Cranial Sutures and Sutural Movement

Information gathered by Avadhan Larson 2019.

Dr. John E. Upledger, along with other researchers, discovered connective tissue, as well as neural and vascular tissues within the intra-sutural material. In some circles these findings are still under question, however there is a wealth of sources which confirm and validate his findings.

Here is what I gathered, and all of controversy around sutural movement, I believe, needs to be evaluated from the framework of Dr. Jean-Claude Guimberteau's fascia work in which he states that so much of what we "know" about fascia we learned from dead fascia. And I think the same principle is true about the intra-sutural material and its behavior. Even in our fresh cadaver dissections we are dealing with dead tissue, as well as unresolved restriction patterns.

Mark Pick has written a tome entitled Cranial Sutures: Analysis, Morphology and Manipulative Strategies, in which he sites some of the following sources as well as provides detailed photographs of the individual sutures.

Cranial Bone Mobility Motion of the Cranial Bones

Cranial bone motion has been the most controversial phenomenon of the Primary Respiratory Mechanism (PRM), but there is ample evidence that the cranial bones do rhythmically move a small but definite amount.

Historically, cranial bone motion was considered an anatomic impossibility. Respected scientists, anatomists, and anthropologists have always assumed that the cranial bones fuse and cannot move.

Most often cited are the works of Bolk,[3] Melsen,[4] Perizonius,[5] Cohen,[6] and Sahni et al.[7] However, a thorough examination of the experimental data gives a totally different point of view.

Todd and Lyon's[8,9] study is sited as a precedent for all of the aforementioned anthropologists and anatomists (with the exception of Bolk[3]), assuming that cranial bones normally fuse and are therefore immobile.

Upon examination of Todd and Lyon's data, the conclusion that cranial bones normally fuse is certainly in question.

Dart[10] states, "In interpreting this data, it must be noted that Todd and Lyon were attempting to establish a pattern for 'normal' sutural closure, and they discounted [eliminated] data, due to prolonged sutural patency [non-closure]."

Singer[11] gives further evidence to doubt the concept of universal sutural fusion. He found a high percentage of specimens with much less closure than Todd and Lyon's.

Pritchard et al.[12] commented in the 1950s that obliteration of sutures and synostosis (total closure) of adjoining bones, if it happens at all, occurs usually after all growth has ceased. In man and most laboratory animal's sutures may never completely close.

Sabini and Elkowitz[13] reviewed 36 human cadaver skulls ranging in age from 56 to 101 years of age, all well above the age when bone growth is complete. Their findings of a significant amount of sutural patency (non-fusion) challenge the theory that all cranial sutures are fused and cannot move.

Retzlaff et al.[14,15] identified sutural elements contradicting ossification and demonstrated the presence of vascular and neural structures in the sutures. The study stated, "...sutures remain as clearly identifiable structures even in the oldest samples."

Retzlaff et al[16] also showed the presence of nerve and vascular tissue large enough to supply connective tissue in the sutures. Nerve endings were traced from the sagittal suture (in the top of the head) to the neck. The existence of these structures within the cranial sutures strongly supports the idea that these sutures remain patent and mobile.

Cranial bone motion in animals is well documented:

Michael and Retzlaff[17] demonstrated cranial bone (parietal) mobility in the squirrel monkey. Heisey and Adams[18-20] demonstrated cat parietal bone motion, in the range of 200-300 microns, induced by laboratory-controlled changes in the Cerebro-Spinal Fluid (CSF) volume.

Jaslow[21] demonstrated in goat skulls (Capra hircus), that patent (non-fused) cranial sutures in adult animals may play a role in shock absorption and re-distribution of forces directed against the skull. Cranial bone motion in humans is also well documented:

Frymann[22] developed a non-invasive apparatus for mechanically measuring the changes in cranial diameter. On the basis of her extensive recordings, she was able to conclude that a rhythmic pattern of cranial bone mobility exists and occurs at a rate that is different than that of thoracic respiration. This work was later cited by NASA scientists.

Heifetz and Weiss,[23] using a strain gauge device, demonstrated cranial vault (bones of the top of the head) expansion associated with a rise in intracranial pressure (ICP) in two comatose patients.

Oleski and Smith[24] measured pre- and post-treatment changes in cranial bone position utilizing x- ray technology. The percentage of subjects with identifiable changes are:

66.6% with the mastoid process
91.6 % for the atlas, sphenoid and temporal bones.

There are plans to expand this research utilizing a larger number of subjects.

Russian Space Research

Assessment of cranial bone motion carried out by the Russian cosmonaut programs used various types of radiographic (x-ray) and ultrasound equipment.

Moskalenko[25,26] First published research on cats in space that described wave phenomenon similar to earlier discussions of "third order waves" in glial cells.

After being introduced to OCF, Moskalenko and associates carried out several studies which illustrated cranial bone motion:

Moskalenko[27] demonstrated, via NMR tomograms, cranial bone motion between 380 microns to 1 mm, and cranial cavity volume increases by 12-15 mL, with a rhythmicity of 6-14 cycles per minute.

Moskalenko[28] used Bioimpedence measurements and Transcranial Ultrasound Doppler Echography to show slow oscillations (back and forth motion) of the cranial bones at 5-12 cycles per minute. Moskalenko demonstrated that these oscillations, "...were of intracranial origin and were related to the mechanisms of regulation of the blood supply to and oxygen consumption by cerebral tissue, as well as with the dynamics of CSF circulation."

Together, Moskalenko and Frymann[29] carried this work toward the formulation of a theory that explains the physiology of the PRM.

US Space Research

In the mid-1990s NASA carried out research and developed an ultrasound device using pulse-phase locked loop (PPLL) technology with sensitivity to 0.1 μm, to more precisely assess intracranial anatomy and physiology.[30-34]

Ballard,et al.[31] carried out a study on two fresh cadavers. Saline was manually pumped into the internal spaces of the brain (ventricles) at a rate of one cycle per second, increasing the Intra- Cranial Pressure (ICP) by 15 mm Hg, and expanding the skull 0.929 mm. These findings were interpreted by the authors as similar to those found by Heisey and Adams,[18] Hiefetz and Weiss,[23] and Frymann.[22]

Ueno, et al.[32] utilized the PPLL device to demonstrate that "when intracranial pressure increases, arterial pulsation produces a higher amplitude ICP pulsation [stronger]. Increased amplitude of ICP pulsations will be manifested by larger fluctuations in distance across the skull."

In their summary, the NASA research team stated, "Although the skull is often assumed to be a rigid container with a constant volume, many researchers have demonstrated that the skull moves on the order of a few μm in association with changes in intracranial pressure." [33,34]

Recent Osteopathic Research on Cranial bone Motion

When palpatory assessment of cranial bone motion is compared with simultaneous Laser Doppler Flowmetry technology, striking correlations have been found.

Nelson, Sergueef and Glonek[35-38] report that Traube-Hering and Meyer oscillations can now be assessed. They describe oscillations which occur about 4 to 6 cycles per minute. These oscillations occur at the same time the osteopathic physician reports a certain phase of the cranial bone motion.

