A study of the rhythmic motions of the living cranium

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The hypothesis of inherent motility of the cranium has been supported by palpation of the living head. The hypothesis that a rhythm synchronous with the arterial pulse and another associated with thoracic respiration might be detected is in accord with known physiologic phenomena. The report of a third palpable rhythm, slower than either pulse or respiration, required more study. This article records a series of experiments conducted with instrumentation suitable for studying minute expansile-contractile motions of the live cranium. The recordings show that there is a cranial motility slower than and distinguishable from the motility of the vascular pulse and thoracic respiration, and that such motion can be recorded instrumentally. Studies of rhythmic cellular function and movement of cerebrospinal fluid have been reported elsewhere. More investigation is needed to establish the relations among the various physiologic phenomena described. Additionally, the clinical significance of the rhythmic motion of the cranium needs documentation.

It has been 70 years since Sutherland conceived the idea that the cranial bones are beveled for articular mobility to accommodate the motion of a respiratory mechanism.[1] His meticulous study of the cranial bones revealed that each bone is beveled reciprocally, with corrugations running transversely, diagonal friction gears, balls and sockets, pivots, pulleys, fulcrums, hinges, and other mechanical arrangements that made provision for movement. Palpation of the living head lent support to the hypothesis, first advanced in 1939,[2] that there is inherent motility of the cranium. It was a plausible contention and in accord with known physiologic phenomena, that a rhythm synchronous with the arterial pulse might be detected, but his report of a third palpable rhythm, slower than either pulse or respiration, needed further study. Does such a motion really occur? Can it be mechanically recorded? If it exists, what is its relation to known physiologic functions?

This paper is intended to present the results of exploration of these three questions. With regard to the first question, as to the existence of such a rhythmic motion, slower than and different from the thoracic respiratory rhythm, within the living cranium, those trained in skillful palpation of the human body have claimed for nearly 30 years that such inherent motility is detectable. The validity of the palpatory findings of persons with trained hands is, however, subject to question by those who lack such palpatory skill. The doubt is due primarily to the plausible hypothesis that the sense of touch will experience systematic tactile illusions when subjected to small cyclic motions.

It can be shown mathematically that if the pressure-sensing nerve ends are acted on by the sum of two oscillatory pressures of different frequency, and if the effective signal developed by the nerves is a nonlinear function of the total pressure, then the signal will contain two pseudo-oscillations of which the frequencies are the sum and the difference of those actually present. Further, if the neural networks are developed by attention and practice to filter out all but the lowest frequency, the sense of touch will experience the illusion that a repetitive motion is clearly felt at a frequency which is the difference between the two frequencies actually present. In palpation, the fingertips are subjected to four cyclic motions of different frequency, one each from the pulse and the respiratory cycles of the operator and of the subject. It may be contended with some force of argument that the apparent sensation of a slow cranial rhythm represents only a "beat" frequency between, say, the two pulse cycles.

It should be noted in this regard that the ear is known to be subject to this same error. When two piano strings vibrate at slightly different rates, a beat note is distinctly heard at the difference frequency, although the note is not physically present. Furthermore, a variety of tactile illusions are known to exist. Perhaps the most common one is generated when an object is touched with the tips of crossed fingers, so that an impression of two objects instead of one is received.

Because exceptions of this sort can be taken as evidence perceived by palpation alone, it was essential to devise an instrument program to demonstrate whether the tactile observations of cranial motility are, in fact, valid.

An intensive search of scientific literature failed to reveal any investigation of the motility of the living cranium. The anatomic studies of Pritchard, Scott, and Girgis[7] substantiated Sutherland's theory that cranial sutures are designed to permit motion and in fact extended this concept to several species of animals, but the physiologic concept thus propounded had not yet been challenged experimentally.

In 1962, therefore, I invited a skilled electronics engineer, F.G. Steele, a designer of computers, to design an electronic recording instrument suitable for investigating minute expansile-contractile motions of the live cranium. This report has been prepared with his assistance, because an understanding of the interrelation between the laws of electronics, the laws of mechanics, and the laws of nerve function is necessary for comprehension of the principles involved in the instrument design and the interpretation of results.

Mechanical recording

Involved in the instrumental problem is the fact that touch is nonlinear. The nervous system will transmit to the brain signals which erroneously include sinusoids having the frequencies of the sums and differences of the actual cyclic motions present.

Tactile illusions of rhythmic motions in the head, or, in fact, in any part of a subject, might arise in the following way:

The experimenter's fingertips are placed lightly on the subject's head, with both head and hands supported in such a way that no relative motions take place. Both the scalp and the fingers will experience slight expansions and contractions due to the two pulse surges. If it may be assumed that the fingers act as linear elastic constraints, a pressure proportional to the sum of the pulse amplitudes will be generated at the contact surfaces.

The next assumption is that the pressure-sensing neurons have a nonlinear response, that is, that a graph of the effective neuron-sensing rate with variations in applied pressure will yield a curved rather than a straight line. One would assume, a priori, that human pressure sensors would show a logarithmic rather than linear response in order to cover the wide ranges encountered.

Under these conditions, it can be shown mathematically that the neurons will not only sense the two cyclic pulses but will develop signals containing two other rhythmic signals with repetitive frequencies which do not exist externally—one at the sum and the other at the difference between the two pulse frequencies.

The automatic recording of small translatory motions—between, say, 0.01 and 0.0001 inch in excursion—has become a common occurrence. A number of sensing devices which can respond to displacements as small as those which now appear meaningful in cranial study are available. Thus the sensitivity of the pick-off is a serious but not dominant concern. Optical techniques are available, if required, which can detect movements of less than 0.000001 inch, and the Mössbauer effect can, in theory, be utilized to detect motions as slow as the rate of growth of a fingernail.

All of the primary design considerations in this application were related to the means of mounting pick-offs to register the motions sought while excluding those which were not desired. The latter arise from at least three sources:

(1) The large motions of the thorax during breathing can produce a variety of small motions of the head.

(2) Involuntary movements of the subject, such as swallowing, sniffing, clenching the teeth, or accommodating fatigue, introduce both transient disturbances and null shifts.

(3) The pulse introduces a cyclic scalp motion with an amplitude on the order of the motion sought.

In addition, variations in the tonus of the muscles of the head and neck must be regarded with suspicion.

There are two fundamental methods of mounting the pick-offs; one is to place them directly on the subject and the other is to attach both pick-offs and subject to a common, rigid frame. The padded table is the obvious unit.

Each method of mounting has inherent advantages and difficulties.

Pick-offs mounted directly on the head and supported by it will be relatively unaffected by motions of the entire head, since they go with it. It is best to apply them with the subject seated. Disturbances from breathing should be at a minimum, but chronic difficulties from large pulse signals are probable. Head-mounted systems will offer difficulty in localizing motion, in sensing the head without "loading" it, in shifting pick-offs to arbitrary positions, and in controlling the pressure of the probes.

With instruments supported externally to the subject, the reverse situation tends to occur. Difficulty with undesired head motions is inherent. It is highly desirable to apply the instruments with the subject supine. Pulse signals are minimized by this application, but breathing signals offer a major difficulty. Pick-offs may be shifted freely in position, are localized in their measurements, and may be applied with controlled pressure.

It was decided to begin work with a system that would duplicate as closely as feasible the standard conditions under which palpation, diagnosis, and treatment normally are performed. External mounting therefore was selected. An important additional consideration was that it was better to be bothered by the breathing than by the pulse, since breathing can be interrupted at will.

Choosing an instrumental system that paralleled palpation seemed the shortest way toward evolving it.

As mentioned, the chief disadvantage of table mounting of pick-offs is their sensitivity to motions of the whole head. To counteract this in principle, the frame must use two matched pick-offs which come in contact with the head on opposite sides. Their signals are combined to subtract when displacements are in the same direction and to add when displacements are in opposite directions. Thus, any shifting of the head cancels out signals, while expansions or contractions produce a doubled signal.

If people were complete blockheads—that is, if the two sides of the skull were parallel—this compensation would be complete. Unfortunately and inconveniently, at most points of interest the sides of the head slant somewhat in two directions—toward the forehead and toward the vault. Breathing, by raising and lowering the thorax, tends to rock the the head slightly about its effective point of support, and this in turn causes the head to move the pick-offs farther apart or closer together by a wedging action.

