (CT) data is a non-invasive method to reconstruct the hip area. We used the CT data from the hip of two patients: the right hip from an 8 year-old boy with normal hip, and a left hip from a 12 year-old girl with Tönnis 3 grade hip dysplasia. From the CT slices we have constructed the geometrical model of the two pelvises. In the tridimensional model construction we have distinguished between cortical bone, trabecular bone, cartilage, and the contact nonlinearities of the joint.

To create the cartilage surface in the joint we have elevated each cortical bone: acetabular and femoral head with half of the distance between them: 1.5 mm.

For the geometric model construction of the Dega osteotomy we used the surgical technic described. We have begun the level of virtual Dega osteotomy in line with 15 mm above the acetabular rim, following the contour of the acetabulum and extended from the anteroinferior iliac spine to the greater ischiatic incisura. It passed toward the triradiate cartilage and stopped just above it. The medial cortex was not resected. We lowered the acetabulum by placing it distal and abducted from the initial position privileging an anterior, lateral, or posterior coverage. We

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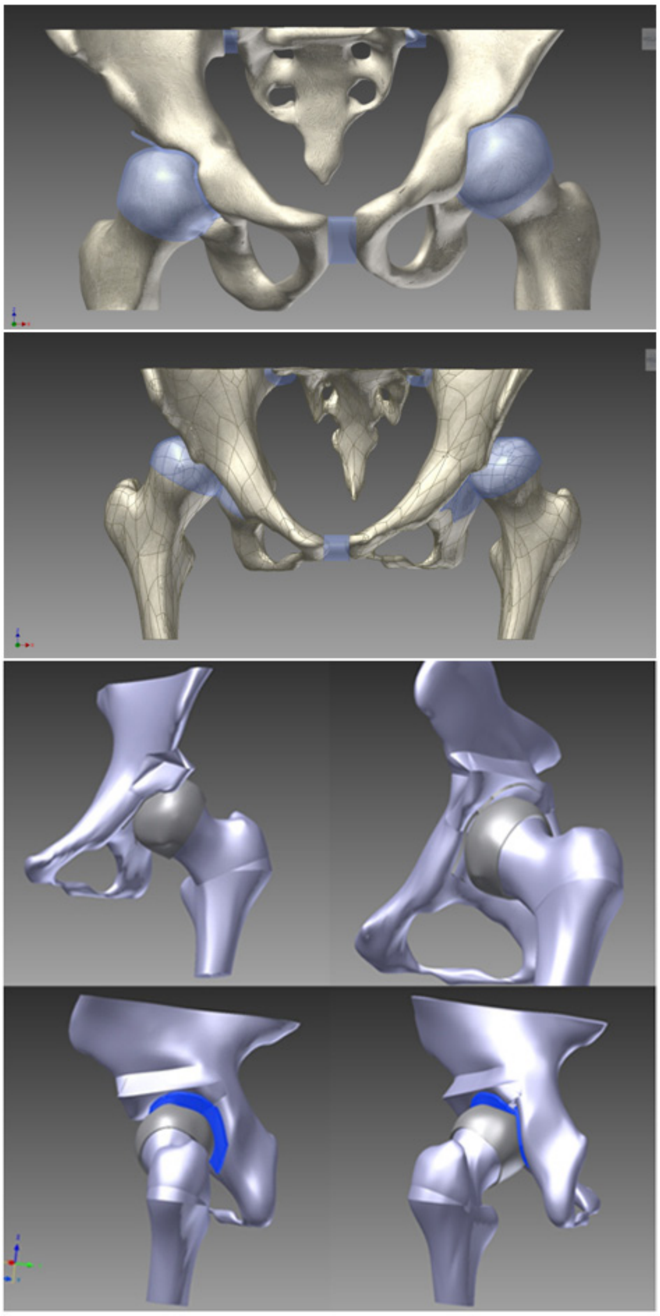

Fig. 1. **The geometrical models: normal, dysplasic, post-Dega osteotomy**

filled the osteotomy gap with a material with identical properties with the bone tissue. After modelling the bone, we created the joint cartilage in a similar method like in the normal and dysplastic hip geometric model. In the dysplasic hip the femoral head-diaphysis angle was 140°, we simulated a Pauwels varisation femoral osteotomy, creating a 120° femoral head-diaphysis angle. We have also simulated

