ANYAGVIZSGÁLÓK LAPJA Elektronikus folyóirat
MINŐSÉGBIZTOSÍTÁS * ÁLLAPOTELLENŐRZÉS 2009/1

METHODOLOGY OF PREPARATION OF FETAL BONE STRUCTURES FEM MODEL

Jakub Słowiński[1], Roman Frątczak[1], Maciej Panek[1], Alicja Kędzia[2], Wojciech Kołosowski[2]

***Kulcsszavak**: koponyacsont, kulcscsont, lapockacsont,véges elemes módszer, magzati cso*ntok*
***Keywords**: skull, clavicle, scapula, FEM, fetal bones*

ÖSSZEFOGLALÁS

A felnőtt emberi csontszerkezet modellezése relatíve könnyű, főként az orvosi diagnosztikai adatok széleskörű és könnyű hozzáférhetősége következtében. Ennek ép ellenkezője a magzati csontozat. A vizsgálatokhoz nem áll rendelkezésre halott magzati alanyok és nincs lehetőség annak láthatóvá tételére sem a Mikro Számítógépes Tomográfia (µCT) és a röntgen besugárzás, valamint a nem lehetségesek a roncsolásos módszerek. Halott magzati csecsemőkön a roncsolásos technikát alkalmazták. A csontokat műanyaggyantába ágyazták és a keresztmetszetükről pásztázó illetve normál felvételeket készítettek és ezeket 3 dimenziós modellekké dolgozták fel. Ezt a csont szerkezeti modellt használták fel méret független a további munkában: a további vizsgálatokhoz, mint például gyors szemléltetésére a geometriai viszonyoknak és a véges elemes numerikusszámításokhoz.

Ezt a módszert használták koponyacsontok, kulcscsontok, lapockacsontok 3 dimenziós szemléltető modelljeinek előállítására és a véges elemes mechanikai számításokhoz.

ABSTRACT

Modelling of adult human bone structures is relatively easy to perform, mainly because of the wide and easy accessibility to medical diagnostics data that is well developed nowadays. In opposition to that is modelling of fetal bone structures. Difficult access to get the fetal cadaver and also lack of possibility of medical visualization using Micro Computed Tomography (µCT) or X-Rays expositions lead to use another, destructive techniques of modeling. One of these techniques was used in presented study is preparing cross-sections of bone specimen embedded in resin, then by scanning (or photographing) each slices and image processing the three dimensional virtual model of bone specimen can be achieved.

Obtained bone-structures models can be used to develop accurate copies of the model with unrestricted scaled size and number for further investigations like rapid prototyping, geometrical (medical) visualization and numerical analysis (finite element method).

As a effect of the works, three dimensional virtual models of skull bone, clavicle and scapula bones were developed. These models were used to perform mechanical numerical analysis using finite element method (FEM).

1 - Wrocław University of Technology; Wrocław, Poland
2 - Wrocław Medical University; Wrocław, Poland
Jakub Słowiński
Institute of Material Science and Applied Mechanics
Smoluchowskiego street 25
Wrocław, 50-370 Poland
Tel. +48 (71) 3202899
Fax +48 (71) 3211235
E-mail Jakub.Slowinski@pwr.wroc.pl

INTRODUCTION

Finite element analysis of skull, clavicle and scapula provides the possibility of estimation of mechanical factors influence on disturbances during delivery. This kind of investigations was not used till now for trauma of bone structures during delivery evaluation. The most dangerous complications come out during delivery is due to nerve system trauma, that is frequently durable and remains lameness. The prematurity problem should be discussed separately. In the early stage of life there are anatomical differences (connected with growing process) in central nervous system, that are significantly exposed to mechanical, septic and hypoxia factors action.

In the last months of fetal life, the largest changes have place in central nervous system. Brain hydration is relatively large, so in case of injury cause widespread trauma. Premature delivery cause initiation of brain strokes due to vessels damages. During delivery, head of premature infant with not fully ossificated skull can be easily damaged during movement through fertile canal. It is possible that flow stagnation in basin of large Galen's vein can occur as soften of white matter. It is combination of hemodynamic disturbances, hypoxia, that cause habitat acidify, veins extension and blood flow deceleration- that favours of creation haemorrhage or thrombus with secondary extravasations.

