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LITERATURE REVIEW

The Controversy of Cranial Bone Motion

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Cranial bone motion continues to stimulate controversy. This controversy affects the general acceptance of some intervention methods used by physical therapists, namely, cranial osteopathic and craniosacral therapy techniques. Core to these intervention techniques is the belief that cranial bone mobility provides a compliant system where somatic dysfunction can occur and therapeutic techniques can be applied. Diversity of opinion over the truth of this concept characterizes differing viewpoints on the anatomy and physiology of the cranial complex. Literature on cranial bone motion was reviewed for the purpose of better understanding this topic. Published research overall was scant and inconclusive. Animal and human studies demonstrate a potential for small magnitude motion. Physical therapists should carefully scrutinize the literature presented as evidence for cranial bone motion. Further research is needed to resolve this controversy. Outcomes research, however, is needed to validate cranial bone mobilization as an effective treatment.

Key Words: *cranial bone motion, craniosacral therapy*

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Cranial osteopathy and craniosacral therapy are in widespread use today by a number of physical therapists, osteopathic physicians, chiropractors, and other health and wellness providers both in the United States and abroad (14, 15). Craniosacral therapy is commonly practiced by physical therapists in this country, and continuing education advertisements under this name are often seen in physical-therapy-related publications (47).

Core to cranial osteopathy is the belief that the cranial vault is a mobile, compliant structure. The originator of this approach is Dr. William G. Sutherland, DO. Within cranial osteopathic circles is the well-known story of a young Dr. Sutherland, who as a medical student at the turn of this century, walked past an exhibit of a disarticulated skull and observed the greater wings of the sphenoid bone. His mind automatically compared them to the gill plates of fish and he wondered if perhaps the skull bones were not mobile and involved in some sort of respiratory process. Twenty years later, this concept of cranial bone motion still nagged at him and he began self-experimenting using a helmet made of leather and thumbscrews. From this initial self-experimentation to later successes in the clinic, the practice of cranial osteopathy was conceived. Based on Dr. Sutherland's theories of cranial bone motion, cranial osteopathy represented a systematic approach to evaluating and treating dysfunction occurring within the articulations of the skull. Adding credibility to this new discipline was Dr. Sutherland's in-depth knowledge of anatomy coupled with a very strong commitment for taking a scientific approach to patient care (21).

More recently, craniosacral therapy has been utilized as a method for evaluating and treating patients. Founded by Dr. John E. Upledger, DO, in the 1970s, craniosacral therapy shares with cranial osteopathy a common theoretical belief in cranial bone motion. Practitioners of craniosacral therapy suggest that periodic fluctuations in cerebrospinal fluid pressure give rise to rhythmic motion of the cranial bones and sacrum. This rhythm is called the craniosacral rhythm. Craniosacral therapists suggest that by applying selective pressure to the cranial bones, they can manipulate the craniosacral rhythm to achieve a therapeutic outcome in their patients.

Little research has been done on cranial bone motion, and agreement to even its existence remains controversial. Though there is more to cranial osteopathic and craniosacral therapy theory than cranial bone motion, without this motion, much of the rationale and many clinical techniques are invalidated. The purpose of this paper is to present the controversy over cranial bone motion and to review the cranial bone literature. Implications of this review and directions for future research are discussed.

Controversy

Classical anatomists generally hold the firm belief that the cranial sutures fuse in adulthood, though it is conceded that there is much individual variation as to exactly when this fusion takes place. The exception to this rule is the metopic suture of the frontal bone which fuses by the age of 2 years (28). Presupposing cranial suture fusion would therefore make any functional movement between the bones of the skull highly unlikely and certainly nonphysiological (8). This is probably the prevailing view taught in most physical therapy programs.

Practitioners of cranial osteopathy and craniosacral therapy see the skull in a different light. In this paradigm, the cranial sutures, again excepting the metopic suture, remain unfused throughout life. Practitioners believe that a small amount of motion between the cranial bones is possible. The unfused sutures between these bones allow for this motion to occur (37,47).

