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METHODS FOR DETERMINING THE COMPLEXITY OF HUMAN ORGANS AND TISSUES

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Fractal geometry can analyze the complexity of human organs and tissues on different scales and be diagnosed on this basis. The complex structure of many biological systems, such as the lungs, liver and brain, can be seen in fractal salinity organs and self-similarity at different levels of the body. For example, describing the branching structure of a bronchial tree in the lungs using fractal geometry, small bronchioles exhibit similarities to large bronchi. This fractal structure ensures effective oxygen exchange and helps to maximize the surface area available for oxygen exchange. Likewise, the branched structure of blood vessels in the cardiovascular system manifests fractal structures, with smaller vessels having a structure similar to larger ones. This fractal structure is important for the efficient supply of nutrients and oxygen to the body's tissues.

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

Fractal analysis has also been applied to the study of the structure of the human brain. The complex network of nerve vessels and their common fractal properties is manifested, and Fractal analysis is used to determine the Fractal measure of brain salinity and to better understand brain activity function.

In general, the use of fractals to analyze the complexity of human organs and tissues contributes to the identification of new methods about the structure and function of the body, as well as the development of new medical technologies, methods of treatment[13].

The main function of the vascular system is to provide all cells of the body with oxygen and other important nutrients. This task is effectively carried out by vascular systems, which are structurally located similar to tree branches, and each division stage is divided and distributed in a binary form. Due to the extreme complexity and multilevel topology of the vascular network, no clear idea is given about which parameters should be used to characterize the structure of blood vessels. In addition, a normal development criterion is necessary to diagnose diseases. Fractal analysis of the assessment of various healthy and pathological circulatory systems has been used to solve these problems. The distribution of vascular networks is not strictly fractal, as they do not show a measure constant in the infinite range, but they have self-similarity

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properties and are the same at each stage of the propagation process, producing images with fractal structure. This suggests that at least the arterial system of the brain consists of a union of two components-that is, a diffuse fractal structure of capillary vascular networks and large vessels that fill the space uniformly. In fractal geometry, the properties of self-like structures observed over a wide range of sequential divisions are quantified using fractal measurement of the complexity of structures. This measurement is similar to knowing how much the surface area occupies, but vascular density analysis is seen as a quantitative determination of space filling. Thus, if the value of the Fractal measure of binary branched blood vessels is closer to two, then the blood vessels fill the gap so efficiently[20]. Therefore, the upper bound of the Fractal measure corresponds to the topological measure. Fractal measurement assessment is used to characterize the human retina, various tumor diseases, as well as to analyze the two-dimensional arterial blood vessels of the human lungs, obtained using computed tomography data. In addition, scientific studies show that vascular networks can be described in various diseases using fractal measurement assessment. It is assumed that any pathological morphology of the blood vessel distribution leads to a decrease in fractal measurement. This makes it possible to more accurately calculate the characteristic topology of large arteries. The image of the deterministic part of the cerebral artery blood vessels is compared to the sets of cylinders. For each of them, the radius and coordinates of their centers are taken as the basis. In this, the radius of the cylinder corresponded to the radius of the stroke. The diameters of fractal-structured cerebral arteries were calculated, and the smaller veins, which were kings of vascular arteries, were separated into a separate stochastic structure. The stochastic part is made in the form of a binary tree[7].

It has been found that bifurcation is almost always formed in accordance with morphometric analysis data and at the time of branching of the vascular system. As the vessels grow, the arterial vessel (i) divides into two vessels, each of which in turn forms divisions until it reaches a level corresponding to the minimum radius of the arterial vessel. In this model, the vascular lengths are 8 mkm. However, each division process consists of several basic steps (figure 1.1). The radius of the input parameters, the length of the blood vessel and the coordinates of the nodes of the arterial vessel, as well as the model parameters that determine the geometric measurements of the vascular branching, are considered important. The reduction in the length of the growing vessels in relation to the length of the arterial vessel is characterized by the reduction index of the length of the vessel (λ):

$$L_{2i+1,2i+2} = \lambda L_i . \qquad (1.1)$$

There is a relationship between the radius of the arterial blood vessel and the radii of the right and left vessels, this relationship is determined by the following formula:

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$$R_i^{\gamma} = R_{2i+1}^{\gamma} + R_{2i+2}^{\gamma}. \qquad (1.2)$$

