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Creating a Fractal Dimension of Organs and Organisms

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Abstract: *The fractality of organs and organisms was discussed in the article. It is shown the fractal the dimension of the bronchial tree in mammals isn't depended from the body size and varied from 1.57 to 1.59. The fractal dimension of vessels of the retina is 1.7 and decreases in aging humans and in complications of diabetes. The value of fractal dimension of the circulatory system of man is in the range of from 2.5 to 2.6. It is found that the urinary system, as well as the bile ducts in the liver, has fractal geometry. It is shown that in the radial branch channels jellyfish Aurelia aurita presented in the form of standard dichotomous branching fractal trees. Provided that all the four sectors jellyfish Craspedacusta sowerbyi morphologically and functionally equivalent and have 4 radial beam symmetry and fractal.*

Keywords: *fractal, bronchi, circulatory system, urinary system, the bile ducts in the liver, jellyfish.*

In order to ensure the maximum exchange area with the environment and intensify the corresponding metabolism, living organisms, using fractal branching structures, increase the areas of phase separation and fill the spaces to the maximum. The biological function of fractal structures is to create a huge variety of biological form and function. Biological fractals are quantitatively characterized by fractal dimension as a measure of space filling. Studies of chaos and fractals in biology gradually cover all levels of organization of the living, from molecules to ecosystems [1, 2, 4, 5, 8-10, 12].

In [9], we showed the features of the fractal structures of biopolymers, such as polysaccharides - glycogen and chitosan, proteins, DNA, and lignin. The article [10] considers the spatial organization of cells and cell ensembles based on the concepts of fractal geometry. The purpose of this work is to discuss the features of the fractal structures of organs and organisms.

Fractality and fractal dimension of organs and organisms

Fractals not only surround us, they are also inside us and many animals and plants, since many organs of the human body and animals, as well as plants, have fractal properties. Using the possibilities of fractal structures, nature has designed the human body with exceptional efficiency. At the level of organs and the body, the fractal organization of the respiratory, vascular, urinary and other systems, as well as the bile ducts in the liver, is being studied [1-3, 12-13].

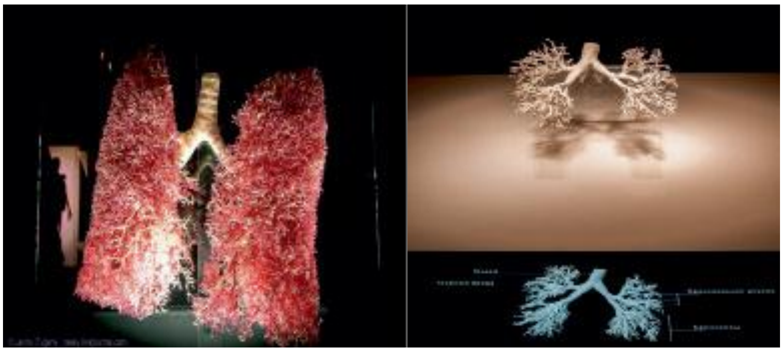
The fractal structure of the respiratory tract, through which air enters the lungs, has been most thoroughly studied.

The lungs are vital organs responsible for the exchange of oxygen and carbon dioxide in the human body and performing the respiratory function. The scheme of the lungs includes three major structural elements: bronchi, bronchioles and pulmonary alveoli.

The framework of the lungs is a branched system of bronchi. Each lung consists of many structural units (lobules). Each lobule has a pyramidal shape with an average size of 15x25 mm. At the top of the lung lobule enters the bronchus, the branches of which are called small bronchioles. In total, each bronchus is divided into 15-20 bronchioles. At the ends of the bronchioles there are special formations - acini, consisting of several dozen alveolar branches covered with many alveoli. The most important structural elements of the lungs are the alveoli, on which the normal exchange of oxygen and carbon dioxide in the body depends. Pulmonary alveoli are small vesicles with very thin walls, braided with a dense network of capillaries. Thanks to microscopic alveoli, the average diameter of which does not exceed 0.3 mm, the area of the respiratory surface of the lungs increases to 80 square meters. They provide a large area for gas exchange and continuously supply blood vessels with oxygen. During gas exchange, oxygen and carbon dioxide penetrate through the thin walls of the alveoli into the blood, where they “meet” with erythrocytes [6]. Thus, the lungs are an example of how a large area is "squeezed" into a rather small space [1].