Thus, the cancellation of directly coupled breathing motions is achieved only partially. To keep the remainder small, much attention must be given to the design of the neck rest. It can be seen that the undesirable feature of the neck rest is its resiliency—which is, unfortunately, the basis for all normal pad and pillow action. The typical cushion is springy. When placed beneath the neck, it is pushed down not only by the weight of the neck itself but by a certain part of the weight of the upper part of the shoulders. As the shoulders are raised by the respiratory motion of the thorax, they lighten the load of the lower part of the neck; the cushion rises up slightly, and rocking of the head ensues.

After much tinkering with shaped wooden blocks and other paraphernalia, the problem was solved with a small sandbag. This proved to be a major inspiration, since sand, by accommodating readily to all shapes, is thoroughly comfortable, yet is completely devoid of resiliency. Immobilization of the head was increased later by the use of a Flexicast pillow. This is a rubber case filled with a powdered plastic that behaves in the presence of air as would any other finely divided solid, accommodating itself to the shape of the head to give comfortable nonelastic support, as does the sandbag. When the air is pumped out of the rubber bag, however, the plastic grains lock together in a shape virtually as rigid and hard as concrete. No comfort is lost because the shape still exactly conforms to the head, which is now immobilized in its "cast." Between the compensating pick-offs and the nonresilient head and neck support, external physical coupling of the chest motion into the head pick-offs can be reduced to a tolerable minimum.

Effective contact between pick-offs and skull presents the second serious problem. At one time there was some talk of putting small screws in a subject's skull and using the projecting screw heads for measuring points. Members of the dental profession suggested the use of small *L*-shaped metal slips of a type which has been used in dentistry for recording motion of the maxillae. One arm of the *L* is slipped under the soft tissue in contact with the bone and allowed to become fixed in its position by fibrosis. The other arm is attached to measuring and recording instruments when needed. A similar application was conceived for recording motion in other cranial bones. It was suggested that the metal slips could be inserted and allowed to become sealed in position and would be available for use when needed. Unfortunately, the line of volunteers waiting outside the door was not as long as had been hoped, so this method was abandoned.

In general, the scalp presents an intervening layer of damping material which not only attenuates the already small motions beneath it but is itself a source of spurious signals. It is desirable to have probes which reduce scalp effects to a minimum and standardize whatever remains. This implies that probes must be applied with specified pressure.

The probes of the pick-offs finally chosen are freely suspended—that is, without frictional contact—by pairs of high quality springs. Their tips are rounded approximately into a small parabola of revolution 0.25 inch in diameter. In present use, they are moved in by setscrews until the subject reports that firm pressure has been established. After a few minutes they must be tightened again. The scalp tissue slowly deforms beneath the probe tip in plastic flow, forming a temporary dent. The remaining tissue between the probe center and skull presumably consists of a cell mass from which the intercellular fluid has been largely expelled, with the capillaries squeezed off.

That this is true is borne out by the fact that pulse signals become negligible so that tightened settings tend to give reduced pulse signals. It appears also that initially tight settings become progessively lighter with the plastic deformation of the scalp tissue. Hence, after equilibrium is reached, light contact will be sufficient. The technique of progressive tightening has not caused discomfort except in a few subjects in whom heavy final pressures were investigated.

Although many years may pass before the final word is said about tip size, shape, material, and pressure, it appears that probes used in about this fashion will give satisfactory results and yet be painless and easy to apply. Since some of the best results were obtained from women subjects with luxuriant hair, it has been possible to stop specializing in studies of bald men.

The pick-offs used are matched differential transformers of high sensitivity.

The oscillograph is especially designed to record signals from this type of device on one of its two pens. The two transformer outputs are wired in opposing series to achieve the cancellation of undesired displacements and the doubling of desired ones. The differential transformer was chosen in preference to other devices because by type it is perhaps the most reliable, repeatable, and trouble-free of standard sensors and gives reputable results.

Report of study

The work may be divided roughly into four periods, as follows:

First period

In the early part of the study, a unit was assembled of a plywood frame, a borrowed oscillograph, and a standard pair of surplus transformers with springs added. The results, although generally negative, justified the quick setup. Enough was learned to warrant proceeding immediately to a relatively finished unit. The most significant discovery at this point was that the cranial motions are much smaller than anticipated, in the range of from 0.0005 to 0.001 inch.

Second period

During the second period, the apparatus now in use was machined (Figs. 1-4), assembled, and put into operation. For pick-offs, the most sensitive differential transformers commercially available at the time of ordering were used. The period was long, and there were a number of minor but obscure difficulties.

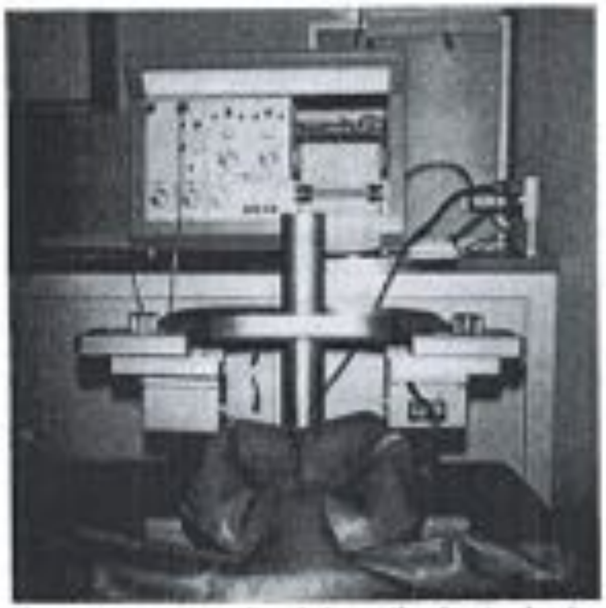

Fig. 1. *Apparatus viewed from the front, showing Flexicast pillow shaped to the head.*

Fig. 2. Close-up *of apparatus, showing pick-offs and carrying yoke.*

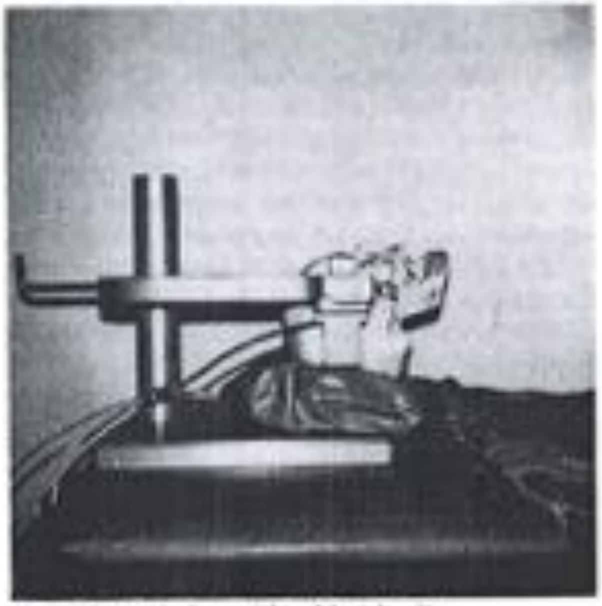

Fig. 3. *Lateral view with subject in situ.*

Fig. 4. *Apparatus viewed from above with subject in situ.*

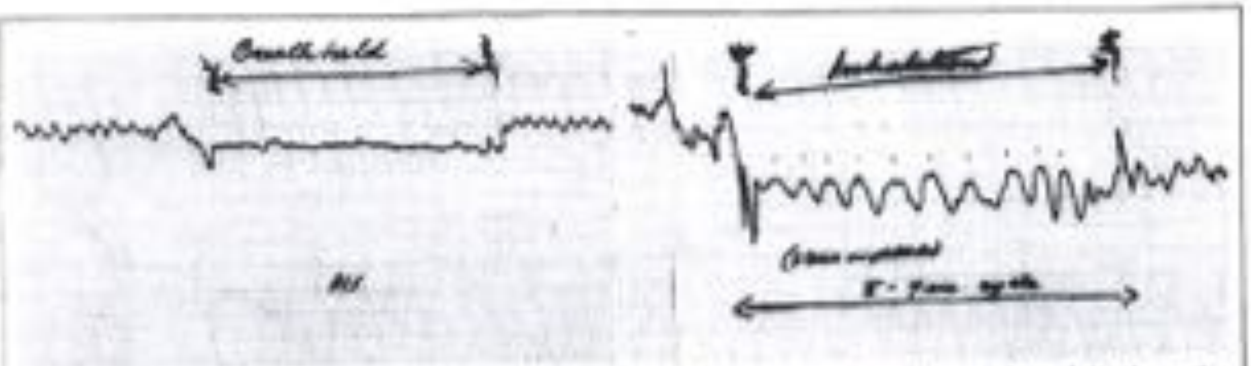

Fig. 5a (left). Recording of May 30, 1963, with the pen moving at 1 mm./sec. From right to left, the cycle synchronous with thoracic respiration is seen before and after a sustained inhalation during which no significant motion other than that of the pulse was recorded. Fig. 5b (right). After tightening of the pick-offs, distinct rhythmic motion was recorded during a sustained inhalation.