The formula of the Murray, where the $\gamma -$ is distribution of the vessels indicator its values vary from two to three. The mean-dimensional radius of the resulting vessels are determined by the minimum radius measurement of the arterial blood vessel[12]:

$$\begin{cases} r_{low} = \dfrac{R_{low}}{R_i}; \\ r_{high} = \left(1 - r_{low}^{\gamma}\right)^{\frac{1}{\gamma}}; \end{cases} \Rightarrow \begin{cases} r_{2i+1} = r_{low} + \left(r_{high} - r_{low}\right) \cdot U(0,1); \\ r_{2i+2} = \left(1 - r_{2i+1}^{\gamma}\right)^{\frac{1}{\gamma}}; \end{cases} \qquad (1.3)$$

here is $R_{low} -$ the minimum radius of the vein in the arterial system; $U(0,1) -$ is standard a uniform distribution. The angles between the radius of the resulting veins and the lengths of the base vein are found below:

$$\begin{aligned} &\phi_{2i+1} = 2\pi U(0,1); \\ &\phi_{2i+2} = \phi_{2i+1} + \pi. \end{aligned} \qquad (1.4)$$

In addition, one can also calculate the angles of the base veins between the resulting veins, relying on radius of main veins:

$$\begin{aligned} \theta_{2i+1} &= \arccos\left(\frac{r_{2i+1}^2}{2} + \frac{r_{2i+1}^{-2}}{2}\left(1 - \left(1 - r_{2i+1}^{\gamma}\right)^{\frac{4}{\gamma}}\right)\right); \\ \theta_{2i+2} &= \arccos\left(\frac{r_{2i+2}^2}{2} + \frac{r_{2i+2}^{-2}}{2}\left(1 - \left(1 - r_{2i+2}^{\gamma}\right)^{\frac{4}{\gamma}}\right)\right). \end{aligned} \qquad (1.5)$$

By calculating the distances to the nearest divisions using their coordinates obtained from the division nodes, the intersections between the veins are determined.

The degree of surface filling under consideration is assessed by the complexity of the blood vessels, therefore, at the final stage, the location of the nodes is checked:

$$\Omega_k = \sum_{i=1}^{n} E_i; \quad E_i = \left\{ \vec{x} : \sum_{j=1}^{n} \left(\frac{x_j - c_{i,j}}{R_{i,j}} \right)^2 \le 1 \right\}, \qquad (1.6)$$

Here $c_{i,j}$ and $R_{i,j} -$ central coordinates of vascular nodes.

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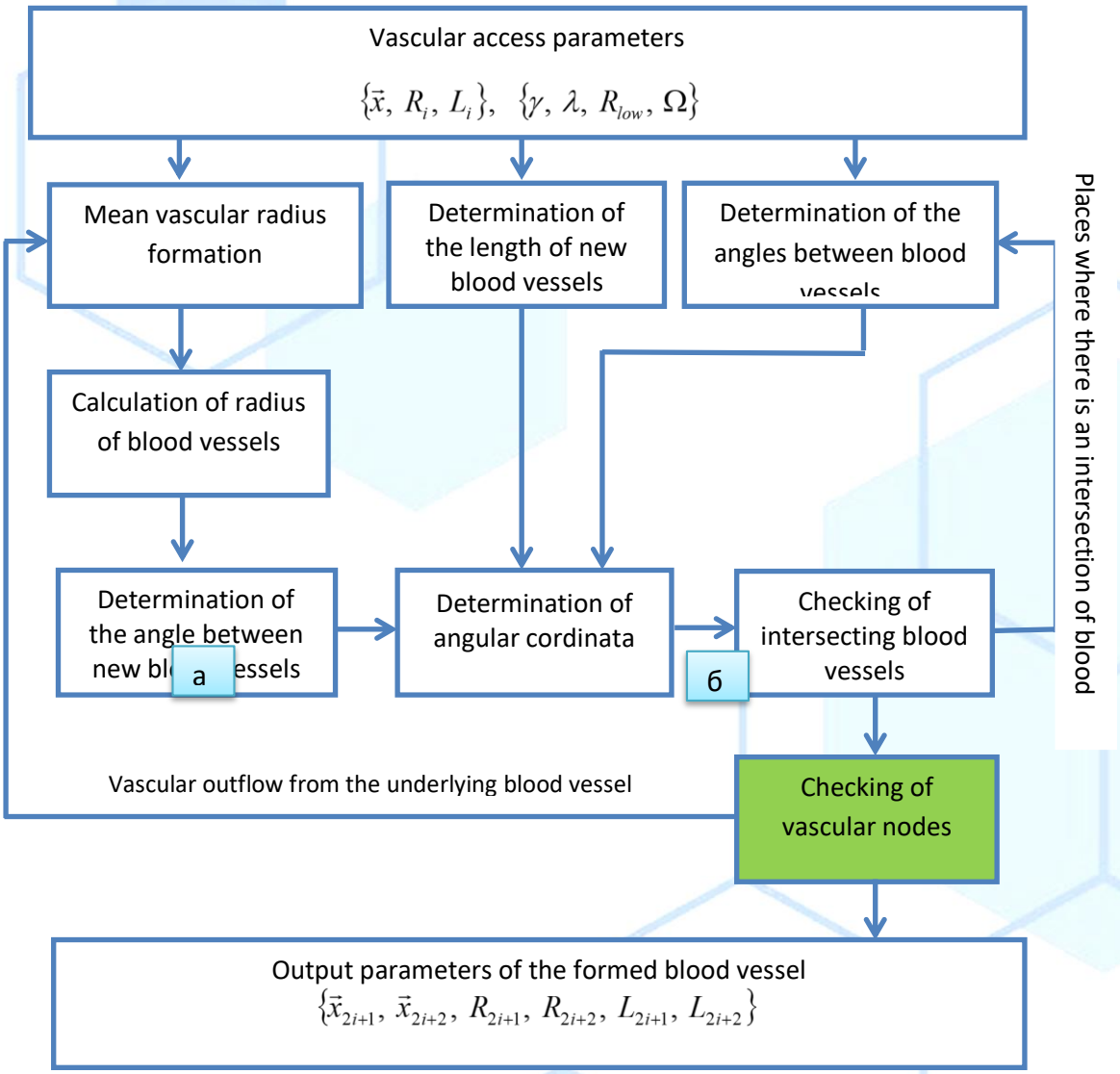
$D-$ this measure is the degree of occupancy (filling) of the surface to which the Fractal-structured image is given, which is defined as: the image is decomposed into cells[18],



