Craniosacral Therapy: The Effects of Cranial Manipulation on Intracranial Pressure and Cranial Bone Movement

Patricia A. Downey, PT, PhD, OCS[1]
Timothy Barbano, BDS, MS, DMD[2]
Rupali Kapur-Wadhwa, BDS, MS, DMD[3]
James J. Sciote, DDS, MS, PhD[4]
Michael I. Siegel, PhD[5]
Mark P. Mooney, PhD[6]

Study Design: Quasi-experimental design.
Objectives: To determine if physical manipulation of the cranial vault sutures will result in changes of the intracranial pressure (ICP) along with movement at the coronal suture.
Background: Craniosacral therapy is used to treat conditions ranging from headache pain to developmental disabilities. However, the biological premise for this technique has been theorized but not substantiated in the literature.
Methods: Thirteen adult New Zealand white rabbits (oryctolagus cuniculus) were anesthetized and microplates were attached on either side of the coronal suture. Epidural ICP measurements were made using a NeuroMonitor transducer. Distractive loads of 5, 10, 15, and 20 g (simulating a craniosacral frontal lift technique) were applied sequentially across the coronal suture. Baseline and distraction radiographs and ICP were obtained. One animal underwent additional distractive loads between 100 and 10 000 g. Plate separation was measured using a digital caliper from the radiographs. Two-way analysis of variance was used to assess significant differences in ICP and suture movement.
Results: No significant differences were noted between baseline and distraction suture separation ($F = 0.045$; $P>.05$) and between baseline and distraction ICP ($F = 0.279$; $P>.05$) at any load. In the single animal that underwent additional distractive forces, movement across the coronal suture was not seen until the 500-g force, which produced 0.30 mm of separation but no corresponding ICP changes.
Conclusion: Low loads of force, similar to those used clinically when performing a craniosacral frontal lift technique, resulted in no significant changes in coronal suture movement or ICP in rabbits. These results suggest that a different biological basis for craniosacral therapy should be explored. *J Orthop Sports Phys Ther 2006;36(11):845-853.* doi:10.2519/jospt.2006.2278

Key Words: *cranial bone movement, cranial sutures, manual therapy*

[1] *Associate Professor, Physical Therapy Program, Chatham College, Pittsburgh, PA.*
[2] *Research Specialist II, Department of Anthropology, University of Pittsburgh, Pittsburgh, PA.*
[3] *Assistant Professor, Department of Orthodontics and Dentofacial Orthopedics, University of Pittsburgh, Pittsburgh, PA.*
[4] *Associate Professor and Chair, Department of Orthodontics and Dentofacial Orthopedics, University of Pittsburgh, Pittsburgh, PA.*
[5] *Professor, Departments of Anthropology and Orthodontics, University of Pittsburgh, Pittsburgh, PA.*
[6] *Professor, Departments of Oral Medicine and Pathology, Anthropology, Surgery Division of Plastic and Reconstructive Surgery, and Orthodontics, University of Pittsburgh, Pittsburgh, PA.*
This work was submitted in partial fulfillment of the PhD degree (PAD), Department of Anthropology, University of Pittsburgh. The protocol for this study was approved by the University of Pittsburgh Institutional Animal Care and Use Committee (IACUC).
Address correspondence to Patricia Downey, Physical Therapy Program, Chatham College, Woodland Rd, Pittsburgh, PA 15232. Email: downey@chatham.edu

RESEARCH REPORT

Craniosacral therapy (CST) is an alternative, complementary therapy that dates back to the early 1900s. CST is practiced throughout the United States and around the world by osteopathic and chiropractic physicians, physical, occupational and massage therapists, and dentists.[13,18,34,44] CST is used in the treatment of a variety of diseases and forms of dysfunction, including, but not limited to, headache,[23] carpal tunnel syndrome,[28] developmental disabilities,[4] temporomandibular dysfunction,[2,12,26] chronic back pain,[26] whiplash injury,[50] and plantar fasciitis.[1] The effectiveness of CST in treating these far-ranging conditions has yet to be established.

CST, or cranial osteopathy, was first described by William G. Sutherland, DO, as consisting of cranial bone movement occurring through a "respiratory mechanism."[23,49] In this view, the primary respiratory mechanism is comprised of the brain, cerebrospinal fluid, intracranial and intraspinal membranes, cranial bones, spinal cord, and sacrum. The brain is said to produce invol-

#2006.118
R-1186

untary, rhythmic movements within the skull. This movement involves dilation and contraction of the ventricles of the brain, which circulate cerebral spinal fluid. This circulatory activity is stated to cause reciprocal tension within the membranes, thus transmitting motion to both the cranial bones and the sacrum.[44]

Palpation of the cranium theoretically allows the examiner to perceive the rhythmic impulse resulting from the widening and narrowing of the skull at rates described variously as 10 to 14 cycles per minute,[15] 6 to 12 cycles per minute,[48] or 8 to 12 cycles per minute.[3] Multiple attempts have been made to demonstrate interrater reliability of this craniosacral rhythm. Intraclass correlation coefficients range from −0.09 to 0.59, with the majority of studies reporting a nonsignificant ($P>.05$) correlation of less than 0.22.[5,17,32,42,46,51] According to Green et al,[13] the reliability studies that were published after the initial Upledger study[46] in 1997 (ICC = .59) had better methodological designs and consistently found assessment of the craniosacral rhythm to be unreliable. Hartman and Norton[4] similarly state that the data collected to date demonstrate that the cranial rhythm is not a "reliably palpable biological phenomenon" and that this invalidates the key tenet of the primary respiratory mechanism as described by Sutherland[44] and endorsed by advocates of CST today.

