The AAO Journal, 2003, V.13, No.2, P.21-33

Physiological Background of the Cranial Rhythmic Impulse and The Primary Respiratory Mechanism

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Introduction

Osteopathy in the Cranial Field has gained a special position within the many dimensions of osteopathic medicine. The underlying causes of severe pathological disturbances are to be found in cerebrovascular insufficiency and impaired cerebrospinal fluid circulation. Throughout the early development of osteopathic medicine, Dr. Andrew Taylor Still, its founder, paid special attention to the cerebrovascular and cerebrospinal systems. The role of these systems was well known to him at the end of the XIX Century. He appreciated their respective dominance in body physiology.

Another enlightened pioneer, Dr. William G. Sutherland, who advanced osteopathy into the cranial field, recognized the significance of slow fluctuations arising within the cranium, which could be responsible for skull bone motion. Thus he defined the function named the Primary Respiratory Mechanism in the late 1930s (and published it in the Cranial Bowl text in 1938). The concept was further expanded by Harold Magoun in 1966.

Decades have passed since the formulation of these concepts. Cerebrovascular and Cerebrospinal physiology have made giant advances toward understanding of the functional and structural organization of the cerebrovascular control system and the mechanism of cerebrospinal fluid. These are critically important for understanding the mechanism of osteopathic technique in the cranial field, for evaluation of the fundamental basis of the Cranial Periodic Impulse and the Primary Respiratory Mechanism.

Already, there are new possibilities for objective monitoring of the Primary Respiratory Mechanism under development, in addition to new ways of intervention to investigate the system taking into account a principle concept of osteopathic medicine namely the dynamic unity of the patient. Functional tests of different forms were used - hypercapnic and hypoxic gas mixture inhalation, 30-50 seconds of voluntary apnea, the Valsalva and Stookey maneuvers.

The aim of this paper is the analysis of the fundamental background of the features of the Primary Respiratory Mechanism based on modern physiological positions. The objective monitoring of some indices reflecting its activity, as well as functional tests of a different nature provide the means for evaluating the efficacy of osteopathic treatment in the cranial field.

Key Words The Primary Respiratory Mechanism; Volume/pressure relations of liquid media inside cranium; slow volume fluctuations of intracranial origin; Cranial rhythmic impulse.

1. Significant points of history of cerebrovascular studies.

Understanding of the concepts of Osteopathy in the Cranial Field should be based on knowledge of the structure and function of the cerebrovascular (CV) system and the cerebrospinal fluid (CSF) circulation, which was known at the time they were defined. Therefore the history of CV and CSF physiology is divided into two periods, the first before Andrew Taylor Still and the second - after Still and before William Sutherland.

The main elements of the structural organization of the CV system and its anatomy were described fully during XVIII-XIX Centuries. The starting point of functional studies was the work of Cotugno (1770), and later Magendie (1843) and Salathe (1876), who found the liquid medium inside the cranium, the cerebrospinal fluid. It circulates within the cranium and can be considered as the "liquid suit" of the brain.

Investigations of CSF movement and its relation to the vascular system have opened a special avenue of CV physiology. Intensive study of this problem advanced during the late XIX and early XX Centuries when it was found that volumes and pressures of liquid media i.e. CV and CSF inside the craniospinal cavity are closely correlated. There are two channels of CSF circulation, first the circulation activated by secretion pressure from the brain ventricles to the brain surface and spinal cord; and second by irregular CSF movements initiated by local and regional blood volume changes and modulated by CSF pressure and the resistance of CSF pathways (Quincke 1872, Hill 1896). Mathematical simulations of these relations (Geigel 1905) were the most significant feature of these studies. All this data provides the foundation for Dr. Still's famous statement "While the rule of the artery is supreme the cerebrospinal fluid is in command".

Since the middle of the XIX Century, functional activity of the CV system has been studied by direct observation of the lumen of the vessels on the brain surface using simple lenses (Forbes, Cobb 1853). This principle is still applied but using a micro-TV instrument connected to a computer instead of lenses. The most important discovery of all in this period was made in 1890 when Roy and Sherrington established the presence of CV control processes. In 1928 Sepp described slow fluctuations of a number of CV and CSF system parameters: periodical fluctuations of vascular tone, CSF periodical movements and fluctuations of its pressure.

These data became known just before the description by Sutherland of the hypothesis, which he named the Primary Respiratory Mechanism (PRM). The PRM according to Sutherland includes a number of structural or anatomical elements namely brain, blood vessels, meninges, the cranial bones with their delicate articular design of sutures and the reciprocal tension membrane of dura mater. Within the cranium there is the source of the special physical forces, which initiate the cranial rhythmic impulse and skull bone motion.

At the second part of the XX Century a number of problems related to the PRM and the Cranial Rhythmic Impulse were solved by new technology for the study of CV and CSF circulation - the technique of implanting electrodes into human and animal brain (Moskalenko et al 1964; Cooper et al 1966; Fedulova et al 1971; Grechin and Borovikova 1982). These investigations clearly demonstrate for the healthy brain that slow fluctuations (4-18 cycles/min) of brain volume, oxygen availability in brain tissue and intracranial pressure have their special features. A resume of investigations of this period is the statement by Magoun (1966) concerning features of PRM: " The inherent motility of Brain and Spinal Cord, the

Fluctuation of the CSF. The mobility of the intracranial and intraspinal membranes, the Articular Mobility of Cranial bones and the Involuntary Mobility of the Sacrum between ilia".

A quarter of a Century has passed and progress in CV physiology, including CV dynamics has been made. The next step toward understanding the fundamental basis of the functioning of the PRM is the analysis of

- volume/pressure relationships of arterial and venous blood and CSF inside the closed cranium, their meaning for the functioning of the process of the circulatory supply of brain metabolism, which in turn should be based on the study of craniospinal biophysical structure;
- principles of the "generating" of physical forces, which may be responsible for periodical CV and CSF volume/pressure fluctuations and skull bone mobility, which in turn should be based on certain control processes, which are special for the CV system.

