L e c t u r e

The symmetry of man

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Abstract. The paper contains a description of basic regularities in the manifestation of symmetry of human structural organization and its ontogenetic and phylogenetic development. A concept of macrobiocrystalloid with inherent complex symmetry is proposed for the description of the human organism in its integrity. The symmetry can be characterized as two-plane radial (quadrilateral), where the planar symmetry is predominant while the layout of organs of radial symmetry is subordinated to it. Out of the two planes of symmetry (sagittal and horizontal), the sagittal plane is predominant. The symmetry of the chromosome, of the embrio at the early stages of cell cleavage as well as of some organs and systems in their phylogenetic development is described. An hypothesis is postulated that the two-plane symmetry is formed by two mechanisms: a) the impact of morphogenetic fields of the whole crystalloid organism during embriogenesis and, b) genetic mechanisms of the development of chromosomes having two-plane symmetry. (www.actabiomedica.it)

Key words: Symmetry, structure, chromosome, skeleton, glands, nervous system, cardiovascular system, crystallography

Introduction

In the development of man as a biological species, it is the principles of structural organization that seem to be one of the major problems.This aspect is of great theoretical and practical value in biological classification and evaluation of the position of man in the animal kindom. As the principles of structural organization have not been yet described in full, biologists and anatomists state the presence of certain organs or their groups classifying them based on their functions.

It is generlally believed that the structure of organisms and organs is determined by their evolutionary adaptation to environment and functionality. Some authors however hold that the structural organization of objects and their forms are determined by certain general principles that become manifest in different groups of the organic world (1-5). As is known, many live organisms are capable of coordinated proportionate volumetric growth during long periods of ontogenesis. This type of growth when every local zone of an object undergoes similitude transformation resulting in a volumetric transformation of the whole organism together with its internal components, significantly differs from the growth of crystals that is expressed as an increment of mass on the surface of crystals without any change in their internal components.

Nevertheless, attempts to draw an analogy between live organisms and crystals have been made since long. Buffon found a similarity between the growth of crystals and the growth of live bodies back in the 18th century. This line of thinking in biology was boosted by Haeckel who proposed the concept of live matter crystallization in his work (6).

In 1904, Koltsov (7) was the first to propose a theory based on the idea that the cell and its components are a complex colloidal system made of fine crystals rather than of amorphous particles. Koltsov also described the mechanism of chemical reactions through the prism of the crystalline cellular structure. An attempt to extrapolate this approach onto the whole organism and consider it as a particular crystal or crystalloid and analyse how its own field influences its form and structure was not made in this work.

The problems of structural organization and biological symmetry have been tackled in different concepts and teachings with a varing degree of in-depth analysis, including N.I. Vavilov's law of homologous series, the theory of morphogenetic fields by A.G. Gurvich, V.I. Vernadsky's hypothesis on the non-Euclidean geometry of live beings, biologically relevant diffusion-reaction model of morphogenesis based on self-organizing growing automata by A.M. Turing (8) and the model of life by J.H. Conway (9-11). Biological symmetry at the macromolecular level was the topic of the Nobel Symposium in 1968 (Symmetry and Function of Biological Systems at the Macromolecular Level) (12). P. Curie came to the conclusion that symmetry cannot be studied or understood without considering the environment, the way the object moves in the environment and the way the environment moves relative to the object. He proposed (13) a broader interpretation of symmetry regarding it as a feature of environment or space where the object is located. The symmetry of space, as if it were, superimposes on the symmetry of the body that is forming in this space. The resulting form of the body preserves only those elements of its own symmetry that coincide with the superimposed elements of the space symmetry.

The majority of authors who had worked in this domain explained symmetry by environmental impact, by the motion (or lack of motion) of organisms in environment and by the very character of that motion. Some authors believe that symmetry is a result of certain vague processes of harmonious development that make live organisms develop in conformity with the golden section rule. The symmetry of many animal species, however, cannot be understood on the basis of these principles. The jelly-fish, for example, actively moves only forward while its structure is characterized by radial symmetry. Man as a vertebrate should possess bilateral symmetry but a more in-depth analysis of the human organism and its separate systems reveals a more complex picture.