In assessing factors that affect intracranial pressure, conventional physiologists do not consider the cranial sutures to play any significant role. The cranium and spinal canal are closed systems. The calvarium is assumed to be an unyielding structure that rigidly contains brain tissue, blood, and cerebrospinal fluid. Any increase in volume in one of these contents must be accompanied by a decrease in the others or else an increase in intracranial pressure will occur. This concept, known as the Monro-Kellie doctrine, helps to explain such events as the decrease in cranial cerebrospinal fluid volume that occurs during a Valsalva maneuver (1,20). However simple this may seem, in reality, the relationship between intracranial pressure and volume is a nonlinear one. In other words, some cranial vault compliance exists within the system. Some authors have proposed that cranial sutures contribute to this compliance by allowing motion between cranial bones (2,13).

Different physiologic episodes increase intracranial pressure and theoretically could cause cranial bone motion. Such episodes include the already mentioned Valsalva maneuver as well as blocking venous outflow, an increase in arterial blood flow, hypercapnea, and transient apnea (1,2,20).

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Theoretical explanations for cranial bone motion invariably describe rhythmic fluctuations in cerebrospinal fluid pressure producing tension on the dura and its osseous connections. These fluctuations are commonly referred to as the craniosacral rhythm and are viewed as a naturally occurring physiologic phenomena just like respiration or heart rate. This rhythm completes 6–12 cycles per minute and is palpable anywhere on the body. Various reasons are given for the cause of these fluctuations (47). Upledger (45) presents a pressurestat model which presumes alternating on/off cycles of cerebrospinal fluid production lasting about 3 seconds each. These cycles are triggered by a neurologic feedback mechanism involving stretch and compression receptors in the sagittal suture.

Conventional medical literature states that a fused cranial suture creates a rigid calvarium which physiologically responds according to the Monro-Kellie doctrine. Cranial osteopathic and craniosacral therapy literature describe a cranial complex which remains mobile throughout life and is compliant to fluctuations in cerebrospinal fluid pressure.

Anatomy of Suture Closure

Theories promoting cranial bone motion suggest the notion that the cranial sutures remain unfused throughout life. Critics of these theories infer that cranial sutures fuse sometime in early adulthood. Investigations into cranial suture closure are therefore central to the issue of cranial bone motion. Several investigators have studied suture closure in both primates and humans.

Retzlaff et al (34,36,39) performed a number of tissue sample studies on primate cranial sutures using light and scanning microscopy. Age of animals, location of suture sample on the skull, and number of tissue observations were uniformly missing from these published reports. Photographic details of findings were also absent from these studies, making independent analysis of findings impossible. Different lab techniques were incorporated and detailed in the articles. Histological findings followed the general five-layered pattern of fibers and cells as reported by Pritchard et al (33). Retzlaff et al reported that adult sutures showed no evidence of fusion. The authors assumed that since collagenous bundles found within the sutures frequently displayed a wavy pattern, elongation of these fibers was possible. The authors further assumed that "elastic" fibers bordering these collagen bundles "may function to control elongation of the collagen bundles (39)." Whether the authors are actually referring to elastin fibers is not made clear. Unfortunately, because of inadequate information given, no substantive conclusions can be drawn from these studies.

A very detailed approach to studying suture closure in humans was conducted by Todd and Lyon (43,44). Starting with an initial cadre of 427 male skulls of verifiable age, they performed visual inspection of ecto- and endocranial suture surfaces. Since the authors *a priori* concluded that cranial sutures do fuse sometime during adulthood, a total of 81 skulls were rejected from the study because of abnormal progress of suture closure, either precocious or absent. The main cited cause for rejection was delayed union. From the remaining sample of 346 skulls, which the authors found "remarkably uniform and harmonious in the information it now gave regarding suture closure," progress of suture closure for a number of sutures was carefully described. Generally speaking, suture closure began in these specimens between 20 and 30 years of age. Sagittal, coronal, and lambdoidal sutures were completely closed by 31 years, 38 years, and 47 years, respectively. The masto-occipital and parieto-mastoid did not close until 70–80 years. The spheno-parietal and spheno-frontal sutures close around 60 years; complete closure of spheno-temporal is rare. An operating definition used by Todd and Lyon that we believe significantly influenced the results of this study should be noted. Todd and Lyon defined as "united" those sutures that displayed what they called a "lapsed union." This type of sutural union was actually a failure of the suture to close in the presence of a concentration of bone along the edges of the articulation. Counting "lapsed unions" as fused sutures may have favored the data toward early suture closure. The authors concluded that although suture closure exhibits a definite periodicity, individual variability makes it unwise to depend upon stage of closure as an age marker. The authors, in reference to earlier works on suture closure by Bolk, stated they too had found skulls in which closure of sutures was either very delayed or never took place. These "antithetic" skulls were eliminated from this study. One can conclude from Todd and Lyon's work that probably a chronological pattern of suture closure does exist, but there is a high degree of individual variability and some cranial sutures may never close.