2. Relationships between volumes and pressures of blood and CSF inside the cranium.

Experimental and clinical observations demonstrate (Figure 1) that relations between main parameters specific for CV and CSF systems are complex. They have connections between different elements of the cranial cavity and the central blood circulatory system. The scheme represents the Biophysical Structure (BPhS) of the CV system and provides understanding of the relations between the single elements. From Figure 1 it follows that the BPhS of the CV system includes several groups of parameters. The principal one is complex - cerebral blood flow, cerebrovascular resistance, brain blood volume and intracranial pressure, which create a functional unit. The first two belong predominantly to the CV system while the latter to the CSF system. It is important to emphasize that all complex parameters are independent interacting only indirectly. Thus it is impossible by observing one parameter to study another. It follows from Figure 1 that although all complex parameters are formed by the same primary factors this influence for every parameter is specific and correlation between them is determined by a

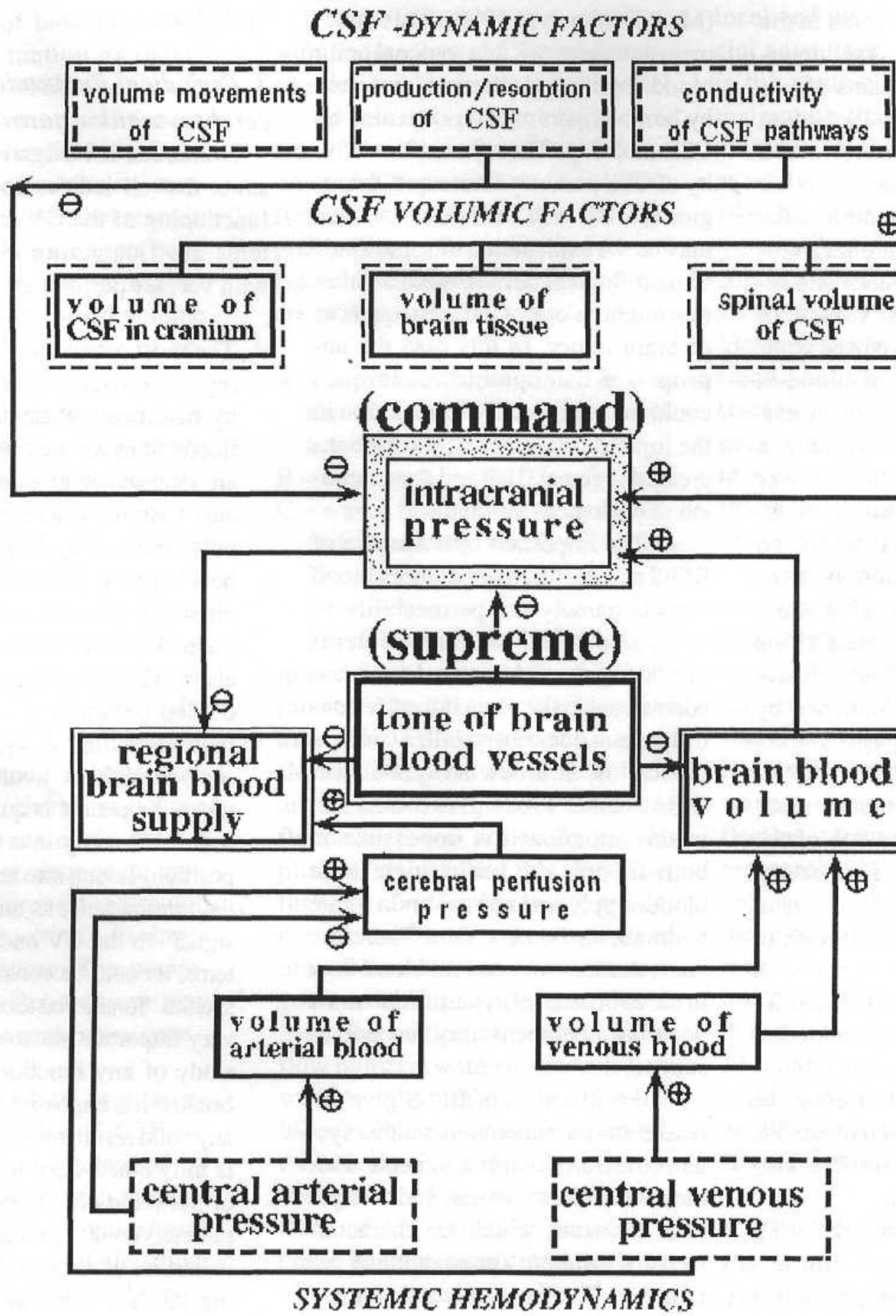

Figure 1: Biophysical structure of the cerebrovascular system. Schematic representation of functional relations between pressures and volumes of liquid media, cerebrovascular tone, central hemodynamics inside craniospinal cavity. (+) - direct influence, (-) - inverse influence between blocks of the scheme.

articular combination of primary factors - pressures and volumes. For example, in one combination of primary factors, if arterial volume increases, cerebral blood flow (CBF) increases together with increase of intracranial pressure (ICP), but if venous volume inside the cranium increases or outflow of CSF to spinal cavity is obstructed, increase of ICP will be accompanied by a decrease of CBF.

BPhS is responsible for a number of important features of the functioning of the CV system and established some rules of its study:

— Close correlation between volume of blood vessels and intracranial pressure, on the one hand, and peculiarities of localization of major arteries at the base of the skull, while, on the other hand, major veins in the vault on the top of the skull determine important mechanisms of utilization of energy of arterial pulsation to facilitate outflow of venous blood from the skull. When the arterial pulse wave reaches the skull it initiates the increase of blood pressure and volume on the base of the skull and replacement of a particular volume of CSF to the veins that have been compressed. Some portion of blood is coming out of the skull. Direct evidence of the presence of such a mechanism has been collected over the years. For example, by direct observation it has been established (Zibulsky 1885) that venous outflow from a dog's head is pulsating while in parenchymal brain vessels blood flow has no pulsations. The most, recent evidence has been obtained by MRI computer tomography (Grietz et at 1992, Enzmann and Pelc, 1992, Poncelet et at 1992), which demonstrates pulsating movements of the brain inside the closed cranial cavity. Note that the amplitude of movement of intracranial media corresponds to the amplitude of skull bone motion perceived by computer MRI and X-ray image analysis (Moskalenko et at 1999). The rhythmic external, internal rotation of the parietal bones of the vault stimulates motion of venous blood through the sinuses that also support this mechanism.

