CRANIOSACRAL THERAPY: IS THERE BIOLOGY BEHIND THE THEORY?

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Purpose: Craniosacral therapy is used to treat conditions ranging from headache pain and temporomandibular dysfunction to developmental disabilities. It is based, in part, on the biological premise that physical manipulation of the meninges through the cranial vault sutures with low levels of force (~5gms) alters the rhythmic fluctuation of cerebrospinal fluid and intracranial pressure (ICP). The present study was designed to test this hypothesis by simulating a craniosacral “frontal lift” technique and measuring cranial bone movement at the coronal suture and resultant ICP changes in a rabbit model.

Methods: Thirteen adult New Zealand white rabbits (*Oryctolagus cuniculus*) were anesthetized for the duration of the study and 1.2mm "Y" microplates were fixed to the frontal and parietal bones on either side of the coronal suture using 4mm long screws. The ends of the plates were secured to a base plate caudally and to an Instrom load cell rostrally. Continuous epidural ICP measurements were made using a NeuroMonitor transducer positioned through a burr hole in the parietal bone. Distractive loads of 5, 10, 15, and 20 grams were applied sequentially at a rate of 0.5mm/minute to the coronal suture. Baseline and distraction radiographs and ICP were obtained. One subject underwent additional distractive force loads of 100, 500, 1000, 2000, 5000, and 10,000 grams. Plate separation was measured using a digital caliper from the radiographs. Two-way ANOVA was used to assess significant differences in ICP and suture movement.

Results: No significant differences were noted between baseline and distraction suture separation ($F=0.045$; $p>0.05$) and between baseline and distraction ICP ($F=0.279$; $p>0.05$) at any load. No significant ($p>0.05$) correlations were noted among distractive load, plate movement, and ICP. In the single subject that underwent additional, higher distractive forces, movement across the coronal suture was not seen until the 10,000 gram force which produced 0.91 mm of separation but no 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 a different biological basis for Craniosacral Therapy should be explored.

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PREFACE

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1. INTRODUCTION

In recent years, alternative and complementary medical practice has received growing attention from the general public and the research community. Reported use of alternative therapies increased in the general population from 33.8% in 1990 to 42.1% in 1997. (Eisenberg et al., 1998) An article published in the New England Journal of Medicine (Eisenberg et al., 1993) looked at the prevalence, costs, and patterns of use of alternative and complementary medicine in the United States. Thirty-four percent of patients surveyed reported having used at least one type of alternative therapy in the past year. The authors estimated the expenditures associated with the use of various therapies in 1990 alone, to have been approximately $13.7 billion. A more recent survey published in the Journal of the American Medical Association (Astin, 1998) demonstrated that individuals who use alternative forms of medical treatment tend to be more educated, have poorer health, and believe the alternatives to conventional medical treatment to be more congruent with their values.

Among the various therapies associated with alternative medicine is Cranial Osteopathy or more recently referred to as Craniosacral Therapy (CST). Dating back to the early 1900's, CST is now practiced throughout the United States and around the world by osteopathic and chiropractic physicians; physical, occupational and massage therapists; and dentists (Sutherland, 1939; Green et al., 1999a; Pederick, 2000; Hartman and Norton, 2002a). Craniosacral therapy is involved in the treatment of a variety of diseases and forms of dysfunction including: headache, visual disturbances, sinusitis, hay fever, asthma, cardiac and digestive problems (Kimberly, 2000), carpal tunnel syndrome (Lusky and Devlin, 2001), developmental disabilities, traumatic brain injury, dysmenorrhea, stress urinary incontinence, ankle sprain (Brooks, 2000), torticollis (Brooks, 2000; Johansson, 2004), temporomandibular dysfunction (Gillespie, 1985; Kotzsch, 1993; Blood, 1986), dyslexia, chronic back pain, depression, anxiety (Kotzsch, 1993), colic, ear infections, irritability, (Turney, 2002), vomiting, hypertonicity, hyperactive peristalsis (Frymann, 1966), and gastroesophageal reflux in infants (Joyce and Clark, 1996), facial spasms, tinitis, Bell's Palsy, whiplash injury, cervical disc prolapse (Wilson, 1999), postural dysfunction (Heinrich, 1991), plantar fascitis (Appleton, 1999), sleep disorders (Pederick, 2000), and fibromyalgia (Muir, 1999). The success of CST in treating these far-ranging conditions has yet to be established.

As is true with many alternative fields, along with its supporters, CST has many detractors. For example, Hartman and Norton (2002a), basic scientists at an Osteopathic college, summarized the literature that had specifically looked at interrater reliability associated with CST, concluding that the interexaminer reliability was close to zero and that the proposed explanation for the mechanism behind the therapy was invalid. They also recommended removal of this coursework from the curricula of osteopathic colleges. Ferré and Barbin (1991) similarly concluded that the theory underlying the osteopathic cranial concept had no scientific basis and was, in fact, contradictory to the findings of basic and clinical science. Having performed a systematic review of the literature to evaluate the pathophysiology of the craniosacral system, the interventions and outcomes, and the validity of assessment, Green et al. (1999b) concluded that there was insufficient evidence to support this type of therapy. They further commented that the research methodology that could potentially demonstrate the efficacy of CST had yet to be applied.

2. LITERATURE REVIEW

2.1. HISTORY OF CRANIOSACRAL THERAPY

Craniosacral Therapy, earlier known as Cranial Osteopathy, originated in the Osteopathic medical field. In 1874, Dr. Andrew Taylor Still began this branch of medicine, establishing the first osteopathic medical college, the American School of Osteopathy, in 1892. In 1900, William G. Sutherland, an osteopathic student of this school, is said to have founded the field of Cranial Osteopathy (Brooks, 2000). During an anatomy lab, Sutherland was reported to have examined a disarticulated skull and noted that the beveled squamous portion of the temporal bones was similar to the gills of a fish. This observation eventually led to Southerland's conclusion that motion occurs at the cranial bones and specifically through a respiratory mechanism (Wales, 1972; Kimberly, 2000).

Sutherland (1939) subsequently taught that the cranium was an "intricate mechanism" requiring specific study of the bony articulations. Such study would, in his view, allow a practitioner to develop a mental picture of the anatomical relationships that would prove useful when evaluating a patient for cranial disorders. For example, Sutherland compared the L-shape of the superior articular surface of the greater sphenoid wings to that of the sacrum. The articulation between the sphenoid and frontal bones was compared to that of the sacrum and the ilia. Motion between the sphenoid and frontal bones was described as an anterior-posterior rotation with an element of sidebending. Sutherland described the skull as a "cranial bowl" where the mobility at the basilar area occurred in conjunction with compensation at the vault. Articular mobility at the cranial base was attributed to the cartilaginous origin of these bones.

The cranial and spinal dura mater along with the falx cerebri and tentorium cerebelli, were described as an "interosseous membrane" uniting the cranial bones and the sacrum.

Sutherland reasoned that with the cranial bones and sacrum bound together by these fibrous links, if any part of the system moved, all parts would synchronously move (Wales, 1972).

The driving force behind the craniosacral membranous articular system was described by Sutherland as the “primary respiratory mechanism” (Wales, 1972). In his view, the primary respiratory mechanism (PRM) is comprised of the brain, cerebrospinal fluid, intracranial and intraspinal membranes, cranial bones, spinal cord, and sacrum. The brain produces involuntary, 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 causes reciprocal tension within the membranes, thus transmitting motion to both the cranial bones and the sacrum. Sutherland described the dilation of the lateral ventricles as an inhalation, which results in expansion of the cerebral hemispheres. Concurrently, the third and forth ventricles also undergo dilation, causing the spinal cord to be pulled upward and fluctuation to occur in the cerebrospinal fluid. Exhalation occurs as the brain hemispheres relax, the ventricles contract, and the spinal cord drops downward as the fluid again fluxes within the subarachnoid spaces and ventricles (Sutherland, 1939). Palpation of the cranium allows the examiner to experience the rhythmic impulse resulting from the widening and narrowing of the skull at approximate rates described variously as: 10-14 cycles per second (Greenman, 1996), 6-12 cycles per second (Upledger, 1983) or 8-12 cycles per second (Bourdillon et al., 1992).

The primary respiratory mechanism (PRM) has been postulated to consist of five elements seen as essential components of the rhythmic cranial impulse. They are as follows (Greenman and McPartland, 1995):

- Inherent Motility of the Brain and the Spinal Cord
- Fluctuation of the Cerebrospinal Fluid

- Motility of the Intracranial and Intraspinal Membranes
- Articular Mobility of the Bones of the Cranium
- Involuntary Mobility of the Sacrum between the Ilia

Sutherland's claim regarding the inherent motility of the brain and spinal cord is based on his earlier observation of the brain during a craniotomy procedure, where he described it as undergoing a "coiling and uncoiling" of the cerebral hemispheres. Uncoiling relates to the upward swing of the cerebral hemisphere described as flexion of the unpaired bones (sphenoid and occiput) and simultaneous external rotation of the paired bones (parietal, temporal) of the cranium. Coiling relates to the descending of the cerebral hemispheres, which causes the unpaired bones to come together in extension and the paired bones to internally rotate (Greenman, 1996; Brooks, 2000). An external rotation or widening of the whole body is associated with the flexion phase of the cranium, while during the extension phase, the body is described as undergoing internal rotation or narrowing (Upledger, 1983).

The second element of the PRM, fluctuation of the cerebrospinal fluid (CSF), relates to the formation of this fluid in the choroid plexuses, with subsequent movement through the ventricles into the cisterns of the skull and along the spinal canal. Reabsorption occurs in the arachnoid granulations and to a lesser extent, in the lymphatic system (Brooks, 2000). The volume in the ventricles increases during the flexion phase of the brain and spinal cord and decreases during the compression phase. The flexion phase is characterized as "filling" while the extension phase is described as "emptying". Together, they are seen as causing the circulation of the CSF (Greenman, 1996; Upledger, 2001).

The third tenet of the PRM relates to the mobility of the dura mater, which lines the skull and is continuous with the falx cerebri, falx cerebelli, tentorium cerebelli, and by extension out from the skull, the spinal dural membrane. These dural membranes are thought to guide and limit movement, similar to the ligamentous structures found throughout the joints of the body. The intracranial membranes are constantly under dynamic tension such that stress produced in one will be reflected in the others. During ‘sphenobasilar flexion’, (occurring at the sphenooccipital synchondrosis) the tentorium flattens and the falx cerebri shortens, while the opposite occurs in extension. The intracranial membranes are firmly attached at the foramen magnum, upper two or three cervical vertebra and second sacral segment. Therefore, movement of the foramen magnum is thought to change the tension on the spinal dura and cause motion at the sacrum (Greenman, 1996; Brooks, 2000).

The fourth tenet of the PRM, or the articular mobility of the cranial bones, occurs because the structure of the sutures of the skull enables small amounts of movement to occur between the cranial bones. Greenman (1996) notes that sutural obliteration does not normally occur during the lifespan. During the inhalation or flexion phase of the primary respiratory mechanism, the cranial bones become shorter and wider in an anteroposterior direction, and longer and narrower in the extension phase (Brooks, 2000).

The last tenet of the PRM is the involuntary mobility of the sacrum between the ilia. The sacrum is said to possess the ability to move synchronously with the cranial rhythmic impulse. During inhalation, the sacral base moves posteriorly while during exhalation, it moves anterior (Uplegder, 1983).

Cranial Osteopathy, as described by Sutherland, has been differentiated from Craniosacral Therapy by a current practitioner, John Upledger, an osteopath affiliated with the Upledger Institute of Florida. Upledger traces the origin of this therapy to observations that he made while assisting a neurosurgeon during spinal surgery in 1970. Recounting that experience, Upledger describes having had difficulty holding the cervical dura mater during a plaque removal procedure because the membrane moved rhythmically at a rate of approximately 10 cycles per second. Following further study in courses that presented Sutherland's cranial osteopathy, he began to demonstrate how the craniosacral system could be used to evaluate and treat a variety of health problems involving the brain and spinal cord. Upledger describes craniosacral therapy as focusing on the membranes and cerebrospinal fluid surrounding the brain and spinal cord as opposed to focusing on the cranial bones. He describes this form of therapy as using the cranial bones simply as "handles" to access the membranes rather than attempting to manipulate the sutures of the skull as did Sutherland and his followers. Upledger reports that the cranial sacral techniques use between 5 and 10 grams of force as compared to traditional cranial osteopathy which uses substantially more (Upledger, 2002). Proponents of cranial osteopathy, however, describe treatment techniques as being "very gentle" (Greenman, 2000) and employing "small movements" in order to bring tissues into balance (Brooks, 2000). The distinction between the forces used in craniosacral therapy versus cranial osteopathy remains unclear.

2.2. CRANIOSACRAL DIAGNOSIS

The cranial diagnostic process is based on a working knowledge of cranial osteology and the dural membrane system (Greenman, 2000). The process includes the assessment of: articular mobility of the cranium and sacrum, tension of the intracranial and spinal dural membranes, rate and amplitude of the cranial rhythmic impulse, and fluctuation of the CSF within the dural membrane. The sphenobasilar (sphenooccipital) synchondrosis, which has been incorrectly described by Sutherland as a symphysis (Upledger, 1983), is described as the locus of motion and of the major strain patterns within the cranium (Bourdillon et al., 1992; Greenman, 2000).