Instrument recordings of physiologic activity which correspond to clinical palpatory experience provide strong support for the concept of cranial bone motion and the PRM in general. This line of research is continuing.

Summary

Substantial support for life-long sutural patency and mobility of cranial sutures in healthy human beings is well established within the scientific and medical literature. Cranial bones can move small amounts, and do possess inherent rhythmic motion.

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http://osteodoc.com/cranial-bone-mobility/

Measurement of Cranial Bone Mobility

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Introduction

Most traditionally trained physiologists and physicians accept the Monroe-Kellie hypothesis, which considers the adult animal's cranium to be a rigid, minimally compliant enclosure within which brain tissue and the intracranial fluid volumes compete for space (Bruce, 1978; Lofgren, et.al, 1973; Marmarou, et.al, 1973; Sullivan, et.al., 1979; Weed, 1929)). An alternative view is that the skull's bones are mobile at their suture interfaces, that they normally move at these fulcra in response to intracranial forces, and that with training, these movements can be palpated (Fryman, 1976; Retzlaff, et.al., 1975)). A large body of anecdotal clinical information has led to a clear conviction that not only do the cranial bones move, but also their motions provide important diagnostic information and affecting them presents therapeutic advantages (Fryman, 1976; Kappler, 1979; Upledger, 1979).

We have direct quantitative evidence that the parietal bones in the anesthetized cat move both laterally and rotationally in reference to the sagittal suture which joins them on the dorsal surface of the skull. These movements can be induced by both external forces applied to the head and by internal ones associated with changes in intracranial pressure (Adams, et.al.t 1992). In some animals the motion is adequately large that the compliance of their sutures needs to be considered as a factor in defining total cranial compliance.

Device for Measuring Cranial Bone Mobility

Lateral and rotational movement of the parietal bones, relative to the sagittal suture, was measured with the isotonic measuring device shown in Figure 1 (pg. 3). The instrument has two sensors, each of which is made of a pair of microfoil strain gages. One sensor, oriented horizontally, measures rotational movements of the parietal bones; the other is positioned vertically and measures relative lateral separation of the parietal bones in reference to the midline suture that joins them.

There are different ways the vertically positioned gage could be activated. It could be displaced just by a change in the lateral separation of the parietal bones at the sagittal suture. In this case, narrowing of the suture would bring the bilateral sections of the device closer together and cause a change in voltage output of the calibrated amplifier to which the bonded pair of strain gages is connected; widening of the suture would cause a voltage output in the opposite direction of the preloaded sensor. The vertical gage could also be deformed were there no change in suture width, but just rotation of the parietal bones around the fulcrum of the sagittal suture. A net outward (counterclockwise) rotation would lever the vertical elements of the device to be closer; a net inward (clockwise) rotation would separate them. The measuring device could be affected in a third way if both lateral and rotational movements of the parietal bones were to occur simultaneously. We use a series of equations based on the geometry of the animal's head and the dimensions of the measuring device to distinguish lateral from rotation movements of the parietal bones when they occur simultaneously. We have observed considerable variation among animals in the magnitude and type of parietal bone movements in response to different experimentally induced perturbations.

Anyway, as we start the spring and summer seasons, many of us who run laboratories are faced with increasing scrutiny from animal care committees and pressure from animal rights groups. It is very important to prepare for the incursions into the domain of science procedure and not be caught off guard. It is important that each of us look critically at our animal use and protocols to make sure they are clearly up to standards and that we are using the most up to date and humane procedures in our work. We must educate the public about the value and necessity of our science, and not take it for granted that everyone understands what we do. We must take a proactive stance in dealing with the public and not be constantly on the defensive. We must make sure that our institutions are ready with a plan to respond to activists who wish to destroy proper scientific inquiry.

The key to this action is mutual support and a proper activism of our own as scientists. Support such groups as iiFAR and the Society for Neuro-science Committee on Animals in Research. Be active-be a part of the solution.

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Surgical Procedures and Measurement of Physiological Parameters

All experiments were performed on anesthetized (Sodium pentobarbital: 36 mg/kg;ip) adult domestic cats which remained fully anesthetized in all procedures. Animals were killed at the end of an experiment with a lethal bolus injection of anesthetic. Cannulas were inserted in a femoral vein and artery for supplementing anesthesia and recording arterial blood pressure, respectively. A pneumotachograph attached to an endotracheal tube recorded respiratory activity. Body temperature was monitored with a rectal temperature probe and held near-constant at 38°C by means of a controlled heating pad on which the animal rested.

The animal's head was rigidly fixed in a Kopf Model 1430 stereotaxic frame with an associated electrode holder. A midline incision from the level of the supraorbital ridges to the back of the skull exposed muscle and connective tissue which were dissected free, excised or retracted. The dorsal skull surface was cleaned and a 20 gauge needle was positioned, stereotaxically (A-P=13.5 mm; lateral=2.5 mm; vertical=nom._ 17J> mm), in a lateral cerebral ventricle through a 2 mm hole drilled in the dorsal skull surface. Dental acrylic was used to seal the hole around the needle shaft and to hold it rigid when the animal was removed from the stereotaxic frame. The needle served as a site for injecting cerebrospinal fluid and for recording intracranial pressure.

Threaded studs to which the measuring device (Fig. 1, pg. 3) was attached were threaded through the full depth of the skull. One 4-40 screw rounded at its end was secured in each parietal bone approximately 1 cm. posterior and lateral to the bregma. Dental acrylic was applied to each stud at the surface of the skull to assure its immobility. Exposed tissue and bone were sprayed with medical-grade silicon to minimize their drying. The animal's head and neck were loosely draped during a test.

Results and Discussion

Initially, the animal's head was secured in the stereotaxic frame to insert and seal the cannula into the lateral cerebral ventricle and to attach our device for measuring parietal bone movement. The animal's head was then released from the stereotaxic frame and allowed to rest without restraint on a padded surface. When baselines for spontaneous bone movement, cardiovascular and ber which amplifies (100X) and band pass filters (100- respiratory activity were stabilized we began our tests, one of which was to measure the effects of an external force applied to the animal's head.