Distribution of the energy during the cardiac cycle provides for adequate cerebral circulation: averaged level of arterial pressure (i.e. DC component) is responsible for blood supply of brain tissue while pulsating arterial pressure (i.e. AC component) is responsible for venous outflow from the skull. Therefore there are two separate ways for arterial pressure energy transmission inside the cranium. Calculations, with the help of a mathematical model, show that owing to this mechanism about 30% of stroke impulse energy delivered to the cranium could be saved (Moskalenko et at 1980). This statement demonstrates that regional brain blood supply is determined not only by hemodynamic factors but also by CSF mobility. Therefore, if resistivity of CSF pathways increases, the regional CBF will decrease, and this may be the explanation of some kinds of neurological deficit. Such a situation might be one of the consequences of brain injury. In this case the appropriate osteopathic techniques could increase the CSF circulation in the injured brain region, promote increased regional CBF and thus diminish neurological problems.

- The important consequence of PhS and peculiarities of brain blood vessels namely the permeability of small brain blood vessels for water is that during arterial hypertension brain edema could take place if the CV control system does not stabilize cerebral blood flow at a new adequate level (Moskalenko 1988).

This means that n this situation it is impossible to both support the initial high brain lood supply and normal brain tissue hydration at the same time. Therefore ome decrease of cerebral blood flow in cases of arterial hypertension must occur as a compensatory reaction to support the brain volume.

- Peculiarities of BPhS give the reason for the statement that this system consists of two components. This means that the system includes structural elements, which are characterized by different time-response parameters. The first structural element is cerebral blood vessels and the second - regional CSF volume/pressure relations. Time responses of volume/pressure relation of cerebrovascular system are sufficiently shorter as compared with CSF regional volume/pressure relations due to limitation of volume conductivity of CSF pathways. For the study of functioning of the CV system it is necessary to record at least two independent parameters, characterizing both intracranial volume processes and ICP, which are responsible for CSF movements.

3. Periodical fluctuations of cerebrovascular parameters.

Numerous investigations demonstrate that all indices characterizing functioning of the CV and CSF systems are fluctuating continuously with various periodities.

A. The most pronounced and most regular are fluctuations, initiated by heartbeats. Patterns of pulse fluctuations, or their wave shape are represented as a complicated curve, similar to a central arterial pulse, but varying their form from beat to beat, depending on the phase of respiration, movement of the patient, and others. They are also dissimilar for the different recorded parameters. Therefore their recording, study, comparison and analysis should be made when the patient is quiet and lying comfortably in a horizontal position. Taking into account that the arterial pulse is an "external signal" to the CV and CSF systems, it could be considered as a special "functional test". This is a very important statement for the study of any functional system because it is impossible to provide any valid result unless the system is fully quiet. Therefore analysis of pulsation of CV and CSF parameters could evaluate some peculiarities of its functioning. Taking into account that latency of control processes in the CV system is not shorter than 1.5-3.0 sec (average 2.3 sec - Moskalenko et al 1996) during the pulse cycle only the passive (as a physical composition) properties of the system under investigation could be studied.

B. Together with pulsation, respiratory fluctuations are also pronounced initiated by the chest movements of breathing. This type of fluctuation as determined from BPhS analysis is derived from two forces (Moskalenko et al 1980). First, the decrease of pulmonary pressure and consequent decrease in blood pressure in the upper body venous system during inspiration. As a result blood volume inside the cranial cavity decreases and ICP decreases, too. Second, at the same time there is increase in visceral pressure below the diaphragm, compression of veins, which have no valves, and replacement of some portion of blood to the spinal cavity. ICP will therefore increase during inspiration. Thus during pulmonary respiration two opposite forces, which, determine brain blood volume and ICP, are operating. Depending on individual characteristics one of these forces could prevail over the other since some individuals use thoracic respiration versus others who use diaphragmatic respiration. The parameters inside the cranium may vary with the respiratory type.

C. Beside pulse and respiratory fluctuations, CV and CSF parameters are characterized by slow fluctuations with variable periodicity (2-16 cycles/min) and unstable amplitude. First, these fluctuations were observed as slow variations of the vascular lumen of surface cerebral blood vessels, slow replacement of CSF and fluctuations of ICP. Later, similar fluctuations of oxygen availability in brain tissue (Cooper et at 1966) and cerebral blood volume (Moskalenko et at 1969) were recorded in human brain. Recently, slow fluctuations in cytochrome "aa3" activity were revealed (Vern et at 1997).

It was found also, that together with fluctuations of CV parameters, similar slow fluctuations are special for the central blood circulatory system. This means that slow fluctuations of CV parameters could have two different origins - one intracranial and the other extracranial. For central circulation, slow fluctuations are of three groups:

A - waves with period 2-20/min, named "plateau waves" are characteristic of pathology.

B - waves with period 1-2 cycles/min.

C - waves fluctuations of central arterial pressure namely Traube-Hering waves.

For determination of the real origin of slow fluctuations of CV parameters the correlation principle of analysis has been used (Moskalenko et at 1980). Although, at that time computer analysis of fluctuations was not easily accomplished, it was found that slow fluctuations of arterial pressure did not correlate with slow fluctuations of brain blood volume and with oxygen availability inside brain tissue. Slow fluctuation of cerebral blood flow however does closely correlate with local fluctuations of brain blood volume and oxygen availability in brain tissue. More precise investigation of the origin of fluctuations of CV and CSF parameters could be done by spectral analysis. This type of analysis is based on the fact that any fluctuation with complicated forms of waves could be presented as a number of simple sinusoid fluctuations of different frequencies derived from the analyzed fluctuations. Determination of the origin of the slow fluctuations of C V and CSF parameters can be provided by comparison of the spectral component of fluctuations, unique for physiological systems of intracranial and extracranial nature. In other words, the initial forces are localized inside cranium. The special advantage of spectral analysis is the principle of amplitude normalization that is to represent the maximal amplitude of each process as a reference unit; by this way it is possible to compare fluctuations of principally different processes. Recent applications of spectral analysis have shown (Moskalenko 2000, Moskalenko et at 2001) that slow fluctuations are composed of extracranial fluctuations of arterial pressure and respiratory chest movements, and of intracranial fluctuations namely redistribution of CSF volumes inside skull.

It has been shown that slow fluctuations of systemic circulation are characterized by spectral components 2-4 cycles/min; they were described in the XIX Century (for ref see Koepchen 1984) as Traube-Hering-Mayer waves (or B and C waves). Spectral components reflecting intracranial fluctuations are represented by 5-15 cycle/min, and they are close to a separate spectral component, which represents respiratory movements. Therefore, it is possible definitely to conclude that there are slow fluctuations 5-15 cycles/min, which are initiated inside the cranium (Moskalenko et at 2001). These data were confirmed recently (Zhang et at 2000).