It was denoted [1], that fetal infants brain prove large tumid promptitude that might cause changes in periventricular surroundings. In other investigations [2], on 75 fetal specimens (from 10th to 27th week of life) in 13 samples occurs tissue softening, in 10 specimens haemorrhages to- and nearventricular, in 5 ventriculomegalia. It was noticed different levels of brain strokes, distorting inside diameter totally or fragmentarily. The strokes sequences are very serious. Large, widespread interstitial haemorrhages has a finish with a death, smaller can cause heavy trauma of brain, that cause cerebral palsy.

Cerebral palsy consists of differential, changed with age motion and posture perturbation, paresis, unmeant reflex, distortion muscles tensions, balance distortion. It is connected with different symptoms of persistent brain trauma – epilepsy, handicap, speech distortion, sigh or audition distortions. Passed haemorrhages can cause distortion in cerebral fluid flow and can be the reason of hydrocephalus.

The new thing in the paper is also application FE method for potential cracks location in fetal clavicle and scapula. After head delivery, the second danger moment for fetal life is shoulder delivery. The clavicle trauma is most frequently injury, and in refer to all delivery injuries is a part of 92,4% [3]. After the delivery of the head, it may be that dystocia can occur, shoulders can not rotate to transverse dimension of entrance and therefore they cannot be adopted to pelvis entry shape.

Nowadays within fast and high advancement of computer techniques, like CAD, FEM (as well in hardware as in software fields) investigations are well supported. Performing simulations, virtualization of models offers to develop fast and relatively precisely execution of experimental investigations. Obtained structure models can be used to develop accurate copies of a specimens, with any scale factor with rapid prototyping or numerical analysis.

Finite element method is used mainly in exact technical science (building industry, materials strength, fluid mechanics). Thanks to that, nowadays it is wide used in orthopaedics, bone surgeon, biomechanics and also in medical science. High detailed three dimensional models lets providing the slices in whichever plane selected organism part. It also is possible to perform medical visualization complicated structures, that can be use for surgery planning as well as didactic backup.

Presented method lets to perform a step to identification the most unfavourable load cases and the most unfavourable locations in reference to damage.

MATERIAL AND METHOD

FE model was build on basis of fetal bone specimens (approx. 24th week of pregnancy) of skull, clavicle scapula. Bones have already some level of mineralization, after initial analysis but due to fact, that specimens were cleared from soft tissue and stored in alcohol it was impossible to perform adequate density measurements or fundamental mechanical properties.

Geometrical model creation conception was based on cross-sectional slices usage of prepared specimen. To suppress the variability of the specimen shape during cutting process, it was necessary to inundate in epoxy resin Epidian-5 or Methyl-Methacrylate – Fig. 1. These resin was differentiate of physical properties - mainly transparency.

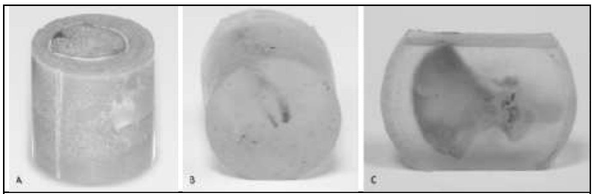

Fig. 1. Samples in resin: skull (A), clavicle (B), scapula (C)

ndate in Methyl-Methacrylate and the scapula with clavicle were inundate in Epidian-5 resin. After resin polymerization, the two rows on specimen edges were cut as a reference markers (to get the possibility of proper slice orientation and to avoid the unneeded view rotations). As a next step, the main plane of prepared resin with specimen was planned to keep the parallelism of each created slice. The cross section were obtained through conventional machining method, like turning and grinding – Fig. 2a. After settings the reference surface it was possible to get good accuracy of 70 slices for skull specimen, 23 for scapula and 23 slices for clavicle. The distance between each slices was 1mm. All obtained cross sections were scanned via computer scanner – Fig. 2b.

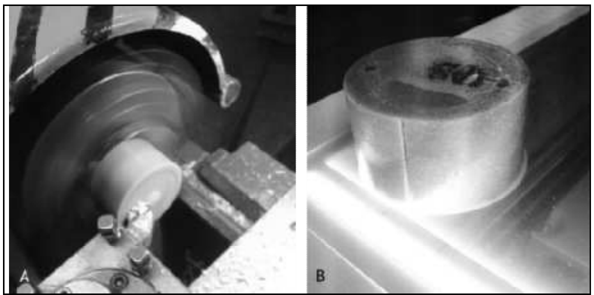

Fig. 2. Preparing of the model: mounted specimen with resin in lathe handle (A); scanning samples (B)