A second basic tenet of CST, which is also controversial, is the existence of articular mobility at the cranial bones. At one extreme of this debate are practitioners who claim that movement at the cranial sutures occurs throughout an individual's life.[15,16,44,47,48] Upledger[47] for example specifically stated, "Our research . . . did indeed prove beyond a doubt that skull bones continue to move throughout normal life"; and Greenman[14] avowed that "sutural obliteration does not appear to occur normally during the aging process." Others[10] assert that movement of the cranial bones associated with the anterior and middle cranial fossae is impossible beyond age 8. According to this view, any functional movement between cranial bones is "highly unlikely and nonphysiological."

One of the studies frequently cited in support of CST in general and cranial bone motion in particular,[11,25,36,40] is a 1956 article by Pritchard et al[38] on the structure and development of sutures. One of the conclusions from this study is that sutures form a union between adjacent cranial bones, while nonetheless allowing for slight movement. The subjects in this study included humans as well as 5 other types of mammals. Of the specimens evaluated, all but 1 was less than 1 year old, therefore limiting the conclusions that could be drawn from the study in regard to CST and adult sutures. A second study often cited by proponents of CST as evidence that sutures do not completely fuse was performed by Kokich.[24] This study demonstrated serial age changes from 20 to 95 years in the frontozygomatic suture. The author concluded that this suture undergoes synostosis during the eighth decade but does not completely fuse by even 95 years of age. It should be noted, however, that the zygomatic suture, being a facial suture, has no dural attachment and therefore even when patent, it probably is not involved in the primary respiratory mechanism.

In a similar vein, critics of CST cite the classic 1924 work of Todd and Lyon[45] on suture closure, which indicates that cranial sutures generally fuse by the fourth decade. Proponents of CST, however, state that this study is biased because the authors eliminated 81 skulls from analysis due to abnormal progress in suture closure such as premature closure and absence of ossification in sutures.[14,41] Also in contrast to the claims of continued movement at the cranial sutures, a computerized tomography (CT) assessment of the chondrocranium of 189 children between the ages of newborn to 18 years was performed to chronicle suture and synchondrosis development in children. Results demonstrated complete fusion in 95% of the females by the age of 16 years and 95% of the males by the age of 18 years.[29] Similarly, a retrospective study, utilizing high-resolution, thin-section CT scans of the sphenooccipital synchondrosis, examined 253 patients between the ages of 1 to 77 years. The authors concluded that there was progressive, predictable ossification of this synchondrosis, which was complete by the age of 13 years.[33]

The neurosurgery literature has provided some evidence of cranial bone mobility. Heifetz and Weiss[19] applied skull tongs containing strain gauges to the skulls of 2 comatose patients. By increasing intracranial pressure (ICP) between 15 to 20 mm Hg, they demonstrated a voltage change indicating movement of the skull tongs and, therefore, an expansion of the cranial vault. Canid[37] and felid[20] studies similarly have demonstrated skull expansion related to increases in ICP.

Losken et al[27] investigated sutural response to distraction osteogenesis whereby a bone distractor was placed across cranial sutures in normal rabbits and in rabbits with delayed-onset craniosynostosis to create a bone growth response. The researchers were able to produce force/displacement curves for coronal sutures in both groups of rabbits. This study demonstrated that 20 kg (20 000 g) of force was required to produce 1 mm of movement across normal rabbit coronal sutures and 48 kg (48 000 g) of force in rabbits with delayed-onset craniosynostosis. This amount of force far exceeds the 5 to 10 g recommended[15] by craniosacral therapists to manipulate human sutures.

Despite the number of studies (including those described here) and the strong claims made by researchers from a variety of fields regarding the

mobility of the cranial bones and other tenets of CST, the research on cranial bone motion done to date is far from conclusive. Insufficient reporting of details regarding methodology in several of the previously mentioned studies limits the conclusions that can be drawn. These studies as a group, however, offer evidence that cranial bone motion can occur related to changes in the ICP or large distractive forces. The extent of this motion is still unknown, and none of the previously cited literature has demonstrated conclusively that cranial bone motion can occur solely through manual techniques using the small amount of force described in the craniosacral literature.

A review paper by Rogers and Witt[41] entitled "The Controversy of Cranial Bone Motion" made several recommendations for future research. These authors stressed that ICP monitoring or documentation of a known external force was essential to establish whether cranial bone movement could occur with therapeutic levels of stimulus. In addition, they recommended direct measuring of cranial bone motion across sutures as opposed to use of the tong-like devices previously employed in the past.

The objective of this study was to examine several of the tenets of CST as recommended for additional study by Rogers and Witt.[41] Specifically, these include simulating the craniosacral frontal lift technique (distraction of the frontal bone in an anterior direction)[15,48] on anesthetized adult rabbits, with progressive distractive forces in increments of 5 g (5, 10, 15 and 20 g) applied by an Instron load cell. A rabbit model was chosen for this study because of the similarity in sutural structure between rabbit and humans.[35] Prior to and following the application of distractive forces, radiographs were taken to measure movement across the coronal suture. Epidural ICP measurements were also taken predistraction and postdistraction to note any change associated with the frontal-lift technique.

This study hypothesized that low levels of distractive force applied to the frontal bone will result in significant ICP changes and significant movement across the coronal suture. This study is significant because craniosacral manipulation is a type of therapy that is widely practiced and promoted yet lacking in sound scientific and clinical research. It will assist clinicians in evaluating one of the proposed biological mechanisms of CST.