In this connection, it stands to reason to consider the symmetry of biological objects in the framework of a broader concept that describes these objects as particular macrobiocrystalloids with certain properties. This approach can be quite meaningful in life science as it proposes a model that more fully and adequately reflects real live objects.

Definition of the macrobiocrystalloid

A macrobiocrystalloid can be defined as a dynamic spatially contained biological object or its part, characterized by an orderly structure and ability to self-organization and internal coordinated growth that takes place under the impact of interacting forces generated by the constituent elements of the object. The object's composition determines its structure, symmetry and function while the latter influences the composition, structure and symmetry of the object. The composition can be heterogeneous, therefore the interaction of forces of its constituent elements creates a certain symmetry which differs from that of the constituent elements.

When comparing mineral and biological entities we should consider the latter as an active near-the-surface part of a crystal taken together with its crystal-forming medium around it as the latter controls the crystal growth and modifies the whole system depending on the current structural changes of the growing crystal. The structure of concentration flows is reflective of crystal nutrition and elimination of wastes. Crystallographic analysis of biological and non-biological minerals does not show any basic differences between the two, which is indicative of common crystallization process in them (14). The boundary zone of a crystal is an integral component of the growing crystal-medium system and is in itself an integrated system consisting of concentration, thermal and dynamic layers. The boundary zone "is not just an area of physical and chemical regulation but also a kind of membrane filter sorting crystal-forming particles on their way to the crystal. It is in this zone that metabolic processes take place and concentration waves and flows are formed with a resulting stratification of the solution". The growing layer of a crystal together with the boundary layer of the mineral-forming medium where concentration flows of crystallogenetic stratification are in action is characterized by the most important feature of biological matter - an ability to extract, transform and utilize energy from outside. It is probable that additionally to maintaining it can also build up by inertia its energy reserve. It is here that self-regulation processes take place to prevent the disintegration of the whole structure and maintain the stability of the organism. This is indeed a living mineral organism (14).

Environmental impact can induce changes in the form and composition of the object, which in its turn can lead to changes in its structure and symmetry. In the course of evolution, the internal forces of the macrobiocrystalloid that create a morphogenetic field tend to construct the organism symmetrically in two planes, sagittal and horizontal, the sagittal plane being predominant. Additionally, elements of radial symmetry can be found in the development of some organs but again, radial symmetry is subordinated to plane symmetry. We shall now examine how this complex radial two-plane (quadrilateral) symmetry is manifest at different levels.

Symmetry of the chromosome

The human chromosome is characterized by symmetry. At mitosis prophase, the chromosome consists of two chromatids, morphologically identical intertwined threads of the same diameter. At metaphase, the chromosome straightens up and two of its chromatids now run parallelly being divided by a narrow cleft so that the chromosome looks like a double rodlike structure. The centromere that divides the chromosome into two arms lies at the primary chromosomal strangulation. Figure 1 from Steffensen (15) shows that the chromosome is symmetric in two planes if the chromatid arms are considered as antimeres. As is known, the chromosome is the carrier of information in the process of embryogenesis and, being symmetric in two planes, can predetermine the two-plane symmetry of the whole organism.