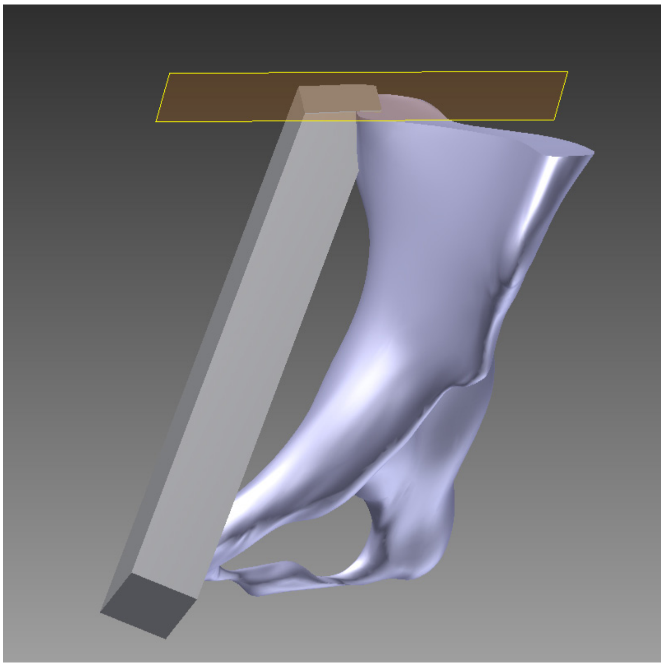

Fig. 2. **The suspension bony bridge**

a virtual hip reposition by placing the femoral head down with 2 mm in X coordinate, 2.5 mm in Y coordinate, and 2.1 mm in Z coordinate, achieving the best possible femural head coverage. In the geometrical construction we have not changed the position and the orientation of the pelvis, and the orientation of the femural component (Figure 1).

For vertical loading we created a suspension bridge between the medial margin of the iliac joint line and the medial part of the pubic bone. The material characteristics of the bone bridge were similar with bone material characteristics (Figure 2).

For the finite element analysis of models we used the Autodesk Inventor 2009 software. Linear solid hexahedral elements were used to form the meshes of the cortical bone, trabecular bone, cartilage. A total of 29,907 hexahedral elements and 55,627 nodes were used in the normal hip model, 27,594 hexahedral elements and 51436 nodes in the dysplasic model, and 3129 hexahedral elements and 57,392 nodes in the virtual osteotomy model. The number of elements and nodes used for different anatomical structures are described in Table I.

The used loading conditions were the single-leg stance calculated from the weight of the patients. A mount of vertical load was placed on the superior aspect of the iliacal-pubic bone bridge: 240 N for the normal hip model, and 320 N on the hip dysplasic and the post- osteotomy mod-

Table I. **Numbers of elements and nodes used for finite element analysis**

Nr. nodes/ elements	Cortical bone pelvis	Trabecular bone pelvis	Cartilage pelvis	Cortical bone femur	Trabecular bone femur	Cartilage femur	Mash
Normal hip	20,147/11,233	9,787/5,007	2,104/1,000	10,528/5,710	6,440/3,596	4,576/2,298	55,627/29,907
Dysplasic hip	16,635/8,978	8,328/4,500	1,695/802	11,630/6,341	5,852/3,255	5,031/2,500	51,436/27,594
Dega + Pauwels osoteotomy	19,536/10,666	10,007/5,469	1,789/814	13,331/7,370	6,945/3,970	3,519/1,784	57,392/31,291

Table II. Material properties

	Density (g/cm³)	Young	Poisson	Yield tensile strength (MPa)	Yield compressive strength (MPa)	Ultimate tensile strength (MPa)	Ultimate compressive strength (MPa)
Cortical bone	1.05	11.22 GPa	0,3	35	62	114	135
Trabecuar bone	0.60	5.33 MPa	0,2	7	15	30	80
Cartilage	1.1	0,6 MPa	0,45	1	1.5	4.4	20

el. Simulated abductor force was applied over the middle gluteal muscle attachment and the great trochanter of the femur.

With regard to the boundary condition, the joints of the sacral mount were fixed on the transverse plane, and the distal end of the left femur was fixed in all directions.

Results

To understand the efficiency of the hip osteotomies we compared the results of the finite element analysis with the values from the normal hip model.

The distributions of von Mises stress in hemipelvis in the normal hip joint model showed a band of stress distribution from the sacro-ilacal joint through the femoral head to the Adams arch on the femur. In the dysplasic hip model the von Mises stress distribution was different from the normal model, with a stress concentration and value elevations up to 8.5 MPa in the area of contact between the subluxed femoral head and the superior margin of the bony acetabulum. The maximal values of the von Mises stress were measured in the fixed points between the bone bridge and iliac bone and in the femoral Adams arch 8.5 MPa. The von Mises stress values in the cortical bone of the femoral head were 2.9 MPa in the normal hip model. The distributions of von Mises stress of in each hip model are shown in Figure 3.

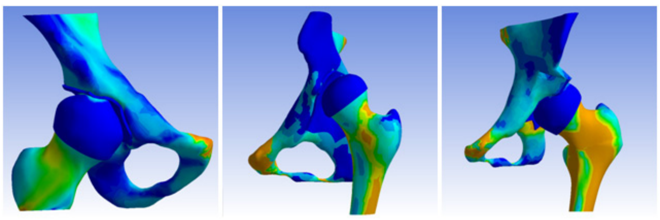

Fig. 3. The distribution of von Mises stress: normal, dysplasic, post-osteotomy

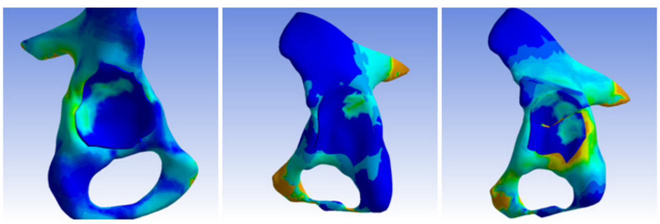

Fig. 4. The distribution of von Mises stress in the acetabulum: normal, dysplasic, post-Dega