METHODS

Thirteen New Zealand white rabbits (Oryctolagus cuniculus) were either bred in the vivarium at the Department of Anthropology, University of Pittsburgh, or purchased from a breeder (Myrtle's Rabbitry, Thompson Station, TN), and housed in the vivarium. Prior to beginning the experimental procedure, power analyses were performed to determine the number of animals needed. These analyses were based on 2 data sets from previous research by Fellows-Mayle,[8] one involving ICP changes in rabbits between the ages of 10 to 84 days and the second examining ICP variation over time during 1 observation session. With an alpha of .05, the sample size, to reach a power of 80%, was calculated to be 17 animals using the first set of data (mean difference, 3.43 mm Hg; SD, 4.65 mm Hg) and 17 animals using the second set of data (mean difference, 1.85 mm Hg; SD, 2.54 mm Hg). After data collection was completed on 13 rabbits, it was concluded that no further animals needed to be sacrificed to achieve statistical significance.

The 13 animals (5 female and 8 male) were housed in stainless steel caging, and food and water were supplied ad libitum. The age range was between 84 and 1484 days, with the median age being 89 days (mean age ± SD, 380 ± 490 days). The minimum age of 84 days was chosen based on the maturity of the cranial sutures, cessation of brain growth, and the documented stabilization of the ICP.[9]

Prior to surgery, all of the rabbits were anesthetized with an intramuscular injection (0.59 ml/kg) of a solution of 91% Ketaset (Ketamine Hydrochloride, 100 mg/mL) and Rompun (Xylazine, 20 mg/mL). The animals were placed in ventral recumbency, the heads depilated and an approximately 25-mm incision was made through the skin over the sagittal suture with a number 15 surgical blade. The coronal suture was identified, and a 1.2-mm Vitallium Y plate and 1.7-mm-diameter and 0.4-mm-length surgical screws (Mini Würzburg Titanium Implant System; Stryker Leibinger GmbH & Co, Freiburg, Germany) were attached centrally to the parietal bones, 5-mm caudal to the coronal suture. A second "Y" plate and screws were attached centrally to the frontal bone, 5-mm rostral to the coronal suture. Figure 1 illustrates the surgical plates attached to a dry skull.

A burr hole, approximately 2-mm in diameter and penetrating the entire thickness of the calvaria, was placed on the right parietal bone, 3 mm lateral to the caudal screws. The burr hole was made using a Bell drill (Robbins Instruments, Chatham, NJ) and a 2-mm cutting burr. The dura mater was identified and a Neuromonitor transducer was threaded 2-mm rostral, to confirm that the burr hole penetrated the calvaria.

The animals were then positioned in dorsal recumbency and the parietal plate was attached by way of an 11 × 10-mm, S-shaped hook to a 63-mm straight surgical plate (Mini Würzburg Titanium Implant System; Stryker Leibinger GmbH & Co, Freiburg, Germany). The plate was then fixed to a C-hook mounted on a rigid plate at the base of the tabletop load frame (model 5500; Instron Corp, Canton, MA). The frontal bone plate was attached to the 10-lb (44.48-N) tension load cell (model 5560; Instron

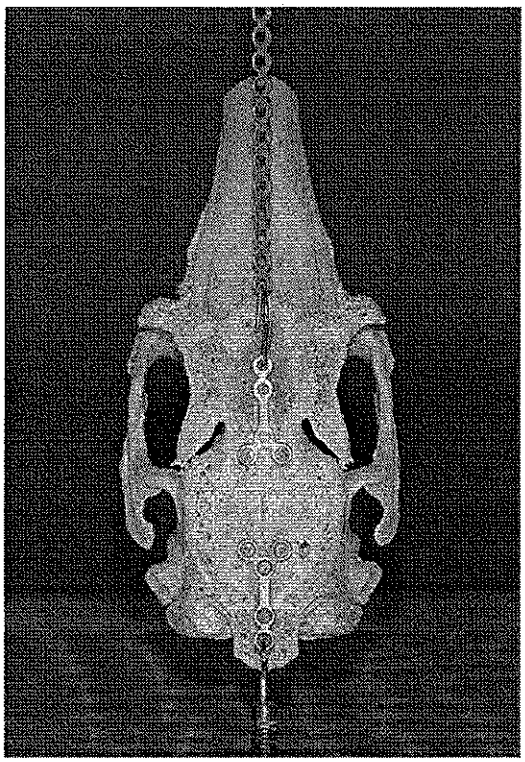

FIGURE 1. Surgical plates attached to a dry skull.

Corp, Canton, MA) by way of a C-hook (Figure 2). The load cell was electronically calibrated prior to the head fixation.

Intracranial pressure (ICP) measurements were taken using a NeuroMonitor (Codman and Shurtleff, Inc, Randolph, MA). The monitor is accurate to ±1 mm Hg. The NeuroMonitor was calibrated at the beginning of each daily measurement session and the microtransducer was calibrated prior to each animal trial. ICP measurements were recorded by inserting a microsensor transducer into the burr hole and gently moving it approximately 2 mm rostral within the epidural space. The transducer placement was confirmed by the waveform pattern on the NeuroMonitor.

After positioning the microsensor transducer, ICP was allowed to stabilize for 15 minutes to allow the rabbit to acclimate to the ICP transducer. During this 15-minute period, a baseline dorsoventral radiograph of the coronal suture was taken using a Philips Oralix 70 dental radiographic unit and the Instron software was opened to the appropriate tension file.

A baseline measurement of ICP was recorded after the initial 15 minutes. The Instron load cell was then zeroed and 5 g of axial tension was applied to the frontal bone of the anesthetized rabbit at a rate of 0.5 mm/min. Once 5 g of tension was reached, as indicated on the computer monitor, ICP was recorded. At 1-minute intervals, baseline ICP was again recorded and this procedure was repeated twice, with ICP recorded each time. A repeat dorsoventral radiograph of the coronal suture was performed at the end of the third distraction, while the tension was maintained on the frontal bone.