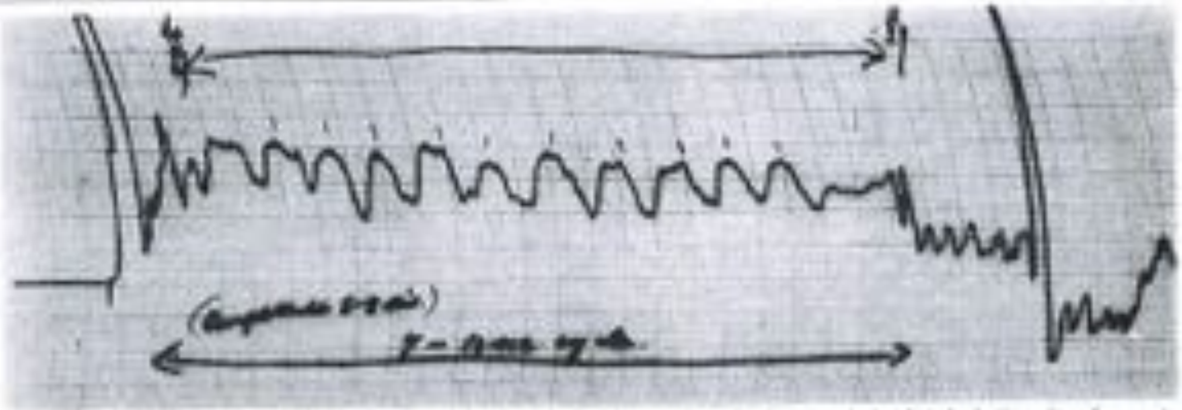

Fig. 5c. After a second tightening of the pick-offs, rhythmic motion during sustained inhalation is of greater amplitude and slower than the respiratory rhythm preceding and following it. The patient developed severe headache following the test, in which the pressure was increased to the point of discomfort.

only humorous on hindsight, which blocked successful recording. There had, however, been one significant recording, on May 30, 1963, which sustained the effort through this depressing period (Figs. 5a, 5b, and 5c). At this time, the first unmistakable recording of a cranial rhythmic impulse independent of and different from pulse or respiration was made.

The subject suffered from a severe headache due to tightness of the large pick-offs, but it had been established that such motion did exist and could be recorded. Minor modifications were made in the apparatus to make it less traumatic to the subject. In all subsequent experiments, pick-offs of 0.25 inch were used.

Figure 6 is a recording made of a man with excellent respiratory control and shows reduction in amplitude of the wave and some variation in frequency during a period of interrupted respiration. Results are better when a subject is able to interrupt respiration at the midpoint between inhalation and exhalation,

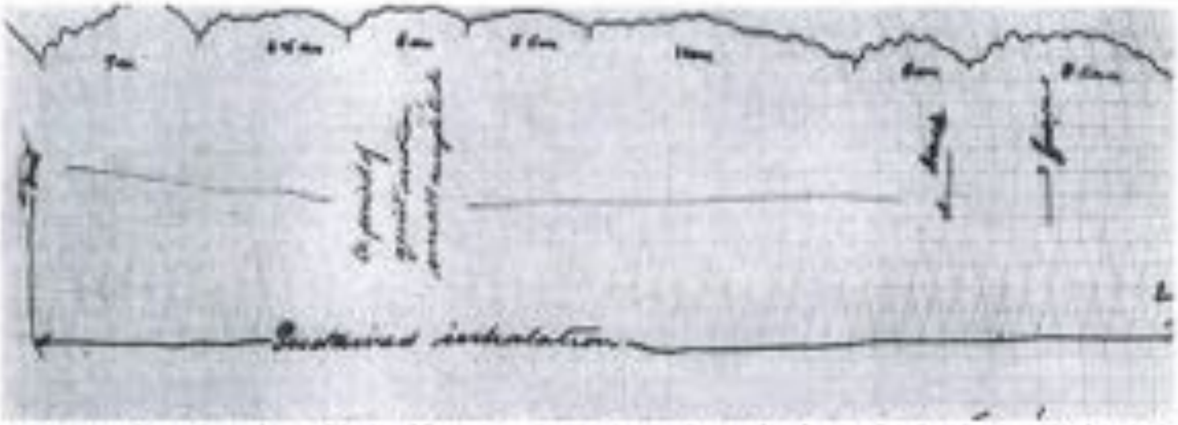

Fig. 6. Recording of another subject, with pen moving at 2 mm./sec., showing reduction in amplitude of the wave and variation in frequency during interrupted respiration.

but few subjects have the necessary control to do this and tend to inhale vigorously when asked to stop breathing.

Third period

In 1964 recordings of the cranial rhythmic impulse and simultaneous pneumographic recordings of thoracic respiration were made on the same record. Now significant recordings were being obtained. After that the frequency of recordings which showed the Sutherland cycle steadily increased. At this time it probably is possible to get such records from most subjects or to obtain recordings from the same subject on most occasions.

Twelve sample recordings are presented here. It must be remembered that a typical recording may average 50 feet in length, but only a few inches can be presented in the cut. Not all of the sections have been chosen as the best ones to exhibit the cranial rhythm, although these are now common. Some of them, however, illustrate surprising results, which appear to suggest unexplored vistas.

In the early part of the study it was difficult to determine the optimum pressure of the pick-offs on the head. This was a problem also with the pneumograph around the chest. I therefore served as the subject so that I might correlate my own subjective observations with the objective recording. When the pick-offs were first positioned on the head, I was conscious of a throbbing arterial pulsation. After a brief period it gradually subsided. When the pick-offs were tightened, I was aware of the transmitted respiratory motion, that is, of a motion of the head related to thoracic motion. Additional tightening made me gradually conscious of the rhythmic, cyclic increase and decrease of pressure from within the head against the pick-offs. This would wax and wane, depending on the direction of motion inside the head. If the motion was predominantly lateral and medial, I was aware of the pick-offs. When the motion was in an anteroposterior direction, pressure on the pick-offs was reduced. Correlation of these observations with the recordings proved that periods of low-amplitude recordings coincided with anteroposterior motion within the head. When thoracic respiration was interrupted at an easy midpoint in the cycle, the cranial motion was easily palpable from within against the pick-offs. If, however, a forceful inhalation was held, the increased intracranial pressure induced thereby seemed to reduce the amplitude of movement. The degree of tension of the pneumograph around the thorax was important, because it affected the cranial motion. When it was applied tightly enough to present resistance to thoracic expansion, there was immediately an increase in the diaphragmatic and abdominal excursion on the one hand and in the transmitted respiratory motion of the head on the other. It became apparent that the chest band must be tight enough to move with the chest wall, but loose enough not to restrict its excursion, if the cranial impulse was to remain uninfluenced by it.