Often referenced in the osteopathic literature, Pritchard et al's (33) classic study on suture development used only fetal or newborn human subjects. Their proposal that viable sutures may allow slight motion is therefore limited to this population alone and does not shed much light on sutures in adults. Also, there is evidence to suggest that the five cellular layers described by Pritchard et al may not even persist into adulthood, again reflecting the limitations of drawing conclusions from this study (22).

The use of orthodontic appliances to stimulate craniofacial suture remodeling and correct malrelationships of these bones is well known. Sutural fusion makes malrelationships less amenable to treatment and so knowing when these sutures fuse is essential to the timing and placement of these appliances. In a study that we believe sets a standard of excellence in suture closure research, Kokich (22) investigated a method for documenting age-related changes in a craniofacial suture. Using radiographic and histological techniques, he clearly documented age-related changes in the frontozygomatic suture. This suture was ideal for study because its relatively small size allowed it to be examined along its entire length. Any evidence of bony union affecting suture patency was positively identified. Sixty-one human specimens were used and were categorized according to age at 5-year intervals. Results demonstrated that the human frontozygomatic suture does not undergo synostosis until the eighth decade of life and is not completely fused by the age of 95. The morphology of this suture became increasingly irregular with advancing age because of the formation of bony interdigitations between the suture surfaces. Drawing from other investigators, Kokich stated this irregularity reflected the length of time the human frontozygomatic suture remains patent and the tensile forces produced across the suture by the masseter muscle. Direction of collagen fibers within the suture also consistently reflected tensile forces. Kokich concluded that the frontozygomatic suture remains a functional articulation until late in life and is capable of orthodontic remodeling during adulthood.

Retzlaff et al (38) performed gross and microscopic analysis of sagittal and parieto-temporal sutures from 17 cadavers, ranging in age from 7 to 78 years of age. Results were described without supportive documentation. They reported no evidence of sutural obliteration by ossification in any of the samples studied. Sutural structure reported was consistent with primate findings, including the existence of blood vessels and nerve fibers within the sutures. Age-related changes noted are a reduction in the number of collagen bundles and increased interdigitation of approximated bone edges. The authors conclude that sutural structure is such that movement of cranial bones is possible at all ages studied. As before from this group of investigators, inadequate information is given in which to base any independent conclusions.

Sukekawa (42) looked at adult human sagittal suture using scanning electron microscopy. Neither sample size or ages were reported. He categorized the sutures as being either preadhesion or postadhesion. In the preadhesion suture, he noted numerous blood vessel holes surrounding calcified matrix fiber bundles. These bundles were oriented in a parallel, nonfused fashion. Postadhesion sutures were in a dormant state. Here the calcified bundles were oriented either irregularly or in parallel as before. In the irregular pattern, scattered calcium globules about 10 microns in diameter were often observed. Sukekawa describes the adult suture as being in a resting stage, having a distinct border, and being adherent rather than fused.

A general statement about whether and when suture obliteration occurs in adulthood cannot be made from existing research. Kokich's approach to this problem should provide a model for future studies and gives a compelling argument for the viability of at least one human cranial suture well into adulthood.