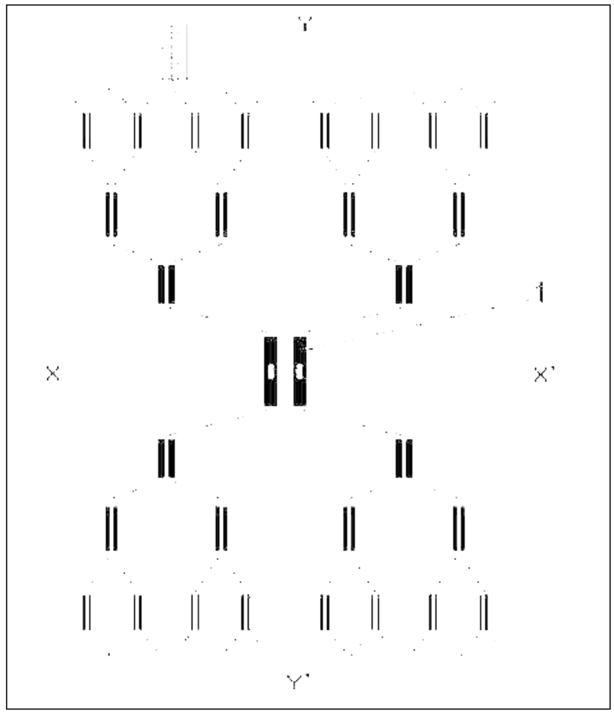

Figure 1. The schematic chromosomal structure. X - X'; Y - Y' - the planes of symmetry; 1 - the arm of the chromatid

Symmetry in embryogenesis

Studies of the initial stages of human development show that the plane of the first cleavage (the future sagittal plane) goes through the polar bodies. Soon after the first cleavage is over, the second mitotic spindle is formed in each of the first two blastomeres. In mammals, the spindle in one of the blastomeres rotates by 90 degrees during the second cleavage and a crosslike structure is thus formed at the four-cell development stage. In mammals, the subsequent cleavage of the blastomeres is asynchronous. In vitro studies with early embryoes washed out from the Fallopian tubes of apes and later observations of human embryoes after in vitro fertilization showed that the cell cleavage in primates is similar to that in other mammals and that the zygote divides in three mutually perpendicular planes (16, 17). This implies that phylogenetically the human ancestor could be symmetric in three mutually perpendicular planes.

In the ovum, the animal pole corresponds to the cranial end of the body of a future embryo while the vegetative pole - to the caudal one. Therefore, the ovum itself predetermines the embrional craniocaudal axis. The planes of symmetry cannot be yet determined in the ovum. The features of two-plane symmetry become manifest when a spermatozoid penetrates into the ovum and a grey crescent is formed in the zygote. The embryo becomes more clearly oriented in the two planes, sagittal and horizontal, starting with the development of the chorda and other provisory organs. The chorda development initiates a sequence of important events at late gastrula. It is under its impact that the nervous system and then other organs are formed.

The symmetry of the skeleton

Figure 2 shows the schematic of the two-plane symmetry of the human skeleton. The bones of the visceral skeleton are not included here. The two planes of symmetry, sagittal and horizontal, divide the skeleton into four antimeres. The similarity of the antimeres versus the sagittal plane is obvious, while the antimeres versus the horizontal plane differ considerably both in form and size. When evaluating symmetry of live organisms, it is necessary to correlate only similar structures. The horizontal plane of symmetry divides the spine with metamerically located vertebrae into a cranial and caudal antimeres. The middle part of the two has a girdle with a pair of limbs. The total number of bones in the lower and upper extremities with their girdles is equal while the location of the pairs of limbs relative to the horizontal plane of symmetry is caudally shifted along the craniocaudal axis. The antimere of the axial skull bones lies in the coccygeal bones.

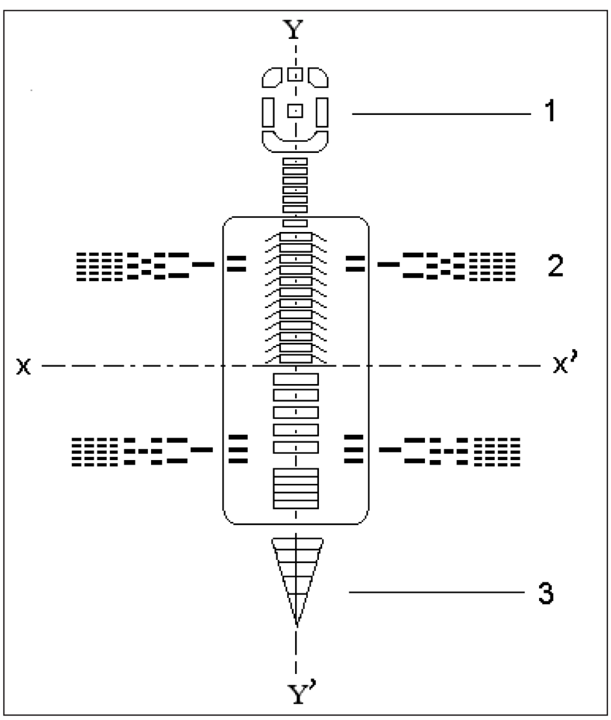

Figure 2. The schematic of the human skeleton in the two-plane symmetry. Visceral bones are not shown in the schematic. X X'; Y Y' - the planes of symmetry; 1 - bones of the axial skull; 2 - limb bones with a girdle; 3 – coccyx