Figures 7a, 7b, and 7c show three sections of the same recording, with the cranial tracing above and the pneumogram below. The pneumogram shows two respiratory cycles before the interruption of respiration, with slow, shallow exhalation continuing throughout. Although there was no slow cycle of motion in the cranial recording during the interruption of breathing, the respiratory cycle started a full cycle earlier in the head than in the lungs. It is not probable that this reflected a strong

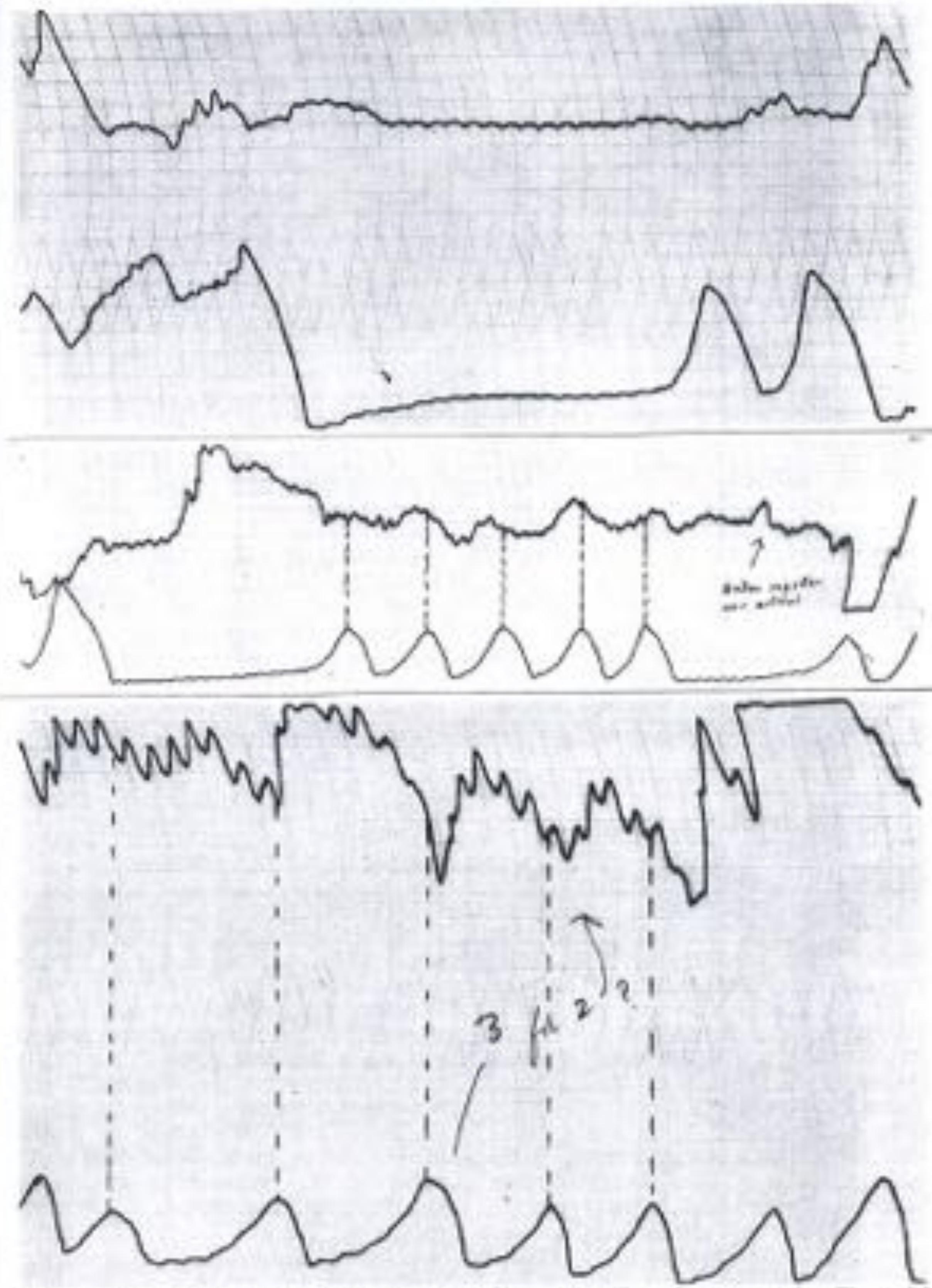

Fig. 7a (top). Three sections of recording from same subject, with oscillograph set at 5 mm./sec. The cranial tracing appears at the top and the pneumogram below. From right to left the pneumogram shows two respiratory cycles, before interruption of respiration, with continuing slow, shallow exhalation throughout.
Fig. 7b (middle). Later section shows cranial rhythm lagging behind chest movement and peak of motion during interrupted respiration which is neither respiratory nor arterial.
Fig. 7c (bottom). Still later section shows tracings out of phase.

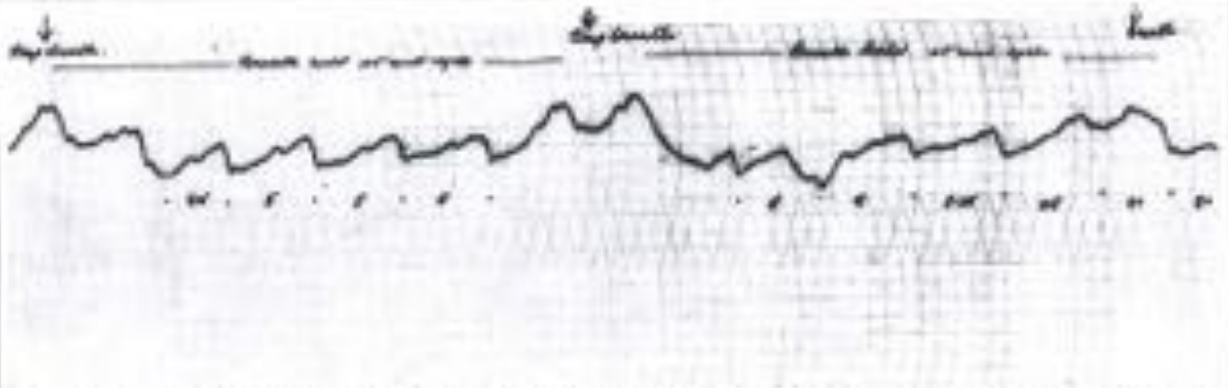

Fig. 8. Cranial recording during two periods when breath was interrupted at middle of respiratory cycle after deep inhalation. Cranial cycles of approximately 5 seconds can be seen.

involuntary muscular effort to breathe which was blocked in the mouth and throat, since the pneumograph is directly sensitive to such muscular actions and would clearly reveal an aborted breathing attempt. Instead it shows slow exhalation continuing until inhalation occurred.

In the second section the cranial rhythm lagged behind the chest movement, and there was a peak of motion, which was neither respiratory nor arterial, in the period of interrupted respiration.

In the third section the two tracings were out of phase.

Figure 8 shows a cranial recording of two periods when the breath was interrupted at the middle of the respiratory cycle. A deep inhalation preceded each period.

Subjects selected for these experiments were known to have mobile cranial mechanisms, for the purpose of the study was to ascertain the activity within a healthy head. However, an exception was made to this rule when a patient with hypertrophic frontalis presented herself (Figs. 9a and 9b).

Figure 10 shows three sections from the recording of a remarkably mobile cranial mechanism. There were many interesting variations in character of the excursions, phase relations to respiration, superimposed rapid oscillations, and slow waves, and the correlation with chest movements was highly erratic. Later, the amplitude of the cranial rhythm was greater than that of the respiratory cycle. This made it much easier to distinguish than it had been before, although it was still distorted by the mixing. The superimposed pulse signal was unusually large.

Figures 11a and 11b show a remarkable degree of cranial mobility in an athletic octogenarian. His astonishing breath-holding ability made him an ideal subject for the study, and he had the added qualification of being completely bald. The cranial and respiratory rhythms were not synchronous.

Figure 12 is a recording made on the cranium of a 19-year-old youth. During a period of holding the breath the cranial rhythm changed from a pattern synchronous with thoracic respiration to the Sutherland cycle, which is slower than and separate from thoracic respiration. His respiratory rate was approximately 15.5 cycles per minute and the cranial rate was 12.8 cycles per minute.

Fourth period

In 1965 the second channel of the oscillograph was used for a plethysmographic instead of pneumographic study. The fourth phase of this research was directed toward determining what relation might exist between volumetric changes in the finger or the forearm and the rhythmic cycles of the cranium. The plethysmograph registers changes in volume of the part it encloses. Changes are primarily in blood volume, but movement of tissue fluids must not be overlooked as an important though minor contributor to the volume change.