The axial tension was then released and ICP left to stabilize for 5 minutes to allow for recovery after the application of the distractive force. This procedure was repeated for 10, 15, and 20 g of axial tension. Pearson product correlations for measure-remeasure reliability for ICP recordings were performed for all 3 trials at each of the distractive loads. A perfect correlation of $r = 1.00$ ($P<.01$) across all trials was recorded.

The last animal (age, 576 days) underwent additional distractive forces of 100, 500, 1000, 2000, 5000 and 10 000 g, while both ICP was monitored and baseline and distraction radiographs were taken. Following each session, the rabbits were euthanized with 300 ml/kg of pentobarbital IV, preceded by ketamine/xylazine sedation.

Each radiograph was placed on a lighted view box and tracing paper was placed over the image of the rabbit's skull. The horizontal end of the surgical plates was identified on the frontal and parietal bones and marked on the tracing paper. The distance between the surgical plates was measured using electronic digital calipers (Mix-Cal Electronic; Ted Pella, Inc, Redding, CA). The calipers are accurate within ± 0.03 mm. Ten percent of the radiographs were randomly chosen, retraced, and remeasured by 2 of the investigators, to calculate intrarater and interrater reliability for landmark identification. A Pearson product coefficient of $r = 0.998$ ($P<.001$) was calculated for both intrarater and interrater reliability.

Data Analysis

ICP was measured and averaged for all subjects at each baseline (before distraction) and during cranial distraction for each of 3 trials at 5, 10, 15, and 20 g of force. A 2-way analysis of variance (ANOVA) compared mean ICP across the distraction forces. Mean coronal suture separation was calculated by subtracting the baseline measurements between the frontal and parietal bones from the distraction measurements between these bones and then averaging these for each level of distraction. A 1-way ANOVA was performed to compare the mean differences for coronal suture movement at the various levels of distractive force. A Pearson correlation coefficient for ICP versus cranial bone movement was also calculated for each level of force.

The radiograph measurements, ICP data, and animal demographics were recorded on a Microsoft Excel spreadsheet, and data analysis was performed using SPSS 11.0 for Windows.

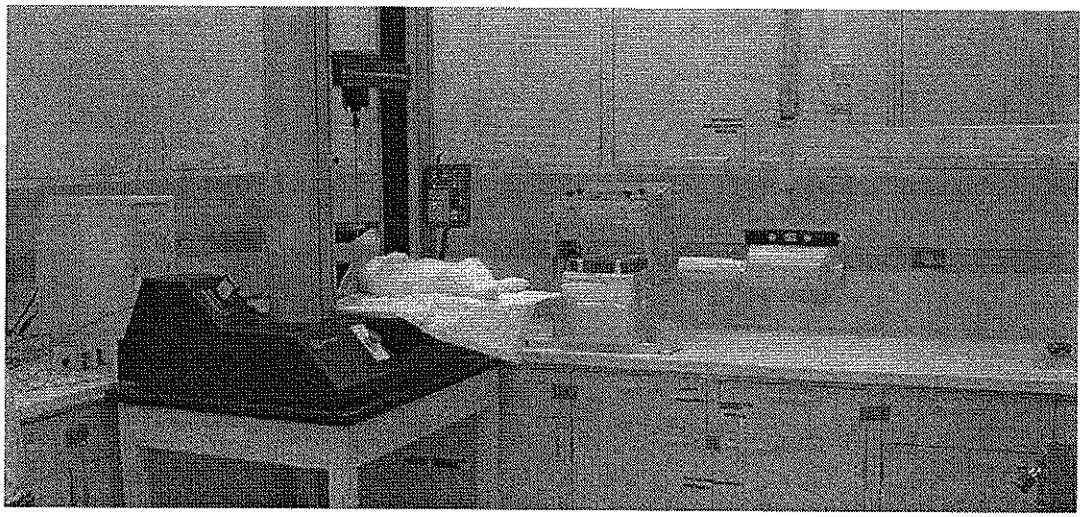

FIGURE 2. Animal attached to Instron load cell.

RESULTS

Figure 3 illustrates the change in ICP between baseline and distraction for each of 3 trials at 5, 10, 15, and 20 g of force. The mean ICP at 20 g was higher than the mean ICP at lower distractive loads, but this was not statistically significant. A 2-way ANOVA, comparing mean ICP across distraction forces (5, 10, 15, or 20 g), demonstrates no significant change ($P>.05$) in ICP at any load (Table 1).

The mean measurement for coronal suture separation (mean difference between final distractions minus baselines for each of 5, 10, 15, and 20 g of force) is outlined in Table 2. Animal 2982 was the first to undergo the experimental procedure and the radiographic unit was not positioned correctly, therefore, no radiograph was obtained for this subject (n = 12). The 15-g distraction radiograph for animal 2502 was double-exposed and therefore no data were recorded for this trial (n = 11). A 1-way ANOVA demonstrates no significant difference ($P>.05$) between the mean differences for coronal suture movement at any level of distractive force (Table 3).

No significant ($P>.05$) linear relationship was demonstrated between ICP and coronal suture movement at any distractive force. The Pearson correlation coefficient for ICP versus movement at 5, 10, 15, and 20 g were $r = 0.092$, $r = 0.306$, $r = -0.100$, and $r = 0.216$, respectively. The Pearson correlation coefficient for overall average ICP versus sutural movement was $r = 0.062$ ($P>.05$).