4. Physiological basis of slow fluctuations of cerebrovascular and CSF parameters.

The physiological background for understanding the of origin of the intracranial slow fluctuations, and thus of the PRM, should follow from the modern interpretation of the general principles of the physiological mechanism responsible for adequate blood and metabolite supply of the brain under different living situations. This mechanism is characterized by two functional goals: one is to support the metabolic supply of brain tissue and the other is to support the water balance of brain tissue. Both of these goals are realized by the same executive mechanism - the brain and parenchymal blood vessels. Therefore, CV control processes have been based on a multi-link control system, including a neurogenic link with several types of efferent innervation, a myogenic link based on sensitivity of the vascular wall to stretch forces, and a humoral link based on sensitivity of the vascular wall to hormones. (Moskalenko et at 1988).

Synergistic functioning of these control links supports both metabolic supply and water balance of brain tissue. The mechanism of "generation" of slow fluctuations of CV and CSF parameters is based on the fact that control links supporting metabolic supply and water balance of brain tissue are characterized by different time constants because one of the conclusions of the theory of complicated control systems is the declaration that any system having two or more control links with different time constants should produce some fluctuations This explanation was accepted for the understanding of the mechanism of the slow fluctuations of central arterial pressure (Koepchen 1984, Miyakawa et al 1984). This should be fully accepted for the CV system because numerous experiments have shown (Moskalenko et al 1989, Moskalenko et al 1996) that latency for metabolic supply, e.g. for oxygen delivery to brain cells, is rather short - l-3s, but for support for water balance of brain tissue is longer - 8-12s.

Thus one may conclude that slow fluctuations of CV system related with the CSF parameters are maintaining the metabolic supply of brain tissue and support of its water balance by interaction of these control links. This conclusion supports the concept that the slow fluctuations of intracranial origin, manifesting as the cranial rhythmic impulse are generally independent from the other bodily rhythms (Magoun 1966) but may be responsive to external or internal pathological influences. It is therefore possible to conclude that the fundamental basis of the PRM; its frequency and amplitude, reflect peculiarities of functioning of the CV control system, as well as CSF mobility. If frequency of PRM decreases while amplitude increases - it means that brain tissue metabolism increases.

5. ***Fundamental basis of cranial rhythmic impulse and skull bones motions.***

Questions connected with understanding the fundamental principles of the Cranial Rhythmic Impulse (CRI) and the PRM are based on the evaluation of physical forces that could be responsible for skull bone motion. First, what type of motion is most relevant? There are three types of structural deformation - stretch deformation, deformation of rotation, and curve deformation. Taking into account the physical properties of living bone it is impossible for any kind of these deformations, to occur. The physical forces that would be required are not physiologically present. Only one explanation is feasible. Skull bone motion may be considered as comparative changes of the position of bones at their sutures. In other words, mobility of skull bones is localized in sutures. This statement is supported by many published investigations (Frymann 1971, Adams et al 1992). During the last decade, using various methods a rhythmic periodicity of skull bone motion of 6-15 cycles/min has been clearly demonstrated (Chaitow 1999, Moskalenko 2000). In order to fully appreciate this evidence however, it is necessary to evaluate the physical forces that could exist within the closed cranium. There are three sources that will be considered. The first is the CV System, which initiates periodical fluctuations of ICP. This statement is supported by direct observations of patients under intracranial angiography investigations. For this purpose subjects were given an injection of 20 ml X-ray contrast solution into the internal carotid artery. (Only subjects without pathology were included in this study). Measurements made in rest state indicated mobility with an amplitude of 0.2 - 0.4 mm immediately after the injection movement increased up to 1.0 mm in 1.5 seconds. Calculations, using a simple model, demonstrate that the reason for this movement was the increase of ICP due to increase of arterial volume in the cranium (Moskalenko et al 1999). Thus it is clear that slow fluctuations of brain arterial blood volume are due to CV control processes and could initiate skull bone mobility.

In connection with these suggestions it is necessary to mention one recent publication, which declares that the PRM is absent and is some artifact, connected with personal sensitivity of physicians (Herniou 1998), because, as it follows from the author's data (no references), amplitude of skull bone mobility is very small, much less than could compare with the above-mentioned data.

Unfortunately, it is difficult to analyze results of the calculations presented in that paper, and compare them with other results, because the author gives only final results of some calculations without either initial data or method of calculations. Is the initial subject under investigation a living structure or a cadaver? However, it is possible to mention, that out of their theoretical analysis and presentation the skull and CSF as a biomechanical couple, appear to be most questionable. The author declares that velocity of CSF is about 5 cm/min! - but this value is difficult to accept, because data obtained even 40 years ago described linear flow, which is much higher, according to numerous measurements using radioactive markers (Vassilevsky, Naumenko 1959). Additionally, the author of the paper did not take into account numerous MRI data (Grietz et al 1992) demonstrating pulsating movements of CSF. However, the author gives interesting and valuable data, concerning microstructure of living skull sutures.

The second possibility of skull bone motion is based on reciprocal tension of brain membranes (Greenman 1989, Magoun 1966). It is significant that the membranes are firmly attached to the skull bones and are characterized by thick inelastic connective tissue structure. But it is not recognized up to the present time as a source of motivating forces, which could be responsible for periodical skull bone motion. However, without any doubt, it is possible to suggest, that these membranes play a significant role as a passive modulator, which determines directions and comparative changes in the position of particular bones. The third possibility is based on the fact, that glial cells could change their volume under different conditions (Roitback 1993). For acceptance of this position it is necessary to establish "volume-pressure" dependence for glial cells, to find time constants of this process and to establish the connection of glial cells volume changes with ICP and control processes of the CV system.

Therefore taking into account the data collected up to the present time the first statement appears to be the most feasible concerning the nature of the PRM. Periodical fluctuations of vascular tone are called "vasomotion". Understanding the PRM should reflect, first, the nature of the initial forces, fluctuations of vascular tone which are determined by peculiarities of CV control processes; second, the possibility for CSF replacement inside the cranium and between cranial and spinal cavities. Following from this fundamental basis of the PRM its activity can be described by the complex of objective parameters, as well as from the results of spectrum analysis, which is the most adequate method for the analysis of slow fluctuations with changeable frequency and amplitude.