All visceral arches develop in a similar way from the same skeletogenic material and have a similar disposition, i.e. they are homodynamic. The bones of the visceral skull formed originally the skeleton of the anterior bowel and were presumably located along the trunk (18).

Symmetry of glands

Phylogenetically, the location of glands was metameric and corresponded to the primary segmentation. This was a reflection of the two-plane symmetry of the organism. During integration, some glands within segments merged to form organs of radial structure (we define glands of radial structure as glands that have a reservoir or originally form around a cavity). Precursors of liver and lungs were located at the cranial end while that of kidneys and gonades in the caudal end of the body. Figure 3 shows the layout of big segmented glands of radial structure in the two planes of symmetry of the organism. Lungs and kidneys, though not regarded as glands, can be included into the group of organs of radial symmetry due to their development and structure.The gonades and liver are included into this group for the same reason. All these organs have ducts and possess endo- and exocrine properties. P.Lesgaft (19) noted that earlier anatomists had regarded lungs and kidneys as glands.

Lungs are generally regarded as a pair structure though they are not such by way they develop. Firstly, the development of the respiratory system starts with the formation of the non-pair laryngotracheal sulcus that originates in the posterior pharynx to run along the midline of the embryonal ventral primary intestine, i.e. from the very beginning it develops as a non-pair structure. This sulcus gradually becomes deeper and ultimately separates from the intestine. Thus for-

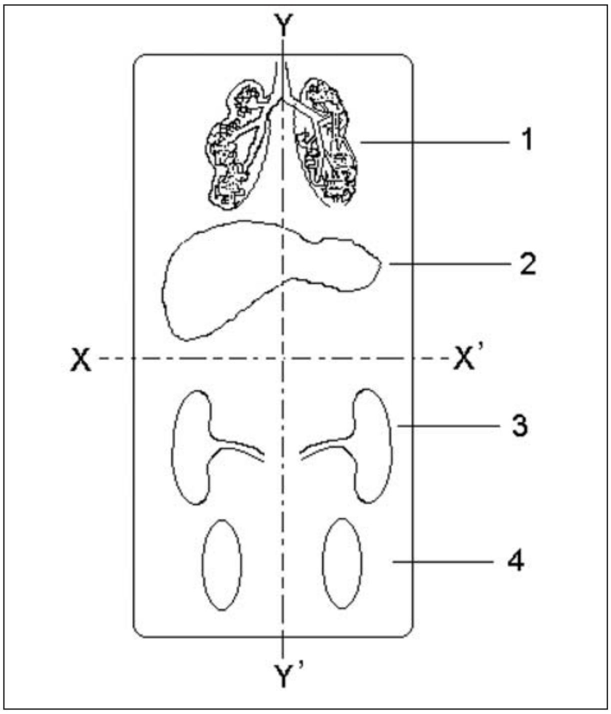

Figure 3. The layout of glands of radial structure in the two-plane symmetry. X X'; Y Y' - the planes of symmetry; 1 - lungs; 2 - liver; 3 - kidneys; 4 - gonades

med, the diverticulum elongates caudally to form a trachea. After the trachea has grown to a certain size, its caudal end bifurcates and continues growing to become a branched tracheal tree. Another argument to support the view that the lungs are a non-pair organ is the fact that symmetric elements of pair structures are located at a significant distance from the sagittal plane while in non-pair ones they are located together. The kidneys have five segments apiece while there are totally five lobes (primary segments) in the lungs. The right and left lungs are a single non-pair organ and the way they is located in the body relative to the sagittal plane is similar to the location of the right and left lobes of the liver.