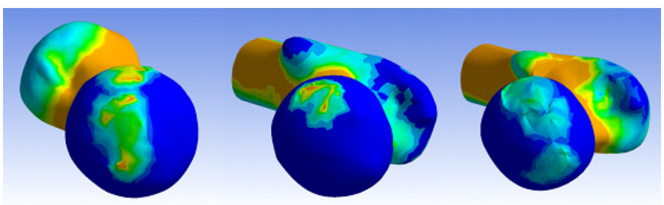

Fig. 5. The distribution of von Mises stress in the femural heads: normal, dysplasic, post-Dega

In the acetabulum and acetabular cartilage the von Mises stress showed a bean shaped distribution in the antero-superior-posterior region. The acetabular dysplasia model showed a stress concentration in the acetabular superior margin in a smaller area compared to the normal hip joint. In the post-osteotomy model the contact area in the acetabulum was bigger than in the dysplasic model, and almost reached the size and shape of the contact area in the normal model. The measured contact areas in the acetabulum are showed in Table III for each hip model.

The distributions of von Mises stress of in each acetabulum model without the femur are shown in Figure 4.

In the normal hip model the von Mises stress distribution in the femoral head showed a uniform distribution over the entire head. The acetabular dysplasia model showed a stress concentration in a smaller area in the medial part of the femoral head corresponding to the areas of contact with the acetabular edge. The von Mises stress distribution in the post-osteotomy model were similar to that observed in the normal hip joint model. The distributions of von Mises stress in each femoral head are shown in Figure 5.

Discussions

To the best of our knowledge there are very few studies in the literature regarding the finite element analysis of the pediatric dysplasic hip, and this is the first study investigating the effects of the Dega osteotomy on the biomechanics of the hip with the help of finite element analysis. The main cause of this is the small number of children pelvic CT data, and the leak of data in children bone material properties. Most of the finite element analysis studies were made for adult hips for hip arthroplasties, revision arthroplasties.

Table III. Acetabulum contact areas

	Contact area in the acetabulum (mm^2)
Normal hip model	471,672
Dysplasic hip model	205,272
Post-Dega hip model	408,619

Zhao et al created a finite element model of a dysplasic hip from a normal adult hip using the MSC.Marc/Mentat2005r3 software. They performed a virtual corrective pelvic Ganz osteotomy on that model. In their results the intrarticular pressure decreased in the post-osteotomy model and the contact area increased almost to the size in the normal model [12]. In our model the Dega pelvic osteotomy had the same effect. In the acetabulum the localization of the contact area in the post-osteotomy model moved from marginal to central distribution and increased in size, but had not reached the normal pattern. The results were considerably better than in the dysplasic model.

Armiger et al used a discrete element analysis of the hip in adult to evaluate the postoperative results after Ganz osteotomy. They used triangular elements in their method, and demonstrated that the intrarticular contact area increased with an average ratio of 1.4 [13]. In our postoperative model the intrarticular pressure decreased to 3.5 MPa from 5.7 MPa in the dysplasic model. The results of previous studys demonstrated no significant differences when using sufficient numbers of linear or quadratic, tetrahedral or hexahedral elements [14,15].

For children pelvis Kim et al constructed a subject specific finite element model in slipped capital femoral epiphysis and in Legg-Perthes-Calve disease. They simulated a virtual Shelf osteotomy for Legg-Perthes-Calve disease model, a varus osteotomy in slipped capital femoral epiphysis model and biomechanical analysis with finite element method for all of their models. They used MRI findings to reconstruct the cartilaginous surface. We used the method that Anderson et al. had proved that the construction of the articular cartilage can be done with god accuracy by elevating the cortical bone of the articular components in the leak of MRI data [16]. In the postoperative model constructed by Kim et al. for Legg-Perthes-Calve disease the values of von Mises stress decreased and the intrarticular contact area increased. In the postoperative femur osteotomy model for slipped capital femoral epiphysis the contact area increased, but the localization remained pathological [17,18].

Conclusions

Finite element analysis offers early postoperative results without operating on patients. The advantages of subject specific modelling are that the surgeon can be prepared to the particularity of bone deformity in different patients. After constructing the geometric model the biomechanical finite element analysis offered the possibility to clearly visualize the benefits of the performed virtual osteotomy in hip dysplasia. The applied surgical treatment method improved the values of the analyzed biomechanical characteristics: the von Mises stress intra articular contact area in the analyzed finite element model. Using this method we demonstrated that the Dega pelvic osteotomy, combined with varisation femoral osteotomy in our model is an effective method to treat the developmental hip dysplasia in children younger than 12 years of age. In our opinion this method can be applied for preoperative planning in hip osteotomies in the treatment of developmental hip dysplasia.

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