The final animal (2833) underwent additional distraction forces of 100, 500, 1000, 2000, 5000, and 10 000 g. Results demonstrated no change in ICP following the application of distractive forces except for 1000 and 2000 g when the ICP decreased from 3 to 2 mm Hg. Figure 4 plots the mean ICP for animal 2833, who underwent additional larger distractive forces. The range of radiographic measurements for the distraction forces between 5 and 10 000 g for animal 2833 is between –0.09 and 0.91 mm (Figure 5). The largest measurement of coronal suture movement, 0.91 mm, occurs between baseline and the 10 000-g distraction. Figure 6 compares this study's distraction data with that of the previously mentioned work of Losken et al,[27] which demonstrated that 20 kg (20 000 g) of force was required to produce 1 mm of movement across normal rabbit coronal sutures.

DISCUSSION

This study hypothesized that low loads of distractive force applied to the frontal bone of anesthetized rabbits, which simulates a craniosacral frontal-lift technique, would result in significant ICP changes and movement at the coronal suture. Neither of these hypotheses was supported by the data.

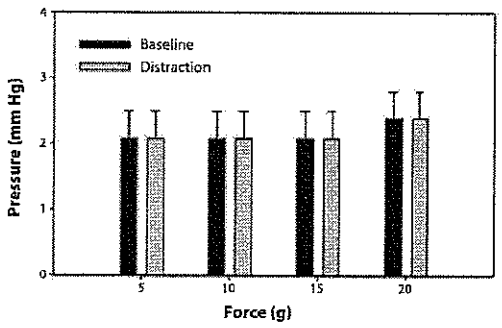

FIGURE 3. Mean intracranial pressure for each cranial distraction force and their corresponding baseline value for all animals (n = 13).

TABLE 1. Two-way ANOVA results of the changes in intracranial pressure across force and distraction conditions. Both main effects and the interaction term show lack of significant difference ($P > .05$).

Source	Type III Sum of Squares	*df*	Mean Square	F	*P* Value
Corrected model	1.846	7	0.264	0.120	0.997
Intercept	482.462	1	482.462	218.791	0.000
Distraction	0.000	1	0.000	0.000	1.000
Force	1.846	3	0.615	0.279	0.840
Distraction × force	0.000	3	0.000	0.000	1.000
Error	211.692	96	2.205		
Total	696.000	104			
Corrected total	213.538	103			

TABLE 2. Mean difference between distraction and baseline measurements for coronal suture separation.

Tension (g)	N	Mean (mm)	SD	SE	95% CI for Mean Lower Bound	95% CI for Mean Upper Bound
5	12	−0.0750	0.31032	0.08958	−0.2722	0.1222
10	12	0.0600	0.11740	0.03389	−0.0146	0.1346
15	11	0.0627	0.19850	0.05985	−0.0706	0.1961
20	12	−0.0675	0.11771	0.03398	−0.1423	0.0073
Total	47	−0.0064	0.20663	0.03014	−0.0671	0.0543

There was no significant change in ICP in response to low loads of distractive force, 5 to 20 g, over the 13 animals. The ICP mean associated with the 20-g distraction trials was slightly higher than the means for the 5- to 15-g trials, but this was not statistically significant, nor did it appear to occur in response to cranial distraction. In 6 of the 13 animals, mean ICP is seen to change during the stabilization period following the 15-g distraction trials but prior to the 20-g trials. Of the 6 animals that did demonstrate a change in ICP, 5 experienced a 1-mm Hg increase and 1 animal experienced a 1-mm Hg decrease during this stabilization period. If these changes in ICP were related to the distraction force applied to the coronal suture, the ICP should have decreased in response to a distractive force and the change should have occurred during the distraction period. Instead, the ICP increased during the stabilization period. Given that all of these changes occurred during the same relative period, following the onset of anesthesia (approximately 30 minutes), one possible explanation may be that this is a natural fluctuation in ICP due to the anesthesia. Ketamine has been shown to increase ICP by causing cerebral vasodilatation.[39]

Coronal suture movement, as measured from the radiographs taken prior to and during the applied distractive forces, did not occur at forces between 5 to 20 g. No significant difference was found between the average amount of movement (distraction measurement minus baseline measurement) at any of the applied forces between 5 to 20 g. To determine if ICP change or coronal suture movement would occur at higher loads of frontal bone distraction, the last animal (2833) underwent additional distractive forces of 100, 500, 1000, 2000, 5000, and 10 000 g applied to the frontal bone. ICP remained constant until 1000 g of distraction, following which it decreased from 3 to 2 mm Hg. These larger distractive forces were applied only to 1 animal, therefore, statistical analysis and subsequent conclusions are limited. Whether the change in ICP that occurred during the 1000-g distraction is a result of the intervention or just a natural variation in ICP is difficult to say without additional data. What can be concluded, however, is that ICP is not shown to change significantly during distractive forces that replicate those used clinically by craniosacral therapists. The only ICP change that appears to occur in response to distraction occurs at forces 100 to 200 times greater than those used clinically.

TABLE 3. One-way analysis of variance of the mean difference for coronal suture movement across distractive force conditions.