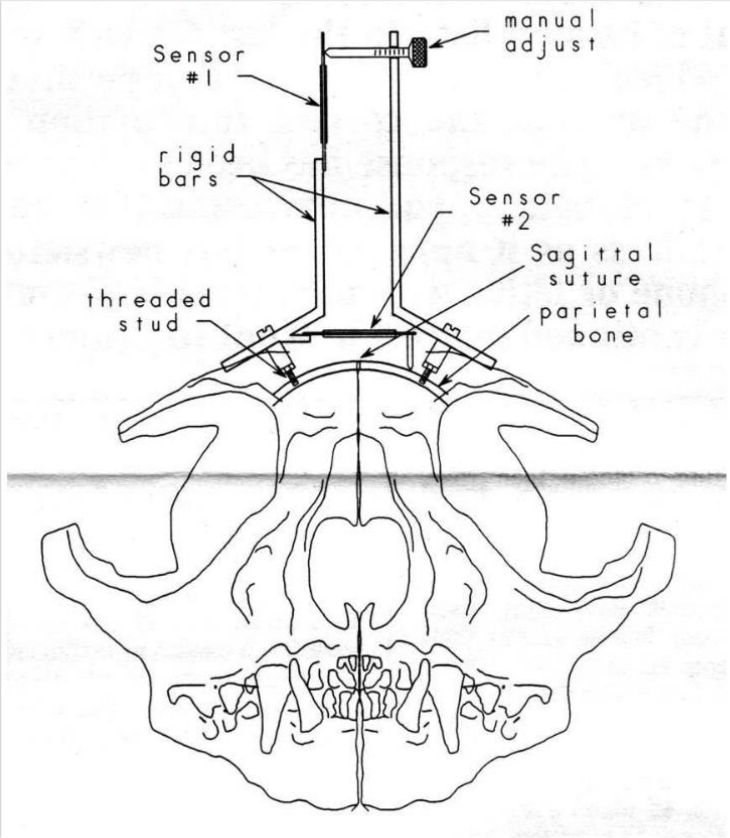

Figure 1. Cranial motion was measured by securing a customized device to each bilateral parietal bone with a threaded stud. One microfoil strain gage (Sensor #1) monitored lateral movement of the bones at the sagittal suture and another (Sensor #2) transduced their relative rotational movement Both sensors were calibrated to record movement with a resolution of 1 micron as a function of the output of a voltage divider and amplifier to which they were connected (electrical connections are not shown).

Representative data (Fig. 2, pg. 4) show the effects of head compression using a thumb and forefinger to compress and hold firmly the temporal bones of the animal's head. Coincident with the application of this inward directed force, the parietal bones moved laterally closer and underwent inward rotation. Release of the manually applied external force was accompanied by a return of the parietal bones to their near-rest position. The data show that there is spontaneous movement of the parietal bones around the fulcrum of the sagittal suture which reflects cardiovascular and respiratory activity. An external force, applied to the head, caused movement of the parietal bones resulting in increased intracranial pressure and transiently altered cardiovascular and respiratory activity. An external force, applied to the head, caused movement of the parietal bones resulting in increased intracranial pressure and transiently altered cardiovascular and respiratory activity. Release of the force resulted in a return to the previous condition. These responses were easily duplicated in subsequent tests on the same animal; animals with less compliant sutures showed less parietal bone movement and smaller changes in intracranial pressure and physiological responses. How much the parietal bones move in response to changes in intracranial volume and pressure depend not only on the mechanical properties of the skull's sutures but also on any extra-cranial restrictions that are imposed. Representative data (Fig. 3, pg. 5) show responses when the animal's head was held firmly in a stereotaxic frame ("RESTRAINED") and when it was free of restraint ("UNRESTRAINED"). Controlled volumes of fluid were injected as a bolus into a lateral cerebral ventricle and the change in intra-cranial pressure and lateral movement of the parietal bones were measured. Intracranial pressure and parietal bones were allowed to return to their preinjection levels before subsequent injections were made.

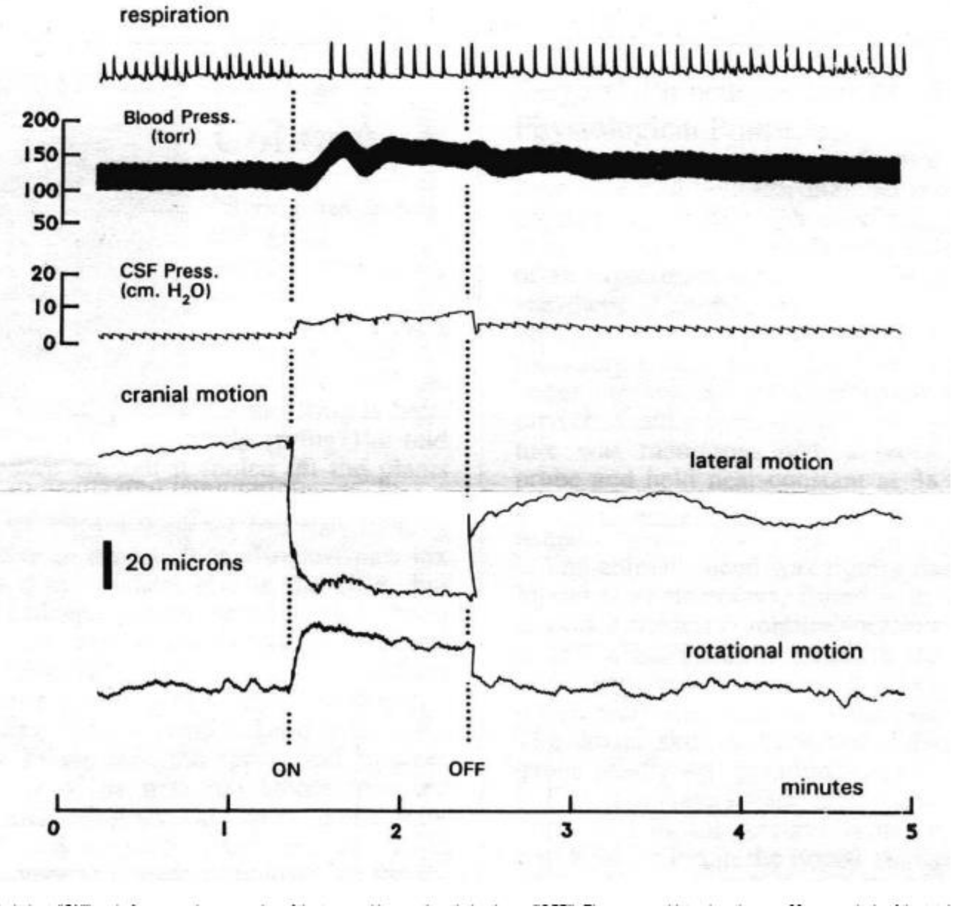

Figure 2. Respiration, systemic arterial pressure, CSF pressure and lateral and rotational parietal bone motion traces in an anesthetized cat as it rested without head restrain (prior to"ON") and after manual compression of the temporal bones, then their release ("OFF"). The measured lateral motion was 60 μm. analysis of the total geometry of the system, including the rotation angle (0.19°), yields a total calculated suture movement of 220 μm.

The data demonstrate that restraining the head in the stereotaxic frame caused greater increases in intracranial pressure in response to ventricular injections (upper left, Fig. 3, pg. 5) and restricted sagittal suture movement (upper right, Fig. 3, pg.5). The effect of restraint is also reflected in a reduced total cranial compliance (calculated as the ratio of change in intracranial volume to change in intracranial pressure; lower left, Fig. 3, pg. 5) and a reduced suture compliance (calculated as the ratio of change in suture width to change in intracranial pressure; lower right, Fig. 3, pg. 5). Determinations of total cranial compliance in the cat are often made with the animal's head secured in a stereotaxic frame (Marmarou, et.al., 1978; Sullivan, et.ai, 1979). Our data indicate that this external restraint not only influences the cranial compliance, but also masks contributions of suture movement to the total compliance of the skull and its contents.

