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Significance of the cranial venous system in anthropogenesis in the light of contemporary clinical and experimental data

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Abstract

The manner of the appearance of the *Hominidae* family is still a very controversial issue, since there is no general agreement among the authors upon whether it was an isolated and extraordinary event in the natural history or rather a necessary consequence of the evolution process. Rapid augmentation of the cranium capacity which occurred in this group had been probably preceded by the development of the erect body posture. Elevation of the head created new, better conditions for the outflow of the venous blood from the cranium due to the involvement of the gravitation force into this mechanism. A new model of venous outflow from the cranium must have been developed.

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According to the classical views, having originated as long ago as in the previous century, blood within venous sinuses of cranial dura mater was to flow from the anterior and upper part towards the posterior and lower part of the cranium, heading towards jugular foramina and flowing out through emissaries. However, due to the lack of valves [BOCHENEK, REICHER 1993] this prevailing direction of the blood stream could change depending on momentary differences in the blood pressure. Based on these views, cranial emissaries are considered to have a very important function in the generation of collateral circulation bypassing the jugular foramen forms as a result of a uni- or bilateral ligation of the internal jugular vein [AHN, SINDELAR 1989, BOCHENEK, REICHER 1993, SCHELLING 1978]. Undoubtedly, cranial emissaries play also an important role in the spread of intracranial inflammatory complications originating in the head and neck organs [DANZIGER, PRICE, SCHECHTER 1980].

Contemporary studies in the field of anatomy, physiology as well as clinical observations prove that the mechanisms of blood circulation within the head are far more complex than previously believed. The directions of the blood flow in intracranial blood vessels, in the large sinuses of the dura mater in particular, depend also on factors other than the pressure gradients. Any changes of these directions enforced by a surgical intervention always lead to the dysfunction of

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the central nervous system. Hence, in spite of undeniable progress in anaesthesiology and intensive medical care in recent times [AHN, SINDELAR 1989, SHELLING 1978], a relatively high mortality rate is still observed following the operations of the uni- or bilateral ligation of internal jugular vein, especially if performed at the same procedure, This is in opposition to the established view supported by numerous clinicians on relatively easy generation of collateral circulation following this type of operation. Furthermore, it should be emphasised that the radiological intravital tests of the arterial and venous vessels of the cranium seem to indicate that in some completely healthy people venous blood does not enter but leaves the cranium through ophthalmic veins, and that direction of this flow depends on an individually variable configuration of large tributaries to the cavernous sinus. This causes the changes of the pressure between this sinus and orbital veins [SERVO 1981]. Experimental function tests conducted on healthy volunteers indicate that the direction of the blood flow in ophthalmic veins may vary for the same individual. It depends on the thermic situation of the system in a given moment, which is probably of significance for the thermoregulation mechanism of the brain [CAPUTA 1982]. Other experimental studies indicate that blood enters the cranium [TYCHMANOWICZ 1992] also through other emissaries. It seems that the intracranial direction of the blood flow indicated by the very position, and in particular by the angle at which some important emissaries permeate the cranium wall [PIASECKI, WYSOCKI, SKARŻYŃSKI, REYMOND 1995]. The mechanisms regulating the directions of the blood flow within the head are without doubt very precise and efficient, since they make it possible to maintain constant pressure in the superior sagittal and sigmoid sinuses in spite of serious and long-lasting disturbances in venous outflow. This is a trait acting to the advantage of the organism, since these sinuses are the zones of the most intensive absorption of the cerebrospinal fluid [TYCHMANOWICZ 1992]. These mechanisms are probably based on the existence of extremely rich autonomous innervation of the sinus walls, of the cavernous sinus in particular, with numerous baroreceptive endings, as well as on the presence of valves in the openings of large venous emissaries to sinuses [AUER, JOHANSSON 1981, CAPUTA 1982, KĘDZIA 1987, TYCHMANOWICZ 1992].

There are two phenomena, very important for the understanding of the principles of blood circulation in the head, which nevertheless have been neglected by majority of the authors of clinical papers. These are lateralisation and sexual dimorphism. Lateralisation of the cranial venous system consists in directing the main stream of blood through a single jugular foramen and further through a single internal jugular vein. This probably promotes faster outflow, since, according to the Bernoulli principle, a stream of liquid loses energy in each branching point. As a result, almost always one of the jugular foramina, usually the right-hand one, is larger than the opposite foramen. Foramina of similar size are found extremely rarely [SCHELLING 1978]. The lateralisation phenomenon seems to be a universal feature, characteristic of the vertebrates with the erect body posture, which is suggested by its occurrence also among

birds [KRASNIKOV 1988]. The lateralisation of the jugular foramina of the cranium is not observed in the majority of quadruped mammals [HEGEDUS, SHACKELFORD 1965]. The fact that among humans lateralisation is stronger in female individuals seems to suggest that also sexual dimorphism should be taken into consideration in the study of the venous system of the cranium [BAUER 1971]. The occurrence of easily identifiable lateralisation and sexual dimorphism was ascertained recently also by Polish authors, also by the author of the present paper [PIASECKI, WYSOCKI, SKARŻYŃSKI, REYMOND 1995]. Anatomical studies on the mastoid emissaries of the cranium indicate that all metric characteristics of these emissaries show significant statistical differences depending on the sex of the individual and the side of his/ her body. Clinicians sometimes fail to observe the described phenomena. Some clinical studies, however, devoted to intracranial inflammatory complications deserve attention. Materials covering large groups of patients prove that the male individuals suffer from complications much more often than females (from 1.5 to 3.5 times more often). So far the phenomenon has not been explained [DANZIGER, PRICE, SCHECHTER 1980]. This is a confirmation of sexual differences in the structure of the cranial venous system observed in anatomic studies which so far have not been sufficiently supported with basic physiological studies.