6. Principles of the study of PRM and CRI.

The study of PRM and CRI include the next important positions:

1. Methods for recording parameters and collecting data, which could be used for presentation of quantitative indices characterized by PRM and CRI.
2. Methods for analyzing collected data in order to express them in a comparable and acceptable form for physicians.
3. Methods for investigations of studied system should be based on the application of some functional tests. This could make some peculiarities of the activity of PRM and CRI visible which are "silent" and not revealed at the rest conditions.

It follows from analysis of the BPhS, that it is necessary to provide simultaneous recording of at least two different parameters for the study of functioning of the PRM and CRI that is necessary to provide simultaneous recording of at least two different parameters. For this purpose, as it was shown earlier (Moskalenko 1999, Moskalenko 2000), the most acceptable would be the combination of simultaneous recordings of Bio-Impedance (B-Imp) and transcranial dopplerography (TCD), because these methods are based on different physical principles and, therefore, reflect different aspects of the functioning of CV and CSF systems. Indeed, B-Imp records the change of electrical conductivity between plate electrodes, placed on the human head, for high frequency (50-70 kHz) electrical current. Because electrical conductivity of blood and CSF are different (for blood it is about half that for CSF), their comparative volume changes will change the electrical conductivity between electrodes. This method is used in clinical practice for cerebrovascular examination (Jenkner 1987, Moskalenko, Weinstein 1983, and others). TCD method is based on Doppler's effect - that is change of frequency of ultrahigh sound in moving media - e.g. moving blood inside vessel. For investigation and monitoring purposes it is necessary to investigate the same brain region. For this purpose, the fronto-mastoid position of B-Imp electrodes and focusing of TCD probe -on segment M1 of middle cerebral artery (MCA) (close to the circle of Willis) must be used on the same brain hemisphere.

There are two principles of analysis of simultaneous recording of B-Imp and TCD. One is used during short time intervals when no control processes in the investigated system could exist. This could be suggested as a passive one. The second principle of analysis is based on statistical calculations, therefore rather long-time recording intervals have been taken, when active properties of the system were revealed and analyzed.

The most appropriate way for the first principle is to analyze B-Imp and TCD recordings during the single cardiac cycle. This period is significantly shorter than any control process in the CV system. Therefore only passive relations representing the Blood/CSF volume replacements could be evaluated. In such situation TCD changes will be proportional to ICP changes, because pulsatile changes of linear velocity of blood flow in MCA initiate volume pulse fluctuations of its major branches, and regional ICP will increase. Therefore, simultaneous recordings of B-Imp and TCD during pulse cycle will represent indirectly relations between changes of ICP and CSF volume inside investigated region of cranium - the first is the initiating force and the second is result of its action. For the most correct interpretation of pulse, TCD and B-Imp pulse patterns they must be taken in the expiratory phase, because venous brain volume depends on secondary respiration and could modulate the interrelations between TCD and B-Imp pulsatile peaks. This is important for the first principle of data analysis. For the second principle of data analysis it is important to derive from the slow fluctuations of intracranial origin of TCD and B-Imp their secondary respiratory components. That is why the respiratory movements of the chest should be continuously recorded. Thus, it is possible to predict, that TCD changes will be ahead to B-Imp changes, because CSF volume could change only if CSF moves inside investigated region, but for this some time is required due to limitation of conductivity of CSF pathways.

For the second principle of analysis of simultaneously recorded TCD and B-Imp the most appropriate way is to analyse continuous recordings of these parameters during 45-60s. This would permit the application of the spectral (or Fourier) type of analysis for evaluation of slow fluctuations of intracranial origin (Figure 2), which represent the activity of PRM and CRI.

For the study of CV and CSF systems it is important to apply some functional tests which should be directed to particular aspects of the functioning of the system under investigation. Physiological and clinical experience of the study of the functioning CV and CSF systems shows that for these purposes the following functional tests are the most acceptable:

- The role of brain arteries could be evaluated under the application of functional tests that change their tone. This is 60-90 second gas mixture inhalation 7.5% $C0_2$ in air, which actively dilates cerebral arteries (Lassen 1978). However, increase $C0_2$ in air also stimulates brain respiratory center. Nearly the same effect is noted for respiratory arrest. Reverse effect gives a voluntary hyperventilation functional test. Inhalation of low oxygen (6% O2) gas mixture acts primarily on brain arteria.

