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Human portal system morphometry based on 3D computer aided modelling

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SUMMARY

There is no discussion about human portal system variability. Features of interposition, veins branching included in this system, stereometric and lineal characteristics define its development, stream and ways of operation interference for several surgery diseases, which all in all decides the end of surgery pathology. Morphometry study of portal system using computer-aided modelling and methods of computational anatomy has been performed. DICOM data segmentation was performed using Dragonfly software (Object Research Systems, Canada) at the Innovation Technology Management Resources of the Reaviz University. Using series with arterial and vein contrast, we performed the segmentation of contrasting vessels, obtained three-dimensional data topology in .obj format. Then we processed the obtained models using scripts prepared for the pythonOCC framework. We built the central lines of the vessels and formed the branching tree. Methods of computational hemodynamics were implemented using the Visual-CFD application for OpenFOAM environment (ESI, France). Veins forming the portal vein are presented by three systems; in every one of them there are scapi and affluxes, which are different in branching types and other morphological characteristics. The superior mesenteric vein, for instance, is characterized by interjacent branching type, has one scapus 93,5 (78,5; 119,5) mm in length and diameter 9,5 (6,5; 12,0) mm, going to portal vein under the corner 170,0 (160,0; 175,0)^{0}, and formed by venous inflows of majority unpaired organs of upper and down floors in abdominal cavity. Affluxes of the superior mesenteric vein have almost the same diameter from 3,5 to 12 mm but the length. The shortest affluxes are jejunal ones (40,0 (38,5; 46,5) mm) and right gastroepiploic vein (45,0 (38,5; 53,5) mm), then iliac (50,0 (48,5; 53,5) mm), middle colonic (60,0 (58,5; 63,5) mm) and iliac colonic (70,0 (68,5; 78,5) mm) veins. The system of inferior mesenteric vein contains a lower number of veins going to its bed in comparison with vessels net of superior mesenteric vein. Magistral type of branching of inferior mesenteric vein is found in 23% of cases and in 77% of cases it has interjacent type of branching. In case of interjacent type of branching mesenteric vein goes to superior mesenteric vein between right colonic and jejuna veins. Inferior mesenteric vein of magistral type goes to splenic vein in most cases (as it is shown on picture 1) or it is independent afflux of portal vein. Its diameter is significantly less than diameter of superior

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mesenteric vein and makes 4,5 (2,0; 6,5) mm. The current research gives quantitative orienting points for main vein structures of portal vein system. The research results have allowed adding science materials about types of branching and morphological patterns of portal vein and its branching. Variations common for every system are preferably being used for regulation of the discussed subject in terms of tactic patients' curing with syndrome of portal hypertension or at the step of pre surgical preparation.

Key words: Portal system – Morphometry – 3D modelling – Computational anatomy – Computational fluid dynamics

INTRODUCTION

There is no discussion about human portal system variability (Khamanarong et al., 2016; Sharma et al., 2017; Cheluvashetty and Rachapalli., 2017; Guerra et al., 2017). Features of interposition, veins branching included in this system, stereometric and lineal characteristics define its development, stream and ways of operation interference for several surgery diseases what all in all decides the end of surgery pathology (Gayvoronskiy et al., 2018; Iqbal et al., 2017). According to main abdominal surgeons, diagnostics development of portal system features building gives answers for many questions about curing and diagnostic tactics in pre-surgical (Nakamura et al., 2002; Schmidt et al., 2008; Sakamoto et al., 2017).

Medical imaging of vessels, organs and whole systems research in different areas of medical practice shows good diagnostic results (Akagi et al., 2019; Karunakaravel, 2016). The research made by a standing X-ray instrument in order to find out features of portal-system rectal vessels has shown a high informative capacity of the method, and allowed to find out characteristics postmortem –morphometry, location and vein branching (Silant'eva, 2009; Gibson et al., 2018; Ghesu et al., 2019).

