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Measurement of Cranial Bone Mobility

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Introduction

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

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

Device for Measuring Cranial Bone Mobility

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

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

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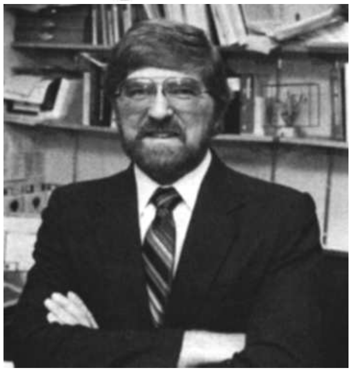

Editor's Column

"Spring has sprung, the grass is riz, I wonder where my mower is."

Yes, it has finally happened here in good old Athens, Ohio-spring is here. We had a false alarm (a pseudo-spring?) in mid March and sure enough it fooled all the plants into coming up and starting to bloom, then froze them right off. Now I think we can start looking for the mower in ernest. It is also just past tax day here (and everywhere else in the USA, but downtown Chicago where because of a flood they get another week). Seems like the IRS gets most of what we make. Is it true that the tax form next year will really be simple? Just two items: 1. What did you make last year? 2. Send it in.

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

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

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Surgical Procedures and Measurement of Physiological Prarmeters

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

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

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

Results and Discussion

Initially, the animal's head was secured in the stereotaxic frame to insert and seal the cannula into the lateral cerebral ventricle and to attach our device for measuring parietal bone movement. The animal's head was then released from the stereotaxic frame and allowed to rest without restraint on a padded surface. When baselines for spontaneous bone movement, cardiovascular and

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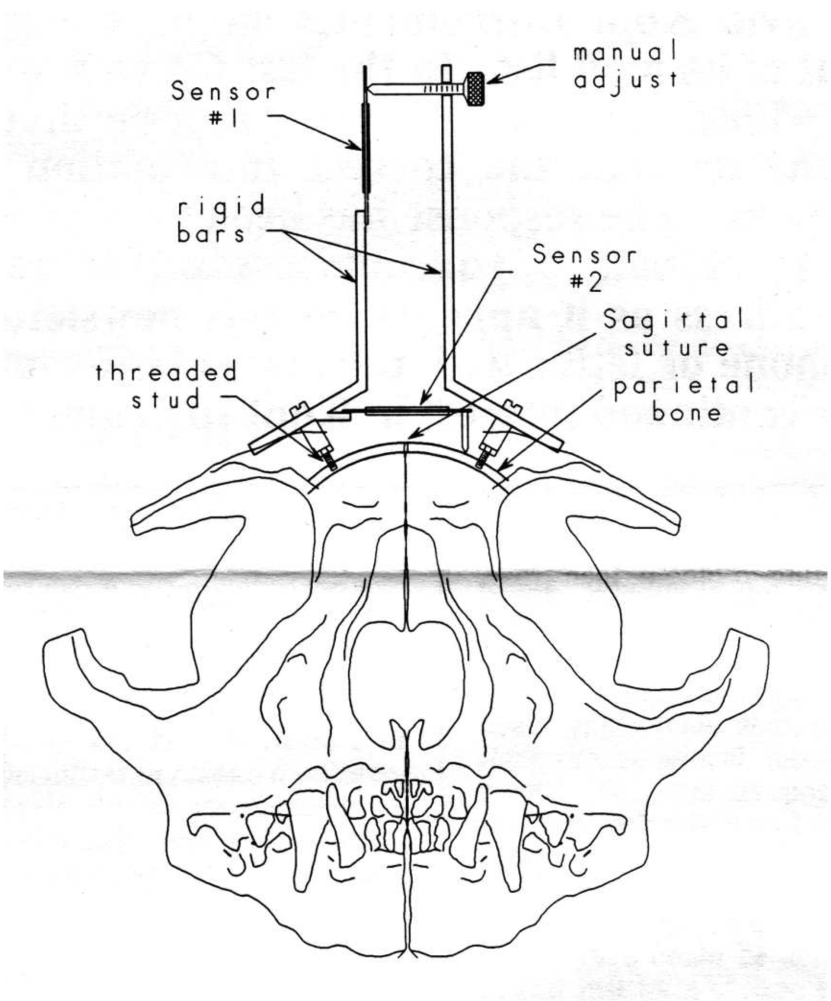

Figure 1. **Cranial motion was measured by securing a customized device to each bilateral parietal bone with a threaded stud. One microfoil strain gage (Sensor #1) monitored lateral movement of the bones at the sagittal suture and another (Sensor #2) transduced their relative rotational movement Both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

ber which amplifies (100X) and band pass filters (100- respiratory activity were stabilized we began our tests, one of which was to measure the effects of an external force applied to the animal's head.

