Cut to the Bone

Simulation reduces surgery duration and patient risk in treating infants with skull disorders.

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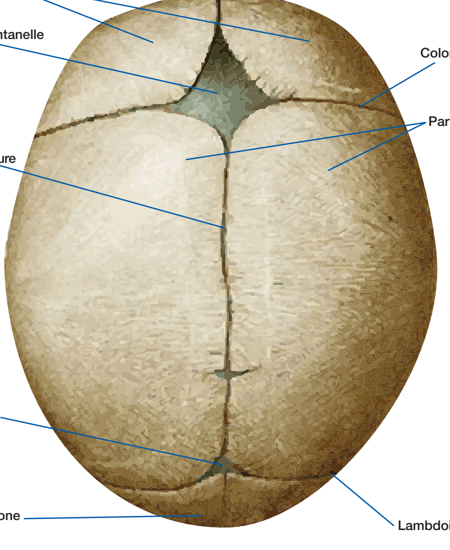
Craniosynostosis is a pediatric condition in which the sutures between the bone plates of an infant's skull close before brain growth is completed. The head is often misshapen, but more important is that the condition might lead to developmental difficulties. Craniosynostosis can be treated via surgery to separate the fused structures. Determining where to cut and how many cuts to make is difficult. Researchers at the Silesian University of Technology in Poland are using ANSYS Multiphysics software to reduce the number of cuts required for bone expansion. After 20 successful operations, neurosurgeon Dawid Larysz of the Medical University of Silesia reports that the approach has helped to improve patient outcomes through reduced surgery duration.

A newborn's brain grows and develops rapidly, doubling in volume in the first nine months and tripling within three years. The skull must expand rapidly to accommodate this growth. The normal infant skull consists of several bone plates separated by fibrous joints called sutures. These sutures respond to brain growth by stretching and producing new bone, allowing the skull to grow in unison with the underlying brain. In time the sutures close, forming a solid piece of bone.



Sutures in the infant skull

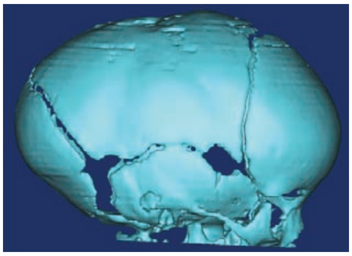
A child with craniosynostosis requires frequent medical evaluations to ensure that the skull, facial bones and brain are developing normally. The least invasive type of therapy involves use of a form-fitting helmet or band that fits snugly on the prominent areas of the head but allows the recessed and flattened portions to gradually expand into the open areas of the helmet, molding the head as it grows.

With craniosynostosis, the sutures close too early, reducing expansion and new bone creation, causing the brain to take the path of least resistance. Ultimately, the shape of the brain, skull and face becomes distorted. Severe forms of craniosynostosis may result in developmental delays or mental retardation. The condition affects one in 2,000 live births; it affects males twice as often as females.

In severe cases, surgery is the recommended treatment. The surgeon flattens the forehead bone to make it more flexible and then makes radial cuts, called osteotomies, in the bone to weaken it, intentionally allowing it to deform as the brain develops. Ideally, surgical correction should occur between the ages of three months and six months.

The challenge for surgeons is to perform the minimum number of osteotomies that will allow the brain to grow to its proper size without deforming the skull or reducing its strength. Once the osteotomies have been completed,

Infant prepared for corrective surgery

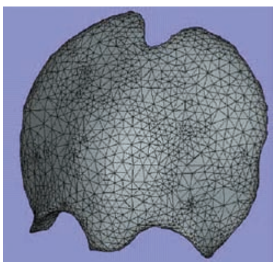


Three-D model of skull before correction

the skull should duplicate as closely as possible the mechanical properties of a normal skull.

Neurosurgeons rely on knowledge and experience during pre-operative planning. Their natural tendency is to err on the side of safety, performing enough osteotomies to ensure there is optimal room for brain growth. However, a larger-than-necessary number of osteotomies lengthens surgery time, increasing risk to the infant. Another potential consequence is a permanently weakened skull.

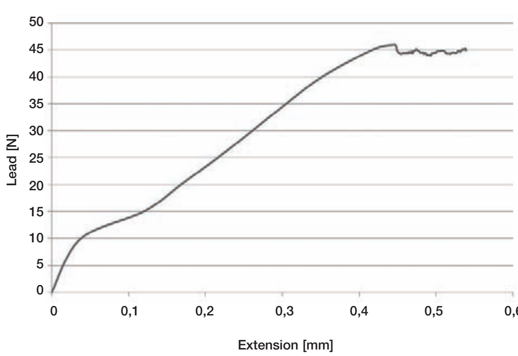
Silesian University of Technology researchers have pioneered the use of finite element analysis to determine the minimum number and location of osteotomies that are required to enable brain growth. They use computed tomography (CT) scans to generate a 3-D model of the infant's skull with the use of Mimics® software. This image-processing package, developed by Materialise® NV, generates 3-D models from stacked medical images. The researchers then export the Mimics model to ANSYS Multiphysics software for analysis.



Finite element model of forehead bone

The team determined the bone's material properties by performing physical tests using skull material that had been removed in previous operations on an MTS Insight 10 kN test stand.

In the recent case of an infant with trigonocephaly, a special type of craniosynostosis that involves fusion of the metopic suture in the forehead, researchers created 3-D models of the forehead bone in five variants and exported them to ANSYS Multiphysics software. These variants included intact bone, flattened forehead, five osteotomies, six osteotomies and eight osteotomies. Doctors had previously determined that the bone should deflect 20 mm to accommodate brain growth. Using the simulation software, analysts determined the amount of load that was required to achieve 20 mm deformation with each variant. Analysis of the structural results showed that eight osteotomies provided the best skull correction conditions for this patient. Without simulation, doctors probably would have performed unnecessary additional osteotomies to be sure there was enough room for brain expansion.



Material	Young Modulus [MPa]	Poisson Ratio	Peak Load [N]
Bone of three-month-old child	380	0,2	45

Material properties determined by physical testing

Structural analysis results show load required to deflect bone and deformation of the forehead bone after deflection.

Type of Correction	Deflection (mm)	Load (N)
Intact forehead bone	20	52
Flattened forehead	20	37
Five osteotomies	20	15
Six osteotomies	20	10
Eight osteotomies	20	4

Table of bone deflection after deformation summarizes the structural results.

The geometry of each skull is different, so researchers have analyzed the skulls of 20 infants with craniosynostosis. In each case, they were able to determine the minimum number of osteotomies that would provide the needed room for brain expansion. The simulation results helped the surgeon to prepare better for the operation; the procedure itself was much faster, and it was easier on the infant because of the reduced number of osteotomies. Operations were successful on each of these patients, and the children are all doing well.

The results unexpectedly revealed the important influence of age on correction results. By the time a child is three months old, the skull has stiffened to the point that a substantially larger number of osteotomies is needed to accommodate brain growth. Performing the operation at an early age reduces both the number of osteotomies needed and the invasiveness of the operation.

This case exemplifies how biomechanical modeling can be used to support surgical procedures.

The utilization of biomechanical and fluid flow modeling tools for surgical planning is growing in many areas beyond pediatric skull surgery, including orthopedic implant placement, cerebral aneurysm procedures and soft tissue repairs. In each of these situations, simulation results are helping to reduce surgery time and provide optimal treatment.