The variant anatomy of magistral vessels of the portal vein was learnt by a number of authors (Lang et al., 2019; Durand et al., 2020). Gaivoronskiy and his coauthors presented main results in 2018, which were characteristic of formation variants of the portal vein scapus, quantity measurements of vein length and diameter and its roots, showing a wide range of morphometric characteristics. The results obtained by MSCT of abdominal cavity were defined as markers allowing to plan an optimal surgery tactic, and to reduce, after operation, difficulties from the side of the mesoportal system, taking into account terebrant major thrombosis of the portal vein or the superior mesenteric vein (Gayvoronskiy et al., 2018). However, the results might be implemented only in case of operation of abdominal organs where magistral vessels of the portal system work. According to Kolsanov (2017), for a full research of the portal system living people, it is eligible and competent to use computer tomography with bolus contrasting, which is one of the most precise methods to estimate morphometric features of vessel formations. Such research is the best to learn variant angioanatomy with a visualization of vessels of 1 mm diameter and more, as it allows to use this method not only in choosing the tactic of surgery curing of portal hypertension, but also in all types of liver and pancreas resection, liver transplantation, etc. (Kolsanov et al., 2017).

A new branch of human morphology is computational anatomy. Computational anatomy is now understood to be a new discipline at the junction of human morphology and information and computing technology. Despite the fact that the object of its study is the human body, computational anatomy offers a new, synthetic approach to cognition, in which organs and tissues are studied by layers of data, in their movement and function, and the visual approach is supplemented by a superficial one, using artificial intelligence technologies.

MATERIALS AND METHODS

Our aim was to perform morphometric study of portal system using computer aided modelling and methods of computational anatomy.

Contrast research was done among 53 men who were patients in surgery departments at Krasnoyarsk regional hospital #1, Russia (KRH). Criteria for taking part in this research were patients with surgery diseases of abdominal organs without blood interference. The average age of the patients was 54.9 ± 1.7, from 36 to 71 years old. Estimations were made using 3D models of portal system (working stations GE Advantage Workstation, Siemens singo.via), based on multi-slices computed tomography of abdominal cavity with bolus contrasting with help of medication “Ultravist-370”. The volume of the used contrasting stuff made 100 ml, the speed of infiltration was 4 ml per second, and the average radial strain was 11,3 m3v. DICOM data segmentation was performed using Dragonfly software (Object Research Systems, Canada) at the Innovation Technology Management Resources of the Reaviz University. Using series with arterial and vein contrast, we performed the segmentation of contrasting vessels, and obtained three-dimensional data topology in .obj format. Then we processed the obtained models using scripts prepared for the pythonOCC framework. We built the central lines of the vessels and formed the branching tree. Methods of computational hemodynamics were implemented using the Visual-CFD application for OpenFOAM environment (ESI, France).

X-ray research was made in order to learn formation variants of portal system and morphometric patterns, and types of vessel branching at different levels of structure organization.

To define types of portal vein division and its branching formation, the Nakamura et al. (2002) classification was used to define types of branching, and Shevkunenko classification was used (magistral, interjacent and loose types) (Shevkunenko, 1949; Gadzijev and Eldar, 1996).

The length, diameter, and corner of formation of portal vein towards the middle line of the human body were estimated, as well as corners of vessel formation creating the portal vein in the frontal plane. Measurements were made by building a central vessel line with further measure of lineal patterns (Kolesnikov, 2003; Covey et al., 2004).

Statistics processing was made by using analysis SPSS Statistics 17,0. Normality of dividing was defined based on Shapiro-Wilk criteria. Characteristics of variant rows for quantity features with non-parametric dividing and data with parametric dividing taking into account their small number were presented with help of measures of central tendency —middle (M), median (Me), mode (Mo) and dispersion measures– mean square departure, swing, interquartile interval (P25; P75). Comparing two independent selections of nonparametric data and nonparametric criteria Mann-Whitney (U-test) was used.

Ethic rules and normal ranges were obeyed in full during the research (extract from meeting report of local ethic committee №84/2018 dated 06.06.2018).