	Sum of Squares	*df*	Mean Square	F	*P* Value
Between groups	0.207	3	0.069	1.686	.184
Within groups	1.757	43	0.041		
Total	1.964	46			

In relation to movement across the coronal suture in animal 2833, the range of movement measured during the 5- to 5000-g distractions was between −0.09 and 0.31 mm. The final distraction at 10 000 g produced 0.91 mm of movement. Again, no statistical analysis could be performed and, therefore, conclu-

sions about these data are limited because only 1 animal underwent distraction at the higher levels. However, this is comparable to the results of Losken et al,[27] who, using distraction osteogenesis in 25- to 84-day-old rabbits, demonstrated that it took 500 g of force to even show movement at the coronal suture and 20 000 g of force to produce 1 mm of movement in the coronal suture of normal rabbits. In contrast, in rabbits with pathological prematurely fusing coronal sutures it took approximately 48 000 g of force to produce 1 mm of movement in the coronal suture. In normal rabbits, the coronal sutures stay patent throughout life. In contrast, rabbits with delayed-onset coronal suture fusion show bony bridging and progressively slower coronal suture growth from 25 to 84 days of age, which make this analogous to the cranial vault sutures seen in 20- to 25-year-old humans. It is interesting to note that the forces needed to distract normal patent rabbit sutures are hundreds of times greater than those used clinically by craniosacral therapists to achieve movement at adult human cranial vault sutures, which are significantly larger than those from rabbits in the present study.

CST is a diagnostic and therapeutic technique based on the biological model known as the craniosacral mechanism or primary respiratory mechanism. This model is explained by the inherent mobility of the nervous system and fluctuation of cerebrospinal fluid resulting in a rhythmic pulsation, which is translated through the dural membranes to the cranial bones.[4] Based on a review of literature related to CST, Green et al[13]concluded that there is evidence for cerebrospinal fluid pulsation as measured by magnetic resonance imaging, encephalography, myelography, and ICP monitoring. Part of the controversy surrounding CST, however, is that both the diagnostic and intervention aspects are based on manual palpation of the cranial rhythm. Multiple studies have shown poor reliability in palpating this rhythm.[6,17,32,42,51]

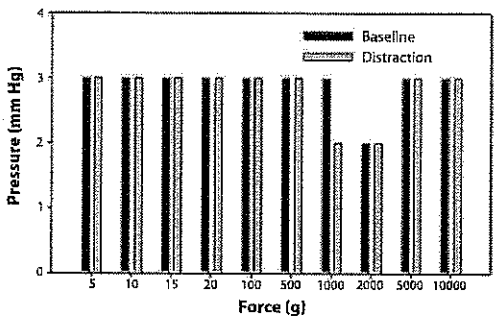

FIGURE 4. Mean intracranial pressure for each cranial distraction force and their corresponding baseline value for animal 2833.

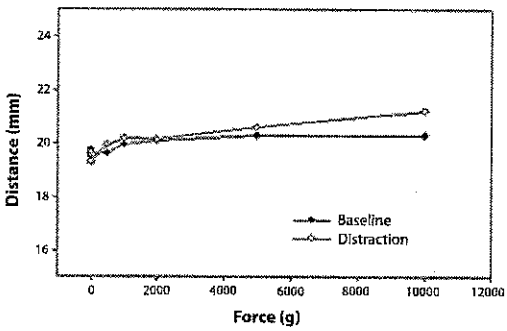

FIGURE 5. Coronal suture distance measurements taken with radiographs at various distraction forces and their corresponding baseline for animal 2833.

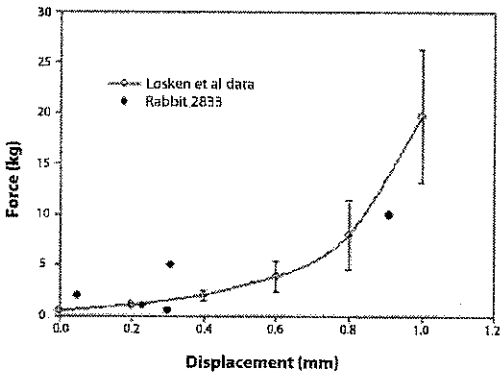

FIGURE 6. Force displacement curve for the coronal suture from normal rabbits (presented by Losken et al[27]) versus rabbit 2833.

The goals of craniosacral treatment according to Greenman[15] are to improve articular and membranous restrictions, reduce neural entrapment at the base of the skull, enhance the rate and amplitude of the cranial rhythmic pulse, and improve circulation by reducing venous congestion. As indicated in the literature review of this paper, there is support for small amounts of movement that occur between cranial bones based primarily on the role that sutures have in cranial compliance related to increases in ICP.[19,20,37] Biomechanical studies have demonstrated that sutures are more compliant than cranial bone and that their bending strength does not match that of cranial bone.[21,22] Losken et al[27] also demonstrates that movement can occur at patent or fusing sutures between cranial bones in response to large distractive forces. What has not been demonstrated, however, is the claim by craniosacral therapists that there is articular mobility at cranial sutures and that by applying manual techniques using small amounts of force, movement can occur between cranial bones. This study demonstrates that at therapeutic loads, between 5 and 20 g of distractive force, simulating a

craniosacral frontal lift technique, there is no significant movement across the coronal suture, nor is there significant change in ICP. In 1 animal, however, at forces significantly greater than those described for clinical use, ICP decreased in response to a distractive force, and movement across the coronal suture was documented.