Representative data (Fig. 2, pg. 4) show the effects of head compression using a thumb and forefinger to compress and hold firmly the temporal bones of the animal's head. Coincident with the application of this inward directed force, the parietal bones moved laterally closer and underwent inward rotation. Release of the manually applied external force was accompanied by a return of the parietal bones to their near-rest position. The data show that there is spontaneous movement of the parietal bones around the fulcrum of the sagittal suture which reflects cardiovascular and respiratory activity. An external force, applied to the head, caused movement of the parietal bones resulting in increased intracra-nial pressure and transiently altered cardiovascular and respiratory activity. An external force, applied to the head, caused movement of the parietal bones resulting in increased intracranial pressure and transiently altered cardiovascular and respiratory activity. Release of the force resulted in a return to the previous condition. These responses were easily duplicated in subsequent tests on the same animal; animals with less compliant sutures showed less parietal bone movement and smaller changes in intracranial pressure and physiological responses.

How much the parietal bones move in response to changes in intracranial volume and pressure depend not only on the mechanial properties of the skull's sutures but also on any extra-cranial restrictions that are imposed. Representative data (Fig. 3, pg. 5) show responses when the animal's head was held firmly in a stereotaxic frame ("RESTRAINED") and when it was free of restraint ("UNRESTRAINED"). Controlled volumes of fluid were injected as a bolus into a lateral cerebral ventricle and the change in intra-

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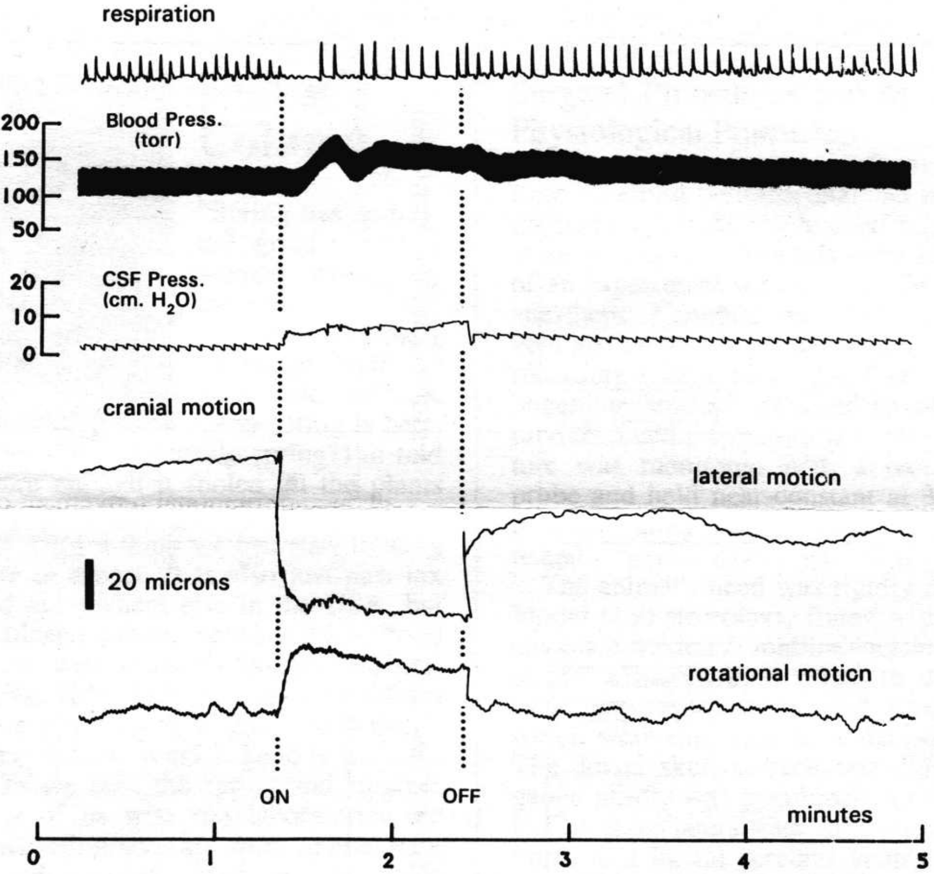

Figure 2. Respiration, systemic arterial pressure, CSF pressure and lateral and rotational parietal bone motion traces in an anesthetized cat as it rested without head restrain (prior to"ON") and after manual compression of the temporal bones, then their release ("OFF"). The measured lateral motion was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

cranial pressure and lateral movement of the parietal bones were measured. Intracranial pressure and parietal bones were allowed to return to their preinjection levels before subsequent injections were made. The data demonstrate that restraining the head in the stereotaxic frame caused greater increases in intracranial pressure in response to ventricular injections (upper left, Fig. 3, pg. 5) and restricted sagittal suture movement (upper right, Fig. 3, pg.5). The effect of restraint is also reflected in a reduced total cranial compliance (calculated as the ratio of change in intracranial volume to change in intracranial pressure; lower left, Fig. 3, pg. 5) and a reduced suture compliance (calculated as the ratio of change in suture width to change in intracranial pressure; lower right, Fig. 3, pg. 5). Determinations of total cranial compliance in the cat are often made with the animal's head secured in a stereotaxic frame (Marmarou, et.al., 1978; Sullivan, et.ai, 1979). Our data indicate that this external restraint notonly influences the cranial compliance, but also masks contributions of suture movement to the total compliance of the skull and its contents.