In Figure 13a and following figures the cranial record appears at the top and the plethysmographic record below. The recording in Figure 13a was made during easy, quiet respiration and shows a sharp decrease in volume in the right forearm that almost coincided with the contractile phase of the

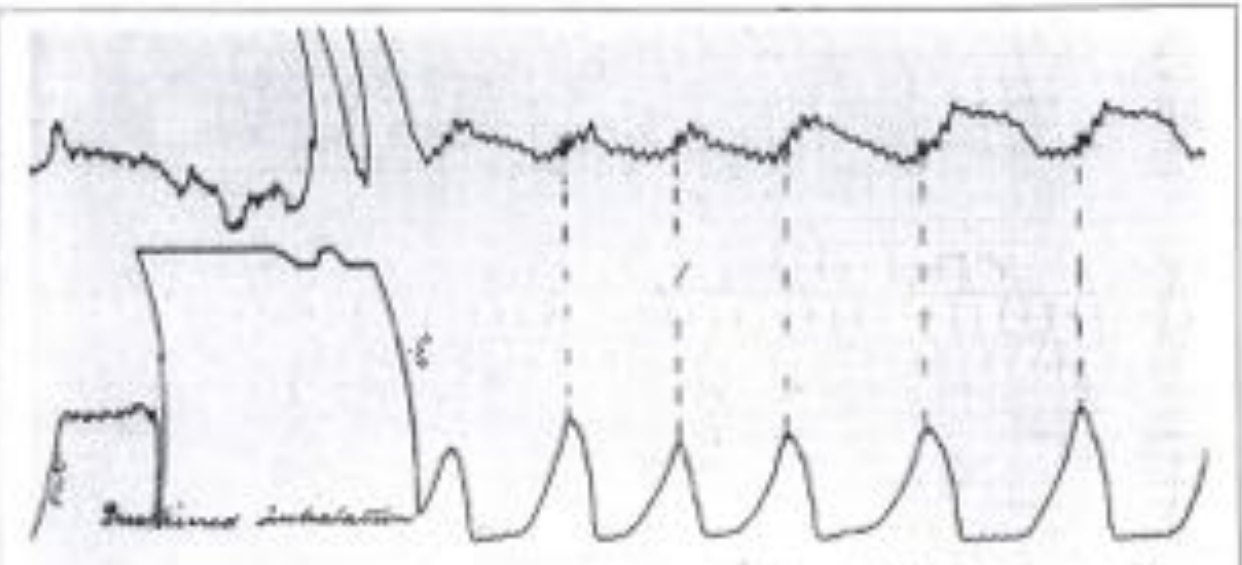

Fig. 9a. Recording of patient with hypertrophic osteitis frontalis. With cranial pick-offs on the parietal bones, there is a pronounced lag between the cranial peaks in the upper tracing and the respiratory peaks in the lower. Forceful inhalation is accompanied with wide cranial deflection and two cycles of motion before exhalation is recorded on the pneumogram.

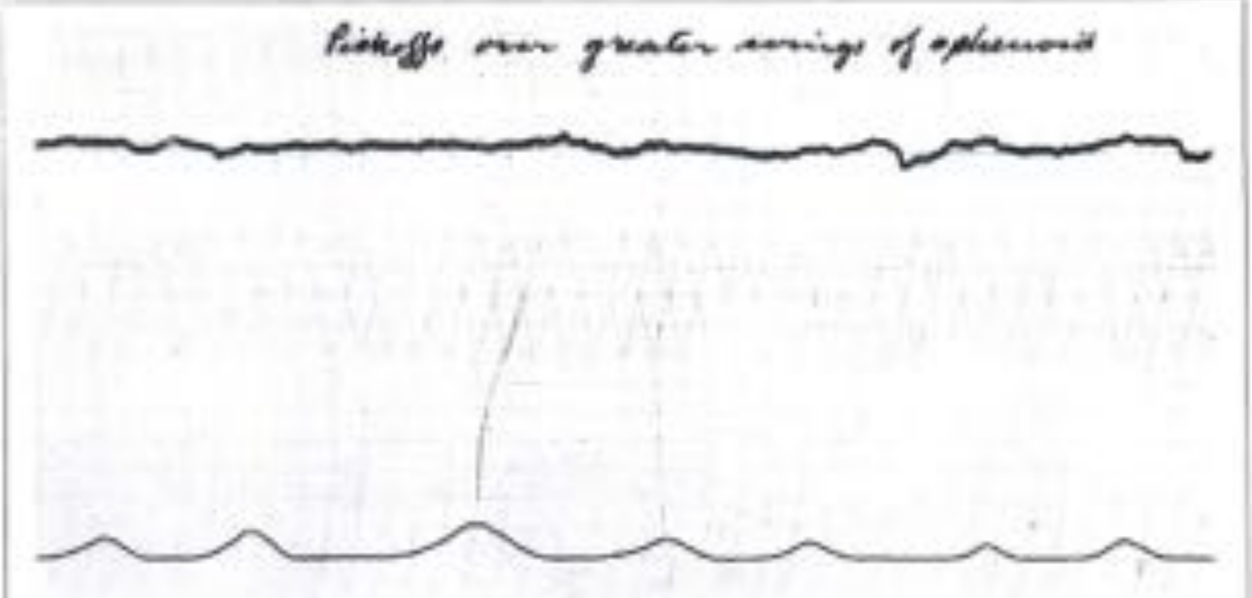

Fig. 9b. Same patient as above. With pick-offs placed over the lateral angles of the frontal bone, the recording showed little significant motion. This was consistent with the results of palpation.

cranial rhythm.

Figure 13b is a later recording of the same subject during a period of interrupted respiration. During the three cranial cycles at the beginning of the period there was a delay in the decrease in limb volume in comparison with that during respiration.

Figure 13c is a record of the same subject at a later date, with the plethysmograph on the left middle finger. During both sustained inhalation and easy respiration the peak of cranial expansion almost coincided with the trough of low volume in the finger.

Figure 14 was recorded with the plethysmograph on the forearm and again shows the peak of cranial expansion coinciding with the trough of low volume in the forearm.

In many other records this pattern was

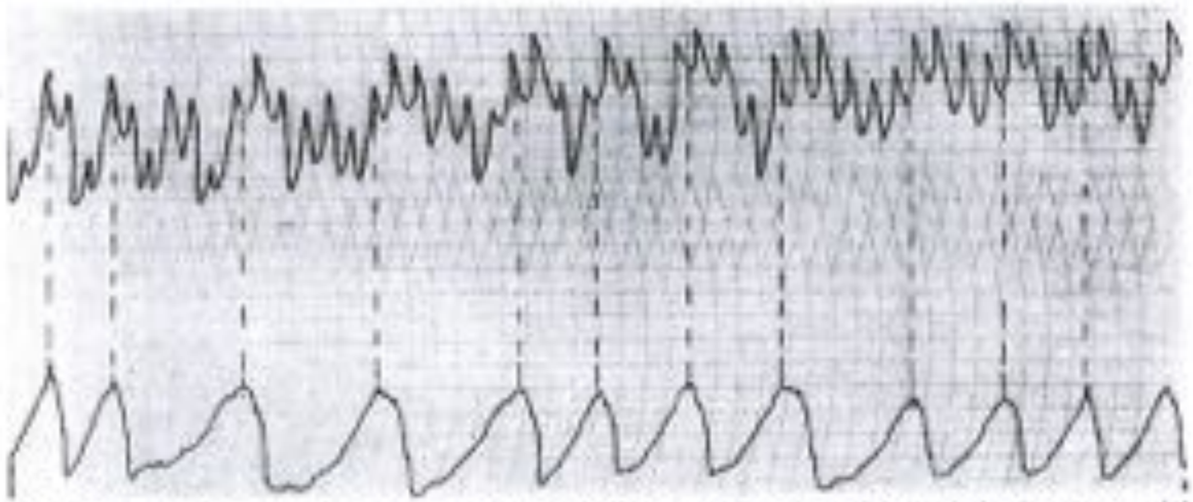

Fig. 10. Three sections from the same tape show interesting variations. Left, the correlation between cranial and chest movements is highly erratic. Center, amplitude of cranial rhythm has increased beyond that of the respiratory cycle. Right, a period of independent cranial rhythm during respiration.

observed during both respiration and its interruption. I venture to suggest that the cyclic changes in volume in the extremity are closely related to the cyclic changes in the head, whether the subject is breathing or not. This observation provokes many questions which deserve further study and analysis.