This junction is said to retain “flexibility” throughout a lifespan even though the joint structure is acknowledged to not be clearly definable as an adult. It is at this synchondrosis that the physiologic motion described as flexion and extension is said to occur.

Practitioners of CST such as Brooks (2000), emphasize that questions should also be asked about aspects of a patient’s particular history such as:

- Details of present and past trauma
- Birth history and neurological development
- Surgical history
- Nutrition, dietary habits, and lifestyle
- Mental and emotional status including history of abuse

Upledger (1983) claims that with an experienced practitioner, the craniosacral motion can be palpated anywhere on the body, but most readily at the skull. He recommends that when palpating for the rhythm, the practitioner first assesses the cardiovascular pulse and respiration in order to differentiate these rhythms from that of the craniosacral system. Evaluation of the quality and rate of fluctuation in cerebral spinal fluid is thought to be an important diagnostic tool in assessing an individual’s health status (Brooks, 2000). According to Upledger, the normal rate is between 6-12 cycles per second although pathological circumstances can produce a rate lower than six or higher than these twelve cycles per second. A lower rate alone is generally seen as indicative of a chronic state, while both a lowered rate and amplitude are believed to indicate a more significant craniosacral problem (Greenman, 2000; Brooks, 2000).

Palpation also allows the practitioner to assess the cranial base and the associated dural membranes for specific strain patterns. Greenman (2000) describes four strain patterns: lateral, vertical, side-bending rotation, and sphenobasilar torsion. The lateral strain is described as rotation of the sphenoid and occipital bones in the same direction around a vertical axis. A vertical strain results in the sphenoid moving in a superior or inferior direction in relation to the occiput. The side-bending rotation strain is the result of the sphenoid and occiput moving about two different axes while the torsion strain occurs when these two bones rotate in opposite directions around an A-P axis.

Upledger (1983) adds two additional strain patterns to the assessment of the sphenobasilar joint: flexion-extension and compression. The motion of flexion-extension has previously been described. The strain pattern would be called a "flexion lesion" if the bones moved readily into flexion but resisted extension, and an "extension lesion" if the opposite was palpated. A compression lesion is palpated as resistance to anteroposterior expansion. Palpation of individual cranial bones and the sacrum are also aspects of the diagnostic process (Brooks, 2000).

The end feel of the motion testing leads the practitioner to determine whether the restriction is articular, involving the suture, or membranous, involving the dural tissue (Greenman, 2000). During palpation of the craniosacral rhythm, a "resistance barrier" may be perceived. This is described as a hesitation in the rhythm or the inability to pass through that place in the cycle. The barrier can either be rigid, in the case of a bony barrier, or elastic, representing abnormal membrane tensions. A skilled practitioner of CST can theoretically palpate a restriction anywhere on the body because of the fascial continuity. This is because the palpated motion is thought to be related to the fluctuation of the cerebral spinal fluid within the nervous system, which in turn affects the tonus of the body tissues (Upledger, 1983).

Primary or secondary dysfunction of the craniosacral system can occur. Primary dysfunction is usually a result of a trauma such as a fall, motor vehicle accident or occupational/sports injury. Birth trauma can also cause dysfunction to the cranium, especially when the delivery is by forceps or vacuum extraction. In addition, chronic postural stress and subsequent muscle imbalances of the cervical spine are thought to be a source of primary dysfunction resulting in decreased mobility of the osseous cranium.

Secondary problems related to dysfunction of the craniosacral system are also thought to occur. Because of the anatomical proximity of the cranial nerves to the cranial base, craniosacral dysfunction can theoretically affect the brain and peripheral nervous system. Endocrine problems are also said to result due to the location of the pituitary gland near the sphenobasilar synchondrosis. Restriction of the posterior cranial quadrant is said to be associated with acute and chronic visceral disease, because of the anatomical location of the vagal nerve (Greenman, 2000).

2.3. CRANIOSACRAL TREATMENT

The general goals of craniosacral treatment are as follows (Greenman, 1996):

- Improve articular restrictions
- Reduce membranous tension restriction
- Improve circulation by reducing venous congestion
- Reduce neural entrapment from exit foramina at the skull base
- Enhance rate and amplitude of the cranial rhythmic impulse

In general, through the mechanism of cranial adjustment, craniosacral therapy is said to balance intracranial membranous tension in order to improve an individual’s overall health.

Thus, the techniques of CST can produce local effects within the skull and distal effects throughout the body (Greenman, 1996; Pederick, 2000).

An important osteopathic principle of CST originally put forth by Sutherland states that the body is a self-healing mechanism. This principle is based on the belief that if a patient's body can be facilitated into making a correction using its own inherent force as opposed to an external force, the results will be safer, more profound, and longer-lasting (Brooks, 2000). Based on this principle, craniosacral treatment is described as being either indirect or direct (Greenman, 2000, Upledger, 1983).

An indirect technique is one that releases a restriction by facilitating motion in the direction of ease, which is usually opposite of the direction of the restriction. The practitioner "follows" the restriction into the direction of ease and gently holds it there. Craniosacral therapists believe that the inherent motion of the structure will attempt to return to neutral against the hold. Eventually a release or "tissue softening" occurs. The opposite occurs with a direct technique in which the restricted structure is assisted to pass through the abnormal barrier in the direction of the restriction and then return to a neutral position (Upledger, 1983).

With these techniques, the practitioner assists the motion either away from or into the restriction, but the main force in treatment is seen as being the primary respiratory mechanism. The fluctuation in cerebral spinal fluid is seen as the intrinsic activating force that can be directed from the exterior of the skull. Respiratory assistance is utilized as a secondary activating force since voluntary inhalation is thought to enhance the flexion movement and exhalation to enhance the extension movement (Greenman, 1996).

The literature describes specific techniques used to diagnose and treat the intracranial membrane system and the spinal dural tube (Wales, 1972; Upledger, 1983; Greenman, 1996;

Joyce and Clark, 1996; Upledger, 2001). With these techniques, the intracranial membrane system is divided into vertical and horizontal subsystems. The technique for treating a restriction in an anterior-posterior direction, part of the vertical subsystem, is called a frontal lift. With the client positioned supine, the frontal bone is lightly grasped with the 3rd or 4th fingers along the lateral ridges, just anterior to the temporal fossae. The rest of the fingers are placed along the frontal bone, anterior to the coronal suture, and a light (5 grams of pressure) anterior traction is applied until a release is noted. A release is described as the frontal bone lifting and "floating" once the sutures are disengaged. This procedure takes anywhere from a few seconds to minutes to complete (Upledger, 1983). To treat a restriction of the superior-inferior aspect of the vertical subsystem, a similar technique called the parietal lift used. With the client again in the supine position, the fingers of the practitioner are placed along the parietal bone, applying a gentle medial compression followed by a superior traction. As with the frontal lift, as traction is maintained, internal fluid pressures are said to disengage the sutures and lift the parietal bones, producing a release. This fluid pressure is said to then laterally spread the bones (Upledger, 2001).

Treatment techniques for the horizontal subsystem include the sphenoid compression, sphenoid decompression, temporal wobble and ear pull, and cephalad and caudad mandibular traction. Lumbosacral release is also described as part of the horizontal subsystem. As the lower lumbar spine is stabilized with one hand, the sacrum is gently distracted with the other until a release is noted. Two specific dural sleeve treatment techniques are also described. The first is the dural tube rock in which the practitioner places one hand under the sacrum and one under the occiput and encourages a gentle rocking in sync with the craniosacral rhythm. This technique is said to release transverse rings of fascia in the dural tube. The second technique, the dural tube glide, is similar to the above-mentioned technique, except that a gentle gliding pressure is added at the end of each rhythmic cycle alternating between the occiput and the sacrum (Upledger, 1983; Upledger, 2001).

A common technique of CST originally described by Southerland (1939), is a still point induction, or if specifically applied to the occiput, a CV-4 technique. CV-4 means compression of the 4th ventricle of the brain and was believed to affect all the vital nerve centers located in its vicinity. Greenman (1996) describes the goal of this technique as to treat a “hard, rigid skull” by enhancing the flow of venous blood through the sinuses, thereby decreasing venous congestion. Upledger (1983) describes the CV-4 as an excellent “shotgun” technique for many problems since it is said to enhance tissue and fluid motion and restore flexibility to the autonomic nervous system.

With a CV-4 technique, the practitioner cups their hands in a “V” shape under the patient’s occiput. As the occiput narrows during the extension phase of the craniosacral rhythm, the practitioner’s hand follows this motion then resists the occiput’s attempt to widen during flexion. This resistance continues for several cycles or until the rhythm temporarily stops. This cessation is known as the still point. Once the occiput attempts to move into flexion again, the practitioner allows this to occur. Theoretically, a still point can be induced anywhere in the head or body. It is believed that once the still point has occurred, the craniosacral rhythm resumes, generally with better symmetry and amplitude (Upledger, 1983).

Upledger (1983) also describes a V-spread technique that he acknowledges calls into question the credibility of craniosacral therapists. With this technique, two of the practitioner’s fingers are spread in a V-shape across a restricted area on the skull, and a finger from the opposite hand is placed directly across the skull from the restriction. The practitioner then directs energy between the hands until a softening occurs and a therapeutic pulse is perceived.

Lastly, diaphragmatic releases are also described as craniosacral techniques. Anatomically the areas targeted include the pelvic diaphragm, respiratory diaphragm, thoracic inlet and hyoid bone. The first three diaphragms are treated by placing one hand below the area (under the client) and one hand over the area. Gradually a gentle compression is applied by the upper hand until a release is noted. The hyoid release is achieved by gently rocking the bone side to side (Upledger, 2001).

Some craniosacral practitioners strongly advocate early intervention in newborns. Kimberly (2000), for example, even recommends therapy beginning in the hospital nursery. Although unreferenced, he states that hospitals using cranial manipulation have reduced infant mortality and decreased the frequency of infant vomiting and inability to suckle. Kimberly also states that young children lacking in verbal skills or those who develop spasticity, convulsions, or ataxia, also benefit from cranial manipulation. Wales (1972) claims that craniosacral intervention on infants requires the least effort because of the infant's innate ability to self-correct. He believes that treatment of the infant prevents future problems that would otherwise be traced back to early restrictions in the dural membrane. Upledger (2003) advocates for a craniosacral system evaluation, if not in the delivery room, then soon after birth. He states that CST has proven effective in identifying and treating dyslexia, hyperkinetic behavior and motor control problems.

General contraindications to cranial sacral therapy include patients with acute, unstable neurological signs, increased intracranial pressure, intracranial bleeding, and nonhealed fractures of the cranial vault or base. Seizure disorder is considered a precaution (Greenman et al., 1996).

In the case of acute skull fracture or cerebral hemorrhage, Brooks (2000) advocates indirect treatment by way of the sacrum.

In a study of 55 patients diagnosed with traumatic brain injury between 1978 and 1992, adverse reactions associated with CST were reported in 5% of patients. One patient experienced increased vertigo during the evaluation and cardiac, respiratory, and gastrointestinal symptoms following application of a sphenobasilar decompression technique. A second patient complained of increased headache pain followed by a "disturbing psychiatric problem" requiring hospitalization. The final case involved a full body spastic reaction (Greenman and McPartland, 1995). Other more anecdotal reports include a case of pituitary dysfunction and a separate case of retinal detachment (Brooks, 2000).

2.4. EVIDENCE RELATED TO CRANIOSACRAL THERAPY

One of the criticisms surrounding craniosacral therapy has to do with the general paucity of research on this approach and the lack of scientific rigor in the studies that do exist. Greenman et al. (1996), a group of practicing physicians and proponents of CST, readily admit that there is "limited serious scientific study" related to the efficacy of this type of therapy to date. However, responding to earlier letters to the editor that appeared in both osteopathic and physical therapy journals, Upledger, a leading proponent and teacher of CST, commented that: "…precise compliance with the dictates of experimental design (as used in the more exact sciences) is frequently, if not always, impossible" (1979) and continued …"I am convinced that we should not allow strict adherence to the rules of experimental design to fetter human intelligence, nor should we allow it to stifle our creativity" (1995).

Citing "A Systematic Review and Critical Appraisal of the Scientific Evidence on Craniosacral Therapy," sponsored by the Canadian Office of Health and Technology, Green et al. (1999a) concluded that there was insufficient evidence to support and recommend this therapy for any medical condition. Similarly, Hartman and Norton (2002b) in a letter to the editor of Physical Therapy, indicated that the National Council Against Health Fraud had concluded in 1998 "cranial osteopathy is more a belief system than a science." A subsequent review of the literature related to interexaminer reliability of cranial osteopathy concluded "there is little science in any aspect of cranial osteopathy" (Hartman and Norton, 2002a).