The attempt of digital photo-camera was also included, but the necessity of proper specimens orientation (angles to lines normal) was quite time consuming and relatively inaccurate. In case of small contrast between resin and bone specimen, the machined surface was painted with standard

ANYAGVIZSGÁLÓK LAPJA
MINŐSÉGBIZTOSÍTÁS * ÁLLAPOTELLENŐRZÉS
Elektronikus folyóirat 2009/1

white board marker to have the possibility of removal it from resin an keep it on the bone surface - thanks to that the contrast between resin and specimen's structures was increased. All scanned slices were aligned and oriented to common coordinate system using prepared cutted markers on resin specimen. All of pictures were treated in graphical processing using GIMP software. On the bitmaps the bone structures was separated from resin surface – Fig. 3.

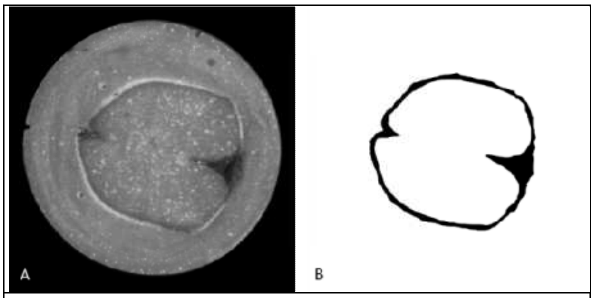

Fig. 3. Picture of skull sample cross-section (A) and result of image processing (B)

After image processing, the bitmaps was converted using authors [4] software to transfer obtained digital geometry to three dimensional matrix, and therefore also to develop the ANSYS APDL script with geometry description.

By described method, description of specimens geometry - clouds of points was created – Fig. 4. In next step the points were connected with straight line (the Bézier's splines or different curves can be also used, but it produce more problem during proper meshing). The lines allow to create all surfaces, that describe volume of virtual skull, scapula or clavicle model – Fig. 5.

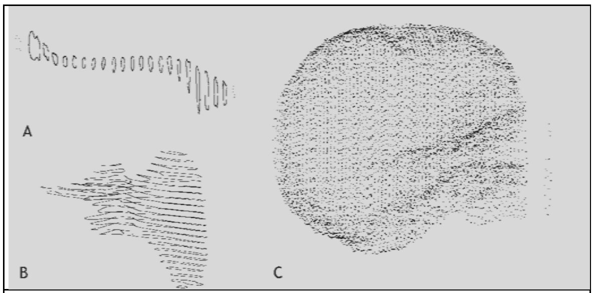

Fig. 4. Geometry of samples – clouds of points

With finished geometry it is quite easy to mesh the volume using 8 nodes tetra elements – Fig. 6. The most problem for this part of modelling was to develop the proper material properties- due to lack of valid experimental tests on real probes and qualitative character of the investigation, the material properties was set according literature [5], [6].