Summary

External head restraint provided by a stereotaxic frame restricts free movement of the cranial bones in the anesthetized cat. A consequence is that intracranial pressure and volume relationships are different when the animal's head is restrained and when it is unrestrained as are calculations of intracranial compliance and elastance.

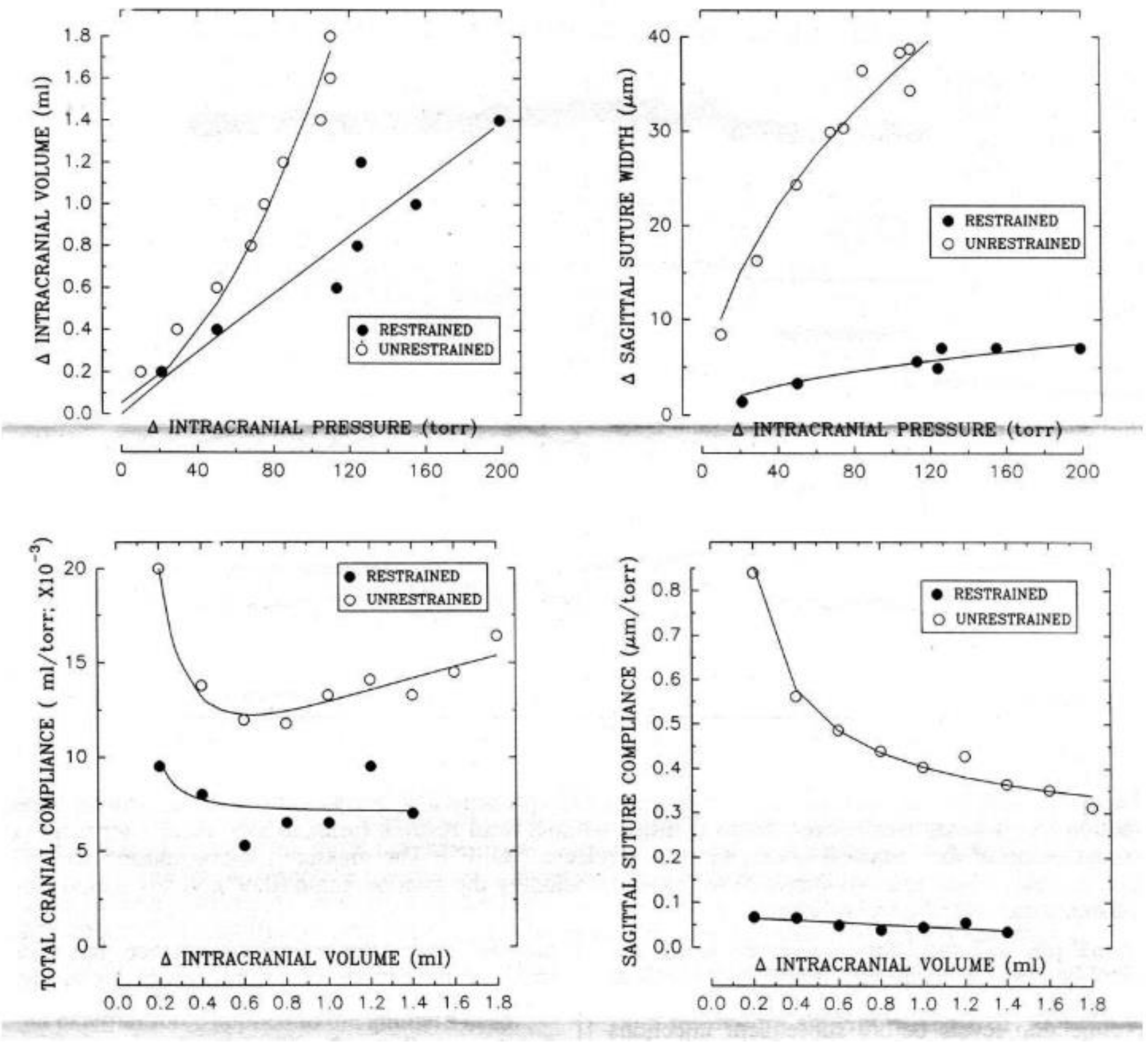

Figure 3. Data in the upper panels show the change in intracranial volume and sagittal suture width, respectively, as a function of the change in intracranial pressure resulting from controlled injections into a lateral cerebral ventricle. Data in the lower panels show cranial compliance ()V/)P) and sagittal

suture compliance ()L/)P), respectively, as a function of the change in intracranial volume resulting from the controlled injections. Lines through data points are computer-assisted best-tit curves.

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Radiographic Evidence of Cranial Bone Mobility

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Abstract: The purpose of this retrospective chart review was to determine if external manipulation of the cranium alters selected parameters of the cranial vault and base that can be visualized and measured on x-ray. Twelve adult patient charts were randomly selected to include patients who had received cranial vault manipulation treatment with a pre- and post-treatment x-ray taken with the head in a fixed positioning device. The degree of change in angle between various specified cranial landmarks as visualized on x-ray was measured. The mean angle of change measured at the atlas was 2.58 degrees, at the mastoid was 1.66 degrees, at the malar line was 1.25 degrees, at the sphenoid was 2.42 degrees, and at the temporal line was 1.75 degrees. 91.6% of patients exhibited differences in measurement at 3 or more sites. This study concludes that cranial bone mobility can be documented and measured on x-ray.

Osteopathic physicians have long believed that the bones of the cranium are mobile. Unfortunately, there have only been a few scientific papers to support this hypothesis, and the palpatory findings of cranial movement are considered to be subjective. This study was designed to determine whether this cranial bone mobility could be visualized and measured on A-P radiographs.

Kragt, et al, (1) showed that movement was possible at the sutures in a macerated human skull, and Retzlaff, et al, (2) documented that the cranial sutures do not fuse with age. Taking this information a step further, Zanakis, et al, (3) attached infrared markers to the skin over selected skull bones, and used a 3-D kinematic system to analyze individual bone motion. Motion of the cranial bones was labeled complex, involving more than one axis of movement and not a simple hinge- operation.

In 1970, Greenman (4) published an article in which he described a method to diagnose cranial dysfunctions with an e-ray of the cranium. With a set of specified landmarks, and a vertical axis, torsions, and sprains could be viewed as deviations from the horizontal plane. It was also noted that a good clinical correlation existed between the x-ray findings and the palpators' diagnoses. The landmarks and practices Greenman used are those from which the protocol for this study was derived.

Demonstrating scientific evidence of cranial suture movement in living humans has many implications for future treatments and diagnoses. These cranial manipulations are administered by the practitioner applying gentle forces with the hands to the dysfunctional regions of the patient's cranium. In fact, many cranial manipulation diagnostic findings have already been revealed.

For example, Greenman and McPartland (5) determined that the average cranial rhythmic impulse was low when at least one strain pattern was present, and one or more bony restrictions were evident in patients with a traumatic brain injury. They

believed cranial manipulation to correct these dysfunctions would aid in the treatment of traumatic brain injury. Also, Gregory (6) noted that temporomandibular disorder (TMD) was improved following chiropractic sacro-occipital technique treatment and that concurrent chiropractic and dental treatments may improve the success rate of TMD resolution.