The bronchi and bronchioles of the lung form a "tree" with numerous branches. Quantitative analysis of airway branching showed that it has a fractal geometry.

The average fractal dimension of the bronchial tree of rats, rabbits and humans is 1.587 1.58 and 1.57, respectively [13]. Thus, the fractal dimension of the bronchial tree in mammals does not depend on body size.



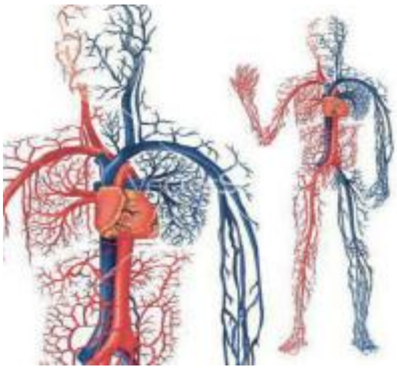
Rice. 1. The structure of the respiratory tract

Blood vessels are full tubes that carry blood. The vessels that carry blood from the heart to the organs are called arteries, and from the organs to the heart are called veins. Arteries and veins do not carry out gas exchange and diffusion of nutrients, they are just a delivery route. As blood vessels move away from the heart, they become smaller. The exchange of substances between blood and interstitial fluid occurs through the permeable wall of capillaries - small vessels connecting the arterial and venous systems. The vessels themselves and the blood circulating through them occupy a very small space - about 5 percent of the volume of the body. Humans have about 150,000 km of blood vessels. In one minute, about 60 liters of fluid seeps through the walls of all human capillaries [6].

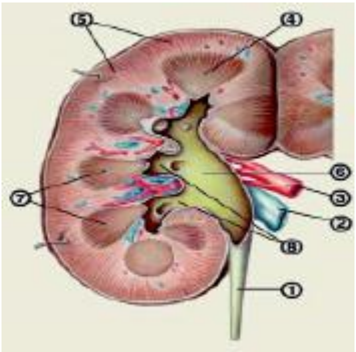
The fractal topology of retinal vessels, whose fractal dimension is 1.7, has been studied in detail [3, 12]. The review [3] provided evidence of a decrease in the fractal dimension and simplification of the retinal vasculature during human aging and complications of diabetes mellitus. It should be noted that the fractal dimension of the human circulatory system lies between 2.5 and 2.6 [1, 12].

The human urinary system is a system of organs that form, accumulate and excrete urine in humans. Consists of a pair of kidneys, two ureters, bladder and urethra.

The main role of the kidneys is to filter waste materials from the blood. The blood flow in the kidneys is carried out through the renal arteries (branches of the abdominal aorta) and is 1.25 l / min (25% of cardiac blood flow). The renal pelvis continues downward with the ureters descending to the bladder. The bladder serves to store urine. The final part of the excretory system is the urethra (urethra). As a result of filtration, reabsorption and secretion, the kidneys form urine - a hyperosmolar solution that accumulates in the bladder. On average, a person produces approximately 1.5 liters of urine per day [6, 11].



Rice. 2. Circulation



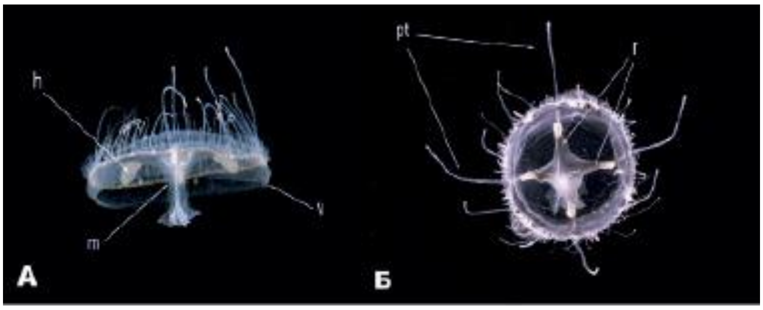
Rice. 3. Scheme of the structure of the kidney: 1 - ureter; 2 - renal vein; 3 - renal artery; 4 - medulla; 5 - cortical substance; 6 - pelvis; 7 - renal pyramids; 8 - large renal calyces.

