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# An Anomaly in Vertebrates' Evolution as Limit of Human Evolution

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**Abstract:** During several years we have studied the so-called "intracranial system", that is the system constituted by a container, rigid and not expandable (skull and dura mater), and by non-compressible contents, represented by the brain parenchyma, cerebrospinal fluid, and blood. We studied this system in different animal models, *in vitro* in a physical model, and in patients. While the circulatory system is different in the various types of vertebrates, less complex in fishes and more complex in birds and in mammalians, the intracranial system is always the same, constituted by the same things, skull, dura mater, subarachnoid spaces, ventricles, parenchyma, blood, and cerebrospinal fluid. All these things follow the same rule, that is the Monro-Kellie doctrine. In other words, there is an exact balance between the blood flow inlet and the blood flow outlet for each cardiac cycle. This constitutes, for each instant considered, the constancy of the intracranial blood volume. This phenomenon is always the same in all the species examined: this fact forced us to ask what the real significance of this system in the evolutive field was. Why the circulatory system follows the laws of the evolution, from less to more complexity, and the intracranial system seems to escape from these same laws? The question has two answers: the first relates to the function of this system. Being to be enclosed in a rigid box permits to minimize the necessity of more space to compensate the spontaneous increase in blood volume due to the dilation of the arteries during the systolic period of the cardiac cycle. The second one is relative to the human birth: the birth of a human being is not possible without the protection furnished by a rigid skull.

**Keywords:** Intracranial Pulsatility, Brain Tamponade, Trauma Birth

## 1. Introduction

The concept of evolution in its intrinsic significance in biological terms implies a progressive increase of complexity starting from the time in which a certain form sources and ending to the moment in which we observe the last expression of this form. A clear example of this concept is represented by the circulatory system in the vertebrates [1]; we know that in fishes the circulatory system is constituted by a simple circuit in which two cardiac cavities (one atrium and one ventricle) are recognizable. Thus, it is a 2-chambered heart. In amphibians the atrium is completely divided into right and left chambers; there is a unique ventricular cavity, while the conus arteriosus divides into systemic and pulmonary vessels by a spiral valve. In reptiles appears a further advancement of the heart: the atrium is always completely separated into a right and left chamber while the ventricle is partly divided by a septum in most of these species. In birds as in mammalians, the ventricle is double, so that the heart is four chambered (2 auricles and 2 ventricles). There is a complete separation of venous and arterial blood. Thus, there is double circulation in which there is no mixing of blood at any place. This change produces a better utilization of the oxygen for metabolic necessities following the progression from the fishes to the mammalians. We may cite many different examples involving other organs or apparatus. This seems to be an internal rule for any kind of evolutive mechanism.

But there is an apparatus, better known under the diction of "system", which seems to slip this condition: it is the "intracranial system", that is the system characterized by the association of a rigid and non-expandable container (skull and dura mater) and incompressible contents (brain parenchyma, blood and cerebrospinal fluid [CSF]): what links these different substances in this particular condition is only one rule (or better "law"), the Monro-Kellie Doctrine, that is the absolute constancy, within the intracranial system, of the volume of blood for each instant considered as stated by the very pioneer works of Alexander Monro [2] and George Kellie. This means that, as it was demonstrated by the famous physiologist Starling and published in his Principles of Human Physiology [3] in 1912, there is an exact balance between the arterial and the venous volume for each cardiac cycle: the venous output from the dural sinuses is "pulsatile" synchronously with the arterial pulsation.

Based on these considerations we started to study deeply this problem more than thirty-five years ago performing different experimental preparations on several species of animals, dogs, rabbits, lambs, pigs, and on a physical model of intracranial system represented by a sort of rigid fluid-filled cylinder containing different elements mimicking vascular tree (rubber tubes with different elastic properties reproducing arterial ad venous structures), brain parenchyma and interstitial spaces (sponges and surrounding fluid), and cisternal-ventricular compartment. From this physical system we obtained several responses to different questions; but at the end of this experimental research, we occasionally found a paper which poses another more interesting question on evolutionary field concerning the source of the cranial cavity.

## 2. Materials and Methods

In this section we will describe synthetically what we have performed in the different species of animals and in the physical model; for a complete and analytical description the reader may refer to original papers listed in the bibliography [3-8].

To summarize:

1) Carotid blood pressure (CBP), in animals, and inlet pressure (IP), in the physical model, were recorded in all experiments.
2) Intracranial pressure (ICP) in animals and intra-container pressure (ICoP) in physical model were also recorded.
3) Sagittal sinus pressure (SSP), in dogs and in pigs, and outlet pressure (OP), in physical model, were recorded.
4) Internal carotid blood and intracranial middle cerebral artery blood flow velocities (ICBFV, MCABFV), in rabbits, in lambs and in pigs, respectively, and inlet flow (IF) in physical model were also recorded.
5) Sagittal sinus blood flow velocity (SSBFV) in pigs and outlet flow (OF) in physical model were recorded.

While in physical model we have utilized flowmeters to measure the IF and OF, in animals we have measured the cerebral blood flow velocities at internal carotid, cerebral middle artery and sagittal sinus level. At this last level in pigs, we have considered the measurement equivalent to the true flow passing into the sagittal sinus as its stress-resistant structure. At level of internal carotid artery, in rabbits, the measurement was also considered quite equivalent to a real measure of flow as the special configuration of the experimental preparation; the measurement of the flow velocity in the middle cerebral artery in pigs and lambs were considered only for what concerns the shape of the curve and not for the absolute values of flow.

All these measurements were made during basal conditions and during artificially induced increments of ICP and ICoP until their values approximate those of arterial or IP, reproducing (in animals) the so-called phenomenon of "brain tamponade" condition, that is the condition in which the arterial blood stops at the entrance in the skull.