2.4.1. Outcome Studies

There are multiple studies related to outcomes in the field of CST that are categorized as case studies (Baker, 1971; Wales, 1972; Hollenberry and Dennis, 1994; Joyce and Clark, 1996; Appleton, 1999; Wilson, 1999; Lusky and Devlin, 2001). In a commentary published in Infants and Young Children dealing with a case study related to the treatment of reflux in children, Rosenbaum and Law (1996) acknowledged that although this type of research is a valuable starting point, methodological limitations prevent anything other than observations from being stated.

Philips and Meyer (1995) performed a retrospective, case-matched study of the rate of obstetrical interventions used during labor and delivery by a control group versus a group receiving CST during pregnancy, and found no significant difference. A second retrospective case series published by Blood (1986) descriptively, but not statistically, looked at 130 dental patients with temporomandibular dysfunction and listed the associated craniosacral dysfunction. Greenman and McPartland (1995) also performed a retrospective case series of 55 patients with traumatic brain syndrome. They found all of the patients demonstrated a decreased cranial rhythmic impulse averaging 7.2 cycles per minute. The methodology in this study, however, did not indicate who or how many practitioners performed the initial assessments and whether intertester reliability had been established. Finally, the Canadian Task Force on Preventative Care performed a systematic review of CST, and their report classified all of the above studies (retrospective reviews and case studies) as Level 3, or having the lowest grade of evidence (Green, et al., 1999b).

Several studies have attempted to establish a link between craniosacral dysfunction and poor health outcomes (Frymann, 1966; Upledger, 1978; White et al., 1985). However, the studies by Frymann and Upledger had a cross-sectional design and used subjective methods that lacked both established validity and reliability standards to classifying craniosacral movements. Furthermore, the health status classifications of these studies had been subjectively determined, and so lacked content validity. The classifications used in the Upledger study had been determined by parents, educators, and various health care providers among whom there was no established agreement. The study performed by White (1985) was observational rather than cross sectional. It failed to describe subjects or sample size, and did not report a health measure. No statistical analysis was reported (Green, et al., 1999b).

2.4.2. Studies Related to the Basic Tenants of Craniosacral Therapy

As previously mentioned, there are five basic tenets of craniosacral therapy:

- Inherent Motility of the Brain and the Spinal Cord
- Fluctuation of the Cerebrospinal Fluid
- Motility of the Intracranial and Intraspinal Membranes
- Articular Mobility of the Bones of the Cranium
- Involuntary Mobility of the Sacrum Between the Ilia

The following sections examine the literature related to these tenets from both a basic and clinical science perspective.

2.4.2.1. **Articular mobility of the cranial bones.** In order to fully understand the issue of cranial bone mobility, a basic understanding of sutural biology is needed. Kokich (1986) defines sutures as a type of synarthrosis or relatively immovable joint. They are articulations in which the bone margins are united by a thin layer of fibrous tissue. Persson (1989) classifies sutures as syndesmoses, the union of bones by way of connective tissue. Both agree that during normal growth and development, sutures function as the sites of bony deposition and resorption, thus allowing for morphological changes in the craniofacial skeleton.

Sutural development is somewhat different for the facial versus cranial areas. Embryonic facial bones develop within loose mesenchyme and have fibrous periosteal capsules surrounding them by the 17th week in utero. Since facial bone growth occurs through continual apposition, a thin layer of mesenchymal tissue is trapped between the periosteal capsules of neighboring bones. Thus the suture is thought to have five intervening layers including the two cellular and fibrous layer of each periosteal envelope and the loose mesenchymal layer in-between. Over time, this embryonic suture is thought to be reduced to three layers, and shortly after birth, it becomes a single fibrous membrane that contains cells (Pritchard et al., 1956; Kokich, 1986; Cohen, 2000).

In contrast with the facial area, the cranial bones develop as separate ossification centers located within the fibrous membrane surrounding the brain. As the brain grows, the dermal bones enlarge, but their borders are still widely separated. When the brain growth slows, the calvarial bone margins become more closely approximated as sutures begin to develop. The fibrous desmocranium becomes an outer ectoperiosteal layer and inner dura mater rather than the five-layered structure seen with facial sutures (Kokich, 1986).

The facial and cranial sutures differ in other respects as well. The five-layers of the facial suture may serve as the barrier that prevents early osseous fusion as compared to the cranial suture. Facial sutures, with the exception of the midpalatal, do not fuse before the seventh to eighth decade of life as compared to closure of the cranial sutures, which occurs early in adulthood (Cohen, 2000). Experimental research involving embryonic cranial sutures in rats has shown that the dura mater is not required for initial suture formation but is essential for long-term maintenance of the suture site. It is theorized that the dura mater initially provides a stabilizing signal to the newly formed suture, and once it is stabilized, it induces an osteoinhibitory effect. Failure of this stabilization or osteoinhibitory function of the dura mater would result in premature synostosis (Opperman and Ogle, 2002).

Sutures are very adaptable during growth and development, and function is seen as a clear determinant of sutural morphology. At birth, areas where cranial sutures will eventually develop permit the bones to overlap as the head passes through the birth canal. As previously mentioned, growth of the skull is related to growth of the brain. As the brain expands, the bones of the cranial vault, which are contiguous with the brain via the connective tissue stroma and meningeal linings, are passively displaced in an outward direction. The bones are therefore separated at their sutures. The resulting tension created between the bones from growth stretch, appears to cause new bone deposition along the sutural margins. This, in turn, enlarges the circumference of each bone. Concurrently, bone is being deposited along both the ectocranial and endocranial surfaces with the exception of the endocranial surface that has contact with the dura mater. The overall result is a flattening (or decrease in curvature) of the skull (Enlow, 1996). As has been noted, cessation of growth, however, does not always reflect sutural closure. The brain ceases growing years before the cranial sutures close, and the facial sutures remain patent long after active growth has ceased (Herring, 2000).

Initially, sutures tend to have straight edges interspersed with connective tissue. However, with time and loading, interdigitations become more prominent, thereby suggesting epigenetic control over the complexity of the morphology. Interdigitations may permit adjustive types of movement and provide shock absorption and the overall architecture of the sutures may depend on the type and distribution of forces encountered. Facial sutures tend to be more interdigitated than cranial, which may in part be due to their prolonged patency and/or the forces associated with mastication (Cohen, 2000; Herring, 2000). Jaslow (1990) for example, looked at the structural integrity and strength of sutures and found that increased sutural interdigitation provided increased resistance to bending forces.

Histologic examination of sutures reveals the presence of fibronectin, osteonectin, collagens, noncollagenous proteins, and proteoglycans. Fibronectin appears to be expressed early in sutural development and remains expressed by well-differentiated osteoblastic cells. Osteonectin is found in mineralized and nonmineralized osteoid deposits along the osteogenic front. Types I and III collagen are associated with active sutural growth, while type V collagen is associated with osteoprecursor cells. Chondroitin sulfate proteoglycan is found in newly laid matrix and within active osteoblasts. As sutures begin to close, the number of fibroblasts within the connective tissue decreases, and collagen fibers become more irregular (Cohen, 1993). Two types of structural and obliteration patterns have been demonstrated both in humans and rabbits. In one structural pattern, the collagen fibers were perpendicular to the sutural margin, but in the other the fibers were parallel. Obliteration patterns demonstrated either bone spicules extending from the margins and bridging the gap, or irregular, acellular, calcified nodules that were either attached to bony spicules or seen as free entities (Persson et al., 1978).

Patterns of suture closure have been studied and documented for years, most notably in the 1920's by Todd and Lyon (1924), who in one study, documented endocranial suture closure in 307 white, male skulls of known age. In 2000, Cohen using in part data from Todd and Lyon, documented suture closure in humans as follows in Table 1:

Table 1. Human Suture Closure

Cranial Suture	Closure Begins	Facial Suture	Closure Begins
Metopic	2 years	Palatal	30-35 years
Sphenofrontal	22 years	Frontomaxillary	68-71 years
Sagittal	22 years	Frontozygomatic	72 years
Coronal	24 years	Zygomaticotemporal	70-71 years
Lambdoid	26 years	Zygomaticomaxillary	70-72 years
Masto-occipital	26-30 years	Frontonasal	68 years
Sphenotemporal	28-32 years	Nasomaxillary	68 years
Sphenoparietal	29 years		
Squamosal	35-39 years		

The craniosacral tenet of the existence of articular mobility at the cranial bones has produced an ongoing debate within the scientific literature. At one extreme of this debate are practitioners who claim that movement at the cranial sutures occurs throughout an individual's life (Sutherland, 1939; Upledger and Vredevoogd, 1983; Greenman, 1996; Greenman et al., 1996). Upledger (1991), for example specifically stated, "Our research …. did indeed prove beyond a doubt that skull bones continue to move throughout normal life," and Greenman (1996) avowed that "sutural obliteration does not appear to occur normally during the aging process."

At the opposite extreme of this debate are scientists who believe that movement of the cranial bones associated with the anterior and middle cranial fossae is impossible beyond age 8. In their view, any functional movement between cranial bones is “highly unlikely and nonphysiological” (Ferréand Barbin, 1991).

One of the studies frequently cited in support of CST in general and cranial bone motion in particular (Retzlaff et al., 1975; Kostopoulos and Keramidas, 1992; Pick, 1994; Frymann, 1971), is a 1956 article by Pritchard et al. 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 five other types of mammals. Of the specimens evaluated, all but one was less than one 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 (1976). 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.

In a similar vein, critics of CST site the classic work of Todd and Lyon (1924) on suture closure, which indicates that cranial sutures generally fuse by the fourth decade. This study has been criticized as 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 (Rogers and Witt, 1997; Green et al., 1999b).

One important aspect of Sutherland’s (1939) description of cranial mobility is that which occurs at the junction between the sphenoid and occipital bones. He described the presence of a disk at the sphenobasilar junction up to the age of twenty-five to thirty years and then followed by "a mere movable articulation." Greenman et al. (1996) described this cartilaginous articulation as having a slight amount of motion that persists throughout life. Similarly, Upledger (1983) wrote that the motions of flexion and extension occur throughout life at this flexible synchondrosis.

In contrast with these claims of continued movement at the cranial sutures, a computerized tomography (CT) assessment of the chondrocranium of one hundred eighty-nine children between the ages of newborn to eighteen was performed in order to chronicle suture and synchondrosis development in children. Results demonstrated complete fusion in 95% of the females by the age of 16 and 95% of the males by the age of 18 years (Madeline and Elster, 1995). Likewise, 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 old. The authors concluded there was progressive, predictable ossification of this synchondrosis, which was complete by the age of 13 years (Okamoto et al., 1996).

However, additional radiographic studies directly looking at the claim that cranial bone mobility occurs in a therapeutic sense as well have been published. For example, Pick (1994), a chiropractor who utilizes CST, published a single case study utilizing magnetic resonance imaging (MRI) to document such mobility. A baseline image of a 42-year-old subject's maxillary palate and frontal/parietal area was performed while two investigators made manual contact with these areas but did not apply pressure. A subsequent scan was performed while the investigators applied "firm" external cranial pressure over the same contact points. Comparison of the two MRI's demonstrated the elimination of a 5-mm space along the superior border of the corpus calosum and a 4-mm decrease in the width of the fornix column. The amount of pressure applied by the examiners was never measured or defined. The author concluded, based on this single case, that suture mobility in the human skull does exist and cranial manipulation can alter the cranial vault.

Greenman (1970) published a study comparing x-ray results to clinical claims of altered cranial structures. Twenty-five subjects were x-rayed and their cranial lesions documented from the films. It was not made clear however, who documented the lesions. Ten of the twenty-five subjects then underwent clinical diagnoses by a physician trained in the cranial osteopathic concept. The lesions diagnosed included skull flexion, extension, sphenobasilar torsion, and/or sphenobasilar sidebending. For seven of the ten subjects, there was a correlation between the radiographic and the clinical diagnosis. However, this study provided insufficient detail with regard to methodology. For example, there were no selection criteria describing the subjects and no mention of blinding for the examiners performing the x-ray or the clinical evaluation.

Several studies evaluating cranial bone motion in squirrel monkeys have been published by researchers at the Michigan State University School of Osteopathy. In one study, measurement of right parietal bone movement was performed using a screw attachment and a displacement transducer. The animals' heads were fixated while pulse, blood pressure and respiration were monitored. Two spontaneous cranial bone motions were detected; one was associated with the animal's respiration rate and the second one occurred at a slower rate of 5-7 cycles per minute and could not be attributed to any other physiological rhythm. A digital force of less than 10 grams was then applied to the skull in several locations resulting in movement between the parietal bones as measured by a Statham FT03C transducer (Michael and Retzlaff, 1975).

A similar, subsequent study was performed that recorded parietal bone displacement, but this time the monkey's heads were not firmly fixated as before, and both parietal bones had screw implants. The results demonstrated two distinct movement patterns between the parietal bones, one being synchronous with respiration and the other synchronous with the cardiac pulse. By then flexing and extending the head position, thereby changing the CSF pressure, a proportional increase in the oscillatory wave was produced. The authors concluded that alterations in the CSF pressure were responsible for the parietal bone movements. By fixating the skull, each of the parietal bones demonstrated its own frequency of movement, independent of the cardiac or respiratory systems. (Retzlaff et al., 1975).