The liver is the largest digestive gland, designed to secrete bile and process substances brought by blood through the portal vein. The biliary system of the liver should include bile capillaries, septal and interlobular bile ducts, right and left hepatic, common hepatic, cystic, common bile ducts and gallbladder.

Vessels, nerves and bile ducts pass through the gates of the liver, which are located in its transverse groove. The common bile duct joins with the pancreatic duct and empties into the duodenum. The gallbladder is located in the right longitudinal groove. This is a kind of reservoir for bile, which is emptied as needed at the time food enters the duodenum. The liver consists of hepatic lobules with a diameter of 1-2 mm, which are formed by hepatic cells located around the central vein in the form of radial beams. Each lobule is entwined with a dense network of small branches of the hepatic artery and portal vein. Capillaries depart from them, which penetrate into the lobules between the hepatic beams. Capillaries, flowing into the central vein of the lobules, merge to form larger veins that open into the hepatic veins. The latter are tributaries of the inferior vena cava. Between the liver cells of the beams are bile capillaries, or passages, which at the exit form interlobular grooves. Connecting, they form the left and right hepatic ducts, which in the region of the gate of the liver are connected to the common hepatic duct [6].

Rice. 4. Bile ducts of the liver

The jellyfish Aurelia aurita was chosen and considered as a fractal model of an organism in [4]. The jellyfish system is represented by branching epithelial canals located almost in the same plane - the jellyfish umbrella. The gastrovascular system of scyphomedusa performs the functions of transporting nutrients and excreted substances, as well as reproductive products. In the scyphomedusa Aurelia aurita, it is customary to distinguish three types of radial gastrovascular canals: 8 non-branching adradial, 4 branching perradial (located in the same plane as the oral lobes and flow into the oral cavity) and 4 branching interradial (flow into the gastrocirculatory canals bordering the lateral surfaces stomach pockets). Fluid with food particles from the gastric (more precisely, gastrogenital) pockets enters the adradial canals, and then into the annular canal. From the annular canal, the fluid collects into the perradial and interradial canals, from which it eventually enters the oral cavity [14]. In the gastrovascular channels, intracellular digestion occurs. The most suitable for analysis are the so-called perradial channels, each of which has one common trunk located between the gastric pockets. It is shown that the branches of the perradial canals of the jellyfish Aurelia aurita are presented as standard dichotomously branching fractal trees.



Rice. Fig. 5. Structure of the jellyfish Craspedacusta sowerbyi A – side view, B – dorsal view, h – gonads, m – oral proboscis or manubrum, v – sail, pt-perradial tentacles, r – radial canals of the gastrovascular system.

On fig. 5 shows the structure of the jellyfish Craspedacusta sowerbyi. The shape of the body of a newly budded jellyfish (about a millimeter in diameter) is close to spherical, but changes during growth, turning into an oblate hemisphere with a diameter of up to 20 mm. In addition, in the course of development, the number of tentacles significantly increases (from 16 to 500), as well as the balance organs absent in young individuals, statocysts, are laid down and increase in number. As in other members of the family Olindiasidae, the corolla of the tentacles is significantly shifted to the upper side of the umbrella. The four radial channels of the digestive system are associated with the gonads, which have the shape of pockets hanging down into the cavity of the umbrella. The oral proboscis is well developed and protrudes beyond the umbrella [7].

As can be seen, all four sectors of the jellyfish Craspedacusta sowerbyi have radial 4-beam symmetry, are functionally and morphologically equivalent, and are fractal. New branches originate from the annular canal.

Summary

1. It is shown that the fractal dimension of the bronchial tree in mammals does not depend on the size of the body, varies within 1.57 - 1.58.
2. The fractal dimension of the vessels of the retina is 1.7 and decreases with human aging and complications of diabetes mellitus.
3. It turns out that the fractal dimension of the human circulatory system varies from 2.5 to 2.6.
4. It has been established that the urinary system and bile ducts in the liver have a fractal geometry.
5. It is shown that the branches of the perradial canals of the jellyfish Aurelia aurita are presented as standard dichotomously branching fractal trees.
6. All four sectors of the jellyfish Craspedacusta sowerbyi are functionally and morphologically equivalent and have radial 4-beam symmetry and fractality.

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