Potential limitations of this study include the use of an animal model to simulate a clinical technique that is performed on humans. Does an animal, in this case a rabbit, possess a "craniosacral system" similar to a human? According to Upledger,[48] a leading proponent and instructor of CST, the craniosacral system is made up of the following anatomical parts: meningeal membranes, osseous structures to which the membranes attach, nonosseous connective tissue structures, cerebrospinal fluid, and structures related to production, resorption, and containment of the cerebrospinal fluid. Anatomically, a rabbit has by Upledger's definition, a craniosacral system.[8,9,31] Upledger[48] further states that the craniosacral system produces a rhythmic motion that occurs in "man, other primates, canines, felines, and probably all or most other vertebrates." Multiple articles referenced in the craniosacral literature utilized animal studies in an attempt to support the biological claims regarding this therapy.[20,30,37,40,43]

Another potential concern related to the use of animals in this study is the difference between human and rabbit sutures. A morphological and histochemical study comparing suture closure in man and rabbits was performed by Persson et al.[35] The overall structural and obliteration patterns were shown to be very similar between humans and rabbits. The differences noted (more tendon-like collagen bundles in the rabbit sutures and more calcified bodies in the human sutures) seem to suggest that rabbit sutures are actually more pliable as compared to human sutures, and therefore, we would more likely see movement across the rabbit sutures and changes in ICP in response to distractive forces.

The sample size for this project was relatively small (n = 13). The original power calculation based on data from previous ICP research on rabbits[8] indicated that 17 animals were required to reach a power of 80%. The previous data were based on rabbits between the ages of 10 and 84 days, while the rabbits used in this study were between the ages of 84 and 1484 days. After performing the experimental procedures on the initial 13 animals, we noted lower ICP values than those in the study by Fellows-Mayle[8] and more than enough power to establish a lack of effect of the distractive forces. Therefore, no further animals were sacrificed.

Finally, the use of Ketamine as an anesthetic agent may have influenced ICP readings during the experimental procedures. Research has shown that Ketamine increases ICP by causing cerebral vasodilatation,[39] but that the effects of Ketamine on ICP are short-lived and that reliable results can be obtained.[5] The dosages of Ketamine in this experiment were consistently maintained based on the animal's mass, and each procedure was consistently timed; so even if this anesthetic caused an increase in ICP, all of the animals would have been affected in the same manner.

Evidence for the efficacy of CST is absent and the biological mechanisms of cranial manipulation resulting in changes to cerebrospinal fluid pressures appear invalid. Therefore, future research in CST should focus on establishing its efficacy in a particular patient population. If therapeutic benefit is found, researchers should investigate mechanisms other than cranial bone movement and cerebrospinal fluid pressure changes as the mechanism.

CONCLUSION

This study has simulated a craniosacral treatment technique, the frontal lift, by applying accurately measured distractive forces, while monitoring ICP. Based on the theories proposed by craniosacral practitioners, we hypothesized that therapeutic levels of distractive force, 5 to 20 g, applied to the frontal bone, would result in significant change in ICP and movement across the coronal suture. Both of these hypotheses were rejected. No significant differences were noted for coronal suture separation or ICP at therapeutic levels of distraction. Change in ICP and movement across the coronal suture were noted in 1 animal following the application of forces dramatically greater than those used clinically in the practice of CST.

REFERENCES

1. Appleton M. Listening to the living process: the mind/body connection in craniosacral therapy. *Positive Health*. 1999;48-51.
2. Blood SD. The craniosacral mechanism and the temporomandibular joint. *J Am Osteopath Assoc*. 1986;86:512-519.
3. Bourdillon JF, Day EA, Bookhout MR. *Spinal Manipulation*. 5th ed. Oxford, UK: Butterworth-Heinemann; 1992.
4. Brooks RE. Osteopathy in the cranial field: the approach of WG Sutherland, D.O. *Phys Med Rehabil State Art Rev*. 2000;14:107-123.
5. de Bray JM, Tranquart F, Saumet JL, Berson M, Pourcelot L. Cerebral vasodilation capacity: acute intracranial hypertension and supra- and infra-tentorial artery velocity recording. *Clin Physiol*. 1994;14:501-512.
6. Drengler KE, King HH. Interexaminer reliability of palpatory diagnosis of the cranium. *J Am Osteopath Assoc*. 1998;98:387.
7. Fellows-Mayle W, Hitchens TK, Simplaceanu E, et al. Age-related changes in lateral ventricle morphology in craniosynostotic rabbits using magnetic resonance imaging. *Childs Nerv Syst*. 2005;21:385-391.