The few examples presented here and many more that have been recorded permit the assertion that there is a cranial motility which is slower than and distinguishable from the motility of the vascular pulse and thoracic respiration. It has been demonstrated also that this motion can be mechanically recorded. Figure 9 demonstrates that the mechanical recording and the palpatory findings regarding the range of mobility are compatible.

Relation of cranial motion to other physiologic phenomena

This project has been a study of motion, the inherent motion within the organism. The motility of cardiac muscle and the vascular system creates the familiar arterial pulsation. The motility of the diaphragm, intercostal muscles, and lungs brings about the rhythmic motion of respiration. The inherent motility of the gastrointestinal system, known as peristalsis, is an essential factor in digestion, assimilation, and elimination. A peristaltic type of motion propels urine along the ureter and bile down the bile ducts. The motility of the germ cells is an essential factor in fertilization. Laborit[7] has expressed the opinion "that any excitable entity is endowed with automatism." He cited the Wintrebert experiments on the automatism of embryonic muscles, and stated: "This author, while investigating the development of the cartilaginous fish, noted rhythmic movements in the muscles of the embryo." Laborit further wrote:

> The differentiation in structures and functions makes this rhythmic periodicity in cell functioning less apparent in adult organisms, retaining this aspect only at the level of some privileged groups, such as the nodal tissue, or some nervous centers such as the respiratory centers.

Best and Taylor[8] stated:

> The vasomotor center exhibits inherent automaticity, since its continuous discharge goes on even after elimination of all incoming nerve influences.

Ruch and Fulton[9] also described the tonic activity of neurons of the vasomotor center. They also reported:

> The rhythm of the impulse groups is often associated with the respiratory rhythm; at other times it is related to the heart rate, although not infrequently *it bears no relationship to any other observable cyclic phenomenon in the body* (italics supplied).

At certain times they observed the waves of rhythmic function to be much longer than those associated with respiration. Rhythmic variations in activity of the vasomotor center are manifest as periodic waxing and waning of the general arterial pressure. These waves of changing pressure are usually designated as

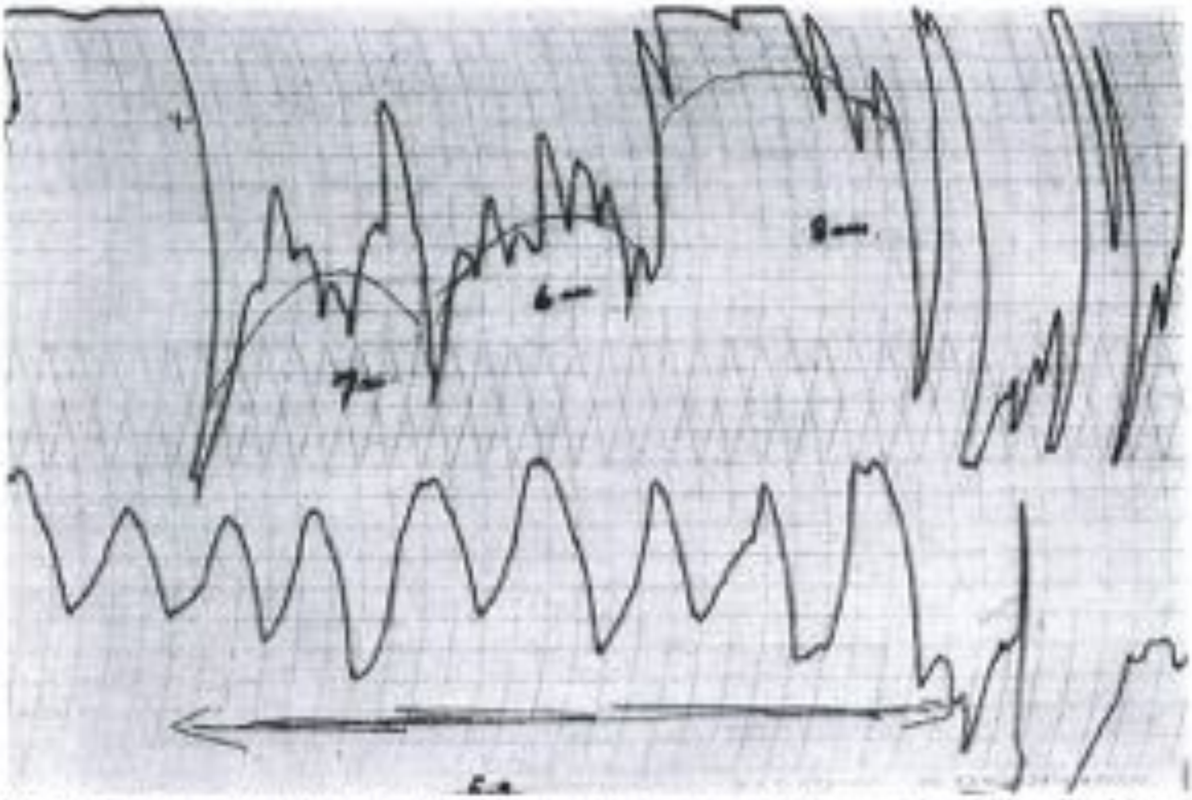

Fig. 11a. Sections of recording of athletic octogenarian show remarkable cranial mobility. Cranial and respiratory rhythms are not synchronous.

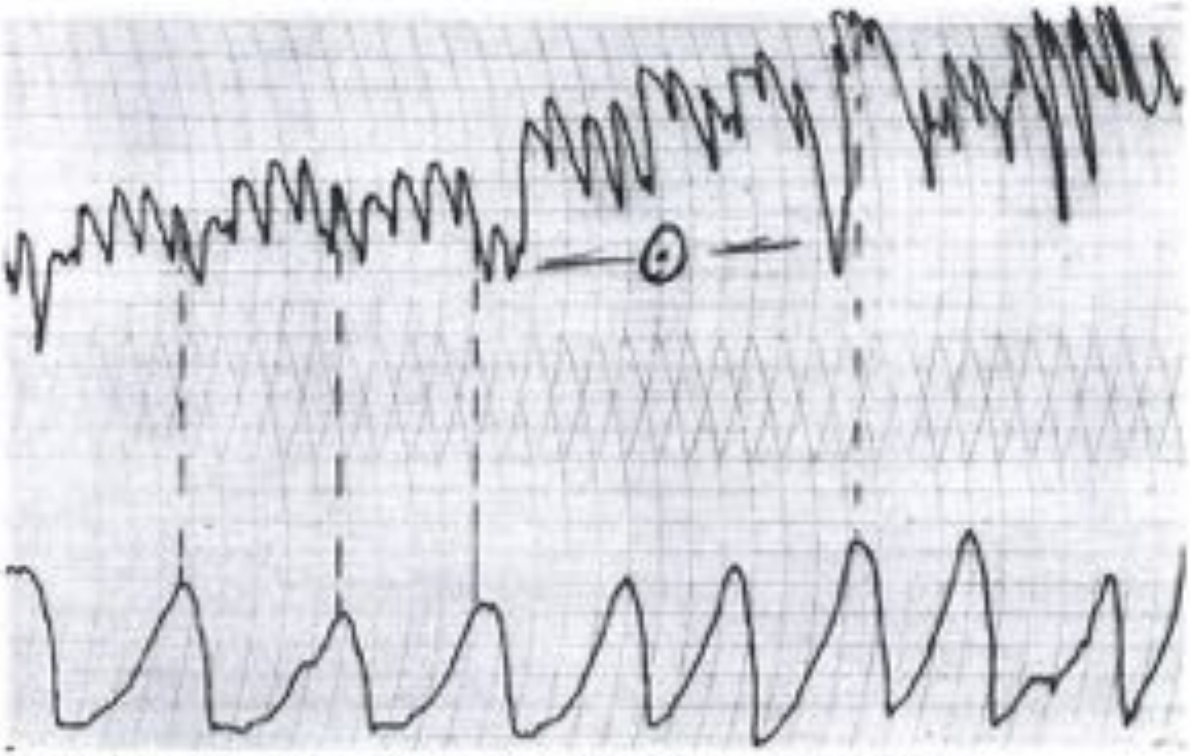

Fig. 11b. Same subject as above. Slow cranial recordings during sustained inhalation.