Summary

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

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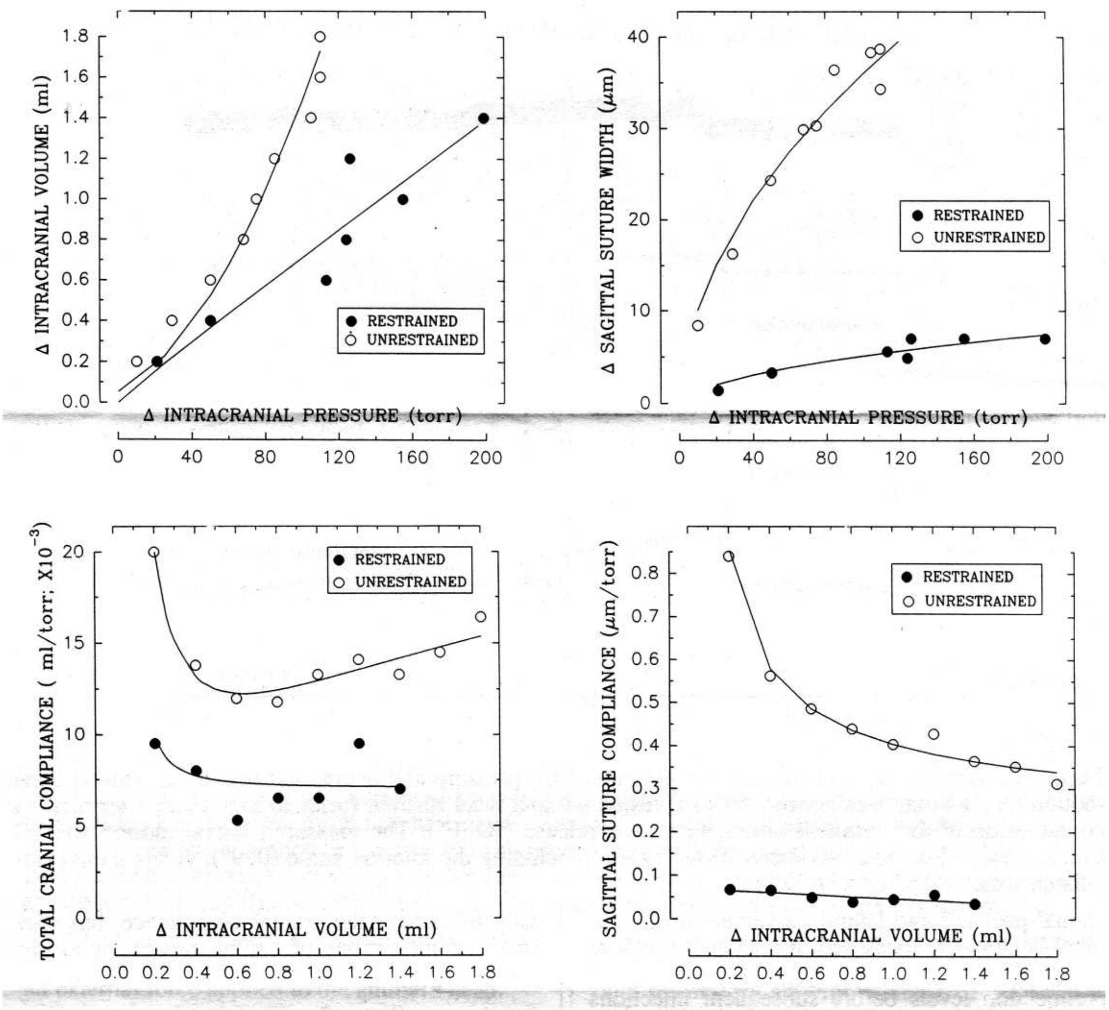

Figure 3. Data in the upper panels show the change in intracranial volume and sagittal suture width, respectively, as a function of the change in intracranial pressure resulting from controlled injections into a lateral cerebral ventricle. Data in the lower panels show cranial compliance (ΔV/ΔP) and sagittal suture compliance (ΔL/ΔP), respectively, as a function of the change in intracranial volume resulting from the controlled injections. Lines through data points are computer-assisted best-tit curves.

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