

Orthotic Cranioplasty: Material and Design Considerations

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External cranial remolding dates back to 2000 B.C. Egyptian culture.¹ This methodology was used to alter the shape of the infant skull resulting in a dramatic alteration of the cranial shape. The rapidity to bring orthoses to market since the 1992 Back to Sleep Campaign has produced many “carbon copy” designs, often sacrificing orthotic design considerations that are the specialty of orthotic professionals.² Designing an orthosis requires a detailed understanding of material science and how material combinations will affect correction.

External forces upon the infant’s skull act to compress the aspect of the skull that is in direct continuous contact with that substance while intrinsic brain growth expands the cranium laterally along the surface of contact.⁴ McCarthy, et al, equated this to a water balloon being placed onto a rigid surface.⁵ (Fig 1) External forces from the surface combined with gravity pulling the balloon downward, produces a compression of the contact surface producing a lateral displacement of the balloon and a distortion of the shape. As the balloon is further filled, it expands parallel to the contact surface. The fetal skull is incapable of withstanding prolonged exposure to force (i.e. surface contact and gravity). In 1982, Kriewall examined sections of infant parietal bone under load for stiffness, modulus of elasticity, and density, concluding that the load-bearing capacity of the fetal skull is directly related to the stiffness of the bone and the bone’s thickness.⁶ These findings support the work of Kelly, et al, linking early orthotic intervention with a greater success.⁷ In addition to the increases in bone stiffness and higher load bearing capacities, the growth rate of the skull is significantly reduced, reducing the outwardly directed force required for cranial modeling.

When considering two forces, Newton’s Law of Reaction states that “For every action, there is an equal and opposite reaction”, producing equilibrium. When considering a single force exerted onto a surface, one must consider the structural properties of the surface. Although counterforce by a material is not a true force, the resistance returned by the material is real. For example, a section of steel and a section of foam will possess markedly different load bearing capacities under force. Four historical methods for cranial molding stand out in literature.⁸ The least effective was manual manipulation by a parent. Force applied by the molder’s hands lack strength and longevity to produce alteration of the cranium. More effective was tightly woven cords to “bind” the skull, which were adjusted to direct the cranium. The most effective method was boards positioned along the frontal and occipital aspects of the skull held together by tightly wrapped cords which were adjusted to produce deformation. The latter two examples cite a “cranial-surface relationship” where the surface enacted upon by the infant’s skull was of greater stiffness and rigidity than the skull, and the duration of this interaction was of sufficient length of time to allow growth and gravity to influence the counterforce and the cranial shape.

An orthosis's material must be of sufficient stiffness and rigidity to withstand the force acted upon it by the cranium over a given timeline, and delivers a consistent counterforce to overpower the bone's load bearing capacity. The material of a cranial molding orthosis must be biocompatible and hypoallergenic as infant skin lacks many of the defenses possessed by mature skin. The material of choice must resist force from two directions. A thermoplastic should possess strength and rigidity to provide adequate force at the sites of linear contact without deflecting.⁹ Any deflection will allow the prominences to advance and retard the normalization of the skull.

The orthosis must also resist gravity's pull of the child's head and orthosis onto the surface of contact (i.e. bed, car seat, stroller). This could mimic the deformational effect of the cranium. Heat is absorbed through conduction into the material of the orthosis. A child will perspire in any orthosis worn and experience slightly higher than normal temperatures at sites of direct contact. Perspiration may also adversely interact with polymers that possess the ability to uptake water molecules into their polymer chains potentially altering the structure of the polymer. Monomers are combined into multiple configurations to create large complex polymers, yielding plastics of differing mechanical properties.¹⁰ The polymer chains of thermoplastics form weak bonds, allowing them to slide past one another under energy. The bonds reform during cooling, allowing for the formability of thermoplastics. Copolymer, Surlyn, and PETG may be combined with an internal liner of Aliplast or Pelite, or with no liner for direct contact with the skull. Traditionally, "Band" style orthoses combine a rigid polymer with an internal liner, whereas "helmet" style orthoses maintain a direct polymer-skin contact. The Clarren style orthosis is the only helmet style orthosis cleared for use that combines a rigid polymer shell with a foam liner.

The focus of this paper is to provide a better understanding of the mechanics of cranial remodeling, introduce current cranial orthoses from a biophysics perspective, and provide data and research regarding the effectiveness and shortcomings of orthosis designs.

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