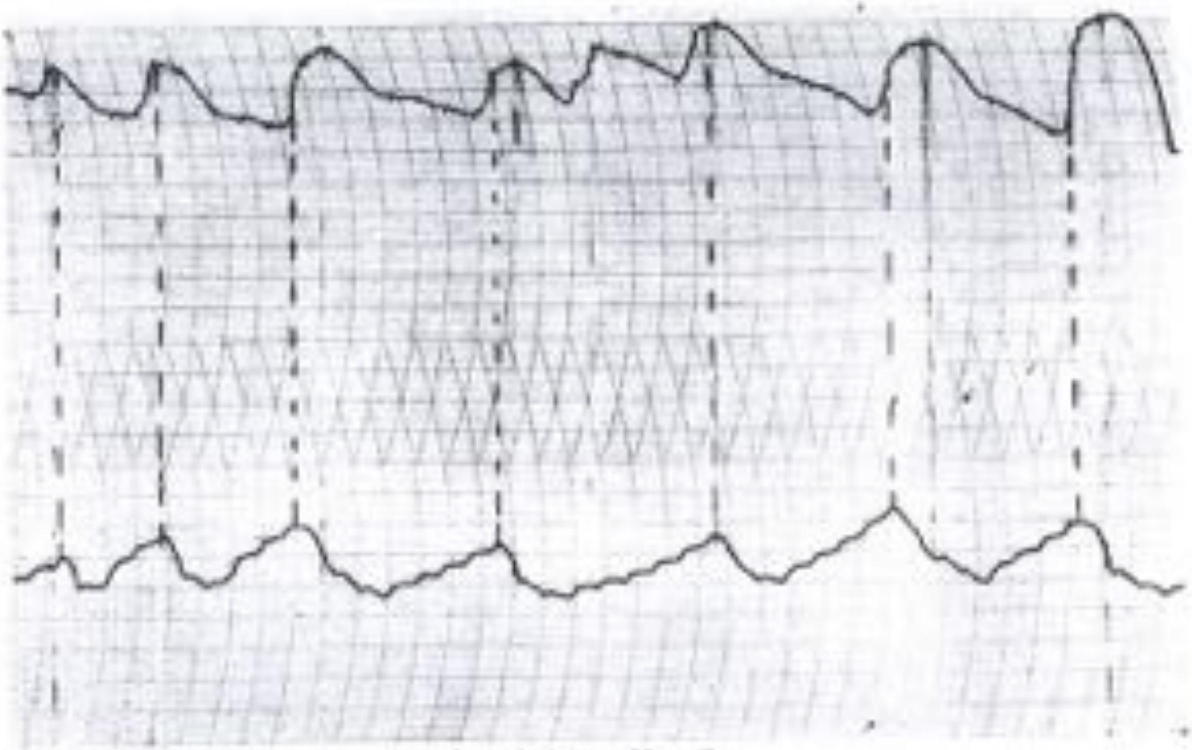

Fig. 12. *Recording at 1 mm./sec. on cranium of 19-year-old youth.*

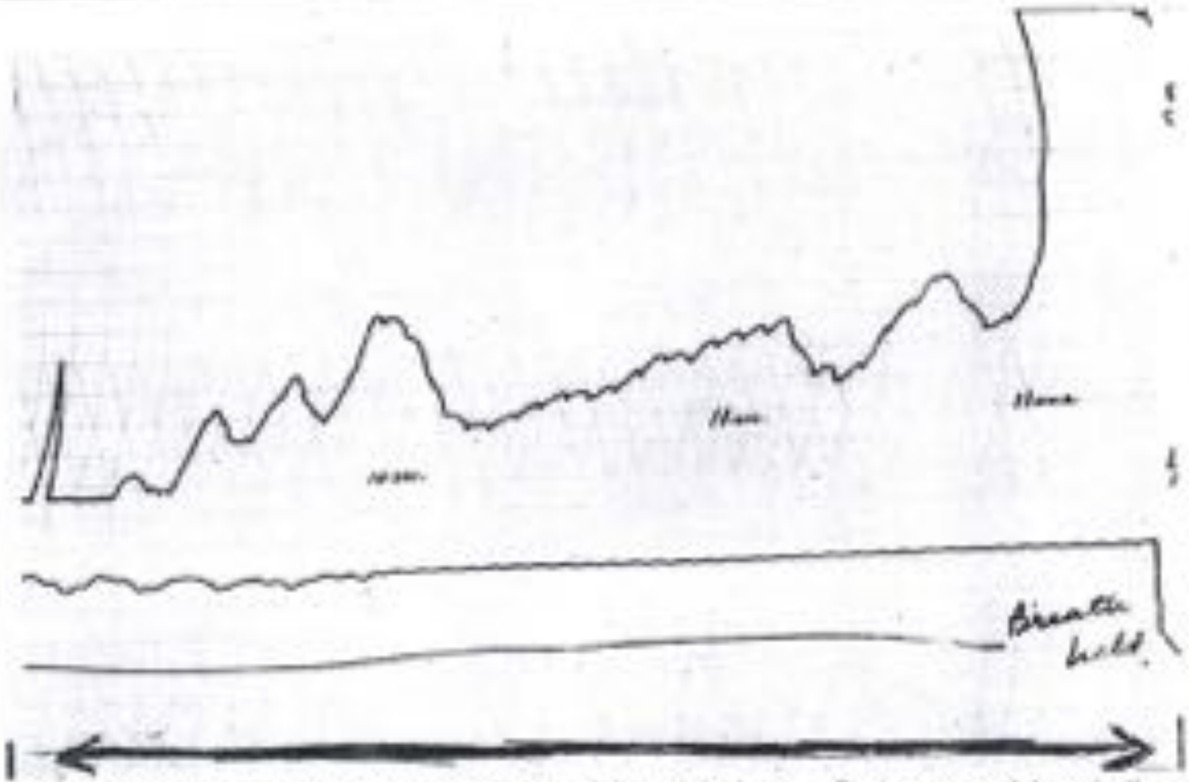

Fig. 12a. *Cranial tracing and plethysmographic record from right forearm. During easy, quiet respiration a sharp decrease in limb volume almost coincides with the contractile phase of the cranial cycle.*