A third study from this same lab (St. Pierre et al., 1976) was published as an abstract. The authors mounted capacitance plates on opposite sides of a cranial suture and claimed that the output on a chart recorder represented cranial bone movement.

All three of these studies have come under criticism because of insufficiently detailed methodologies. In a publication dealing with the ongoing controversy over cranial bone movement, Rogers and Witt (1997) commented that the first two studies from the Michigan State lab did not adequately describe the transducer placement, thereby calling into question the authors conclusions as to where the detected motion was really coming from. The last of the Michigan State articles was criticized for lack of reporting the methodology, including sample size, subject ages, and experimental conditions.

Several other studies have attempted to directly or indirectly investigate cranial bone motion with devices that measure change in cranial diameter. For example, Frymann (1971) developed a noninvasive frame with a differential transformer placed on each side. This frame was placed on the head of live subjects and the transformer translated changes in skull diameter signaled by displacement of a metallic rod into analog signals. Sample recordings were presented with this study although again, detailed information on the study's methodology, including sample subject information, was lacking.

The neurosurgery literature has also provided some evidence of cranial bone mobility. Heifetz and Weiss (1981) applied skull tongs containing strain gauges to two comatose patients. In the first patient, intracranial pressure (ICP) was increased by applying intermittent jugular compression, while in the second patient, ICP was increased by injecting 7-12 cc of fluid into the ventricles of the brain. The results demonstrated that each time the ICP was increased between 15-20 mm Hg, there was a voltage change indicating movement of the skull tongs and therefore, an expansion of the cranial vault. Pitlyk et al. (1985), similarly placed Gardner-Wells tongs with strain gauges first on a dried cadaver skull, then on a fresh cadaver and six live dogs. ICP pressure was increased by manipulating a Swan-Ganz catheter or by saline infusion into the intraspinal subarachnoid space. The authors were not able to consistently increase the ICP in the cadaver skulls but were successful with the dog model. Changes in skull expansion were recorded with increases in ICP as small as 2 mm Hg. Magnitudes of skull expansion, however, were not documented.

A subsequent study in Neurosurgery looked at cranial bone mobility in calculating total cranial compliance. Changes in ICP were induced in adult cats while strain gauges measured any changes in cranial expansion. The authors concluded that at low-pressure changes, sutures move but that shift in blood and cerebrospinal fluid volumes are primarily responsible for cranial compliance. At higher-pressure changes however, cranial bone movement was alone seen as preventing further increases in ICP (Heisey and Adams, 1993).

One of the few studies that looked at cranial bone motion via an applied craniosacral technique was reported by Kostopoulos and Keramides (1991). A craniosacral frontal lift technique was simulated in an embalmed cadaver by placing two nails into the frontal bone and attaching various weights to a pulley system to provide distractive forces. An oscillator, connected to a piezoelectric element, was attached to the falx cerbri by way of a vacuum silicon gel in order to record elongation. This study reported a relative elongation of the falx cerebri of 0.37 mm after the application of 242 grams of distraction and concluded that movement does occur along cranial sutures. This study was published attempting to validate the scientific basis of CST, yet came to the above conclusion based on employing distractive forces almost 50 times greater than those used clinically. In a follow up publication, these authors applied multiple craniosacral therapy techniques to an embalmed cadaver again while measuring the elongation of the falx cerebri. The article reported the relative elongation of the falx cerebri (-0.33 mm – 1.44 mm) following various applied techniques, but it failed to publish the amounts of force applied to the cranial bones in order to produce the elongation (Kostopoulos and Keramides, 1992).

Many studies across multiple fields have indirectly provided data that has been cited by proponents and critics of craniosacral therapy. For example, studies looking at the mechanical properties of cranial bones and sutures have provided information in exploring the CST tenet related to the presumed mobility of the cranial bones. In one such study, Hubbard et al. (1971) applied bending and failure tests to various samples of embalmed versus unembalmed cadaver cranium. They demonstrated that cranial sutures are “slightly” more compliant than layered cranial bone and that unembalmed sutures are more compliant than embalmed sutures. Jaslow (1990) similarly demonstrated different properties for sutures versus cranial bone. The bending strength of sutures increased with increasing bone interdigitation but did not exceed that of cranial bone. The sutures did, however, demonstrate higher energy absorbing capabilities than bone, thus reinforcing the theory that sutures have a shock-absorbing role.

In a study investigating sutural response to distraction osteogenesis in rabbits with delayed onset craniosynostosis, Losken et al. (1999) were able to produce force/displacement curves for coronal sutures in 10 normal and 9 rabbits with delayed onset craniosynostosis. This study demonstrated that 20 kgs (20,000 grams) of force was required to produce 1 mm of movement across normal rabbit coronal sutures and 48 kgs (48,000 grams) of force in rabbits with delayed onset craniosynostosis. (Figure 1) This amount of force far exceeds the 5-10 grams recommended by craniosacral therapists to manipulate human sutures.

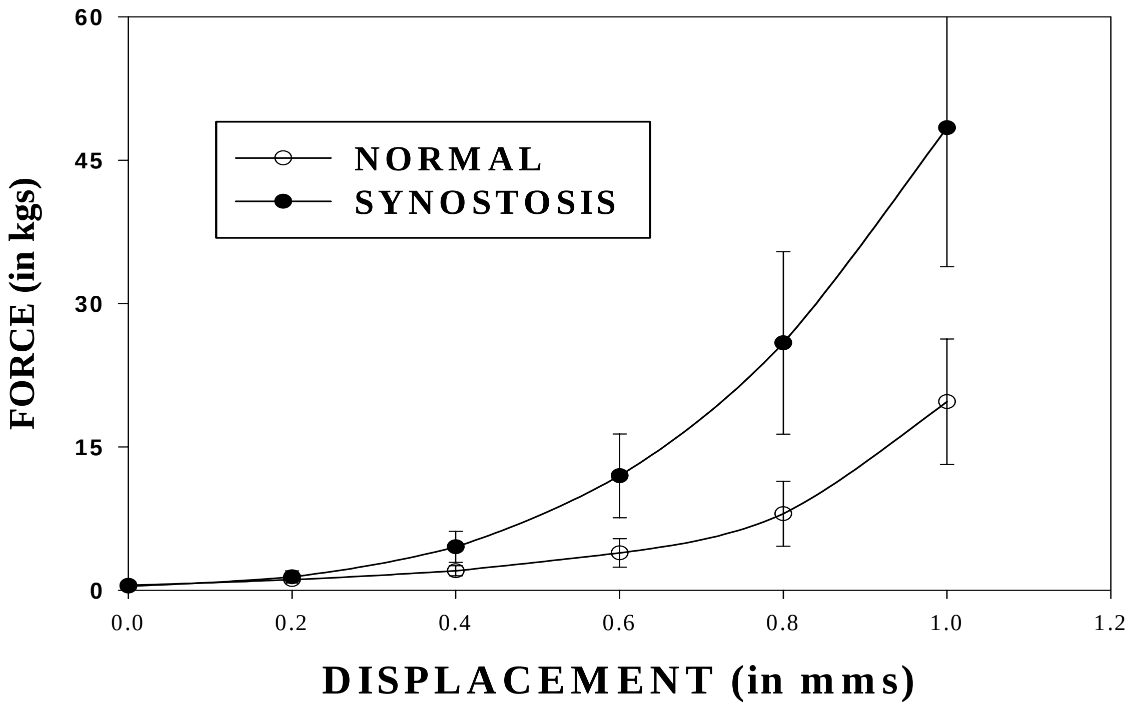

Figure 1. Coronal suture force displacement

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.

2.4.2.2. **Inherent motility of the brain and spinal cord / Fluctuation of the cerebrospinal fluid.** As noted in the introduction of this chapter, the basic biological model used to explain the diagnostic and therapeutic aspects of craniosacral therapy is known as the craniosacral mechanism or the primary respiratory mechanism. The basis for this model lies in the inherent motility of the nervous system and the fluctuation of the cerebrospinal fluid. This motility and fluid shift produces a rhythmic pulsation that is translated through movement of the dural membranes and can be palpated at the cranium and throughout the body (Brooks, 2000). Palpation of this rhythm is the key aspect of the diagnosis and therapeutic interventions related to craniosacral dysfunction (Upledger, 1983; McPartland and Mein, 1997; Hollenbery and Dennis, 1994; Greenman and McParland, 1995; Greenman, 1996; Greenman and Mein, 1996).

Multiple explanations have been put forth in an attempt to explain the existence of a craniosacral rhythm, or cranial rhythmic impulse (CRI). Some of the studies cited below are from theories put forth by craniosacral therapists based on observations but not direct research. Other theories that have been presented extrapolated from magnetic resonance imaging data.

Much of the criticism regarding the existence of the CRI is based on the lack of interrater reliability, which also will be presented.

Southerland's theory (1939) related to the production of a CRI believed the cranial motion was due to the rhythmic contraction/relaxation of the ventricles of the brain. Similarly, Bourdillon et al. (1992) attributed the spontaneous motion within the brain hemispheres to the cyclical contraction and relaxation of the neuroglia cells which in turn caused the cerebral spinal fluid to circulate. Upledger (1983) proposed a more detailed pressurestat model. This model states that production of the CSF by the choroid plexus occurs twice as fast as resorption. Once the threshold for production is reached, a homeostatic mechanism causes further production to cease. By contrast, resorption of the fluid is seen as a constant process so that once production is ceased, the fluid pressure steadily decreases as the volume decreases. Once a threshold of pressure is reached, production begins again. It is these changes in pressure that cause the rhythmic changes in the boundaries of the CSF's semiclosed hydraulic system.

Norton (1991) initially proposed a tissue pressure model to explain the CRI. This model assumes that the rhythm is related to the combined respiratory and cardiovascular rhythms of both the examiner and the subject. In a subsequent study examining this model, Norton (1992) concluded that the combined examiner/patient frequencies did not correlate with the CRI. However, McPartland and Mein (1997) built on Norton's original theory, stating that the CRI could be explained as a perception of entrainment, or the "palpable harmonic frequency of multiple biological oscillators." These oscillators include cardiac pulse, Traube-Hering modulation, diaphragmatic excursion, lymphatic vessel contraction, CSF production by the choroid plexus, pulsating glial cells, electric fields generated by cortical neurons, and cortical oxidative metabolism along with other possible oscillators as well.

Craniosacral motion caused by “local venomotion” rather than CSF pulsation was hypothesized by Farasyn (1999). He theorized that a general venous vessel wall pulsation in the brain is responsible for the cranial motion that is palpated. Farasyn does not believe, however, that there is enough tension within the dural tube between the cranium and the sacrum, to cause motion of the sacrum. Rather, he attributes the sacral motion to venomotion of the vena cava.

Several authors have related the CRI to the Traube-Hering-Mayer oscillation (Nelson et al., 2001; Sergueef et al., 2002). This oscillation is measured in association with blood pressure, cardiac rate and contractility, pulmonary and cerebral blood flow, movement of the CSF, and peripheral blood flow including thermal regulation and venous volume. Nelson et al. (2001) for example compared the cranial rhythmic impulse to the Traube-Hering-Mayer oscillation rates in twelve subjects and found that the rates occurred simultaneously. However, Nelson was unable to conclude that they could be attributed to this phenomenon.

In 1999, a review of the scientific evidence on craniosacral therapy was commissioned by the British Columbia Office of Health and Technology Assessment. Green et al., (1999b) the authors of the study, concluded that CSF movement and pulsation are phenomena measurable by encephalogram, myelogram, magnetic resonance imaging and intracranial/intraspinal pressure monitoring. They further stated that the evidence referenced in the craniosacral literature supported the view that a cranial rhythm distinct from cardiac and respiratory activity exists.

The chosen studies for the review were carried out to provide evidence of the pathophysiology pertaining to CSF motion and its relationship to the diagnosis and treatment of neurological disorders. They specifically were not undertaken to contribute to the data on craniosacral therapy (Green et al., 1999b). For example, one of the studies that was reviewed analyzed the CSF pulse wave associated with intracranial pressure. In this study, Cardoso et al.

(1983) documented a three-wave pulse related to the fluctuation of cerebrospinal fluid. They found that the first wave appeared to be related to pulsations originating at the choroid plexus and intracranial vessels, the second wave appeared to be related to cerebral compliance, and the origin of the third wave was unclear.

A second study from the review article was by Feinberg and Mark (1987) using magnetic resonance (MR) imaging to compare the theories that the pulsatile pressure of the CSF is directed by the force of choroid plexus expansion versus brain motion. High resolution MR demonstrated pulsatile brain motion and CSF ejection from the ventricles, suggesting that the second theory was correct and that a vascular driven movement of the brain might be the direct pumping mechanism for the CSF. The observed brain motion was synchronous with cardiac systole, a finding that supports this conclusion. Finally, a later study utilizing both MRI and radionuclide cisternography to examine CSF and intracranial dynamics demonstrated a pulsating flow that was produced by the alternating pressure gradient created by the systolic expansion/relaxation of the intracranial arteries (Greitz, 1993).