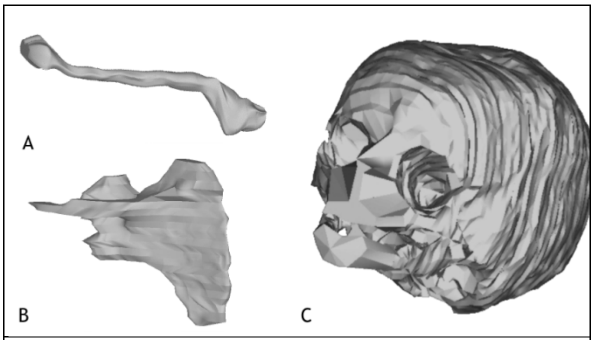

Fig. 5. Geometry of samples – volumes

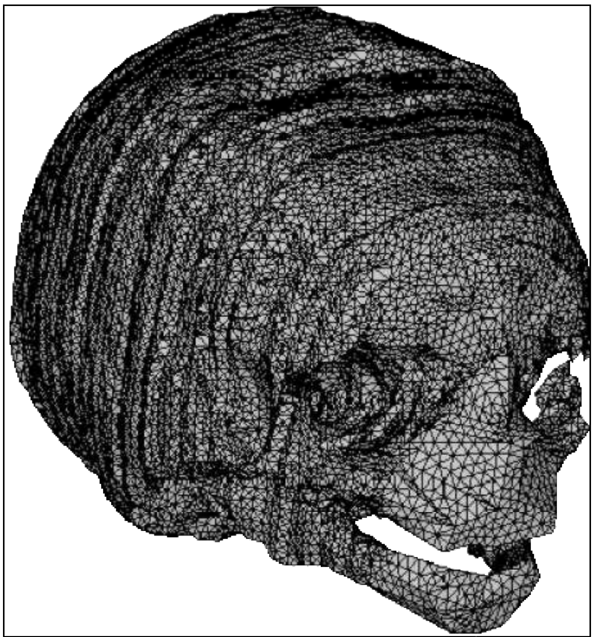
Fig. 6. Meshed model of skull

Assumed material model was isotropic and linear elastic model with Young module of E = 1000 MPa and Poisson's ratio v = 0,42.

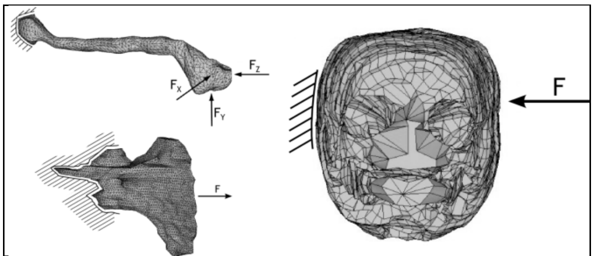

Fig. 7. Loading conditions applied to prepared models

After preparation of the FE models, the most feasible load cases were applied according the highest occurs probability [7], [8] – Fig. 7.

The analysis was performed as a static, the load was applied to node representing the contact body during delivery (acting force). In the study the applied force value was 100N.

RESULTS

As a result 3-dimensional models of skull, clavicle and scapula bone were created. Results which was carried out during investigation show characteristic places where bones could be broken. For clavicle bone fixed and loaded by three forces (three load cases – Fig. 7) results of simulation were almost the same for every load case (place of stress concentration is marked). In this place clavicle has the minimal cross-section area and this is a point where clavicle fractures most often during natural birth – Fig. 8.

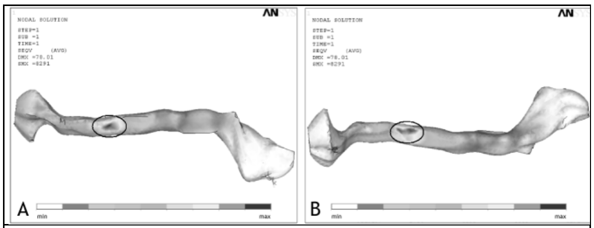

Fig. 8. Huber–von Mises stress distribution in clavicle bone (O – place of the bone fracture). Top view (A), bottom view (B)

During analysis of skull model we observed a stress concentration near intracranial foramens – Fig. 9. From mechanical point of view these foramens are concentrators of stress in skull structure which can lead to fracture and brain damage by e.g. interstitial haemorrhages – Fig. 10.

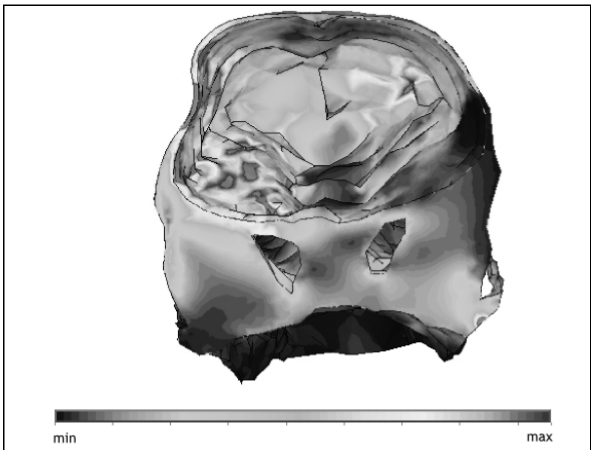

Fig. 9. Huber–von Mises stress distribution in skull structure

For scapula we observed only where lie stress concentration points. Scapula bone lies deeper in the body among muscle tissue and there is no risk of fracture.

DISCUSSION

Fetal bone tissue has small value of Young modulus and during birth possibility of injuries appears. The break of the bone or too big strain may cause soft tissue damages e.g. brain damage which can lead to mental impairment or even to death.