## 3. Results

All the variables above indicated are "pulsatile" and in an exact correlation each with other; in particular, starting from the CBP and IP, the ICP and ICoP are also pulsatile following the arterial walls movements. In turn, the oscillations of the ICP (the so-called "CSF pulse pressure") and ICoP produce analogous oscillations in the venous compartment (at level of bridging-veins) so determining the oscillations in the SSBFV and OF; these oscillations exactly match the same oscillations in ICBFV, MCBFV and IF, thus maintaining exactly constant the intracranial blood volume during each cardiac cycle, which is the direct confirmation of the true significance of Monro-Kellie doctrine.

Another experimental result was the confirmation of the so-called "Starling resistor", that is the presence of a sort of valve between the distal part of the bridging veins and their entrance into the dural sinuses. This structure acts functionally as a unidirectional valve from the intracranial system to systemic venous circulation; while modifications in the systemic venous circulation may influence the intracranial compartment, modifications of intracranial circulation have no influence on systemic venous circulation. This happens because the veins, when ICP and ICoP increase (as at maximum, for instance, in the brain tamponade condition), are compressed and eventually collapse so blocking the passage of blood flow to systemic venous circulation.

This is confirmed by two main results: 1) in dogs [4, 7], in pigs [5, 8] and in hydraulic model [9] the absolute constancy, or even reduction, of the sagittal sinus (outlet) pressures despite of even severe increments of ICP and ICoP to approach those of arterial pressure; 2) in rabbits, lambs and pigs [5, 8], the appearance of the so-called "reverberating waves", that is the to and fro movements of the waves recorded both at arterial and sagittal sinus level, indicating the presence of two columns of blood, one in the arterial district, and the other one in the sagittal sinus district, synchronously oscillating in opposite directions but without any flow communication from each to other one.

All these data agree perfectly with our observations in humans (here not reported but published in many paper in the neurosurgical literature) affected by different pathology, cerebral hematoma, brain trauma, hydrocephalus, idiopathic intracranial hypertension, which show the same pathological condition, that is the brain tamponade, that we have studied during several years in our neurosurgical activity.

# 4. Discussion

We were under a real impression for this great uniformity about the relationship between pressures and flows in different conditions and in so different species (from rabbits to humans) and in a physical model, when we read a paper [10] entitled *"Cerebral Blood Flow Changes in Response to Elevated Intracranial Pressure in Rabbits and Bluefish: A comparative Study"*. In this paper we learned that the fishes have the same intracranial system as the mammalians; have skull, dura mater, sub-arachnoid spaces, and ventricles like those of the mammalians. We started to find if other vertebrates have the same peculiarities and all of them, amphibians, reptiles, and birds have a similar intracranial system [11, 12]. This fact forced us to find what was the real significance of the intracranial system as we know it.

The main factor which characterizes the intracranial system, and best expressed in human being, is the capability of this system to maintain constant the volume of circulating blood in any kind of condition in which may find. This is the so-called autoregulation; mechanically speaking it depends by the balance between the inflow and the outflow from the cranial cavity obtained simultaneously by the arterial vasodilation, following the passage of the cardiac bolus, and the external compression of the veins at Starling resistor point transmitted by the CSF displaced by the movement of artery walls. This may happen only in a rigid box as the intracranial system is. But another very important consequence of this is the necessity to keep very low these movements: less movements, less variations in the blood volume to be compensated by venous compression. This signifies, and it is the answer to our question about the real significance of the intracranial system, that the arteries are always "open", no matter of systolic or diastolic period. In the other part of the body, as, for instance, in legs, in visceral organ, the arteries open during the systole and close in diastole, so maximizing the variations in their caliber, and, for consequence in their volume; in the intracranial system are always open, so minimizing the variations in their caliber, and for consequence in their volume, with minor effect on the venous compression. As consequence of this, the cerebral flow is always constant and always at maximum level; in our body 20% (about 750 milliliters) of our blood is dedicated to the brain, which represents only the 2% of total mass (1.5 Kilograms). This represents the peculiarity of the brain, an organ which is always working at maximum level, even when the other parts of the body are in resting conditions.

There are two main consequences to be enclosed in a rigid box; the first one is that we have just mentioned, that is, the so-called brain tamponade. When, for pathological situations, there is an increase in cerebral artery blood volume, the capacity of the veins progressively decreases in compensating this increase and exhausts, when there is no blood to be displaced from the veins out of the skull; as consequence, the cerebral blood flow stops.

Another consequence, more difficult to be perfectly understanded, is represented by the birth trauma. When a child is born by natural way, he/she suffers a very big head compression, with the pressure, measured by a small transducer inserted between the fetal head and the wall of the birth canal, reaching mean value of 157.9 mmHg (ranging from 38 to 390 mmHg) [13]. These values, surely, do not represent the real value reached by the fetal ICP, but may signify, considering the elasticity of the fetal skull, a condition very similar to a sort of "brain tamponade" for a reduction of available intracranial space. This is the true "birth trauma" as we know.

On the other hand, if we have not the skull, how the birth will be possible? The venous congestion, following to the impact with the inlet of birth canal, with the brain "swollen", because not covered by the skull, will hinder the progression in the canal, so preventing any tentative to be born. This represents the real reason of intracranial system and, in other way, the limit of the evolution of a human being.

We have tried to find other papers dealing with this same argument, but we have not found. We believe this is the first paper in the literature proposing this question: does it exists an evolution in the intracranial system of vertebrate animals?

# 5. Conclusion

In conclusion, we propose with this paper a reflection about the significance of the evolutive process for what concerns the so-called intracranial system; it seems that, differently from what happens with other biological systems, the intracranial system escapes from this rule: it is stable and unmodified from the fishes to the human beings.

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