Biomechanics of Cranial Suture

Cranial sutures during skull growth are generally viewed as dynamic structures that respond to extrinsic biomechanical forces by changing morphology as bones overlap and interdigitate (19,25,29,30). Apparently less is known regarding sutural mechanics in the adult (19).

Jaslow (19) observed mechanical properties of cranial sutures in adult goats. Cranial sutures displayed significantly different properties than cranial bone. Bending strength of cranial suture was positively correlated with a high degree of bone interdigitation, yet did not exceed that of bone. The difference in strength between bone and cranial suture was attributable to the presence of collagen in the suture. Age of the animal had no effect. Increasing the rate of loading only affected the more highly interdigitated sutures which displayed lower bending strengths. All sutures tested had higher energy-absorbing capability than bone, supporting the hypothesis that adult cranial sutures may perform a shock-absorbing role.

A study including embalmed and unembalmed human suture material done by Hubbard et al (17) has important implications for future research in cranial bone mobility. Though differences in bending strength were not as striking as in Jaslow's work, cranial suture compliance (midspan deflection caused by a unit of load) was significantly more than equivalent layered bone. The embalming process significantly strengthened the suture and therefore decreased compliance and increased bending strength compared with unembalmed samples. The authors concluded that the embalmed suture is generally as strong as adjacent bone in bending to failure strength. Therefore, using embalmed cadavers is not a valid approach for making assumptions about cranial bone motion in living persons.

To better understand traumatic head injury, mathematical and mechanical models have been developed to simulate responses of the human head and its constituent structures to various externally applied forces. Cranial bone is one such constituent structure. Cranial bone is in essence a layered panel consisting of inner and outer tables of compact bone separated by a cancellous diploë. Layered beam theory is a mathematical model used to predict the mechanical responses of a layered panel material, such as cranial bone, from the properties and geometry of its constituent materials. Hubbard (16) have shown that the application of layered beam theory for predicting bending responses in cranial bone is valid. Such application for cranial suture does not exist. Jaslow (19) points out that the "mechanical behavior of a complex sutural joint cannot be predicted according to behavior of its individual components."

Biomechanical studies of the adult cranium clearly demonstrate that cranial suture has mechanical properties quite distinct from that of adjacent bone.

Cranial Bone Movement Studies

Direct measurement of cranial bone motion has piqued the interest of practitioners of cranial osteopathy and craniosacral therapy as well as other researchers (13,31). Among the latter, Oudhof and van Doorenmaalen (31) looked at a hemoynamic influence on skull growth. Using beagle puppies, he attached strain gauges to the frontal and sagittal bones. Adult beagles served as controls. Movement between the bones of about 5–10 microns was recorded and was synchronous with aortic flow and electrocardiogram. No movement was detected in any of the adult dogs. Oudhof and van Doorenmaalen state that the lack of movement in adults could reflect a lack of equipment sensitivity or other physiological processes compensating for cranial volume in adult animals.

Adams et al (2) researched parietal bone mobility in adult cats. Using multiplanar strain gauges, the influence of externally applied forces and changes in intracranial pressure on inducing or restricting parietal motion was analyzed. Significant motion did occur, but it was clear that considerable interanimal variability existed in the amount of motion observed. Lateral head compression caused sagittal suture closure and inward rotation of the parietal bones. Increasing intracranial pressure caused a widening of sagittal suture and outward rotation of parietal bones as did direct pressure on the sagittal suture. All animals demonstrated lateral parietal bone motion in response to intracranial injections of artificial cerebrospinal fluid. The magnitude of this motion varied by animal and ranged from approximately 17 to 70 microns. Restraint in a stereotaxic frame decreased motion responses. Using data from the same study, Heisey and Adams (13) described the behavior of total cranial compliance to increased intracranial pressure. At low intracranial pressures, cranial sutures are mobilized but cerebrospinal fluid and blood volume shifts are primarily responsible for compliance. At higher pressures, fluid shifts are maximized and cranial bone movement is theorized as the only mechanism counteracting any further increase in pressure.