Fig. 10. Interstitial haemorrhages

According to investigations [9], traumatology of infant bone structures consist mainly of clavicle injury, brachial bone and scapula joint with shoulder. It is connected with transverse orientation and caesarean section as a next step. Another agents constitutes large weight of newborn, older age of mother, extending delivery action and its mechanical support [10], [11], [12], [3], [14] evaluate the frequency of clavicle trauma in all newborns population on the level of 0,89%, and born in natural was on 1,63%. The main comment is set to increased risk of clavicle trauma: hypoxia, low value of Apgar scale and the complications in shoulder delivery.

From other investigations [15] on large material (67546 deliveries) founds that delivery with forceps was noticed in 1432 women. Most frequently consequences of these deliveries was periost haematoma in skull bone – 6,6% and trauma of clavicle was in 4,1% of cases. Important connection with the issue is on weight of newborns over 4500g, where the cracking of clavicle and paralysis of brachialis plexus due to vacuum usage. In newborns group „large" babes delivered in the natural way has a injuries connected to delivery action in 15,3% and it was mainly clavicle fracture [16]

From the mechanical and biological point of view three dimensional models of fetal structures could be very interesting and for medical sciences these models could be also very helpful (e.g. to measure geometry or to look inside body).Investigated structures had very complicated geometry and complex material properties. Loading conditions during natural childbirth are compound and difficult to simulate. Prepared models and results from simulations has only qualitative character but could be helpful to explain how the fetal skeleton reacts on external forces. Answers for these questions can show how to avoid fractures and other damages during delivery.

REFERENCES

[1] Mossakowski M., Wpływ wieku na obraz morfologiczny procesów patologicznych w ośrodkowym układzie nerwowym, Neuropat.Pol. 1983,21,1-16

[2] Glonek M., Analiza metrologiczna układu komorowego nadnamiotowego człowieka w okresie prenatalnym z użyciem techniki komputerowej, Wrocław 2003

[3] Madsen E., Thyge :Act.Obst .Gynec.Scand 1955,34,1,41

[4] Frątczak R., Metoda tworzenia modelu MES kręgosłupa szyjnego, KOWBAN 2004, Wrocław.

[5] Będziński R., Biomechanika inżynierska. Zagadnienia wybrane, Oficyna Wydawnicza Politechniki Wrocławskiej, Wroclaw, 1997

[6] Wong M., Carter D.R., Mechanical stress and morphogenetic endochondral ossification of thevsternum, The Journal of Bone and Joint Surgery, v.70-A no.7 1988.

[7] Miranda P., Manuel V., Alvarez-Garijo J.A., Perez-Nunez A., Birth trauma and development of growing fracture after coronal suture disruption, Childs Nerv Syst, 23: 355-358, 2007

[8] Allen R.H., Bankoski B.R., Nagey D.A., Simulating birth to investigate clinician-applied loads on newborns, Med. Eng. Phys. v.17 no. 5 pp. 380-384, 1995

[9] Truszewski Z, Nietypowe wielomiejscowe złamania kości u noworodka jako uraz porodowy, Problemy Chirurgii Dziecięcej 1997, XXIV.113-115

[10] Bhat B.V., Kumar A., Oumachigui A, Bone injures during delivery, Indian J. Pediatr 1944,61,401-3.

[11] Many A., Brenner S.H., Yaron Y., Lusky A., Peyser M.R, Prospective study of incidence and predispositing factors for clavicular fracture in the newborn, Acta Obstet. Gynecol.Scand 1996,75,378-5.

[12] Hsu T.Y., Hung Y.J., Lu Y.J., Neonatal clavicular fracture: clinical analysis of incidence, predisposing factors, diagnosis and outcome, Am.J.Perinatol. 2002;19(1):17-21.

[13] Skoczylas M., Kwiatkowska M, Analiza wybranych czynników ryzyka złamania obojczyka u noworodka, Postępy neonatologii,1,9,2006,78-80.

[14] Krajewski P., Skoczylas M., Kwiatkowska M., Analiza wybranych czynników złamania obojczyka u noworodków, Postepy neonatologii 2006, nr 1(9) ,78-80

[15] Klasa-Mazurkiewicz, Poród kleszczowy w materiale Instytutu Położnictwa i Chorób Kobiecych Akademii Medycznej w Gdańsku w latach 1978-1990 i 1991-2001 - analiza porównawcza, Adv.Clin.Exp.Med. 2005: 14(4A),53-57

[16] Król M., Neonatologiczna ocena noworodków olbrzymich, Przegląd pediatryczny, 2000:30(1), 20-24