Multiple attempts have been made to by researchers to demonstrate intertester reliability of this craniosacral rhythm (Upledger, 1977; Wirth-Pattullo and Hayes, 1994; Hanten et al., 1998; Rogers et al., 1998; Drengler and King, 1998; Moran and Gibbons, 2001). Table 2 lists the intraclass correlation coefficients (ICC) for the studies cited below:

Table 2. Reported Intraclass Correlation Coefficients related to craniosacral rhythm

Researcher	**ICC**
Upledger (1977)	.57/.59*
Wirth-Pattullo and Hayes (1994)	-.02
Hanten et al. (1998)	.22
Rogers et al. (1998)	.08
Drengler and King (1998)	-.04
Moran and Gibbons (2001)	-.09 to .31

*Upledger's study did not report an intraclass correlation coefficient; this was subsequently calculated from the study's data by Wirth-Pattullo and Hayes (1994) to be .57 and by Hartman and Norton (2002a) to be .59.

Upledger's (1977) statistical analysis of craniosacral examination findings has drawn much criticism because of his poor research methodology (Wirth-Pattullo and Hayes, 1994; Hartman and Norton, 2002a; Green et al., 1999b). The subjects were children between 3 and 5 years of age, all of whom were judged to have cranial lesions. No "normals" were assessed as a control group. The subject's cardiac and respiratory rates were poorly correlated between the first and second measurements, and although at one time Upledger indicated the rates for craniosacral rhythm had been assessed for a full minute, he later reported that the rates had been counted for just 15 seconds, and then calculated to give a "one minute" reading.

According to Green et al. (1999b), the more recent studies with better designs have consistently found assessment of the craniosacral rhythm to be unreliable. Hartman and Norton

(2002a) similarly state that the data collected to date demonstrates 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 and endorsed by advocates of craniosacral therapy today.

2.5. SUMMARY

Craniosacral therapy is based on the evaluation and treatment of the primary respiratory mechanism, which entails motility of the brain, spinal cord, and dural membranes; fluctuation of the cerebral spinal fluid; and mobility of the cranial and sacral bones. Fluctuation in the CSF is thought to be an intrinsic force that can be directed from the exterior of the skull through light compressive or distractive forces.

In reviewing the scientific literature related to craniosacral therapy, its major claims, basic biological tenets and clinical outcomes, it becomes obvious that many questions remain unanswered. There is evidence for the existence of a cranial rhythm based on the CSF pulsation; however, there is virtually no support for the claim that this rhythm can be manually palpated in a reliable manner. There is also some support for small amounts of movement occurring between cranial bones based mostly on the role sutures play in cranial compliance related to increases in intracranial pressure. However, cranial bone motion based on the manual techniques described by craniosacral practitioners has not been verified. Much of the research on CST that has been presented uses questionable methodology and/or provides insufficient detail regarding the methodology used. These weaknesses make it impossible to replicate the experiments or derive independent conclusions regarding the data.

A review paper by Rogers and Witt (1997) entitled "The Controversy of Cranial Bone Motion," made several recommendations for future research. First the authors stressed that intracranial pressure monitoring or documentation of a known external force was essential to establish whether cranial bone movement could occur with therapeutic levels of stimulus. Second, 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 is to examine several of the features of craniosacral therapy that have been discussed in the literature and recommended for additional study by Rogers and Witt (1997). Specifically these will include simulating the frontal lift technique on anesthetized adult rabbits, with progressive distractive forces in increments of 5 grams (5, 10, 15 and 20 grams) applied by an Instrom load cell. Prior to and following the application of distractive forces, X-rays will be taken in order to measure movement across the coronal suture. Epidural intracranial pressure measurements will also be taken pre- and post- distraction to note any change associated with the frontal lift technique.

Specific Aims of this study include:

1. To perform cranial bone distraction at low loads of force to simulate the clinical procedures of craniosacral therapy.
2. To obtain quantitative measures of intracranial pressure prior to and following cranial bone manipulation.
3. To obtain quantitative measures of cranial bone movement via radiography following cranial bone manipulation.

This study hypothesizes that low loads of distractive force applied to the frontal bone will result in significant intracranial pressure changes and significant movement across the coronal suture. This study is significant because craniosacral manipulation is a type of therapy being widely practiced and promoted yet lacking in sound scientific and clinical research. It will assist clinicians in evaluating the biological efficacy of craniosacral therapy.

3. 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, two different power analyses were performed to determine number of subjects needed. These analyses were based on unpublished data (Fellows-Mayle et al.) collected from ongoing research in the Anthropology Lab where this project was performed. The first calculation involves intracranial pressure (ICP) changes in rabbits between 10 to 84 days of age. With an alpha of 0.05, the sample size needed to reach a power of 80% was calculated to be 17 subjects. (Mean difference = 3.43, Standard dev = 4.65) The second power calculation examines ICP variation over time during one observation session. ICP at baseline was compared to ICP at a 10-minute interval for rabbits at the age of 84 days. With an alpha of 0.05, the sample size would need to be 17 to reach a power of 80%. (Mean difference = 1.85, Standard dev = 2.54) After data collection was completed on thirteen rabbits, it was concluded that no further animals needed to be sacrificed in order to have statistical significance.

The thirteen animals (5 female and 8 male) were housed in stainless steel caging, and food and water was supplied ad libitum. The experimental procedures began once the animals reached a minimum of 84 days of age. This minimum age is based on the maturity of the cranial sutures, cessation of brain growth, and the documented stabilization of the intracranial pressure (Fellows-Mayle et al., 2000). The age range is between 84 -1484 days old.

Prior to surgery, all of the rabbits were anesthetized with an IM injection (.59 ml/kg) of a solution of 91% Ketaset (Ketamine Hydrochloride, 100mg/mL) and Rompun (Xylazine, 20 mg/mL). The animals were placed in ventral recumbency, the heads depilated and approximately a 25-mm incision was made through the skin over the sagital suture with a #15 surgical blade. The coronal suture was identified and a 1.2mm Vitallium “Y” plate (54-05151) and 1.7 mm diameter/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 2)

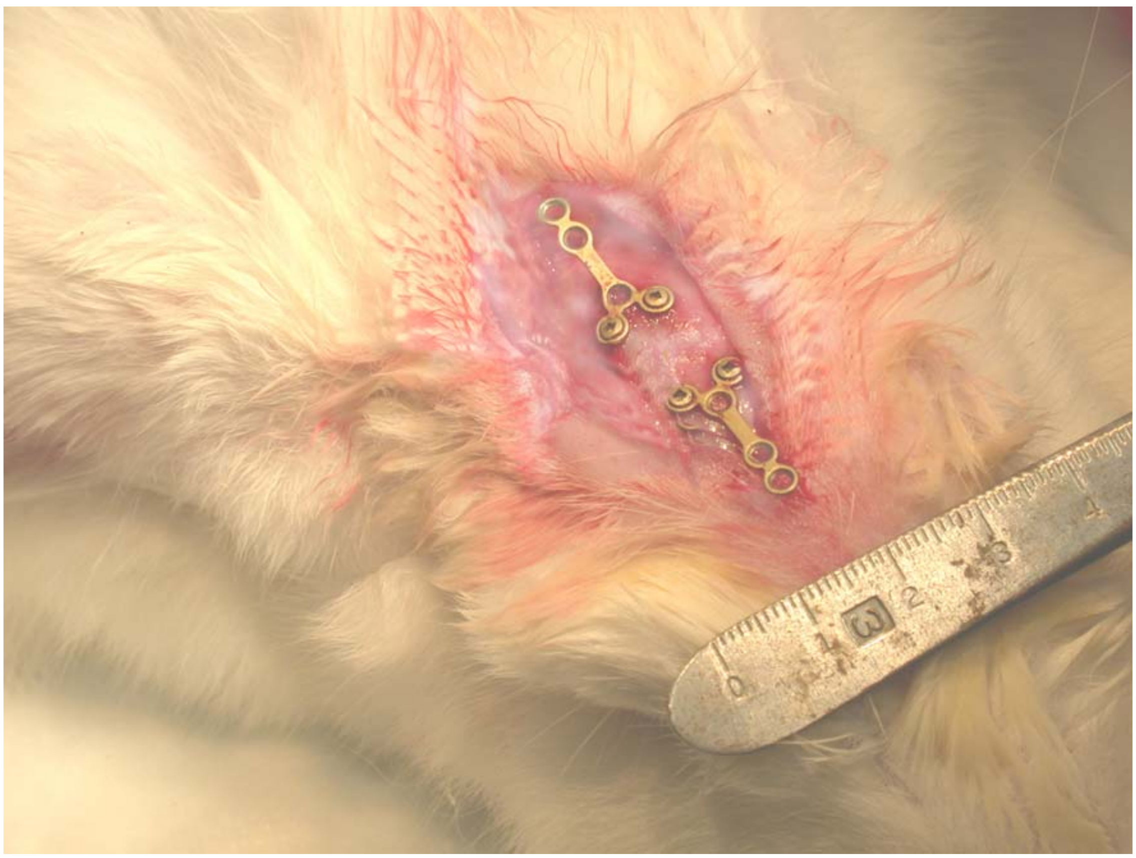

Figure 2. Cranial plate attachment

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, in order to confirm the burr hole penetrated the calvaria. (Figure 3)

Figure 3. Burr hole placement

The animals were then positioned in dorsal recumbency and the parietal plate was attached by way of an 11x10 mm S-shaped hook to a 63 mm straight surgical plate (Mini Würzburg Titanium Implant System, Stryker Leibinger GmbH & Co., Freiburg, Germany). This was then fixed to a C-hook mounted on a rigid plate at the base of the tabletop load frame (INSTROM 5500, Canton, MA). The frontal bone plate was attached to the ten-pound tension load cell (INSTROM, 5560, Canton, MA) by way of a C-hook. The load cell was electronically calibrated prior to the head fixation. (Figure 4)

Figure 4. Plate attachment to load cell

Intracranial pressure 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 prior to proceeding. During this 15 minute period, a baseline dorsoventral radiograph of the coronal suture was taken using a Philips Oralix 70 dental x-ray unit and the Instrom software was opened to the appropriate tension file. (Figure 5)

Figure 5. Radiograph set up

A baseline measurement of ICP was recorded after the initial 15 minutes. The Instrom load cell was then zeroed and five grams of axial tension was applied to the frontal bone of the anesthetized rabbit at a rate of 0.5 mm/minute. Once five grams of tension was reached, as indicated on the computer monitor, ICP and tension were recorded. At one minute intervals, this procedure was then repeated twice, with ICP and tension again being recorded. 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 allowed to stabilize for 5 minutes. During this time a baseline dorsoventral radiograph of the coronal suture was again taken and the 10-

gram tension program was opened. Prior to running the 10-gram distraction trials, the baseline ICP was recorded and the load cell was zeroed. Ten grams of force was applied to the frontal bone at a rate of 0.5 mm/minute. Once 10 grams of tension was reached, ICP and tension measurements were recorded. At one minute intervals, this procedure was again repeated twice, with ICP and tension being recorded. A repeat dorsoventral radiograph of the right coronal suture was performed at the end of the third distraction. This procedure was repeated for 15 and 20 grams of axial tension. Pearson product correlations for measure/re-measure 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 subject underwent additional distractive forces of 100, 500, 1000, 2000, 5000 and 10,000 grams while both ICP was monitored and baseline and distraction x-rays were taken. Following each session, the rabbits were euthanized with 300 mg/kg of pentobarbital IV proceeded 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. (Figure 6)

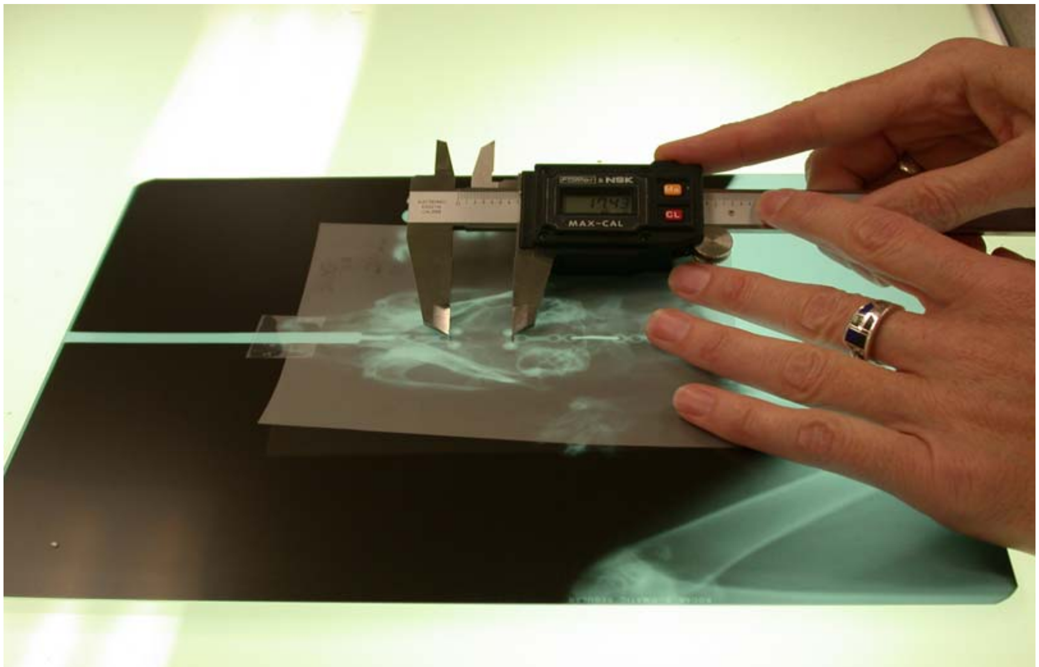

Figure 6. Landmark identification and measurement

Ten per cent of the radiographs were randomly chosen, re-traced, and re-measured by the two of the investigators, in order to calculate intra-rater and inter-rater reliability for landmark identification. Table 3 illustrates a Pearson product coefficient of .998 for both intra-rater and inter-rater reliability.