Researchers affiliated with the Michigan State University College of Osteopathic Medicine have done several studies on cranial bone mobility using adult primates. Micheal and Retzlaff (27) performed direct measurement of right parietal bone motion using a screw attachment and a displacement transducer. With the primate's head firmly immobilized in a stereotaxic frame, bone displacement, mean arterial blood pressure, and heart and respiration rates were simultaneously measured. Central venous pressure was measured in two animals. Spontaneous cranial motion and the effects of applying external forces and passive spinal motion were recorded. Results showed two patterns of spontaneous parietal bone motion. One pattern was synchronous with respiration rate. This was superimposed over a second, slower oscillatory pattern consisting of 5–7 cycles per minute that was not attributable to either heart rate, respiration rate, or central venous pressure. Force applied to the skull in various locations generally produced motion between the parietal bones. Spinal extension or flexion each produced a characteristic pattern of parietal motion.

Retzlaff et al (35) elaborated on the above study by recording parietal bone displacement with the primate's head loosely mounted in the stereotaxic frame rather than being firmly fixated as before. Also different in this study is that force transducers were attached to both parietals via screw-eye screws placed in the midpoint of the bones. Respiration rate and blood pressure were measured using direct methods. As in the first instance, two patterns of spontaneous parietal bone motion were seen; however, this time the slow and rapid wave patterns directly corresponded with respiration and cardiac activity. By increasing the level of head fixation within the stereotaxic frame, the left and right parietals assumed patterns of motion independent from each other and displayed a rapid oscillatory pattern distinct from cardiac activity.

What is troubling in the previous two studies is a lack of detail in experimental methods. This absence of information is clearly apparent compared with the well-described methods of Oudhof and van Dooren-maalen (31) or Adams et al (2). Control of transducer placement and alignment is essential in isolating cranial bone motion from extraneous sources. Choice of transducer placement can account for measuring "spontaneous" parietal bone motion when the head is not fixated in a stereotaxic frame. For example, such spontaneous motion could occur from subtle head motion caused by respiration. Poor description of methods only serves to cast doubt on whether the transducers were actually measuring cranial bone motion. Vagueness in methodology prohibits independent replication and meaningful interpretation of results in the above two articles.

In another primate cranial bone motion study performed at Michigan State University, St. Pierre et al (40) gave a brief account of detecting cranial bone motion in squirrel monkeys. The authors stated that "relative movements of cranial bones that may have physiologic significance were observed in squirrel monkeys." No sample size, animal ages, or even experimental conditions were given so conclusions from this report are impossible.

The clinical meaning attributed to cranial bone motion has obviously stimulated research on humans. A particularly interesting study performed on live subjects was done by an osteopathic physician, Dr. Viola Frymann (9). In conjunction with an electronics engineer, Frymann gradually developed a noninvasive apparatus for mechanically measuring changes in cranial diameter. The apparatus was composed of a large, metallic U-shaped frame with a differential transformer placed laterally on each side. Differential transformers convert displacement of a metallic rod into an analog signal. Subjects placed their head into the U-shaped frame and the metallic rods of the differential transformers were placed laterally against the subject's cranium. Changes in skull diameter were measured by displacement of the metallic rods. The author described the various steps of measurement apparatus development. Results are then presented from each step. Cranial motion was recorded simultaneously with either thoracic respiration or volumetric changes in the finger or forearm. Sample recordings were presented as evidence of findings. Sample subject information such as age and sex were largely missing. Subjects were selected on the basis of having mobile cranial mechanisms as determined by cranial osteopathic evaluation. The author concluded, on the basis of extensive recordings, that cranial motility exists and can occur in a rhythmic pattern that is slower than and distinct from cardiac and respiration rates. The magnitude of motion was estimated to be between 10 and 30 microns. The author related cyclic changes in limb volume to cyclic changes in head diameter. More importantly, perhaps, Frymann implicitly concluded that cranial motion can be instrumentally recorded in living humans using noninvasive techniques. Despite obvious shortcomings in research design, this study provides evidence of rhythmic diameter changes in the living cranium, which could be reflective of cranial bone motion.