Temporomandibular disorder was also studied by Chinappi and Getzoff, (7) who concluded that the disorder was worsened by an instability of the sacroiliac joint, specific thoracic and cervical vertebral subluxations, and cranial suture restrictions. It was improved by adjustments of the spine, neck, and cranial sutures several times a week.

Since the implications for treatment with cranial manipulation appear beneficial, the methods of diagnosis and a means to follow progress require more study. Therefore, we propose to show that cranial bone mobility can be documented and measured on x-ray.

Materials and Methods

Patient charts from a private dental office were randomly selected. These charts were subsequently reviewed to determine whether the patient met the inclusion criteria. In order to be included in this study, the patient chart needed to include two separate A-P radiographs of the patient's head wile in a fixed head positioning device. The patients were required to be over the age of eighteen to eliminate the possibility of craniofacial changes related to normal growth and development. Also, documentation was needed to determine if cranial manipulative treatment was provided to the patient at a time between the first and second A-P radiographs. The authors retrospectively studied the x-rays of these twelve randomly selected adult patients who received cranial manipulation as part of their standard dental care regimen. Exclusion criteria included patients under the age of eighteen, patients with a history of surgery on the cranium, ears, or jaw, or cases in which there were no before-treatment and after-treatment x-rays available. In this study, none of the charts selected were excluded. The study was reviewed and approved by the institutional review board at the Philadelphia College of Osteopathic Medicine, Philadelphia, Pennsylvania.

Experimental Protocol

In order to determine changes in the bony parameters of the skull, it is necessary to fix the head in a positioning device for accurate comparisons of radiographs over time. The cranial fixation device that had been used in taking the x-rays was the Dental Orthogonal Radiographic Analysis method (Margraf Co., Jenkintown, PA) which requires the following equipment: cephalometric holder modified for A-P view (Figure 1); cassette, intensifying screen and grid; eyeglass frame positioner; polyflex registration material molded t the shape of the bridge of the patient's nose; and 90 Kv x-ray unit.

After the eyeglass frame with custom molded nosepiece had been placed on the patient, the cassette and grid sheet were placed on the patient, the cassette and grid sheet into the cassette holder. The patient's head was positioned in the A-P holder and the ear positioners were secured. The patient's head was aligned so that the maxilla was parallel to the floor when the mouth was opened to its maximum position. At this head position the trombone rods of the eye glass frame were extended until they touched the grid sheets. Their position was marked with two ink dots where the metal rods touched the paper grid sheet. After taking the exposure, the length of each rod was measured and the number was entered in the appropriate block on the grid sheet. To insure accuracy the locator glasses were left in position while the x-ray was taken. The frame does not interfere with the analysis of the radiograph.

After the first radiograph was taken, the patient was treated with cranial manipulation by the author (GS). The treatments were customized to the patients and were not standardized throughout. Since the scope of this investigation was to determine whether cranial bone movement could be documented and measured on x-ray, the specific cranial manipulations administered to the patients are not important. After cranial manipulation was administered, the patient received a second A- P radiograph.

To take the second A-P radiograph for treatment comparison, the eyeglass frame was placed back on the patient. The film cassette with the previously marked grid sheet was placed in position. The patient's head was placed in position with the trombone extensions pulled out to the previous measurements making sure they touched the previously marked dots on the grid sheet. The patient was instructed to open his mouth to the maximum position and the exposure was made.

For analysis of the radiograph, a vertical reference line was drawn from the center of the nasion to the tip of the anterior nasal spine using a clear plastic ruler. The vertical reference line bisected the odontoid process along its long axis.

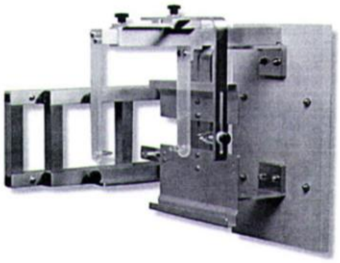

Figure 1

A-P Head Positioner device (Margraph Co., Jenkintown, Pennsylvania) used to fix the head for accurate measurements.

See also:

DORA: Dental Orthoganal Radiographic Analysis

The horizontal plane of the atlas was determined by drawing a line through the two lowest points on the lateral masses of the atlas vertebra. The angle it made with the vertical reference line was measured in degrees with a clear plastic protractor.

The inferior border of the mastoid plane was determined by drawing a line through the two lowest points on the mastoid bones. The angle it made with the vertical reference line was measured in degrees with the protractor.

The malar plane line was determined by drawing a line through the two lowest points on the inferior border of the malar bone. The angle it made with the vertical reference line was measured in degrees with the protractor.

The apex of the temporal bone was determined by drawing a line through the two highest points on the petrous portion of the temporal bones. The angle the line made with the vertical reference line was measured in degrees with the protractor.

The lesser wing of the sphenoid was determined by drawing a line through the two points where it contacted the outer rim of the orbit. The angle the line made with the vertical reference line was measured in degrees with the protractor.

To assess for interobserver reliability, these measurements which were made by the author (SO) were independently compared to measurements charted previously by the dental office staff and were determined to be accurate within 0.5 degrees. The measurements from both sets of A-P radiographs were then compared and analyzed for before-treatment and after-treatment differences.

Statistical Analysis

A D'Agostini test was performed to determine if the change in degree of measurement at the various anatomical landmarks was distributed normally. If the distribution was normal, a simple t-test was performed using the null hypothesis. When the data was not distributed normally, a symmetry and median test was performed, using the null hypothesis, to assess for statistic significance. Finally, a regression analysis was run to determine correlation between the percentage of patients with changes at certain numbers of measurement locations.

Results

The mean angle of change measured off the vertical reference line at the atlas was 2.58 degrees with a range from 0 degrees to 6 degrees. The t-test calculated $p<0.01$ with $n=12$, $ny=11$, and $t=5.17$. the mean angle of change measured at the Mastoid was 1.66 degrees with a range from 0 to 3 degrees. The t-test showed $p<0.01$ with $n=12$, $ny=11$, and $t=3.25$. At the malar line, the degree of change was 1.25 degrees with a range from 0 to 4 degrees. The abnormally nonsymmetrically distributed data yielded a $p<0.01$ via the median test. The mean angle of change measured at the sphenoid was 2.42 degrees with a range from 0 to 8 degrees. Again, these data were not normally distributed and were asymmetrical. The median test yielded $p<0.01$. At the temporal line, the mean was 1.75 degrees with a range from 0 to 5 degrees. The median test yielded $p<0.01$, (Table 1).

The percentage of patients with changes at the various specified landmarks fluctuated (Table 1). The percentage with change at the atlas, sphenoid, and temporal line was 91.6%. The percentage with change at the malar line was 81.8%, and the percentage with change at the mastoid only 66.6%.

The percentage of patients with a change at all five landmarks was 41.6%. While the percentage of patients with a change at three or more landmarks was 91.6%, 100% of the patients exhibited change in at least two landmarks. The regression analysis yielded a $p=0.06$.