$N(r)-$ number of boxes, $r-$ size of boxes. The degree of accuracy of the Fractal measure, of course, depends on the number of boxes.

$$N(r)-r^{-FD}. \qquad (1.7)$$

Application of fractal analysis

There $FD-$is fractal dimension. The method of box counting consists in determining the number of different non-empty boxes. The value of the Fractal measure is calculated based on the approach to the logarithmic curve.

$$FD=\lim_{r\to\infty}\frac{\log N(r)}{\log\frac{1}{r}}. \qquad (1.8)$$

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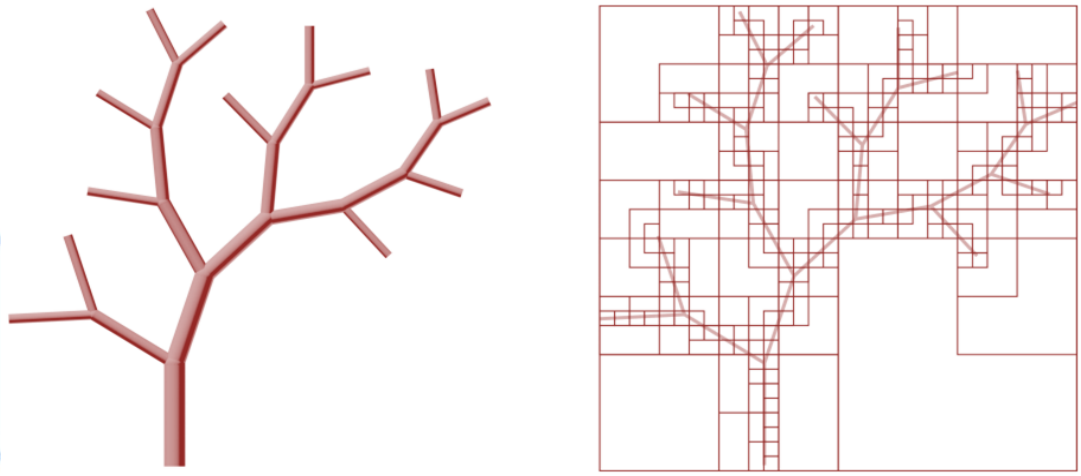
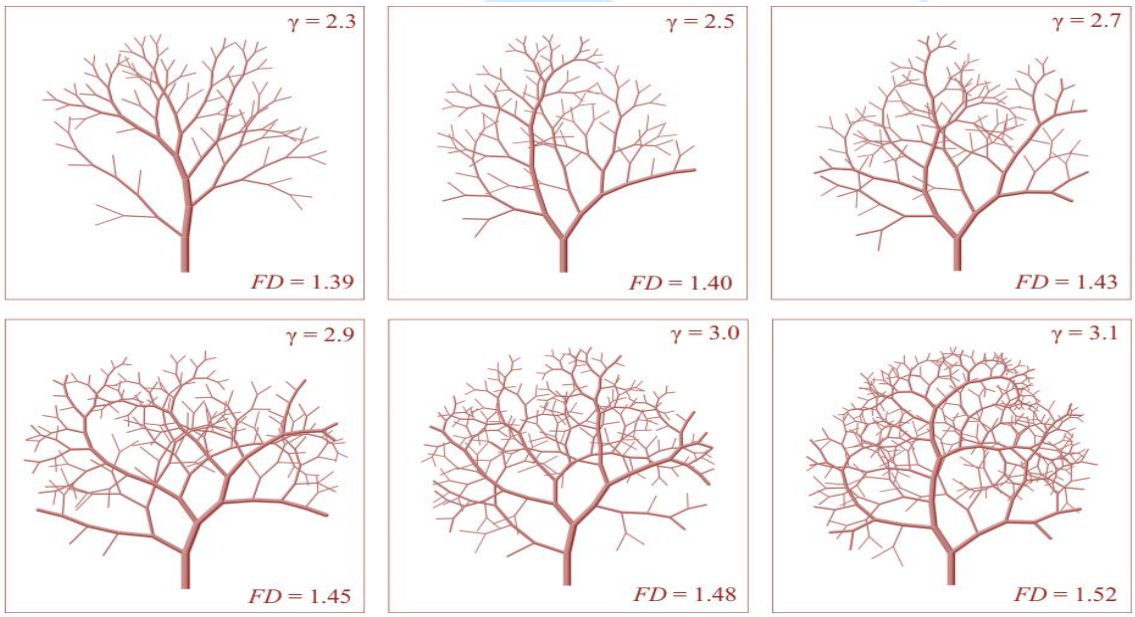