Other studies have measured dimension changes of the cranium using more invasive techniques. Two teams of researchers independently demonstrated the positive correlation between intracranial pressure and bitemporal skull diameter. Heifetz and Weiss (12) used strain gauges attached to a Gardner-Wells tong-like device. This device was attached to two comatose patients via pins inserted into the outer plate of the cranium approximately 6 cm above the external auditory meatus. Intracranial pressure was simultaneously measured. Each time the intracranial pressure was increased between 15 and 20 mm Hg, the skull tong pins were pushed apart. The average magnitude of separation varied between the subjects and was reported as .78 microns and 3.7 microns. Pitlyk et al (32) placed strain gauges on Gardner-Wells tongs. They first affixed the tongs to a dried human skull and found that by applying an external force to the skull, they were able to produce a measurable, reproducible distortion. This distortion was maximal over the parietal bones. Next, they placed the tongs on a fresh cadaver. In this case, strain gauge output was closely correlated to a volume of saline injected intracranially. Finally, the tongs were placed on six live dogs. Intracranial pressure was manipulated via either inflating a balloon catheter inserted into the intracranial subarachnoid space or by saline injected into the spinal subarachnoid space. Intracranial pressure was monitored during the experiments. Results showed that strain gauge output of the tongs correlated very well with intracranial pressure measurements. In other words, skull expansion occurred with an increase in intracranial pressure. Pressure changes as little as 2 mm Hg could be detected with the tongs. Magnitude of skull expansion was not reported. Strip chart output from the tong strain gauges demonstrated minute skull distortion due to cardiac systole superimposed over larger changes because of increased intracranial pressure. The authors concluded that using the tongs to measure cranial diameter changes was a sensitive enough method for use in monitoring intracranial pressure.

Studies that measure gross diameter changes in the skull, such as the last three cited, do not directly measure cranial bone motion. From these studies, it is not clear whether diameter changes incorporate actual motion at the cranial sutures, flexure of bone itself, or some combination of the two. Therefore, interpretation of the results of these studies cannot conclude with certainty that motion occurs at the sutures. Rather, these studies provide indirect evidence for cranial bone motion by assuming that given a change in intracranial pressure, flexion/expansion at the suture would occur prior to flexure of bone. Previously cited anatomic and biomechanical research provides some support for this assumption.

White and White (48) developed a radiographic method to locate points on an X-ray and measure changes in position of these points with accuracy. This method requires locating the central beam of the X-ray as a reference point, identifying the three-dimensional position of a point on the X-ray in relation to this reference point, and calculating distance between points using the Pythagorean theorem. White and White suggest that this technique could be used to detect small motions between bones and quantify the effects of manipulative treatment. Using this radiographic method, along with plaster models of the mouth and other measurements, White et al (49) studied the relationship between craniofacial bone movement and somatic dysfunction in humans. Manipulation of the zygomae, maxilla, and temporal bones provided the experimental condition. They reported movement between these bones along suture lines. Maxillary widening up to 3 mm and separations of the zygomae-maxillary suture in excess of 1 mm were noted. Individuals varied in the amount of motion observed. The authors reported that changes in maxillary bone position cause an ipsilateral palpable tension in the C1 area. This tension, equivocated to somatic dysfunction by the authors, is relieved by manipulating the facial bones, placing wax between the molars, and having the patient swallow.

Another important issue with cranial bone motion is its context within the treatment paradigm of craniosacral therapy.

Kostopoulos and Keramides (23) applied a traction force to the frontal bone of an embalmed cadaver to measure elongation of the falx cerebri. Forces far exceeded therapeutic levels. Since a distinction between flexure of cranial bone and actual motion occurring at the suture was not made, no conclusions about cranial motion can be drawn from this study. Bergevin et al (4) attempted to measure motion across the sagittal and frontal sutures in unembalmed cadavers by increasing cerebrospinal fluid pressure. The authors introduced water into the subarachnoid space via a lumbar puncture to simulate increased cerebrospinal fluid pressure. No cranial bone motion was detected. Owing to the very advanced age of all the sample subjects and no control for actual increase in intracranial pressure, little can be concluded.