Table 3. Intra/Inter-rater reliability for X-ray landmark identification

		XRAYS PD 1	XRAYS PD 2	XRAYS MPM 1
XRAYS PD 1	Pearson Correlation	1	.998**	.998**
	Sig. (2–tailed)	.	.000	.000
	N	107	10	10
XRAYS PD 2	Pearson Correlation	.998**	1	.998**
	Sig. (2–tailed)	.000	.	.000
	N	10	10	10
XRAYS MPM 1	Pearson Correlation	.998**	.998**	1
	Sig. (2–tailed)	.000	.000	.
	N	10	10	10

**Correlation is significant at the 0.01 level (2 tailed)

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

4. RESULTS

Descriptive statistics based on demographic information for the 13 subjects in this study appear in Table 4.

Table 4. Descriptive statistics related to subjects

	N	Mean	Std. Deviation	Minimum	Maximum
Weight	13	3.36 kg	1.03	2.0 kg	4.93 kg
Age	13	380 days	489.69	84 days	1484 days

Intracranial pressure was measured (mm Hg) and averaged for all subjects at baseline (pre-distraction) and during cranial distraction for each of 3 trials at 5, 10, 15, and 20 grams of force. The descriptive statistics are outlined in Table 5.

Table 5. Mean intracranial pressure at baseline and during cranial distraction

Distraction	Force (gms)	Mean	Std. Deviation	N
Baseline	5	2.08	1.498	13
	10	2.08	1.498	13
	15	2.08	1.498	13
	20	2.38	1.446	13
	Total	2.15	1.447	52
Distraction	5	2.08	1.498	13
	10	2.08	1.498	13
	15	2.08	1.498	13
	20	2.38	1.446	13
	Total	2.15	1.447	52
Total	5	2.08	1.498	26
	10	2.08	1.498	26
	15	2.08	1.498	26
	20	2.38	1.446	26
	Total	2.15	1.447	104

Seven of the 13 subjects demonstrate no change in ICP during any distractive load across the coronal suture. Six subjects demonstrate a change in ICP during the trials; however, the change occurs during the baseline period between the 15 and 20 gram distractions. No change in ICP appears to occur in direct response to the applied distraction across the coronal suture. Of the 6 subjects whose ICP changes during the experimental procedures, only 1 demonstrated a decrease, while the other 5 showed an increase of 1 mm Hg. Figure 7 illustrates the change in ICP between baseline and distraction at each load. The mean ICP at 20 grams was higher than the mean ICP at lower distractive loads, but this was not statistically significant.

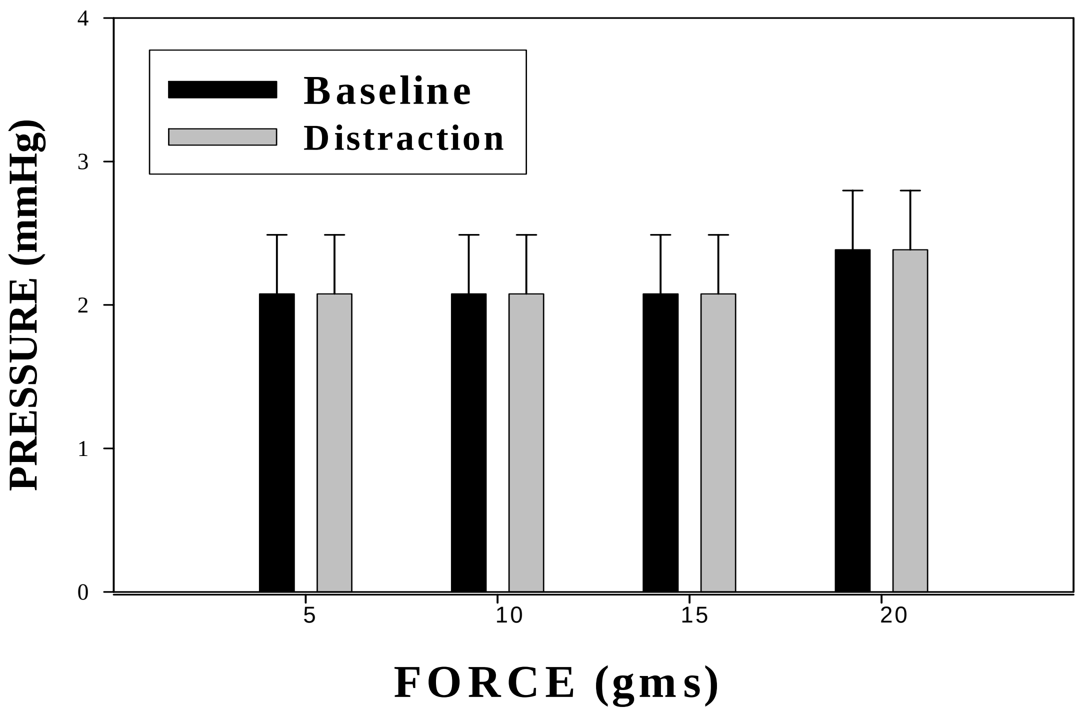

Figure 7. Intracranial pressure at baseline versus cranial distraction

A two-way ANOVA, comparing mean ICP to distraction force (5, 10, 15 or 20 grams), demonstrates no significant change ($p>.05$) in ICP at any load. (Table 6)

Table 6. Two-way ANOVA: ICP versus force

Dependent Variable: ICP

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	1.846[a]	7	.264	.120	.997
Intercept	482.462	1	482.462	218.791	.000
DISTRACT	.000	1	.000	.000	1.000
FORCE	1.846	3	.615	.279	.840
DISTRACT*FORCE	.000	3	.000	.000	1.000
Error	211.692	96	2.205		
Total	696.000	104			
Corrected Total	213.538	103			

a. R Squared = .009 (adjusted R Squared = -.064)

The mean measurement for coronal suture separation (mean difference between final distractions minus baselines for each of 5, 10, 15 and 20 grams of force) is outlined in Table 7. Twenty-one of the 47 radiographic measurements demonstrate a decrease in distance (negative number) between the plates from baseline to post-distraction while 26 measurements show an increase in distance (positive number). Subject # 2982 was the first subject to undergo the experimental procedure and the x-ray unit was not positioned correctly, therefore, no x-ray data is recorded (N=12). The 15 gram distraction x-ray for subject #2502 was double exposed and therefore no data is recorded for this trial (N=11). A one-way ANOVA demonstrates no significant difference ($p>.05$) between the mean differences for coronal suture movement at any level of distractive force. (Table 8)

Table 7. Mean difference between distraction and baseline measurements

	N	Mean (mm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
5	12	-.0750	.31032	.08958	-.2722	.1222
10	12	.0600	.11740	.03389	-.0146	.1346
15	11	.0627	.19850	.05985	-.0706	.1961
20	12	-.0675	.11771	.03398	-.1423	.0073
Total	47	-.0064	.20663	.03014	-.0671	.0543

Table 8. One-way ANOVA: Difference between distraction and baseline measurements versus force

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.207	3	.069	1.686	.184
Within Groups	1.757	43	.041		
Total	1.964	46			

The mean measurements between the cranial plates for both baseline and distraction at the various force levels are presented in Table 9. A two-way ANOVA, that compares force to coronal suture movement measured on x-ray, demonstrates no significant difference ($p>.05$) between baseline or distraction measurements at any load. (Table 10) Figure 8 illustrates the baseline versus distraction measurements.

Table 9. Mean measurements between cranial plates at baseline and distraction for each level of force

Distract	Force (gms)	Mean (mm)	Std. Deviation	N
Baseline	5	16.9350	2.65727	12
	10	16.8608	2.78040	12
	15	16.8775	2.74972	12
	20	16.9558	2.77434	12
	Total	16.9073	2.65226	48
Distraction	5	16.8167	2.89515	12
	10	16.9058	2.75437	12
	15	16.4618	2.42371	11
	20	16.9367	2.75443	12
	Total	16.7870	2.63531	47
Total	5	16.8758	2.71835	24
	10	16.8833	2.70669	24
	15	16.6787	2.54867	23
	20	16.9462	2.70366	24
	Total	16.8478	2.63049	95

Table 10. Two-way ANOVA: Effect of distraction force on coronal suture movement

Dependent Variable: X-ray measurement

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	2.030[a]	7	.290	.039	1.000
Intercept	26930.378	1	26930.378	3613.426	.000
DISTRACT	.383	1	.383	.051	.821
FORCE	1.010	3	.337	.045	.987
DISTRACT*FORCE	.726	3	.242	.032	.992
Error	648.399	87	7.453		
Total	27615.990	95			
Corrected Total	650.429	94			

a. R Squared = .003 (adjusted R Squared = -.077)

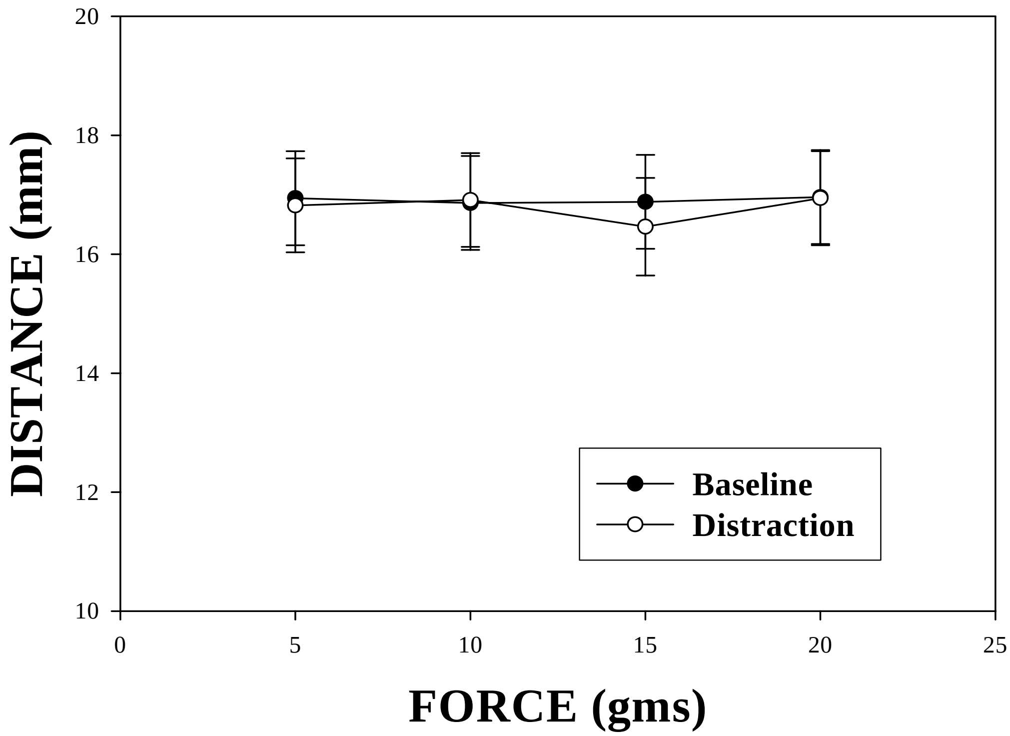

Figure 8. Coronal suture movement following cranial distraction

No significant 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 grams calculate to be 0.092, 0.306, -0.100, and 0.216, respectively. The Pearson correlation coefficient for overall average ICP versus sutural movement was r = 0.062 (p>.01).

The final subject (#2833) underwent additional distraction forces of 100, 500, 1000, 2000, 5000, and 10,000 grams. Results demonstrated no change in ICP following the application of distractive forces until 1000 grams of force was applied and the ICP decreased from 3 to 2 mm Hg. ICP then stabilized at 2 mm Hg during the 2000 grams distraction and increased to 3 grams during the baseline period following the 2000 gram, but prior to the 5000 gram distractive force. ICP remained at 3 grams throughout the remaining trials. (Table 11) Figures 9 and 10 plot the mean ICP for all subjects along with the ICP for subject #2833 who underwent additional larger distractive forces.