In the light of the above, relative to the horizontal plane of symmetry, the pair kidneys have their antimere in the non-pair liver while the pair gonades - in the non-pair lungs. Trying to preserve its symmetry relative to the sagittal plane, the organism places non-pair organs on the opposite sides relative to this plane (the right and left lung, the right and left lobes of the liver).

Symmetry of the nervous system

In the nervous system, two-plane symmetry objects are represented by cerebral nuclei and spinal ganglions. The brain and spinal cord are structures of radial symmetry. The primary cavity of the embryonal nervous tube is preserved in the brain of adult specimens as a series of cavities and ducts filled with cerebrospinal fluid. Each of the two hemispheres of the brain has a cavity called a lateral ventricle. Each of the lateral ventricles communicates via an interventricular foramen with the third ventricle located in the diencephalon. In lower vertebrates, the midbrain has a well developed ventricle which is transformed into a narrow canal (so-called midbrain water-pipe) in amniotes, the fourth ventricle stretching into the central spinal cord canal is located in medullar oblongata. Additionally, some lower vertebrates have a separate ventricle in the cerebellum (20). The spinal cord has a canal running throughout its length and is another structure of radial symmetry. Nervous structures of radial symmetry are symmetrically located in two planes.

As can be seen in the schematic Figure 4, these structures are symmetrically located in two planes. Relative to the horizontal plane, it is the brain (without

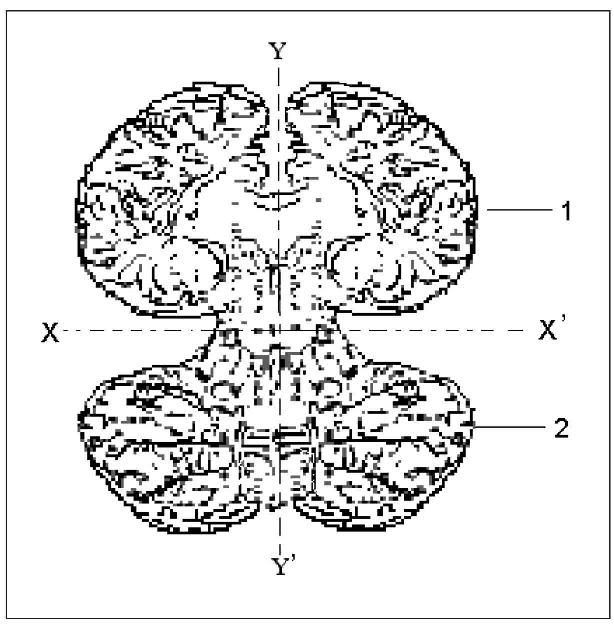

Figure 4. The two-plane symmetry of the brain. X X'; Y Y' - the planes of symmetry; 1 - encephalon, 2 – cerebellum

the cerebellum) and cerebellum itself that are symmetric along the craneocaudal axis. Though this view is not universally accepted, it still can be valid, the more so as the formation of the nervous tube has been debated for many years and some of its aspects still remain unclear (21). Through the prism of the proposed above concept of the crystalloid structural organization of the human organism, the encephalon and cerebellum can be regarded as symmetric structures that came to be located together as a result of integration and their functional load.

The nervous system has a radial structure and there are both pair and non-pair elements in it (the hemispheres of the encephalon and cerebellum are pair structures while the medulla oblongata and the spinal cord are non-pair ones.

Symmetry in the development of the cardiovascular system

The embryonal circulatory system is symmetric in two planes - it consists of four separate circulation arches with the natural center in the heart (Figure 5). Two of the arches, anterior and posterior, are inside the embryo while the other two originate in extraembryonal membranes and are the vessels of the yolk sac and allantois. In the course of further development, the posterior arch transforms into greater circulation while the anterior one partly into greater and partly into lesser circulation.

It can be assumed that ancient ancestors of the vertebrates had a bilateral series of hearts located at the basis of the arterial branchial arches as in Amphioxus lanceolatus. In the process of integration, several stronger segments formed a single non-pair segmented organ. After the spiralization stage, this organ again continued developing primarily in the two planes of symmetry and the resulting heart became a single pair structure when the atrial and then ventral septa had been formed. After the atrial septum is formed, we have cor trilocular biatriatum where the auricles are pair structures while the ventrical is a non-pair one. The two septa divide the heart into four antimeres of the two-plane symmetry. This is shown schematically in Figure 6.