1.2-figure. Schematic view of determining the Fractal measure of the binary distribution of blood vessels. 1.2(a)- blood vessel; 1.2(b)- image of sequential division of a blood vessel into boxes

Figure 1.2 shows the calculation of the Fractal measure of the binary distribution of blood vessels and is represented by a central line to calculate the geometric measure of each branch. But the radius of the branch being considered does not affect the Fractal measure (figure 1.2(a)).

Therefore, in order to more accurately assess the complexity of the vascular network, each blood vessel is evenly divided into cells. The average value of the length of the cells was considered to be about 2 micrometers 1.2(b)-figure.

The main influence on the location of blood vessels and the topology of tree branches is their binary division (γ) also related to the indicators of the reduction of vascular length(λ), but more often refers to the stochastic part of fractal images. Because the geometric measurements of the base blood vessels change less. Additional parameters that limit the complexity of these are the place for the construction of the



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vascular system (Ω), minimum possible radius of blood vessel (R_{low}) and related to the biological properties of the object under study.

1.3-figure. Fractal measure has been defined for different values of the binary partition index(γ)

The main parameters of the considered model are presented in Figure 1.3, a fractal-structured image of a binary tree for different values of the binary scattering index, in order to assess the influence of the vascular system on its topology without taking into account the limiting factors.

In the images being viewed, the radius of the arterial blood vessel is initially 40 mkm. Vascular radius after binary fission is viewed until it meets the 5mkm. From Fractal structured representations of trees, it can be seen that with an increase in the division index, the density of tree branches increases significantly.

This in turn expresses the fact that Fractal-structured images fill the facing surface in a more complex way.

To quantify space filling, the values of the Fractal measure are calculated for each constructed tree.

With a decrease in the vascular growth index, mainly an increase in the index of vascular length contraction, the value of the Fractal measure increases. This corresponds to experimental data on different pathological values of blood vessels[11].

In the analysis of medical images of vascular systems, fractal measurement is usually evaluated on the basis of two-dimensional images. This is due to the difficulty of obtaining images of structures of complete three-dimensional vascular systems and the impossibility of individual segmentation for volumetric imaging. However, assessing the complexity of vascular systems with two-dimensional images, the calculation is most convenient in terms of performing actions.

Summary

In conclusion, the determination of the complexity of human organs and tissues is a multifaceted endeavor that relies on a diverse array of methodologies spanning various scientific disciplines. Through histological analysis, molecular biology techniques, bioinformatics, computational biology, advanced imaging modalities, systems biology approaches, functional assays, organoids, and omics technologies, researchers can elucidate the intricate structural, functional, and organizational characteristics of tissues at different levels of resolution.

These methods not only facilitate the exploration of cellular composition, molecular signatures, and physiological functions within organs and tissues but also enable the interrogation of complex biological networks, regulatory mechanisms, and dynamic interactions underlying their functionality. Moreover, the development of innovative techniques such as organoids and high-throughput omics platforms has

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opened new avenues for studying tissue complexity in vitro and in vivo, offering unprecedented insights into health and disease.

By leveraging these sophisticated methodologies, researchers can unravel the complexity of human organs and tissues with unprecedented detail, advancing our understanding of normal physiology, pathological processes, and therapeutic interventions. Ultimately, the integration of multidisciplinary approaches paves the way for transformative discoveries and the development of personalized strategies for diagnosing, treating, and preventing a wide range of human diseases.

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