Discussion

This is the first study to determine that cranial mobility can be visualized and measured on x-ray. It yielded the interesting finding that cranial mobility can be quantified. The amount of change measured ranged up to eight degrees which is fairly significant since Kostopoulos and Keramidas8 only noted a relative elongation of the falx of 1.44 mm during a frontal lift technique and measurement errors typically account for only a maximum of three degrees of difference.

While the tools used to measure the degrees of change in this study may appear rudimentary in this age of computers, they provided consistent measurements between those charted in the dental office records and those generated by the author. The authors recommend the use of architectural software with digitally scanned radiographs for future studies of this type so as to allow quantification of smaller degrees of change among landmarks and to minimize measurement errors.

The change in landmarks is not likely due to chance since the radiographs were taken of the head in the fixation device. Also, since 58.4% of patients exhibited no change in measurement of at least one landmark, it appears unlikely that head positioning is a factor.

Furthermore, we discovered that the malar bone, or cheekbone, is likely to exhibit the least amount of movement whereas the atlas exhibits the greatest amount. This was not surprising since the atlas, as the first vertebrae, has a great capacity for movement and is biomechanically influenced by the rest of the spine.

Since the malar bone exhibited the least amount of movement, it would stand to reason that it has fewer interdigitated sutures. This conclusion was reached with the knowledge that Jaslow(9) noted a greater bending strength in segments of cranial bone having highly interdigitated sutures. More studies would need to be completed to determine if this is the exact reason the malar bone exhibited the least amount of movement in our study.

Measures
Average degree of change Percentage w/change Range of degree of change

Conclusion

Table 1

Atlas Mastoid Malar Spehnoid Temporal 2.58 1.66 1.25 2.42 1.75
91.6 66.6 81.8 91.6 91.6
0-6 0-6 0-4 0-8 0-5

This pilot study supports the observation that cranial mobility can be recorded and measured on x-ray. No control group was used in this study as it was performed retrospectively. The authors do not believe this is problematic since this study was only looking to determine whether movement could be documented and measured on x-ray and not to compare the cranial bone motion at rest to that generated by cranial manipulation. The authors believe these novel findings require further investigation and confirmation. The authors recommend a large scale double-blind prospective study using digital radiographs analyzed by architectural software for further investigations.

Understanding that the bones of the cranium have mobility and having a method of documenting this motion will provide evidence for numerous cranial manipulative treatment modalities. As evidenced in the literature, these treatments have the capacity to ease discomfort of temporomandibular joint disorder, traumatic brain injuries, headaches, and other somatic dysfunctions.

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Role of cranial bone mobility in cranial compliance.

Heisey SR[1], Adams T. **Author information**

Full text links

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Abstract

Increases in intracranial pressure are normally buffered by the displacement of blood and cerebrospinal fluid from the cranium when there is an increase in intracranial volume (ICV). How much pressure increases with an increase in ICV is expressed in the calculation of cranial compliance (delta ICV/delta P, where delta P is change in pressure) and elastance (delta P/delta ICV). Data reported here indicate that the movement of the cranial bones at their sutures is an additional factor defining total cranial compliance. Using controlled bolus injections of artificial cerebrospinal fluid into a

lateral cerebral ventricle in anesthetized cats and a newly developed instrument to quantify cranial bone movement at the midline sagittal suture where the bilateral parietal bones meet, we show that these cranial bones move in association with increases in ICV along with corresponding peak intracranial pressures and changes in intracranial pressure. External restraints to the head restrict these movements and reduce the compliance characteristics of the cranium. We propose that total cranial compliance depends on the mobility of intracranial fluid volumes of blood and cerebrospinal fluid when there is an increase in ICV, but it also varies as a function of cranial compliance attributable to the movement of the cranial bones at their sutures. Our data indicate that although the cranial bones move apart even with small (nominally 0.2 ml) increases in ICV, total cranial compliance depends more on fluid migration from the cranium when ICV increases are less than approximately 3% of total cranial volume. Cranial bone mobility plays a progressively larger role in total cranial compliance with larger ICV increases.

The Inherent Rhythmic Motion of the Cranial Bones

Hollis H. King, DO, PhD, FAAO

The most controversial phenomenon of the PRM from a scientific perspective is the concept of palpable cranial bone motion. Misgivings have been expressed based primarily on the assumed anatomic impossibility of such motion.[1,2] The basis of the traditional anatomic position of cranial bone immobility is derived primarily from forensic anthropology research done to estimate the age of skeletal remains. However, there is a growing body of literature that brings into question this long held anatomically based dogma. The challenge to the position that cranial bones are incapable of motion is based on examination of basis for this conclusion in the first place and empirical evidence of cranial bone motion in the second place.

To appreciate the conceptual change implied by the concept of cranial bone motion, it is important to know that respected scientists, anatomists, and anthropologists posited the fusion and inherent immobility of cranial bones. Most often cited are the works of Bolk,[3] Melsen,[4] Perizonius,[5] Cohen,[6] and Sahni et al.,[7] all of whom are reported to have held the view that cranial sutures were fused and immobile. Based on thorough examination of this debate, it may turn out that this view has been an anatomic version of “the world is flat” debate of the last millennium.

With the exception of Bolk,[3] all of the aforementioned anthropologists and anatomists cite as precedent for their work, that of Todd and Lyon as central to the idea that cranial bones fuse and therefore are immobile.[8,9] There is reason to question Todd and Lyon’s conclusions based on a close reading of their lengthy manuscripts. Paul Dart, MD states,[10] “In interpreting this data, it must be noted that Todd and Lyon were attempting to establish ‘modal’ norms for sutural closure, and they discounted data that was clearly out of the modal pattern before creating their summary. 11.7% of their 307 white male specimens and 25.8% of their 120 negro male specimens were excluded from the data due to prolonged sutural patency.”

Further reason to doubt the concept of universal sutural fusion was given by Singer.[11] He found a high percentage of specimens with much less closure than Todd and Lyon’s norms, including a 64 year old specimen with no closure at sagittal, lambdoid, or left coronal sutures and 3 specimens ages early 40’s with virtually no sutural closure in the coronal, lambdoid, or sagittal sutures. Also in the

1950s, Pritchard et al.[12] commented to the effect that obliteration of sutures and synostosis of adjoining bones, *if it happens at all*, occurs

usually after all growth has ceased. In great apes synostosis of all sutures occurs immediately after growth has ceased, but in man and most laboratory animals sutures may never completely close.

A recent article by Sabini and Elkowitz[13] gives pictorial and systematic review of 36 human cadaver skulls ranging in age from 56 to 101 years, all well above the age when bone growth is complete. Twenty-six of the skulls showed less than 100% obliteration of the coronal suture, 31 of the skulls had unobliterated lamboidal sutures, and 24 of the skulls had unobliterated sagittal sutures. The lamboidal suture was the least fused on a majority and the attachment of musculature on the occipital bone cited as the probable cause of maintaining sutural patency. The authors speculate that the chewing motion contributes to muscular tension on the bones, maintaining some degree of sutural patency. The endocranial (inner) surface of the skull was not evaluated so that some estimate of through and through fusion of each suture could not be made. However, the finding of a significant amount of sutural patency (non- fusion) certainly brings in to question that all cranial sutures are fused and therefore can not move.