Research on cranial bone motion is obviously in its beginning stages and is far from conclusive. The possibility of motion existing appears real and worth further inquiry to describe its magnitude and meaning.

DISCUSSION

Clinicians need to scrutinize the quality of research presented as evidence for cranial bone motion. Some of the often-cited references coming from the osteopathic literature are abstracts yielding little, if any, substantive information. They are certainly insufficient to form conclusions. Claims that reliable palpation of craniosacral rhythm (and therefore cranial bone motion) is possible turn out to be exaggerated when subjected to statistical analysis (50). There does exist, however, a body of credible research that presents a more convincing, but certainly not conclusive, case for cranial bone motion. Anatomic studies on sutural union provide evidence that sutures may not fuse until late in life and perhaps not at all in some cases. Biomechanical evidence clearly shows that adult human suture has properties very distinct from that of cranial bone, making it highly improbable that sutures are completely ossified as some authorities have contended. Credible research has shown that cranial suture may play a significant role in cranial compliance to increases in intracranial pressure in adult humans and animals, indicating the need for revisiting the concept of a physiologically rigid cranium. Some proponents of craniosacral therapy exercise poor choice in what they adopt as convincing evidence for cranial bone motion. This only serves to undermine credibility. Quality research does exist that provides a convincing argument that at least a small degree of cranial bone motion is possible in adults. It is this research that needs to find its way into discussions and bibliographies on craniosacral therapy.

> ***Anatomic studies on sutural union provide evidence that sutures may not fuse until late in life and perhaps not at all.***

A major proponent of craniosacral therapy recently claimed that "our research. . .did indeed prove beyond any doubt that (human) skull bones continue to move throughout normal life" (46). In a respected peer-reviewed journal, two critics of cranial osteopathy wrote that ". . .it is logical to assert that movements of the bones belonging to the anterior and middle cranial fossae are impossible from the age of 8 years. . ." (8). Both of these statements are inconsistent with the literature review presented here. Research on cranial bone motion in living humans is scant and inconclusive. Physical therapists should be wary of blanket statements regarding cranial bone motion, either for or against. What is presented as proof is often anecdotal evidence or inadequately documented research. There has been virtually no replication of cranial bone motion studies. Many articles claiming to support cranial bone motion contain so little information on methodology and results that reproducing them would be impossible. There is very little evidence which disproves cranial bone motion. No investigators have come forth with valid evidence that reliably shows that cranial bones do not move. Proving a phenomena beyond all doubt implies that the phenomena is observable and reproducible to the point that it becomes common knowledge within a community. This is obviously not the case with cranial bone motion. Continued professional controversy based on a lack of concrete, reproducible evidence shows that the understanding of cranial bone motion is very much in its infancy.

Future Research

Assessment of cranial bone motion is used for evaluation and treatment in both cranial osteopathic and craniosacral therapy practice. Of the two disciplines, physical therapists in this country are probably more likely to use craniosacral therapy. This is evident from material published in the journal, *Physical Therapy* (6,7,11, 50), and a review of continuing education advertising in our various professional publications. The use of craniosacral therapy techniques is becoming more prevalent and some therapists may use this approach exclusively (7). Yet, an acknowledged vacuum of convincing research exists, not only in the very basic foundations of craniosacral therapy theory, such as the existence of cranial bone motion and craniosacral rhythm, but also in patient outcomes.

Basic research aimed at validating the existence of cranial bone motion in living adult humans needs to address three major issues. The first is to establish that cranial sutures remain unfused through adulthood. Kokich's (22) study on the frontozygomatic suture is an example of research addressing this issue and could be replicated on other cranial sutures. The second is to provide evidence that actual motion does take place between the cranial bones rather than flexure within the bones themselves in an intact skull. Pitlyk et al's (32) use of fresh cadaver material could serve as example research. Intracranial pressure monitoring or documentation of a given externally applied force is essential to validating whether an appropriate level of stimulus to move cranial bones is present. Strain gauges could be affixed across one or more sutures rather than using a tong-like device as in their study. The third issue is to document, through unbiased measurement, the existence of rhythmic cranial bone motion in living humans. Using information gained on suture anatomy and experimental behavior of cranial bones on appropriate cadaver material, noninvasive monitoring of cranial distortion, such as replication of Frymann's study, could provide some support for the concept of physiological motion of the cranial bones. Noninvasive monitoring of cranial distortion on patients requiring intracranial pressure monitoring would further clarify this issue by assessing the relationship between cyclic changes in pressure and cyclic changes in cranial diameter.