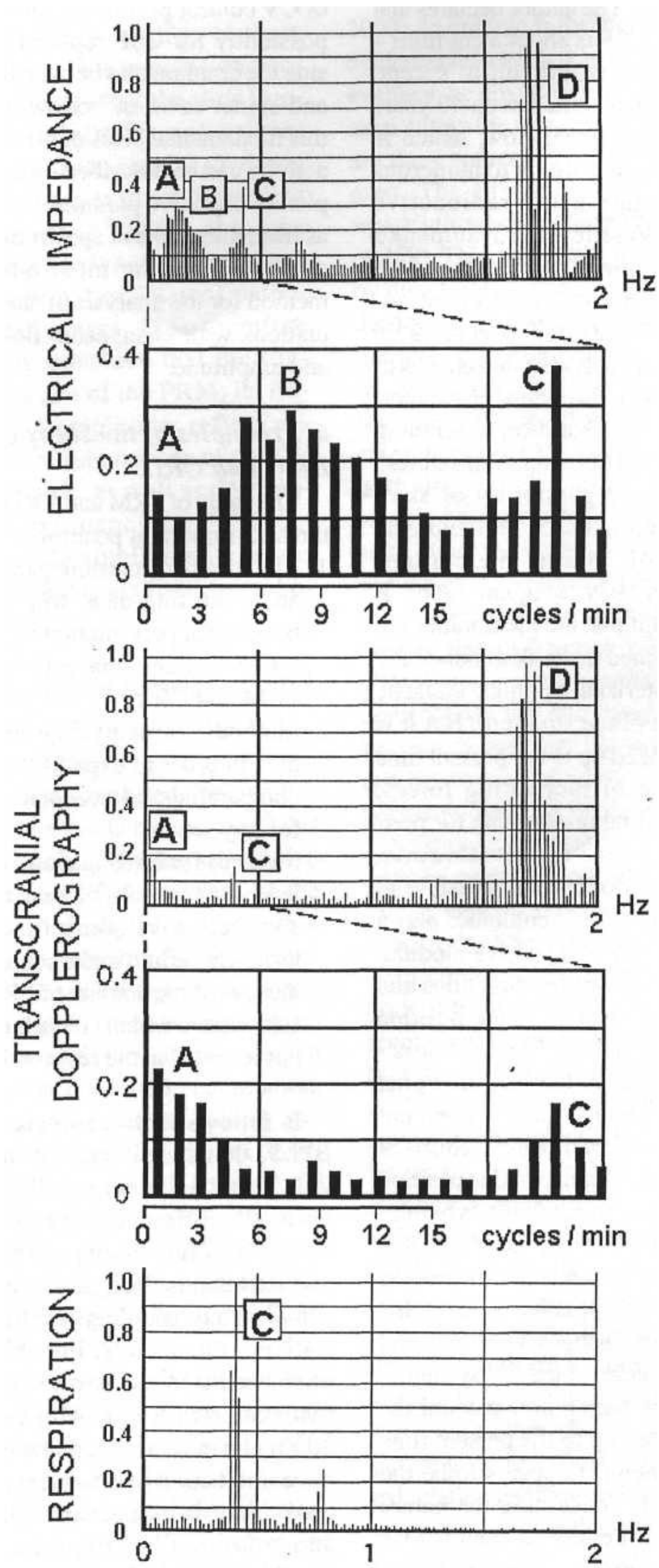

Fig. 2: Low frequency parts of spectral components of simultaneously recorded of Bio-Imp, TCD and chest respiratory movements evaluate slow fluctuations of intracranial origin (B)from similar fluctuations of extracranial origin (A), respiration (C) and heart activity (D).

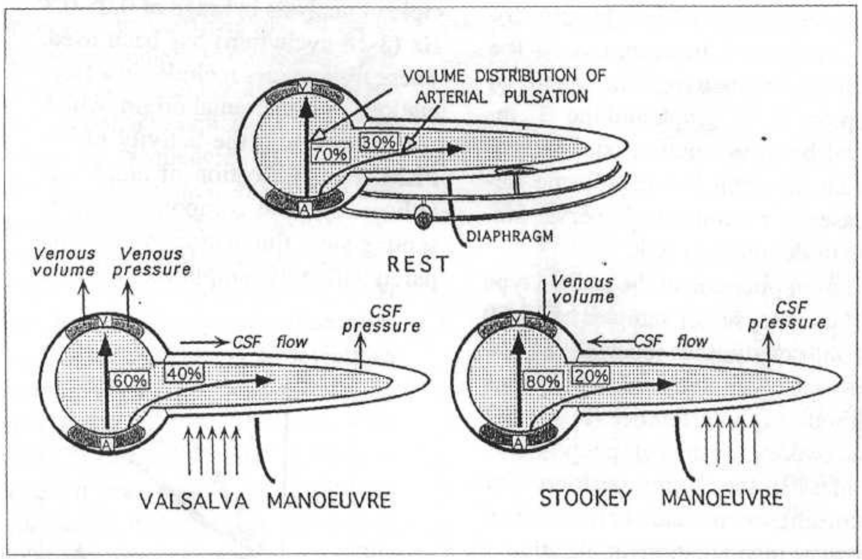

Figure 3: Redistribution of arterial pulsatile volume during cardiac cycle within the craniospinal cavity under the influence of Valsalva and Stookey maneuvers.

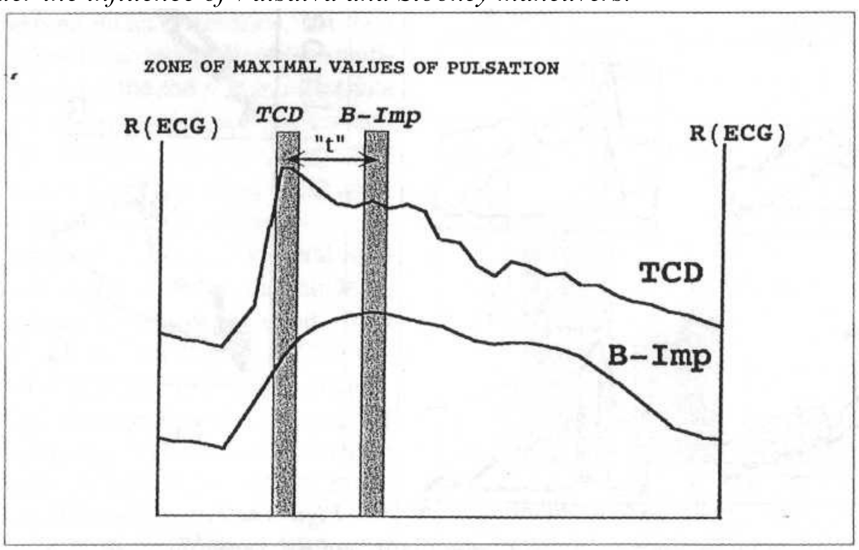

Figure 4: Averaged representation of 15 pulse cycles of TCD and B-Imp obtained in healthy persons, "t" is the time shift between peaks of the two pulsations.

- The application of the Queckenstedt manoeuvre with the head inferiorly tilted 30 degrees provides a direct influence on brain veins.
- A special group of functional tests is directed to the CSF system. They are the Stookey manoeuvre, which consists of moderate pressure to the abdomen, and the Valsalva manoeuvre - the voluntary strain and increase of intrathoracic pressure. They both evoke CSF replacements but in opposite directions (Figure 3).

The application of these functional tests is important for analysing of informational meaning of slow fluctuations of intracranial CV and CSF parameters, which represent the activity of PRM and CRI.

The comparison of patterns of pulse curves of these parameters have shown that is taking place because, maximal peaks of the pulse waves of. B-Imp and TCD are not synchronous and the difference between peaks is characterized by some time shift "t" (Figure 4). Therefore time shift between peaks of TCD and B-Imp is determined by the replacement of some portion of CSF out from (or into) zone of B-Imp electrodes. Thus this time interval represents the mobility of CSF inside the cranium during the pulse cycle. At this period no active processes could operate.