Prior to the Sabini and Elkowitz publication, the work of Retzlaff and associates dealt directly with the nature of cranial suture morphology and cranial bone motion. Retzlaff et al. state, “Gross and microscopic examination of the parieto-parietal and parieto-temporal cranial sutures obtained by autopsy from 17 human cadavers with age range of 7 to 78 years shows that these sutures remain as clearly identifiable structures even in the oldest samples.”[14, p.663] Retzlaff et al. identified sutural elements contradicting ossification and demonstrated the presence of vascular and neural structures in the sutures.[15] These studies also showed the presence of nerve and vascular tissue substantial enough to supply the needs of connective tissue activated beyond mere bony sutural adhesions and ossification. Additionally, Retzlaff et al. traced nerve endings from the sagittal sinus through the falx cerebri and third ventricle to the superior cervical ganglion in primates and mammals.[16] That such structures were found in cranial sutures brings further doubt to the idea that these sutures fuse and are immobile.

Empirically demonstrated cranial bone motion in animals is well documented. Michael and Retzlaff demonstrated cranial bone (parietal) mobility in the squirrel monkey.[17] In cats, parietal bone motion in the range of 200-300 microns was induced by laboratory controlled changes in the CSF volume.[18-20] Jaslow[21] demonstrated in goat skulls (*Capra hircus)*, that patent cranial sutures in adult animals may play a role in shock absorption and re-distribution of forces directed against the skull (e.g. ballistic forces directed against the goat’s skull) and during chewing movements. Thus a compliant skull is a stronger skull in that it is capable of absorbing and re-distributing forces directed against it.

Research involving assessment of human cranial bone motion has been done by neurologists, space physiologists, and osteopathic medical profession physicians and basic scientists. In work later cited by NASA scientists, Frymann[22] developed a non-invasive apparatus for mechanically measuring the changes in cranial diameter. Cranial motion was recorded simultaneously with thoracic respiration. On the basis of her extensive recordings, she was able to conclude that a rhythmic pattern of cranial bone mobility exists and moves at a rate that is different than that of thoracic respiration.

In a 1981 neurology study, by Heifetz and Weiss,[23] using a stain gauge device, they were able to demonstrate cranial vault expansion associated with a rise in intracranial pressure (ICP) in two comatose patients. Utilizing a head holding device similar to Gardner-Wells tongs, accompanied by a strain gauge meter, the skull device was inserted into the calvaria above the external auditory canal. The strain gauge device was part of what is called a “Wheatstone Bridge,” which was designed to detect any expansion of the skull of about 0.0003 mm or greater, which when it occurred, would produce a voltage change of 1uV. They performed 19 trials and each time ICP was artificially elevated, there was a voltage change. This voltage change indicated that the skull tong pins were being spread apart. This could only occur with expansion of the cranial vault.

A promising approach to assessing cranial bone motion after cranial manipulation was carried out utilizing x- rays (Dental Orthogonal Radiographic Analysis) on 12 subjects.[24] The before to after changes in cranial bone position measured in degrees ranged from 0^o to 8^o for atlas, mastoid, malar, sphenoid, and temporal bone position. The percentage of subjects with identifiable changes ranged 66.6% with the mastoid to 91.6 % for the atlas, sphenoid and temporal bones. There are plans to expand this research utilizing a larger number of subjects.

Russian and United States Space Research

One of the strongest areas of research which involved assessment of cranial bone motion has been that carried out by the Russian and United States astronaut programs. The concerns that led to this research had to do with the nature of human response to prolonged weightlessness in space. Without gravity would the human circulatory and central nervous systems function normally? In the process of assessing intracranial fluid dynamics, various types of radiographic and ultrasound equipment have been used to measure intracranial volume as well as cranial bone dimensions, and changes in these dimensions have been observed.

Yuri Moskalenko, PhD first published research on cats in space that described “third order waves” similar to that described above in glial cells.[25,26] After being introduced to OCF, Moskalenko and associates carried out several studies which showed cranial bone motion. One utilizing NMR tomograms, showed cranial bone motion between 380 microns to 1 mm, and cranial cavity volume increases by 12-15 mL, with a rhythmicity of 6- 14 cycles per minute.[27] This work was followed by a study utilizing bioimpedence measures and transcranial ultrasound Doppler echography showing slow oscillations of the cranial bones at 0.08-0.2 Hz.[28] Moskalenko demonstrated that these oscillations, “...were of intracranial origin and were related to the mechanisms of regulation of the blood supply to and oxygen consumption by cerebral tissue, as well as with the dynamics of CSF circulation.[28, p.171] Moskalenko and Frymann have carried this work into a formulation of a theory that explains the physiology of the PRM.[29]

In the mid-1990s NASA was also concerned about intracranial fluid volume changes in astronauts in space. NASA carried out research and developed an ultrasound device, pulse-phase locked loop (PPLL) with sensitivity to 0.1 μm to more precisely assess intracranial anatomy and physiology.[30] This NASA team at the Ames Research Center carried out a series of studies.[31-34]

On two fresh cadavera (less than 24 hours post-mortem), female 83 and male 93, ICP pulsations were generated manually by infusing saline into the intracranial ventricular system at a rate of 1 cycle/second (1 hertz).[31] In this study an increase in ICP of 15 mL Hg caused a skull expansion of 0.029mm, and this was interpreted by the authors as similar to that found by Heisey and Adams,[18] Hiefetz and Weiss,[23] and Frymann.[22]

In another study, 7 healthy volunteers fitted with the PPLL device were placed in $60,^{o}$ 30^{o} head-up tilt, supine, and 10^{o} head-down tilt positions. The average path length from forehead to occipital bone increased 1.038 ± 0.207 mm at 10^{o} head down tilt relative to 90^{o} upright. "In other words, when intracranial pressure increases, arterial pulsation produces a higher amplitude ICP pulsation. Increased amplitude of ICP pulsations will be manifested by larger fluctuations in distance across the skull."[32, p.3]

Summarizing their work to a certain point, the NASA research team stated, "Although the skull is often assumed to be a rigid container with a constant volume, many researchers have demonstrated that the skull moves on the order of a few μm in association with changes in intracranial pressure."[33,p.66] In their last publication in this series they state, "...analysis of covariance reveled that there was a significant effect of tilt angle on amplitude of cranial diameter pulsation ($p < 0.001$)....As a result, amplitudes of cranial distance pulsation increased as the angle of tilt decreased. The observed changes in cranial diameter pulsation are considered to be statistically significant."[34,p.883]

Recent Osteopathic Research on Cranial Bone Motion

Research comparing palpatory assessment of cranial bone motion with simultaneous assessment by laser Doppler flowmetry technology has been done. Striking correlations have been found between cranial palpation reports and the technologically measured physiologic motion phenomena identified by the laser Doppler flowmetry. Nelson, Sergueef and Glonek posit that it is the Traube-Hering and Meyer oscillations that they have now empirically can assess.[35-38] They describe oscillations which occur about 4 to 6 cycles per minute and in their studies have been shown to occur at the same time the osteopathic cranial practitioner reports a certain phase of the cranial bone motion. To have instrumented recordings of physiologic activity correspond to the palpatory experience is strong support for the PRM and the concept of cranial bone motion. This line of research is continuing.