Table 11. Mean ICP versus distraction force for subject #2833

Force (gms)	Baseline Mean ICP (mm Hg)	Distraction Mean ICP (mm Hg)	Change from baseline to distraction
5	3.00	3.00	0.00
10	3.00	3.00	0.00
15	3.00	3.00	0.00
20	3.00	3.00	0.00
100	3.00	3.00	0.00
500	3.00	3.00	0.00
1000	3.00	2.00	1.00
2000	2.00	2.00	0.00
5000	3.00	3.00	0.00
10,000	3.00	3.00	0.00

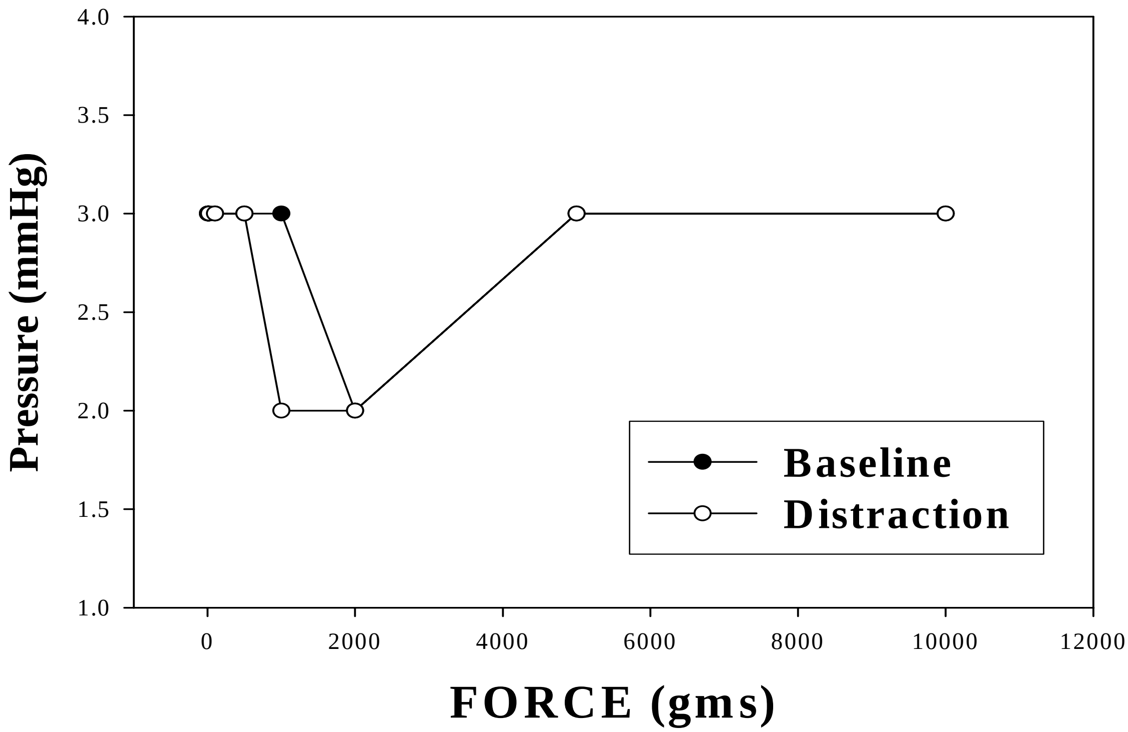

Figure 9. Intracranial pressure following cranial distraction for subject #2833

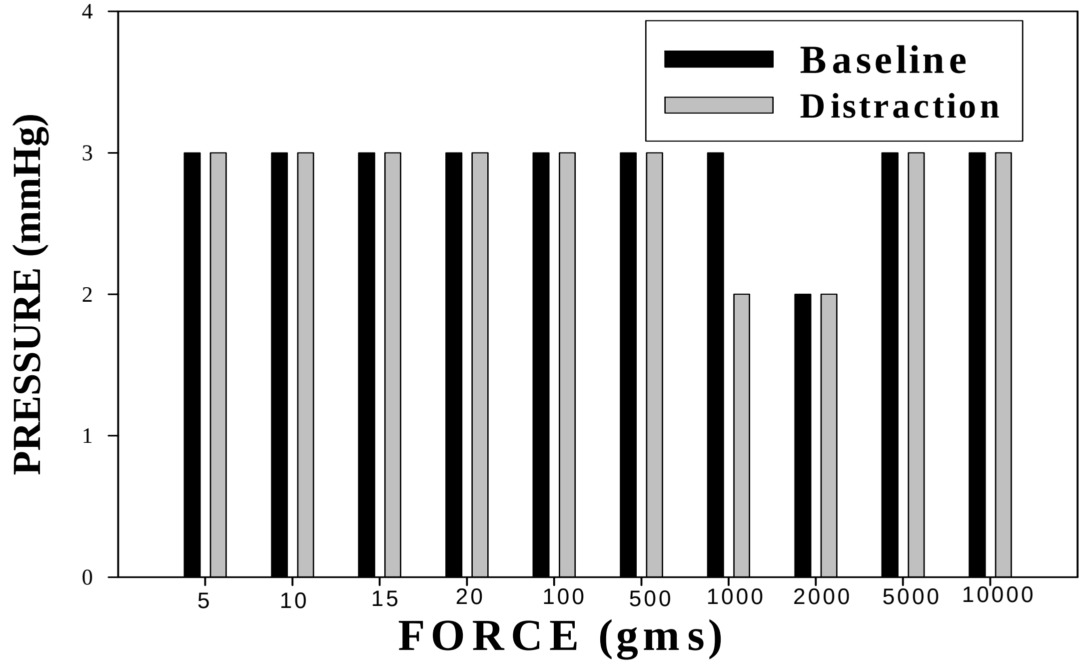

Figure 10. Bar graph of intracranial pressure following cranial distraction for subject #2833

The radiographic measurements for the distraction forces between 5-10,000 grams for subject #2833, including the difference between baseline and distraction, are presented in Table 12. The range of coronal suture movement between 5-5000 grams of distraction is -.09 to .31. The largest measurement occurs between the baseline and the 10,000 gram distraction and is 0.91 mm. Figure 11 illustrates the difference between actual baseline and distraction measurements for subject #2833 at the various levels of applied force. Figure 12 plots the difference values between baseline and distraction from 5-10,000 grams of force.

Table 12. Radiographic measurement versus force for subject #2833

Force (gms)	Radiographic baseline measurement (mm)	Radiographic distraction measurement (mm)	Difference between distraction and baseline
5	19.25	19.29	0.04
10	19.48	19.53	0.05
15	19.55	19.62	0.07
20	19.77	19.68	-0.09
100	19.58	19.55	-0.03
500	19.63	19.93	0.30
1000	19.95	20.18	0.23
2000	20.09	20.14	0.05
5000	20.28	20.59	0.31
10,000	20.29	21.20	0.91

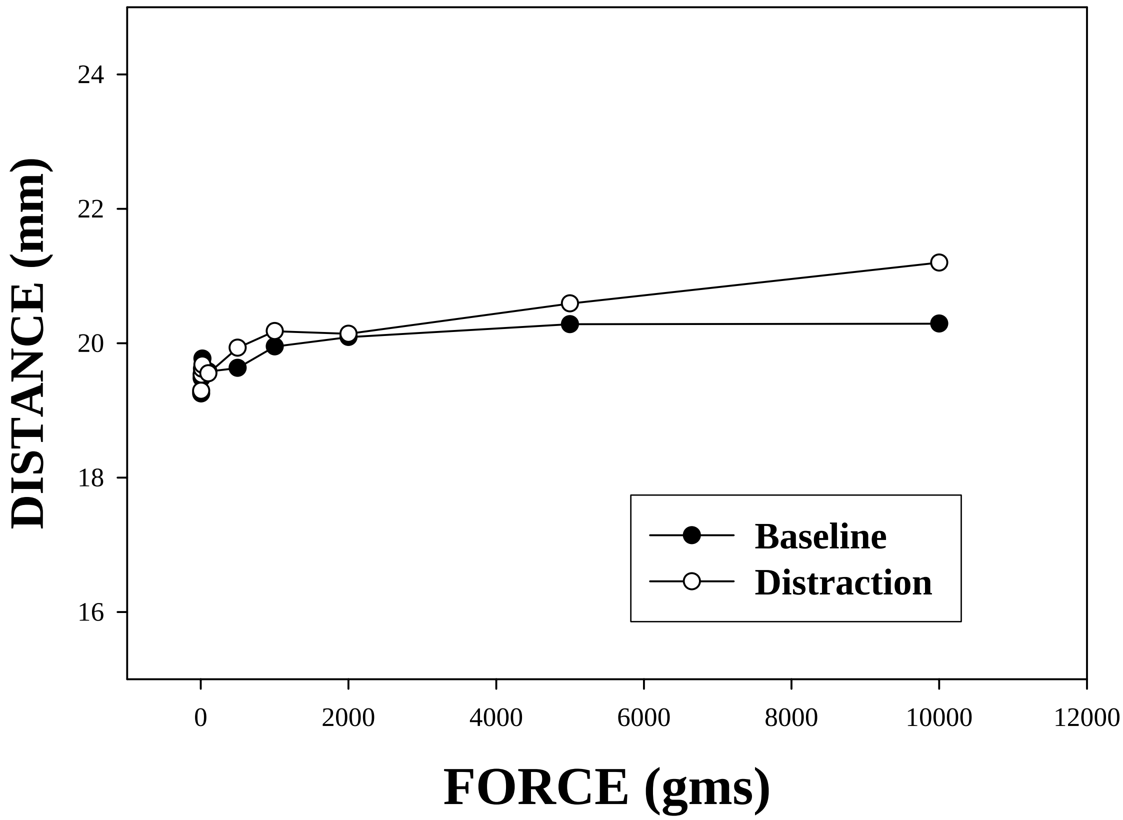

Figure 11. Baseline versus distraction radiograph measurements for subject #2833

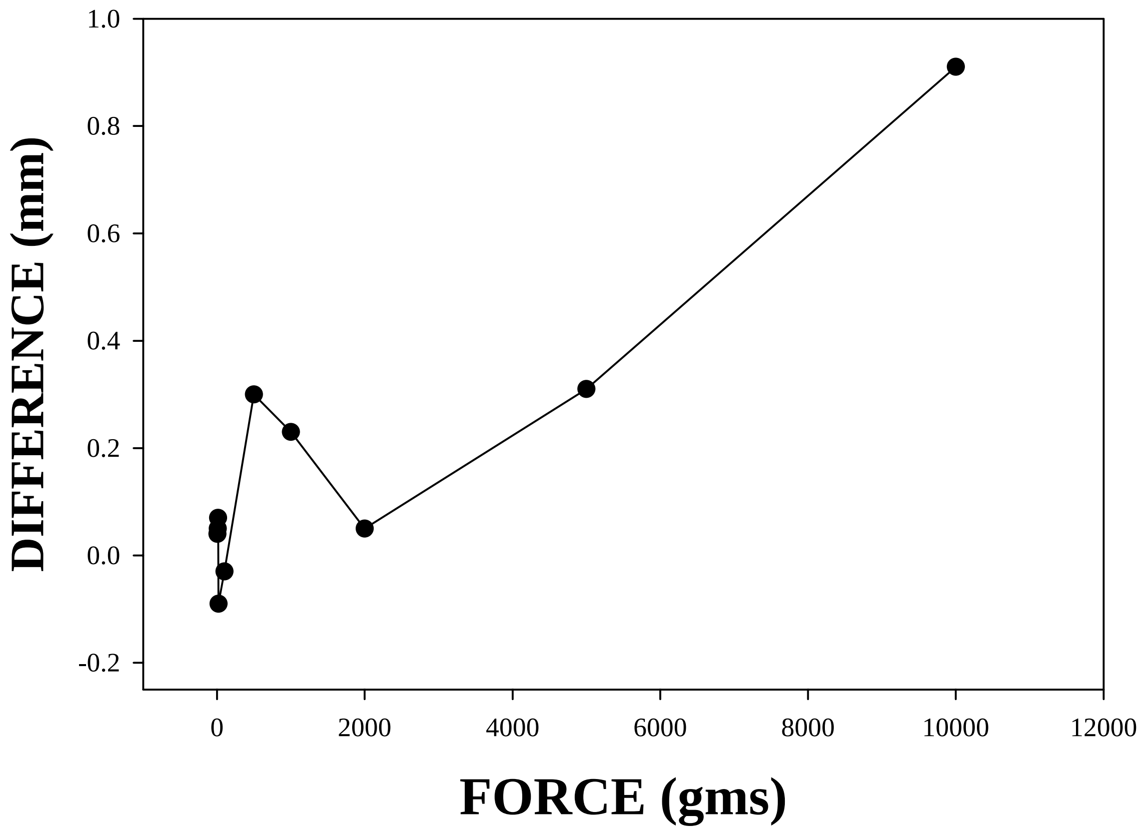

Figure 12. Coronal suture movement following cranial distraction for subject # 2833

Essentially no linear relationship could be demonstrated between the change in ICP and the amount of force applied across the cranial suture ($r = .104$, $p > .05$) for all subjects, including the last subject that underwent additional levels of distraction. A linear regression model demonstrated similar coefficients of determination (R^2) as compared to logarithmic, quadratic, and cubic regression models. The linear regression equation for the relationship between ICP and force is as follows: $Y = a + bX$, or $Y = 2.18 + (0.000098)X$. The regression line was not found to be significantly different than 0 [$_{(.05)}F_{(1,114)} = 1.236$].