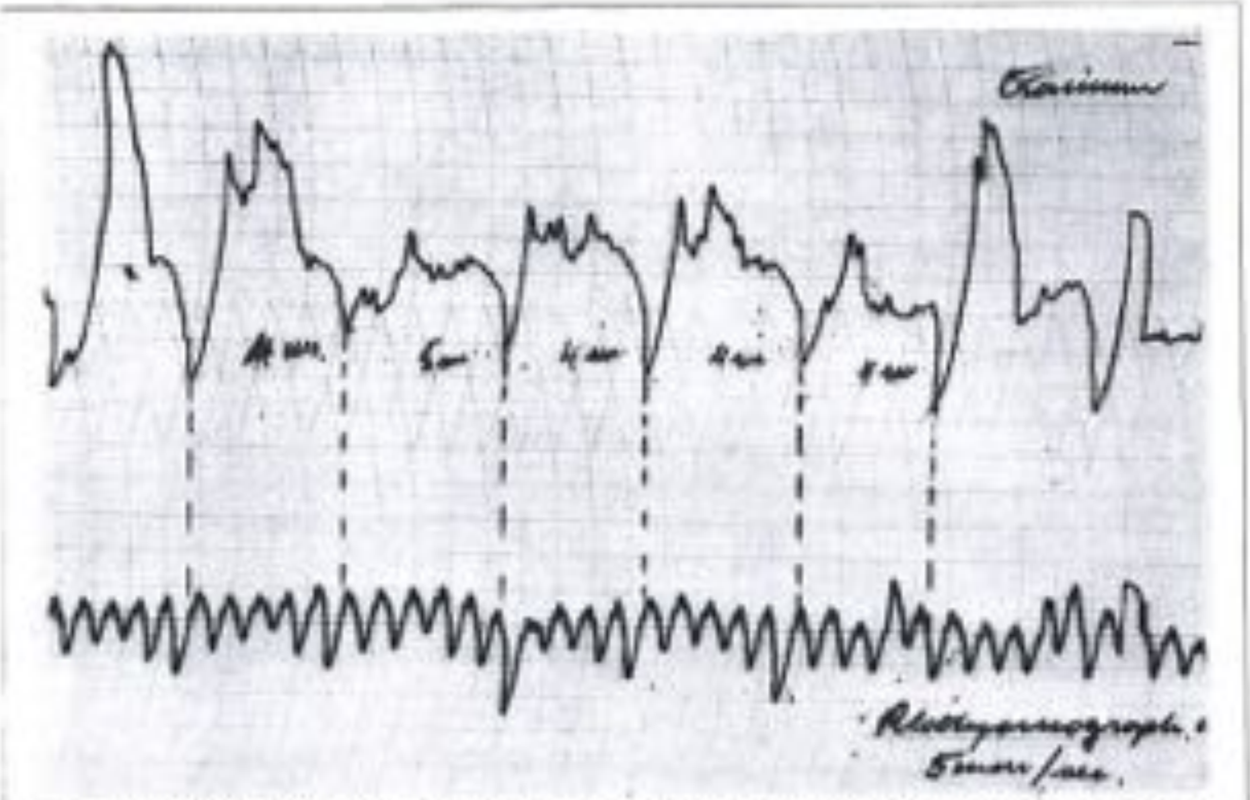

Fig. 13b. Recording during interrupted respiration of subject studied in Fig. 13a. During three cranial cycles at the right there is a delay in the decrease in limb volume in comparison with that during respiration.

Fig. 13c. Simultaneous cranial and plethysmographic recordings of subject in Figs. 13a and 13b at a later date. The left hand was lying beside the body and the plethysmograph was on the left middle finger. During sustained inhalation (left) and easy respiration (right) the peak of cranial expansion occurs at almost the same time as the trough of low volume in the finger. Long, slow cycles of from 30 to 60 seconds seen on the plethysmographic record apparently were not related to cranial changes.

Fig. 14. Simultaneous cranial and plethysmographic recordings of a subject showing the peak of cranial expansion coinciding with the trough of low volume in the forearm.

Traube-Hering waves, although this term, strictly speaking, should be applied only to the waves "which Traube observed in animals with the thorax open and the diaphragm paralysed. These waves, too, result from rhythmic variations in the activity of the vasoconstrictor center. During sleep, certain much longer wavelike variations also occur."

The work of Sears[7] on spontaneously breathing anesthetized cats suggested that the respiratory center in the medulla may have a comparable rhythmic activity, which influences respiration by way of the spinal respiratory motoneurons. By studying intracellular recordings from respiratory motoneurons he made the following observations:

> The membrane potentials of different motoneurones were subjected to slow, rhythmic fluctuations having a respiratory periodicity . . . In the inspiratory motoneurone, the depolarizing phase of its slow potential occurred during inspiration.

On the other hand, he said:

> The expiratory motoneurones occurred during the expiratory pause . . . Since the periodic firing of respiratory motoneurones is causally dependent on these rhythmic slow potentials, it has been suggested that they be called central respiratory drive potentials, abbreviated to CRDPs.

In one of his recordings there was an interesting transition from synchronous potential fluctuation with motoneuron activity to a change of phase between the two "and, finally, a phase of CRDPs alone, due to a steady increase in the average membrane potential and a decrease in the amplitudes of successive cycles of the CRDP." One is impressed by the similarity of this record to some of the cranial and pneumographic recordings in the present study in which a change of phase occurred (Fig. 10). Sears concluded:

> The phased inhibition is of considerable functional significance since it provides one means by which the central nervous mechanism of respiration exerts a control over the segmental proprioceptive reflexes of respiratory muscles.

This effect has not been elicited in spinal animals.

The question to be considered next is whether a relation exists between rhythmic cellular function as described by Traube, Ruch, Sears, and others, and rhythmic motion as recorded in the cranium.

Laborit[4] stated:

> Fessard showed that the initiation of rhythmic activity was a frequent response of a nerve to electrical stimulation. Monnier and his school made an extensive investigation of the rhythmic activity of the nerves and of the factors which dampened it. Laget showed that this dampening action was partly linked to the membrane potential, and that a drop of this potential reduced the dampening and could lead to the development of spontaneous rhythmic activity.

The Russian investigators Moskalenko and Naumenko[5] conducted experiments to clarify the question of the existence of cerebral pulsation in the closed cranial cavity. Their definition of cerebral pulsation was "periodic fluctuations in intracranial pressure." By electroplethysmography they demonstrated that there is a continual movement of fluid between the subarachnoid spaces of the brain and the spinal cord. In their long-term experiments on cats the movement of cerebrospinal fluid was represented in the form of displacements synchronous with cardiac activity, respiration, and third-order waves. These authors defined these third-order waves as Traube-Hering waves. In the record they appeared as similar to but slower than the respiratory cycle.

Comment

By deduction or by direct observation it has been concluded that the vasomotor center and the respiratory center in the floor of the fourth ventricle possess a functional activity which at times manifests a rhythmic periodicity similar to but slower than that of respiration. Grosser experiments have shown that movement of cerebrospinal fluid occurs not only synchronously with cardiac and respiratory movement but with a rhythmic periodicity similar to but slower than respiration. Observation and recording of the minute rhythmic motions of the live cranium have demonstrated that an expansile-contractile motion occurs synchronously with heartbeat and respiration and also with a rhythmic periodicity similar to but slower than respiration. A relation between changing potential and rhythmic activity of a cell has been demonstrated. The perpetual outpouring of impulses from the brain to maintain postural equilibrium, chemical homeostasis, and so on conceivably may multiply the activity of individual cells into a rhythmic pattern of the whole brain, small enough to be invisible to the naked eye, but large enough to move the cerebrospinal fluid, which in turn moves the delicately articulated cranial mechanism.

Further study is necessary to relate the various physiologic phenomena that have been described. However, this rhythmic motion of the cranium, called the Sutherland cycle in honor of the man who first discovered it, not only is of didactic interest, but has vital clinical significance, as the work of Magoun,[9] Woods and Woods,[10] and many other observers have demonstrated.

This is one more demonstration of the assertion of Dr. A. T. Still, as Truhlar[11] quoted him:

"As motion is the first and only evidence of life, by this thought we are conducted to the machinery through which life works to accomplish the results as witnessed in 'motion.'"

Conclusions

Inherent motion does exist within the living cranium. It can be instrumentally recorded, and its relation to other known physiologic functions may be deduced from its similarity to them. The point requires study, however. Its clinical significance also requires extensive documentation.

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1. Sutherland, A.S.: With thinking fingers. Journal Printing Company, Kirksville, Mo., 1962
2. Sutherland, W.G.: The cranial bowl. W.G. Sutherland, Mankato, Minn., 1939
3. Pritchard, J.J., Scott, J.H., and Girgis, F.G.: The structure and development of cranial and facial sutures. J Anat 90:73-86, Jan 56
4. Laborit, H.: Stress and cellular function. J.B. Lippincott Co., Philadelphia, 1959
5. Best, C.H., and Taylor, N.B.: The physiological basis of medical practice. A text in applied physiology. Ed. 7. Williams & Wilkins Co., Baltimore, 1961
6. Ruch, T.C., and Fulton, J.F.: Medical physiology and biophysics. Ed. 18. W.B. Saunders Co., Philadelphia, 1960
7. Sears, T.A.: Investigations on respiratory motoneurones of the thoracic spinal cord. Progr Brain Res 12:259-73, 64
8. Moskalenko, Yu. Ye.: Cerebral pulsation in the closed cranial cavity. Izv Akad Nauk SSSR (Biol) 4:620-9, 61
9. Magoun, H.I.: Osteopathy in the cranial field. Ed. 2. Journal Printing Company, Kirksville, Mo., 1966
10. Woods, J.M., and Woods, R.H.: A physical finding related to psychiatric disorders. JAOA 60:988-93, Aug 61
11. Truhlar, R.E.: Dr. A. T. Still in the living. His concepts and principles of health and disease. R.E. Truhlar, Cleveland, 1950

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