[The Cranial Academy and Sutherland Cranial Teaching Foundation sponsored a "PRM Research Symposium" which was held in October 2003. Pictured was a panel featuring several of the most outstanding cranial osteopathic researchers. From left to right: Viola M. Frymann, DO, Yuri Moskalenko, PhD, Kenneth Nelson, DO, Tom Glonek, PhD and Toshiaki Ueno, MD, PhD.] Can the picture be placed about here – perhaps Mark has a better picture of the panel?

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The Controversy of Cranial Bone Movement

By John Upledger , DO, OMM 5/29/2009

Editor's note: Dr. Upledger has asked guest author Lisa Johnson Zee to share her thoughts on cranial bone movement in this month's column.

In anatomy and physiology, I learned that cranial bones fuse in early adulthood or childhood.[1] *Gray's Anatomy* supports the theory that the sutures grow together, creating a solid mass of bone called the calvarium. The fused skull functions as a helmet in which volume or pressure changes in blood, cerebrospinal fluid (CSF) or brain tissue cause corresponding pressure changes in other systems to prevent an increase of intracranial pressure.

Previous
Issues

However, there is a sizable body of literature that documents a small, rhythmic movement of the cranial bones. The bulk of these studies come from the cranial osteopathy medical field. The following is a synopsis of some of these studies.

Tettambel used force transducers to measure movement between the frontal bone and bilateral mastoid processes of the temporal bone in 30 subjects.[2] She recorded three rhythms including the cardiac and respiratory rhythms. She hypothesized that the third pulse, which averaged eight cycles per minute, was the craniosacral rhythm.

Guidelines

U-shaped frame with a differential transducer.[3] Changes in the diameter of the skull were measured by the displacement of metal rods. This study is unique because it measured movement in live human subjects. Frymann found a pulsating rhythm between six and eight cycles per minute separate from cardiac and respiratory rates. The amount of displacement was measured between 10 and 30 microns.

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Another study by Adams, et al., looked at parietal bone mobility in cats.[4] These researchers fastened strain gauges to feline parietal bones to measure movement

Frymann studied the rhythmic changes in the circumference of the head using a researcher's fastened strain gauges to feline parietal bones to measure movement when injections of artificial CSF were given. The bones moved significantly, varying from 17 to 70 microns. External lateral head compression caused a measurable widening of the sagittal suture with an inward rotation of the parietal bones.

Researchers at the University of Michigan College of Osteopathic Medicine have looked at cranial bone mobility in adult primates.[5] Michael and Retzlaff used a direct screw attachment on the right parietal bone and measured movement with a pressure transducer. They also measured blood pressure, heart rate and respiration rate. The parietal bones moved spontaneously in two distinct rhythms, one corresponding to the respiration rate and a second, slower rate of five to seven cycles per minute.

These four studies indicate cranial bones may show a slow, steady, cyclical movement. A relatively new theory for Western medical science, it represents a dramatic shift. Bringing controversial ideas into the status quo of scientific thought is not easy, but the body of literature supporting cranial movement is growing. Although inconclusive, it deserves to be approached with an open mind.

In CranioSacral Therapy (CST), the rhythm of CSF can be palpated at all parts of the body due to the passive action of fascial connective tissue. The rhythm occurs in two distinct phases: flexion (outward movement) and extension (inward movement). In physical therapy terms, flexion is a decreasing measurement of degrees in the angle of the joint. The sphenobasilar joint is where the posterior sphenoid articulates with a ridge on the occipital bone.

When Dr. William Garner Sutherland, the "father of osteopathy," palpated the movement of these bones, he noticed this joint does indeed flex or reduce angle size on the inferior side. The flexion of this angle is accompanied by subtle outward movement in the body, which Sutherland called flexion. Therefore, in CST, the cranium, along with the rest of the body, is in flexion when it widens and in extension when it narrows.

Anatomy of Suture Closure

To discover more about cranial bone motion, let's examine the nature of cranial sutures. If the sutures remain flexible throughout adulthood, some degree of motion is possible when driven by pressure changes in the craniosacral system. If the tissues fuse and become immobile, rhythmic motion is unlikely.

Several studies have examined the nature of the cranial sutures. Retzlaff, et al., used light and scanning microscopy to examine tissue samples of adult primate sutures.[6] They found connective tissue, blood vessels and nerve fibers present in the sutural space. They described a five-layered pattern of fibers and cells containing collagenous bundles. Tissue was reported to be arranged in a wavy pattern. The researchers hypothesized the purpose of the tissue might be to control the elongation of the collagen bundles. They reported no evidence of fusion in the adult primate sutures.

In a separate study, Upledger and Retzlaff examined the sagittal suture in primate skulls.[7] They found not only connective tissue, but also a vascular network and neuronal plexuses and receptors in sutural tissue. In one specimen, they were able to trace a single dendrite through the dural membrane into the brain, terminating in the third ventricle containing CSF. Further study of this neural tract may bring answers to how the homeostatic feedback mechanism in the brain's CSF hydraulic system functions.

In the 1920s, Todd and Lyon published two articles examining a timeline of sutural closure in the male human skull.[8] These researchers hypothesized that cranial sutures fuse at some point in the human lifetime. They started with 427 specimens, but rejected 81 due to abnormal suture closure or "delayed union." Furthermore, some of the skulls were termed *lapsed union*, which meant failure of the suture to close due to a concentration of bone along the edge of the articulatory surface. For reasons unclear, they counted these skulls as fused, which biased results toward earlier suture closure. The data they found is as follows:

Sagittal suture closed at 31 years.
Coronal suture closed at 38 years.
Lambdoidal sutures closed at 47 years.
Masto-occipital closed at 70-80 years.
Masto-parietal closed at 70-80 years.
Spheno-temporal rarely closed.

The authors concluded that the sutures tend to close along this timeline. However, there is a high degree of variability reported. This study also was conducted some 80 years ago. Standards of protocol in scientific research have changed.

Researchers have studied one suture in-depth using different human specimens. Kokich examined one suture in the facial area - the frontozygomatic suture.[9] Of his 61 specimens, he found none demonstrated closure until after age 80, and some weren't completely fused even after age 90. He noted that bony interdigitations formed along the suture with advancing age, but did not affect the patency of sutural movement. Kokich, like Retzlaff and Upledger, found clear evidence of collagen fibers within the suture. He stated that frontozygomatic suture remains a functioning "articulation" until late in life.

A conclusive statement about whether and when sutural fusion occurs cannot be made from existing research.[10] Clearly the subject remains open for debate. Having palpated the craniosacral rhythm with my own hands, I believe cranial sutures maintain flexibility that might best be called articulation. This flexibility allows the bones to move passively as they are driven by the craniosacral system.

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