Investigations under different conditions have shown that "t" reflects CSF mobility. Indeed, it becomes smaller during increase of brain blood volume by any way due to diminishing possibilities for CSF movements - during inspiration phase or 7.5% C inhalation, tilting head-down or Stookey manoeuvres. Measurements during expiration phase have shown that "t" variations for healthy adult persons are limited by 10-20%. However for the post brain -injury patients "t"-time interval was found to diminish up to 30-50%, and similar less changes were obtained in healthy persons during some functional tests. This can be revealed the most clearly if time scale is normalized by ECG "R-R" interval (Figure 5). This means that such patients are characterized by diminishing CSF mobility. After appropriately administered osteopathic treatment this time interval usually increases indicating an increase in CSF mobility. Some athletes were characterized by increased ‘t’ time intervals, which indicate their compensatory capabilities are higher, as compared to the average "Man on the street".

In addition to patterns of analysis of TCD and B-Imp records, sufficient information can provide the phase type of analysis by presentation of data in an "X-Y" scale (Figure 6). This reveals any disproportions in dynamics of compared curves. Both start at the same point. The loop indicates that tracings "increase" and "decrease" on the curve in an "X-Y" scale without repeating each other. Square of the loop which indicates the disagreement of TCD and B-Imp or, in other words, replacement of CSF are significantly less in the patient with consequences of brain injury (intracranial hypertension) and significantly greater in athletes, intensively trained as divers.

It is important that there is visible correlation between changes of disproportion of TCD and B-Imp during the pulse cycle and cerebrovascular tone, as well as changes of conditions for CSF replacement. For example, when cerebral blood volume increased after 7% $C0_2$ inhalation, or ICP increased in response to the Stookey manoeuvre, the square of loop on "X-Y" graph and the "t” interval became smaller, but both increase if brain blood volume decreases in response to hyperventilation or decrease of ICP.

The application of the second type of data analysis for samples of 45-60 seconds continuous recordings is the most successful if they are performed without any interference. For this it is necessary for the patient to lie motionless in the supine position. The recordings were made before and after some manipulation (application of osteopathic techniques and functional tests). Special attention has been paid to the B-Imp recording because, as was mentioned earlier, this parameter reflects particularly slow fluctuations of intracranial origin. To exclude possible mistakes by involving slow fluctuations of extracranial origin, the other recordings such as respiratory movements of chest, were recorded simultaneously.

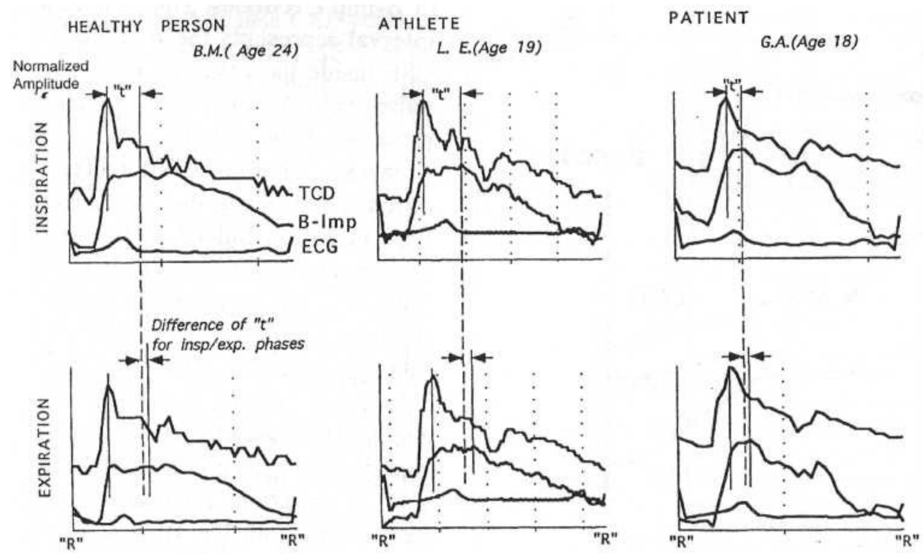

Figure 5: The difference of "t" between inspiratory and expiratory phases of the secondary respiration in a Healthy person, Athlete trained in diving and Patient after head injury.

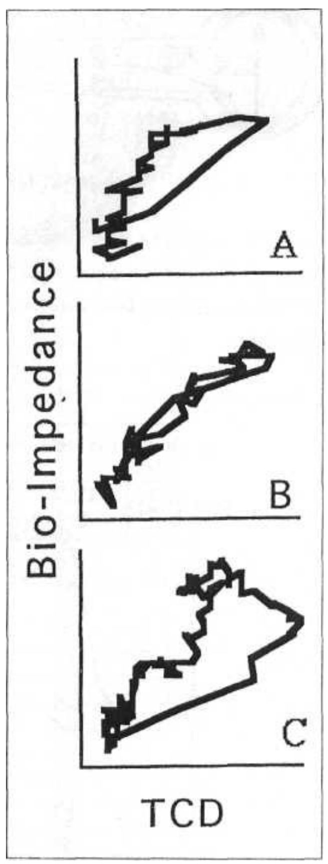

Figure 6: Phase diagrams of B-Imp and TCD in: . A - Healthy person; B - Patient after head injury; C - Athlete

For evaluation of slow fluctuations of intracranial origin the spectral principle of analysis in range of 0.05-0.3 Hz (3-18 cycle/min) has been used. These frequencies include slow fluctuations of intracranial origin, which are representing the activity of the PRM. For unification of amplitude indices, spectral components representing slow fluctuations were compared with pulse amplitude, which is the most pronounced and has been taken as a reference 1.0. In other words, amplitudes of spectral components were expressed as normalized units. It has been shown that under above described conditions for healthy adult persons the average amplitude of slow fluctuations representing PRM and CRI is 0.4+-0.15 normalized units. Frequency ranges are from 5-14 cycles per minute. It is necessary to consider that in these ranges secondary or pulmonary respiratory components may occur. Usually, secondary respiration is characterized by frequencies 15-24 cycle/ min. It is important to emphasize that no correlation was found between averaged (group of 10 patients) changes of frequency and amplitude of PRM and changes of frequency of secondary respiration or heart rate deviations during different function tests namely inhalation of gas mixtures with 7.5%$C0_2$ or 6%0_2 (Figure 7). No correlation was found also between changes of frequency of PRM after voluntary respiratory arrest for 30s before and after application of osteopathic technique venous sinus drainage (Figure 8). These data suggest that PRM and secondary respiration have no direct connection, but their clinical independence is quite significant. All of the above mentioned data showed that the informational meaning of changes of parameters of PRM could indicate the changes of activity of CV control processes, if frequency distribution of spectral lines are changed, or, if only amplitude indices of PRM are changed - this means, that conditions of CSF dynamic were changed. These suggestions demonstrate the meaning of monitoring of parameters of PRM as a way for evaluating efficacy of osteopathic treatment.

