Popular science summary

The human skull is composed of multiple bones that begin forming during fetal development. Interestingly, these bones originate from different types of cells, which causes them to grow at different rates and in different ways, depending on their location in the skull. In newborns, the bones are separated by flexible, fibrous joints known as cranial sutures. These sutures allow the infant's skull to pass through the birth canal and support rapid brain and skull growth during early childhood. Rare cranial malformations are a group of congenital disorders affecting the structure and development of the skull. The most common among them are craniosynostoses—conditions in which one or more sutures close too early. Premature fusion limits the natural expansion of the skull, potentially leading to skull deformities and elevated intracranial pressure, which poses a risk to brain development.

Treatment typically involves surgically opening the fused suture to allow the skull to grow normally. One modern and increasingly used method is endoscopic spring-assisted surgery (ESAS). In this technique, specially designed springs are inserted into the skull to gently push the bones apart over time, guiding the skull into a more natural shape as the brain grows. While this approach offers many benefits, its results are not always predictable. Some patients respond very well, while others experience less favorable outcomes—even when the surgery is performed in the same way.

This research project aims to understand how the microstructural features of fused cranial bones influence surgical outcomes and skull growth in children with rare cranial malformations, especially those with craniosynostosis. Over the course of three years, the study will include up to 40 pediatric patients—those undergoing ESAS for craniosynostosis and a control group of children undergoing surgery for traumatic brain injuries. During standard surgical procedures, small fragments of skull bone are routinely removed and discarded. These materials will be ethically repurposed for advanced analyses using state-of-the-art technologies such as atomic force microscopy (AFM), scanning electron microscopy (SEM), and micro-computed tomography (micro-CT).

AFM will allow researchers to examine the mechanical properties of cranial bone tissue at the nanoscale, especially its stiffness. SEM and micro-CT will provide high-resolution 3D images of bone structure and mineral density—key indicators of how bone composition might influence surgical outcomes and long-term skull development. In addition, 3D surface scans of patients' heads will be used to assess changes in skull shape throughout treatment.

The project will produce a unique, high-resolution dataset describing the micro- and nanostructure of pediatric cranial bones in both healthy and affected children. Its significance goes beyond improving surgical techniques—it also holds promise for advancing craniofacial surgery as a whole. By uncovering details of bone architecture, mineralization patterns, and mechanical behavior, the research aims to support the development of personalized treatment strategies. This may lead to more precise surgical planning, reduced risk of complications, and improved aesthetic and functional outcomes for children with craniosynostosis. Furthermore, the project seeks to bridge the gap between imaging technology and clinical insight. By correlating detailed imaging data with real-world outcomes, researchers aim to create evidence-based guidelines to optimize surgical decisions and enhance overall patient care.

Ultimately, the project will provide medical professionals with a deeper understanding of rare cranial disorders. Through interdisciplinary collaboration, it strives to establish new standards in craniofacial surgery, offering hope for better outcomes and improved quality of life for young patients and their families.