Another important issue with cranial bone motion is its context within the treatment paradigm of craniosacral therapy. Ideally, what we do as therapists should be developed from scientific evidence. Bergman (5) points out that many pediatricians' guidelines for treatment lack sufficient scientific support. We believe this holds true for physical therapists. What is, after all, the best proven treatment for a herniated disc, frozen shoulder, or tension headache? Craniosacral therapy is often criticized for a lack of scientific support for its theory, especially the existence of cranial bone motion and craniosacral rhythm (6,8). Upledger (46) cites disagreement on the existence of cranial bone motion, along with other debated physiologic functions, as the reasons why craniosacral therapy is not incorporated into conventional medical practice. Craniosacral therapy is far from alone in the problem of lacking hard scientific evidence to explain what it does. Prescribing aspirin and administering general anesthesia are two of the most commonly done procedures in medicine, yet there is no adequate explanation of how either works (26,41). The critical difference lies in the multiple efficacy studies justifying the use of aspirin and general anesthesia. The same is not true of craniosacral therapy. There are no published true experimental studies demonstrating its effectiveness over other treatments; therefore, it cannot reasonably be separated from a placebo effect. The opinion of the authors is that the lack of proven efficacy, rather than poorly understood mechanisms of action, is what makes it difficult to promote craniosacral therapy as a mainstream treatment. If craniosacral therapy was demonstrated safe and more effective than comparable treatments, we do not think that disagreement over mechanisms of action would be sufficient to prevent its promotion and use within conventional practice.

Being a gentle, hands-on manual therapy, the potential risks of craniosacral therapy can be easily assessed and controlled by judicious application (14,47), just like many other things we do as therapists. The benefit-to-risk ratio of using craniosacral therapy certainly warrants comparing it with mainstream treatments. There are a multitude of anecdotal testimonies and informal case studies that suggest craniosacral therapy is beneficial for some patients (10,14,15,18,24, 46,47) as well as some scientific support for craniosacral mechanisms (3). However, no controlled outcomes or single-subject design studies are apparent in the literature for craniosacral therapy. The fundamental question asking "Is craniosacral therapy better than anything else we do for our patients?" cannot be answered through existing published qualitative or quantitative research. Controlled single-subject studies and randomized clinical trials could provide outcome support for craniosacral therapy. Qualitative research may give insight into how and why craniosacral therapy may benefit our patients. Like other forms of past and present treatment protocols, scientific proof of its theoretical basis may significantly lag behind proof of its ability to benefit patients. Quality research designed to validate theory, such as measuring and describing cranial bone motion and craniosacral rhythm, is essential to make craniosacral therapy more credible, efficient, and reliable to use, and this paper hopefully provides support for doing this type of research. However, even clear evidence of this phenomena will fall short of answering the real question of whether craniosacral therapy is an effective treatment.

CONCLUSION

Anatomic studies on sutural union provide evidence that sutures may not fuse until late in life and perhaps not at all in some cases. Biomechanical evidence clearly shows that adult human suture has properties very distinct from that of cranial bone, making it highly improbable that sutures are completely ossified as some authorities have contended. Research on cranial bone motion has shown that cranial sutures may play a significant role in cranial compliance to increases in intracranial pressure in adult humans and animals, indicating the need for revisiting the concept of a physiologically rigid cranium. Therefore, a small magnitude of motion may be possible between the bones of the cranium. However, a number of those published studies supporting cranial bone motion lacked evidence of scientific rigor. Physical therapists should carefully scrutinize the literature presented as evidence for cranial bone motion. Further research is needed to resolve this controversy. Outcomes research, however, is needed to validate cranial bone mobilization as an effective treatment. JOSPT

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