RESULTS

3D models of computed tomographic images of the portal system among all examined men are characterized by stability of portal vein existence, its right branch (with front and back branching), left branch (with diametrical and omphalic parts) as well as splenic, superior and inferior mesenteric veins and veins of a higher row creating main afflux. According to X-ray, the portal vein is a cylinder with diameter of 14.5 mm (13.0; 14.5). Length is in the range from 58 mm and to 71 mm and the average length is about 63 mm. The portal vein is created under the corner of 68° degrees towards man’s body middle line corner what proves earlier published data about frequency of the corner (Gayvoronskiy et al., 2018).

Morphometric measures of portal vein branching are shown in Table 1.

Creation corners of the main branching of the portal vein are statistically different ($p<0.05$); the creation corner of the right main branching makes 135.0 (130.0; 141.0)°, so the left branching towards the portal vein makes 53.0 (49.5; 60.0)°. In most cases, both branchings are created according to a classical type of branching (T. Nakamura), and in a few cases there have been trifurcations and intrahepatic departure of front branching. The left branching of the portal vein is longer than the right one (82.0 (79.5; 89.0) mm and 46.0 (39.5; 47.5) mm) but the diameter is almost the same at 13.0 (10.5; 14.5) mm and 11.0 (10.5; 12.0) mm). The right branching of the portal vein is divided dichotomically for front and back branching; the length of the front branching (75.5 (73.0; 77.5) mm) and back one (80.5 (75.5; 81.0) mm) and their diameters (8.0 (7.0; 8.5) mm and 7.0 (6.5; 8.5) mm) are statistically the same with the exception of formation corners. The front branching is a kind of continuation of the right branching and goes under the corner of 160.0 (145.0; 170.0)°, the back branching forms almost a straight angle with the right branching (115.0 (100.0; 125.0)°). Parts of the left branching of the portal vein have peculiarities in length. The diametrical part (53.0 (48.0; 61.0) mm) is always longer than the omphalic one (31.0 (28.0; 39.0) mm), their diameters are statistically the same.

As a result, variants of morphometric patterns of portal vein intrahepatic vessels are obvious, although branching variants are not various and lead to one type.

Veins forming the portal vein are presented by three systems. In all of them there are scapi and affluxes that are different in branching types and other morphological characteristics. The superior mesenteric vein (Fig. 1), for instance, is characterized by interjacent branching type (23), has one scapus 93.5 (78.5; 119.5) mm in length and diameter 9.5 (6.5; 12.0) mm, going to the portal vein under the corner 170.0 (160.0; 175.0)°, and formed by venous inflows of majority unpaired organs of upper and down floors in the abdominal cavity. Affluxes of the superior mesenteric vein have almost the same diameter from 3.5 to 12

Table 1. Morphometric measures of portal vein branches found by X-ray.

Pattern	Length Me [P_{25}; P_{75}] mm	Diameter Me [P_{25}; P_{75}] mm	Formation corner, degree*
1	2	3	4
Portal vein	63.0 [58.0; 71.0]	14.5 [13.0; 14.5]	68.0 [46.0; 72.0]
Right branch of portal vein - anterior branch - posterior branch	46.0 [39.5; 47.5] 75.5 [73.0; 77.5] 80.5 [75.5; 81.0]	11.0 [10.5; 12.0] 8.0 [7.0; 8.5] 7.0 [6.5; 8.5]	135.0 [130.0; 141.0] 160.0 [145.0; 170.0] 115.0 [100.0; 125.0]
Left branch of portal vein - diametrical part - omphalic part	82.0 [79.5; 89.0] 53.0 [48.0; 61.0] 31.0 [28.0; 39.0]	13.0 [10.5; 14.5]	53.0 [49.5; 60.0]