A fair degree of relationship ($r = .413$, $p < .05$) was demonstrated between coronal suture movement and applied distractive force when the last subject's data for coronal suture distraction was included. A cubic regression line was demonstrated to be the best fit with the following equation: $Y = a + b_1X + b_2X + b_3X$, or $Y = -0.014 + (0.000067)X + (-0.00000005)X + (0.000000000005)X$. This linear relationship is consistent with the previously mentioned work of Losken et al. where they were able to demonstrate 1 mm of movement across the coronal suture in normal rabbits that underwent 20,000 grams of distractive force. Figure 13 is a plot of Losken et al.'s data for normal rabbits with the addition of this study's data from the last rabbit.

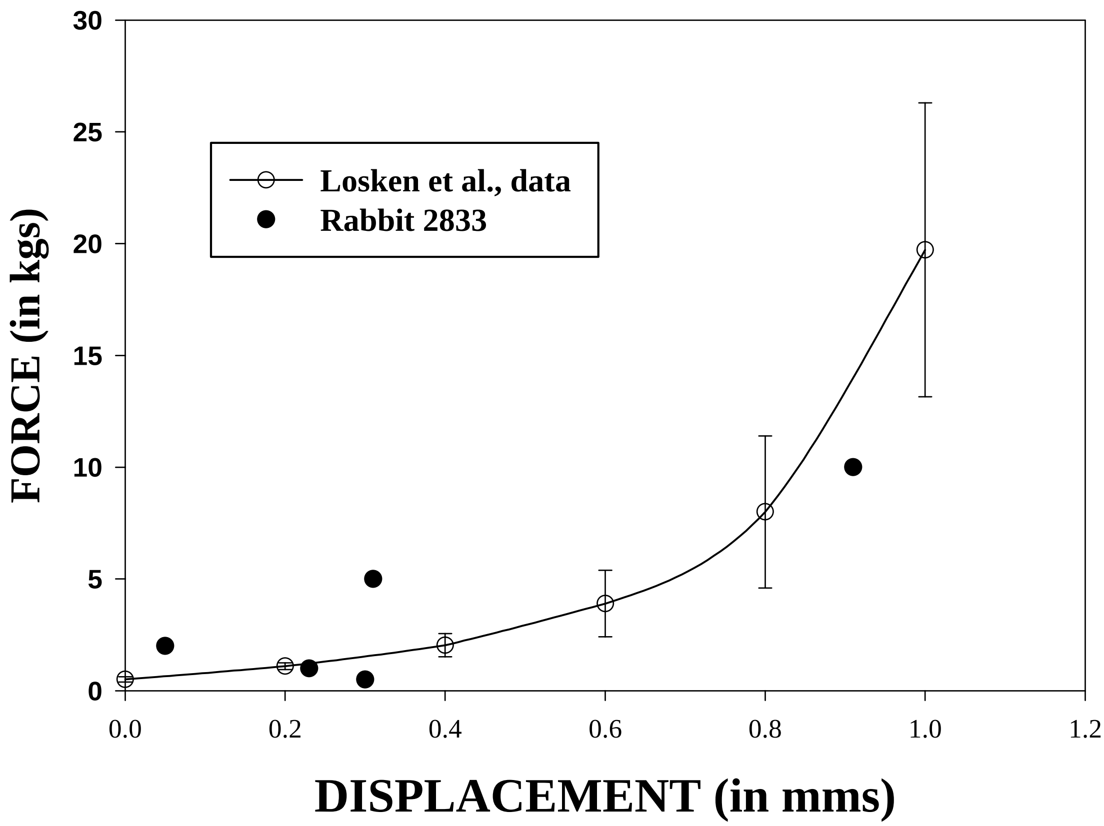

Figure 13. Force displacement for Losken et al. versus rabbit # 2833

5. 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 intracranial pressure changes and movement across the coronal suture. Neither of these hypotheses was supported by the data.

Intracranial pressure did not demonstrate a statistically significant change in response to low loads of distractive force, 5-20 grams, over the 13 subjects. The ICP mean associated with the 20 gram distraction trials was slightly higher than the means for the 5-15 gram trials, but this was not statistically significant, nor does it appear to occur in response to cranial distraction. In 6 of the 13 subjects, mean ICP is seen to change. Interestingly, all of these changes occur during the stabilization period following the 15 gram distraction trials and prior to the 20 gram trials. Given that all of these changes occurred during the same relative time period following the onset of anesthesia (approximately 30 minutes), one possible explanation may be that this is a natural variation in ICP in an anesthetized animal. If these changes were in response to the experimental procedures, it would make physiologic sense that the change would occur during the distraction phase of the procedure, rather than during a baseline period.

Of the 6 subjects who did demonstrate a change in ICP, 5 subjects experienced a 1 mm Hg increase and 1 subject experienced a 1 mm Hg decrease during the stabilization period between 15 and 20 grams of distraction. Again, if these changes in ICP were related to the distraction force applied to the coronal suture, it would make sense that ICP would have decreased in response to a distractive force, not increased. The majority of the subjects (7/13) in this study demonstrated no change in ICP. However, of the subjects who did demonstrate a change, 83% experienced an increase, rather than a decrease, in pressure.

Coronal suture movement, as measured by radiographs taken prior to and during the applied distractive forces, could not be demonstrated at forces between 5-20 grams. The means for the baseline radiographic measurements were not found to be significantly different from each other, nor were the means for the distraction radiographic measurements significantly different from each other. No difference was found between the average amount of movement (distraction measurement minus baseline measurement) at any of the applied forces between 5-20 grams.

In order to determine if ICP change or coronal suture movement would occur at higher loads of frontal bone distraction, the last subject (#2833) underwent additional distractive forces of 100, 500, 1000, 2000, 5000, and 10,000 grams applied to the frontal bone. ICP remained constant during the 100 and 500 gram distractions, then decreased from 3 to 2 mm Hg during the 1000 gram distraction. The ICP remained at 2 mm Hg during the next trial at 2000 grams, then increased to 3 mm Hg during the stabilization period between 2000 and 5000 gram trial. No further change in ICP was noted during the subsequent 5000 and 10,000 gram distraction trials. These larger distractive forces were applied only to one subject, therefore, statistical analysis and subsequent conclusions are limited. Whether the change in ICP which occurred during the 1000 gram 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 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 100-200 times greater than those used clinically.

In relation to movement across the coronal suture in the last subject who underwent additional and larger distractive forces, the range of movement measured during the 5-5000 gram distractions was between -0.09 and 0.31 mm. The final distraction at 10,000 grams produced 0.91 mm of movement. Again, no statistical analysis could be performed and, therefore, conclusions about this data are limited because only one subject underwent distraction at the higher levels. However, when this data is compared to the previously sited study by Losken et al. (1999), which demonstrated 20,000 grams of force was required to produce 1 mm of movement in the coronal suture of normal rabbits we start to see some consistency between the data points. (Figure 8) In the last subject's data, movement at the coronal suture is not seen until forces (500 grams) are applied to the frontal bone that are 100 times greater than those used clinically by craniosacral therapists on human craniums that are significantly thicker than those utilized in this study.

Craniosacral Therapy 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 (Brooks, 2000). Based on a review of literature related to craniosacral therapy, Green et al. (1999b) conclude that there is evidence for CSF pulsation as measured by magnetic resonance imaging, encephalography, myelography, and ICP monitoring. Part of the controversy surrounding craniosacral therapy, 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 (Wirth-Pattullo and Hayes, 1994; Hanten et al., 1998; Roger et al., 1998; Drengler and King, 1998; Moran and Gibbons, 2001).

The goals of craniosacral treatment according to Greenman (1996) 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 indicted 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 (Heifetz and Weiss, 1981; Pitlyk et al., 1985; Heisey and Adams, 1993). Biomechanical studies have demonstrated that sutures are more compliant than cranial bone and that their bending strength does not match that of cranial bone (Hubard et al., 1971; Jaslow, 1990). Losken et al. (1999) also demonstrates that movement can occur 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 5-20 grams of distractive force, which simulates a craniosacral frontal lift technique, there is no significant movement across the coronal suture, nor is there significant change in ICP. In one subject, however, at forces significantly greater than those described for clinical use, ICP decreases in response to a distractive force, and movement across the coronal suture is 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 (1983), a leading proponent and instructor of craniosacral therapy, the craniosacral system is made up of the following anatomical parts:

1. Meningeal membranes
2. Osseous structures to which the membranes attach
3. Non-osseous connective tissue structures

4. Cerebrospinal fluid
5. Structures related to production, resorption, and containment of the cerebrospinal fluid

Anatomically, a rabbit has by Upledger's definition, a craniosacral system. Upledger 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 (Pitlyk et al., 1985; Michael and Retzlaff, 1975; St. Pierre et al., 1976; Heisey and Adams, 1993; Retzlaff et al., 1975).

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 was performed by Persson et al. (1978). It compared suture closure in man and rabbits. The human specimens were between the ages of 15-35 years, while the rabbit specimens were between 25-36 months of age. Two main structural patterns of fibers, both perpendicular and parallel to the suture line, were observed in both the human and rabbit sutures. Thick collagenous, tendon-like bundles were more marked, however, in the rabbit specimens as compared to the human. This study also demonstrates similar sutural obliteration patterns between these species, consisting of slender bony spicules extending from the sutural margins and partially or fully bridging the gap. In the human palatal suture, however, several calcified bodies were also present that were generally not seen in rabbits. 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 that therefore, we would more likely see movement across the sutures and changes in ICP in response to distractive forces.

Finally, the use of Ketamine as an anesthetic agent may have influenced ICP readings during the experimental procedures. Reicher et al. (1987) have shown that Ketamine increased ICP by causing vasodilatation. DeBray and Tranquart (1994) demonstrated that the effects of Ketamine on intracranial pressure are short-lived and that reliable results were able to be obtained. The dosages of Ketamine in this experiment were consistently maintained based on the subject's body weight, and each procedure was consistently timed, so even if this anesthetic caused an increase in ICP, all of the subjects would have been affected in the same manner.

6. CONCLUSION

Rogers and Witt (1997) published a review paper related to the controversy surrounding cranial bone motion. They concluded that either intracranial pressure monitoring or documenting a given, externally applied force are methodological issues essential to validating whether cranial bone motion occurs in response to therapeutic levels of intervention. This study has simulated a craniosacral treatment technique, the frontal lift, by applying documented distractive forces, through use of an Instrom load cell, to the frontal bone of 13 rabbits, while monitoring ICP. Based on the theories proposed by craniosacral practioners, we hypothesized that therapeutic levels of distractive force, 5-20 grams, applied to frontal bone would result in significant change in ICP and movement across the coronal suture. Both of these hypotheses are 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 subject following the application of force significantly larger than those used clinically in the practice of craniosacral therapy.

Much of the controversy between critics and proponents of craniosacral therapy has centered on whether movement occurs at the cranial sutures. It may be that the wrong question is being debated. The literature regarding this controversy is inconclusive because there is not agreement on the definitions of movement across sutures and closure or fusion of sutures. Cranial and facial sutures do demonstrate significant variability in age of closure. Cranial bone movement has been supported by studies demonstrating flexure across the sutures or cranial compliance relative to increased in intracranial pressure. What has not previously been demonstrated however is whether therapeutic forces, either tensile or compressive, are sufficient to create movement across cranial sutures that can influence dural tissues and intracranial fluid dynamics to the extent of having direct or indirect therapeutic benefit.

This study has demonstrated that therapeutic loads of distractive force do not create measurable movement at cranial sutures nor changes in intracranial fluid dynamics as measured by ICP monitoring. These results suggest that a different biological basis for craniosacral therapy should be explored.

This study does not, however, attempt to comment on the clinical validity of craniosacral therapy as a therapeutic intervention. Multiple factors have been identified as to why individuals turn to complementary and alternative therapies including: the value put on practitioners who treat the whole individual (Vincent and Furnham, 1996); the need for alternatives when conventional medicine fails (Furnham and Rawlinson, 1996); and discontent with the side effects of traditional medicine and frustration with high-tech medical care (Shirreffs, 1996).

Clinicians who practice craniosacral therapy should attempt to validate the therapeutic outcomes of this type of alternative therapy. Randomized, controlled, prospective, clinical studies of subjects with a specific diagnosis who undergo craniosacral therapy could be compared to control groups that receive the “laying on of hands” to the cranium but not a specific craniosacral intervention. This would be a logical, scientific attempt to validate the therapeutic outcome of craniosacral therapy.

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