Certain new data widening the scope of our knowledge on the structure and functions of the cranial venous system have been contributed by the studies in the field of comparative anatomy and anthropology. The development of the model of the venous blood outflow from the cranium observed in contemporary people extended over several million of years of the *Hominidae* family evolution [FALK 1986]. In this family of primates a rapid augmentation of the brain capacity took place [LOVEJOY 1981]. In the course of this process the original system underwent thorough transformation. In the original system the main stream of the venous blood left the cranium through the great foramen of the cranium and through emissaries located at the cranial basis and subsequently flowed into vertebral venous plexuses and deep jugular veins. As a consequence of the transformations, in certain *Hominidae* forms [FALK 1986] a considerable development of marginal and occipital sinuses, of condyloid emissaries and sublingual canals was possible. The changes were probably generated by other physical modifications of the organism, especially by the development of the erection body posture, which created new conditions for the venous outflow promoting the jugular foramina as the ones located at the lowest points [FALK 1986]. In the course of the evolution other foramina located within the cranial basis, such as foramen ovale or postglenoid foramen which are the most important venous outlets [HEGEDUS, SHACKELFORD 1965, KĘDZIA 1987] for the majority of quadruped mammals were losing significance. From the point of view of the fluid mechanics laws these foramina, even when they occur in man, which is rare in the case of the postglenoid foramen, play a minor role in the venous blood outflow [SCHELLING 1978]. In the contemporary man approximately 95% of the venous blood volume leaves the cranium through the jugular foramina [TYCHMANOWICZ

1992]. From among numerous venous emissaries only the mastoid and condyloid emissaries [SCHELLING 1978, SOLTER, PALJAN 1973] seem to be of great hemodynamic significance. The transformations described must have been beneficial if they were preserved in the course of the evolution. These were not minor changes, since, for instance, in contemporary birds the relationship between the morphology of the cranial venous system and the animal's life style [KRASNIKOV 1988] is evident. The modification of the manner of venous blood outflow from the cranium was probably one of the leading mechanisms in the process of the brain development, since it facilitated cooling of this organ generating so large quantities of heat [CAPUTA 1982, KUJAWA 1993, MARIAK 1996]. The capacity and, as a result, the mass of the brain were growing in proportion to the sphere radius raised to the third power, while the surface of the organ and surrounding cranium, acting as the medium in the heat exchange – only proportionally to the second power of this radius. Improvement of the flow blood to and from the cranium interior was probably one of the basic problems to be solved in the second stage of evolution [KUJAWA 1993]. A close relationship between the brain capacity and the cross section of the venous sinuses of the dura mater was proved recently following the study of human corpses [SEKELES, GITLIN 1981]. Similarly, a close relationship between the size of the jugular foramina and the size of the two most important venous emissaries: mastoid and condyloid one [SOLTER, PALJAN 1973] was proved.

In the light of the above listed observations it seems clear that also cranial venous emissaries must have played a significant role in the process of anthropogenesis. The fact that there are no scientific publications to support this intuitive presumption shared by many authors from various fields of science is very surprising.

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Streszczenie

Dokonano przeglądu najważniejszych pozycji piśmiennictwa dotyczącego anatomii i fizjologii układu żylnego głowy u człowieka i zwierząt w aspekcie przekształceń zachodzących w procesie antropogenezy. Stwierdzono, że pionizacja ciała była prawdopodobnie jednym z czynników decydujących o szybkim tempie ewolucji *Hominidae*. Nowe, korzystniejsze warunki odpływu żylnego z wnętrza czaszki, powstałe na skutek dołączenia siły grawitacji do dotychczas funkcjonujących mechanizmów rządzących ruchem krwi żylnej, spowodowały prawdopodobnie usprawnienie procesów termoregulacji ośrodkowego układu nerwowego i stworzyły podstawy dla skokowego zwiększenia jego masy. Z punktu widzenia podstawowych praw fizyki i matematyki oczywisty wydaje się fakt, że w miarę wzrastania wielkości obiektu o kształcie zbliżonym do kulistego, stosunek jego powierzchni do objętości maleje. Mózgowie, będąc narządem bardzo aktywnym fizjologicznie i wytwarzającym znaczne ilości ciepła (u człowieka do 15% ciepła ustrojowego) wymaga wydajnego i niezawodnego mechanizmu chłodzenia, zapobiegającego przegrzaniu. Z badań czynnościowych prowadzonych tak na zwierzętach, jak i na ludziach wiadomo, że decydującą rolę w tych procesach odgrywa napływ chłodnej krwi żylnej: u zwierząt ze śluzówki jamy nosowej – u ludzi zaś z pozbawionej owłosienia twarzy. Wydaje się, że siłą sprawczą tego napływu jest złożony system umożliwiający sprawny odpływ żylny z jamy czaszki, stwarzający adekwatne siły ssące. Wydaje się także, że powszechna u ludzi (także u ptaków), a nieobecna u zwierząt czworonożnych lateralizacja głównych otworów żylnych czaszki, sprzyja tym mechanizmom. Z prawa Bernoulliego wynika bowiem, że prąd cieczy traci znacznie więcej energii w przypadkach, gdy rozdziela się on na strumienie równorzędnej wielkości, niż w sytuacjach, w których uchodzi jednym, dominującym otworem. W świetle powyższych rozważań asymetria układu żylnego czaszki powinna być uważana za zjawisko progresywne.