8. Fellows-Mayle WK, Mitchell R, Losken HW, Bradley J, Siegel MI, Mooney MP. Intracranial pressure changes in craniosynostotic rabbits. *Plast Reconstr Surg.* 2004;113:557-565.
9. Fellows-Mayle WK, Mooney MP, Losken HW, et al. Age-related changes in intracranial pressure in rabbits with uncorrected familial coronal suture synostosis. *Cleft Palate Craniofac J.* 2000;37:370-378.
10. Ferre JC, Barbin JY. The osteopathic cranial concept: fact or fiction? *Surg Radiol Anat.* 1991;13:165-170.
11. Frymann VM. A study of the rhythmic motions of the living cranium. *J Am Osteopath Assoc.* 1971;70:928-945.
12. Gillespie BR. Dental considerations of the craniosacral mechanism. *Cranio.* 1985;3:380-384.
13. Green C, Martin CW, Bassett K, Kazanjian A. A systematic review of craniosacral therapy: biological plausibility, assessment reliability and clinical effectiveness. *Complement Ther Med.* 1999;7:201-207.
14. Green C, Martin CW, Bassett K, Kazanjian A. A systematic review of craniosacral therapy: biological plausibility, assessment reliability and clinical effectiveness. *Complement Ther Med.* 1999;7:201-207.
15. Greenman P. *Principles of Manual Medicine.* Baltimore, MD: Williams & Wilkins; 1996.
16. Greenman PE, McPartland JM. Cranial findings and iatrogenesis from craniosacral manipulation in patients with traumatic brain syndrome. *J Am Osteopath Assoc.* 1995;95:182-188; 191-182.
17. Hanten WP, Dawson DD, Iwata M, Seiden M, Whitten FG, Zink T. Craniosacral rhythm: reliability and relationships with cardiac and respiratory rates. *J Orthop Sports Phys Ther.* 1998;27:213-218.
18. Hartman SE, Norton JM. Interexaminer reliability and cranial osteopathy. *Sci Rev Altern Med.* 2002;6:23-34.
19. Heifetz MD, Weiss M. Detection of skull expansion with increased intracranial pressure. *J Neurosurg.* 1981;55:811-812.
20. Heisey SR, Adams T. Role of cranial bone mobility in cranial compliance. *Neurosurgery.* 1993;33:869-876; discussion 876-867.
21. Hubbard RP, Melvin JW, Barodawala IT. Flexure of cranial sutures. *J Biomech.* 1971;4:491-496.
22. Jaslow CR. Mechanical properties of cranial sutures. *J Biomech.* 1990;23:313-321.
23. Kimberly PE. Osteopathic cranial lesions. 1948. *J Am Osteopath Assoc.* 2000;100:575-578.
24. Kokich VG. Age changes in the human frontozygomatic suture from 20 to 95 years. *Am J Orthod.* 1976;69:411-430.
25. Kostopoulos DC, Keramidas G. Changes in elongation of falx cerebri during craniosacral therapy techniques applied on the skull of an embalmed cadaver. *Cranio.* 1992;10:9-12.
26. Kotzsch R. Craniosacral therapy. *Natural Health.* 1993;July/Aug:42-44.
27. Losken HW, Mooney MP, Zoldos J, et al. Coronal suture response to distraction osteogenesis in rabbits with delayed-onset craniosynostosis. *J Craniofac Surg.* 1999;10:27-37.
28. Lusky BW, Devlin K. Alternative therapies in the treatment of upper extremity dysfunction. *Orthop Phys Ther Clin N Am.* 2001;10:667-679.
29. Madeline LA, Elster AD. Suture closure in the human chondrocranium: CT assessment. *Radiology.* 1995;196:747-756.
30. Michael DK, Retzlaff EW. A preliminary study of cranial bone movement in the squirrel monkey. *J Am Osteopath Assoc.* 1975;74:866-869.
31. Mooney MP, Siegel MI, Burrows AM, et al. A rabbit model of human familial, nonsyndromic unicoronal suture synostosis. II. Intracranial contents, intracranial volume, and intracranial pressure. *Childs Nerv Syst.* 1998;14:247-255.
32. Moran RW, Gibbons P. Intraexaminer and interexaminer reliability for palpation of the cranial rhythmic impulse at the head and sacrum. *J Manipulative Physiol Ther.* 2001;24:183-190.
33. Okamoto K, Ito J, Tokiguchi S, Furusawa T. High-resolution CT findings in the development of the sphenooccipital synchondrosis. *AJNR Am J Neuroradiol.* 1996;17:117-120.
34. Pederick FO. Developments in the cranial field. *Chiropractic J Australia.* 2000;30:13-23.
35. Persson M, Magnusson BC, Thilander B. Sutural closure in rabbit and man: a morphological and histochemical study. *J Anat.* 1978;125:313-321.
36. Pick MG. A preliminary single case magnetic resonance imaging investigation into maxillary frontal-parietal manipulation and its short-term effect upon the intercranial structures of an adult human brain. *J Manipulative Physiol Ther.* 1994;17:168-173.
37. Pitlyk PJ, Piantanida TP, Ploeger DW. Noninvasive intracranial pressure monitoring. *Neurosurgery.* 1985;17:581-584.
38. Pritchard JJ, Scott JH, Girgis FG. The structure and development of cranial and facial sutures. *J Anat.* 1956;90:73-86.
39. Reicher D, Bhalla P, Rubinstein EH. Cholinergic cerebral vasodilator effect of ketamine in rabbits. *Stroke.* 1987;18:445-449.
40. Retzlaff EW, Michael DK, Roppel RM. Cranial bone mobility. *J Am Osteopath Assoc.* 1975;74:869-873.
41. Rogers JS, Witt PL. The controversy of cranial bone motion. *J Orthop Sports Phys Ther.* 1997;26:95-103.
42. Rogers JS, Witt PL, Gross MT, Hacke JD, Genova PA. Simultaneous palpation of the craniosacral rate at the head and feet: intrarater and interrater reliability and rate comparisons. *Phys Ther.* 1998;78:1175-1185.
43. St Pierre N, Roppel RM, Retzlaff EW. The detection of relative movements of cranial bones. *J Am Osteopath Assoc.* 1976;76:289.
44. Sutherland WG. *The Cranial Bowl.* Mankato, MN: Free Press; 1939.
45. Todd TW, Lyon DW. Endocranial suture closure: its progress and age relationship. Part I: adult males of white stock. *Am J Phys Anthrop.* 1924;7:325-384.
46. Upledger JE. The reproducibility of craniosacral examination findings: a statistical analysis. *J Am Osteopath Assoc.* 1977;76:890-899.
47. Upledger JE. *Your Inner Physician and You.* Berkeley, CA: North Atlantic Books; 1991.
48. Upledger JE, Vredevoogd JD. *Craniosacral Therapy.* Seattle, WA: Eastland Press; 1983.
49. Wales AL. The work of William Garner Sutherland, D.O., D.Sc. (Hon.). *J Am Osteopath Assoc.* 1972;71:788-793.
50. Wilson W. Craniosacral therapy. *Positive Health.* 1999;July:45-47.
51. Wirth-Pattullo V, Hays KW. Interrater reliability of craniosacral rate measurements and their relationship with subject's and examiner's heart and respiratory rate measurements. *Phys Ther.* 1994;74:908-920.