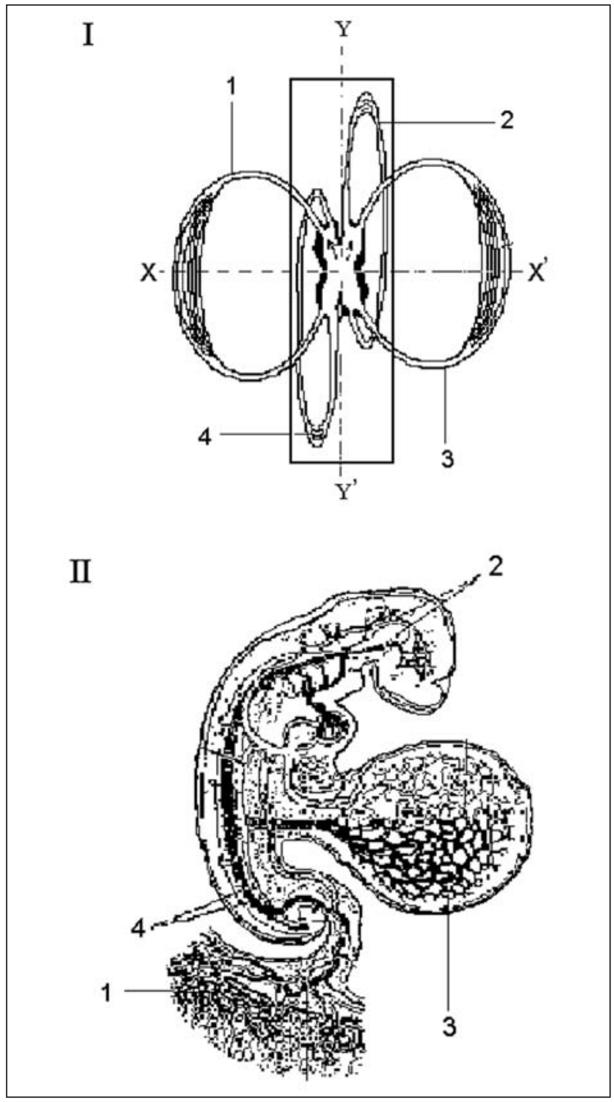

Figure 5. The circulation of the human embryo. I - The schematic of two-plane symmetry of the circulation of the human embryo; X – X'; Y – Y' – the planes of symmetry. II - Semi schematic presentation of the human embryo circulation after B.M.Carlson (21). 1 – Allantois circulation; 2 – anterior circulation; 3 – yolk sac circulation; 4 – posterior circulation

Initially, the heart, arteries and veins had their antimeres in the lymphatic heart and vessels. In this system, arteries and veins were pair structure while lymphatic vessels non-pair ones. The origin of the spleen is dual - as of a muscular organ to pump lymph and of a place for lymphoid tissue collection. In vertebrates, the sites of lymphoid tissue production are scattered throughout the whole organism. In different

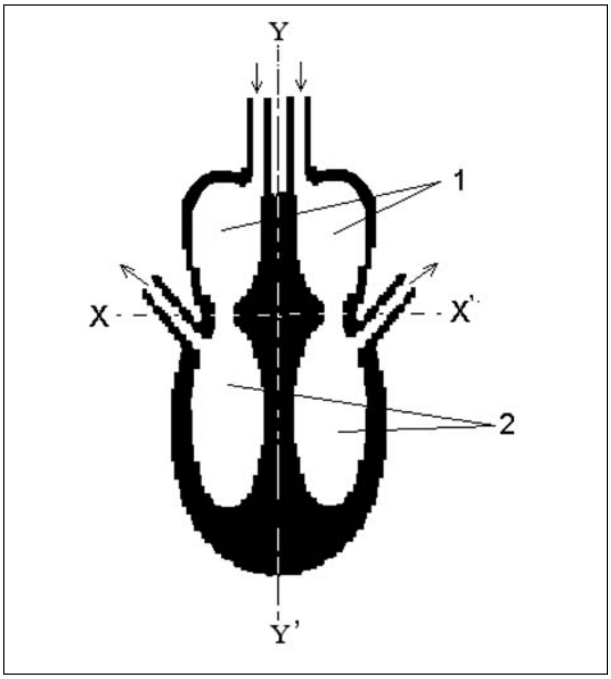

Figure 6. The two-plane symmetry of the heart. X X'; Y Y' - the planes of symmetry. 1 - auricles, 2 – ventricles