Thus, results of investigations of slow frequency fluctuations of intra-cranial origin show, that the phenomenon named by Dr. Sutherland as the "Primary Respiratory Mechanism" is an independent parameter of the functioning of the CV and CSF systems. It reflects indirectly the activity of CV control processes connected with activity of systems, responsible for brain metabolic supply (chemical homeostasis of brain tissue) and maintenance of water balance of brain tissue (physical homeostasis of brain tissue). These include "external" (secondary) respiration, heart activity and control of basic vascular tone, the control centers of which are localized in the brain. They have a functional influence on PRM activity. Therefore indices characterizing activity of PRM are connected with external respiration and heart activity, but these connections are only of a resilient response but not routine functional nature, without permanent and definite correlations.

This data leads to the conclusion that simultaneous recordings of TCD and B-Imp can give valuable information concerning CSF mobility. It also permits monitoring of the efficacy of the osteopathic manipulative treatment.

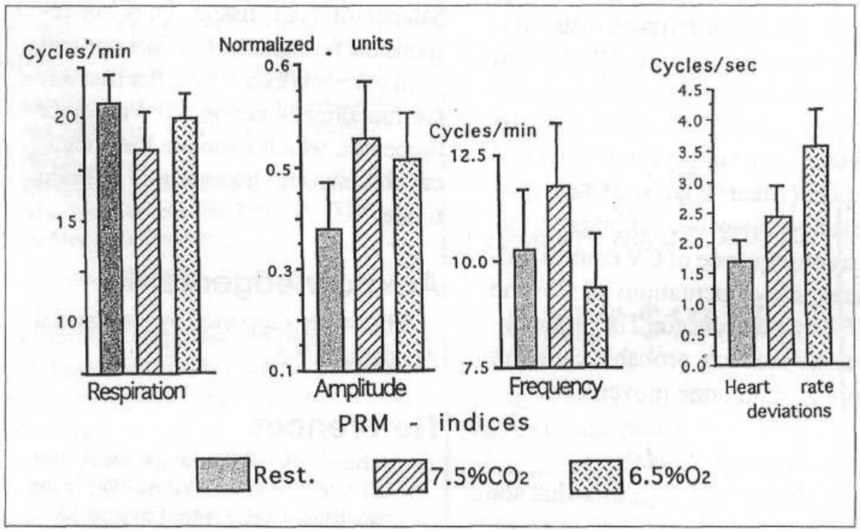

Figure 7: Amplitude and frequency characteristics of PRM, secondary respiration and heart rate deviations in group of healthy persons (n-12) in different situations: Rest, Inhalation of hypercapnic (7.5%CO2) and hypoxic (6.5% 02) gas mixtures.

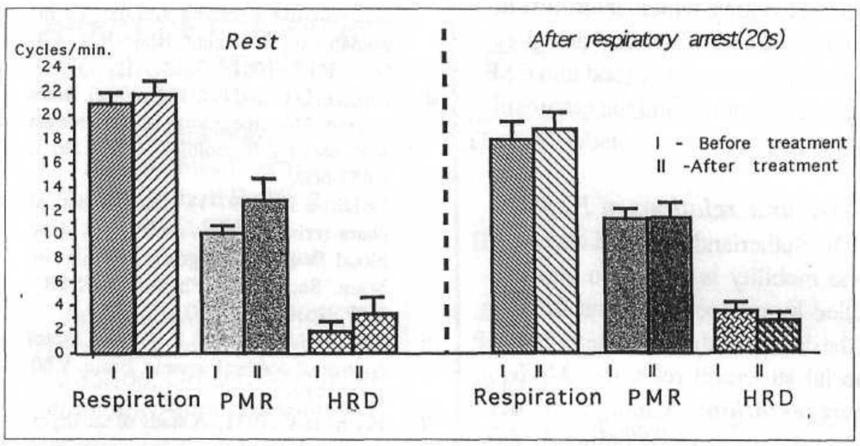

Figure 8: The changes of frequency characteristics of PRM, secondary respiration and heart rate deviations in patients after head trauma (n=10) under influence of osteopathic manipulative techniques I - before treatment, 11 - after treatment.

Conclusions

The presented data demonstrate that CV and CSF systems are characterized by a complicated biophysical structure, which determines the relationship between pressures and volumes of liquid media - blood and CSF inside the closed cranial cavity. Due to special biophysical structure, control processes in the CV system are directed to the complex functional goal, to provide chemical support (metabolites supply) and physical support (water balance of brain tissue) and homeostasis of brain tissue. As a consequence of CV control processes, slow fluctuations of CV and CSF parameters occur. These fluctuations are the most probable cause for periodic skull bone movements.

1. Structure ofPRM:

Dr. Sutherland suggests that the PRM includes brain, CSF, intracranial and intraspinal membranes, articular mechanism of the cranial bones. ***Modern interpretation:*** These elements consist of the special biophysical structures of the craniospinal cavities, which determine interaction between volume and pressure of liquid media - blood and CSF inside the cranium and the craniospinal cavity.

2. Dynamic relations of PRM:

Dr. Sutherland suggests that skull bone mobility is related to and controlled by reciprocal tension function of the dural membranes, determined by special structural relations. ***Modern representation:*** Changes of distances between fixed points in particular skull bones are determined by CSF periodic fluctuations. The presence of reciprocal components in skull bone motions is determined by the modulatory role of membranes.

3. Functioning of PRM:

Dr. Sutherland suggests that the brain is the "motor", and might be visualized as cerebral convolutions. ***Modern representation:*** Slow periodic fluctuations of the parameters of the brain circulatory system, namely brain blood volume and CSF pressure, are the consequence of relation of control links with different time-constants, and support brain metabolic supply and water balance of brain tissue. They are responsible for motion of brain tissue and skull bone motions. These fluctuations are functionally connected with other processes, which maintain the chemical and physical homeostasis of brain tissue.

Acknowledgement

This study supported by the Cranial Academy, USA.

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The AAO Journal, 2003, V.13, No.2, P.21-33.