vertebrate species, lymphoid tissue is collected in the liver, kidneys, gonades, round the heart and in the intestinal wall. In adult specimens, out of all hemopoietic tissues only the spleen and lymph nodes inherent in mammals acquire the status of individual organs. Lymphatic hearts as a muscular organ are found in the tail of bony fishes. In amphibians, reptiles and some birds there are lymphatic hearts, small two-chamber muscular structures located at the junction of lymphatic vessels with veins and intensively pumping lymph over into the blood circulation. Data available make it possible to assume that the non-pair series of lymphatic hearts transforms in the process of integration into a single lymphatic heart.

Therefore, similar trends are observed in the development of the lymphatic system and that of the cardiac-arterial-venous system, i.e. the formation of a metameric series of hearts with their subsequent integration into a single heart and formation of structures in conformity with the two-plane symmetry and the pair/non-pair principle.

Later on, due to the loss of the motor function, the lymphatic heart becomes a place for lymphoid tissue collection and transforms into a spleen with its inherent hemopoietic function. With the loss of the motor function of the lymphatic heart, its relation to the development of the heart is severed. From that moment on, the blood heart continues developing autonomously in the two planes of symmetry.

Symmetry in the development of the digestive system cavities

On the whole, cavities develop in the same pattern as the whole organism, i.e. in conformity with the principles of symmetry and segmentation into pair and non-pair structures. As a result, there develops a non-pair antimere (the primary intestine) and pair structures (coeloms). Later on, the relationship between the two weakens, and these structures continue developing independently of each other.

Initially, the embrional intestine has the shape of a uniform tube closed at both ends. This structure can be rightfully regarded as an object of two-plane symmetry. Further development of the tube leads to its elongation and differentiation into definitive organs. Splanchnomesoderm surrounding the digestive tube forms the primary mesentery consisting of a ventral and dorsal parts. In the process of peritoneum development, the ventral mesentery is reduced while the dorsal mesentery remains actually unchanged. The reduction of the ventral mesentery is a result of intestinal spiralization.

If the gastrointestinal tract is visualized as a straightend tube starting with the oral cavity and ending with the rectal ampulla, the similarity of antimeres versus the sagittal and horizontal planes becomes clear.

In man, different segments of the gastrointestinal tract lying on the opposite sides from the horizontal plane are morphologically similar to a certain extent.

Conclusion

The above shows that the structural organization of man is characterized by a complex symmetry, which additionally confirms the validity of considering biological objects as particular macrobiocrystalloids.

The adult human organism has a radial two-plane (quadrilateral) symmetry where the plane symmetry is predominant. Out of the two planes of symmetry, sagittal and horizontal, the sagittal one is predominant:

a) the layout of organs is ruled by two principles - of two-plane symmetry and of radial symmetry around cavities;
b) the layout of organs of radial symmetry is subordinated to the two-plane symmetry principle;
c) out of the four antimeres of the two-plane symmetry, two are pair structures while the other two form a single structure;
d) some organs that are antimeres relative to the horizontal plane of symmetry, are located at the cranial end of the organism (the sensory organs, encephalon - cerebellum, heart - spleen and others).

This work and certain ideas of general crystallography show that the consideration of man as a macrobiocrystalloid and application of fundamental mathematics and physics in this domain can significantly contribute to the development of theoretical concepts of morphogenesis. This article is just a brief description of the proposed hypothesis and therefore many authors who have worked in the domain of crystallography and structural organization of biological bodies are not mentioned in it and many aspects of the human structural organization have not been included for brevity considerations. The proposed concept is more fully presented in our earlier publication (22).

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