*Formation corner of portal vein towards middle line of a man’s body

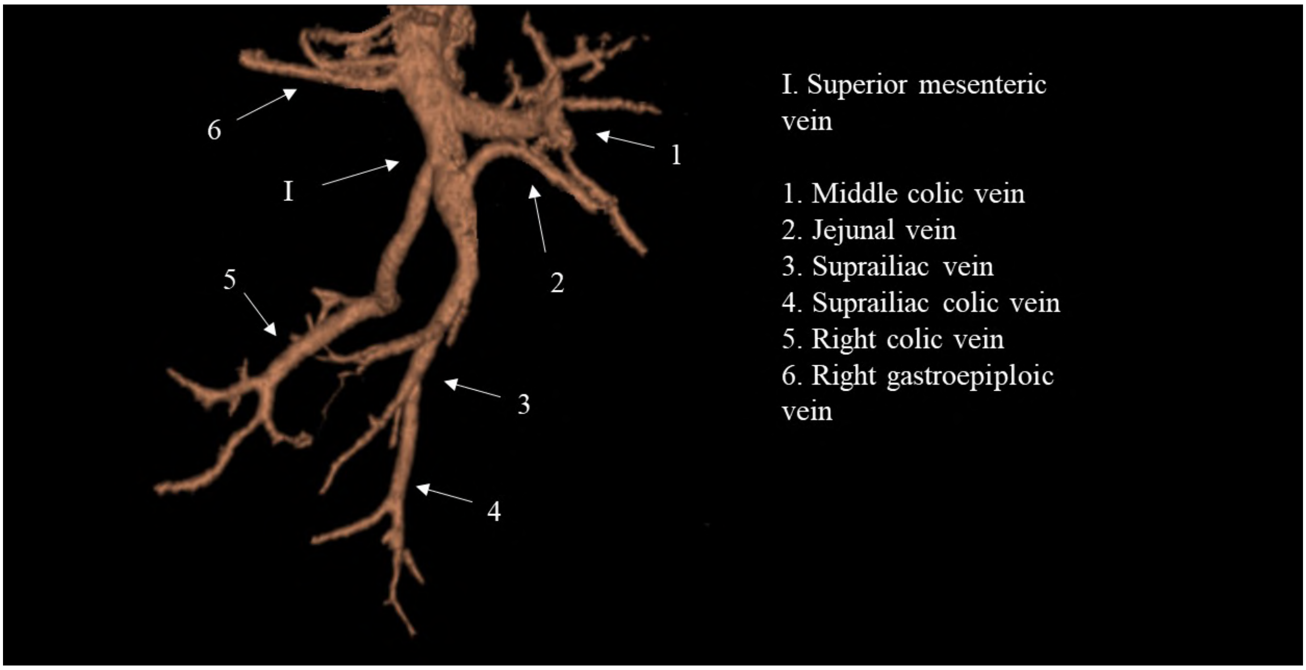

Fig. 1.- 3D model of human superior mesenteric vein.

mm but the length. The shortest affluxes are the jejunal ones (40.0 (38.5; 46.5) mm) and the right gastroepiploic vein (45.0 (38.5; 53.5) mm), then the iliac (50.0 (48.5; 53.5) mm), the middle colonic (60.0 (58.5; 63.5) mm) and the iliac colonic (70.0 (68.5; 78.5) mm) veins. The maximum length is defined in the right colonic vein (115.0 (108.5; 120.5) mm), draining ascending and diametrical colonic parts of the colon. Angles of convergence of every afflux of the superior mesenteric vein are defined by internals from which venous drainage is made. As long as iliac and iliac colonic veins are caudal branches, so their corners measures lead to large scale and make 160° (155.0; 171.0) and 160.0° (150.0; 171.0). The given measure is statistically maximum towards angles of convergence of other veins of this system. The average measure is for the middle (120.0° (110.0; 131.0) and right (140.0° (130.0; 145.0) colonic veins. Minimal measures are common for jejunal and right gastroepiploic veins (70.0° (60.0; 81.0) and 85.0° (80.0; 91.0), respectively.

The system of the inferior mesenteric vein (Fig. 2) contains a lower number of veins going to its bed in comparison with vessels net of superior mesenteric vein. Magistral type of branching of inferior mesenteric vein is found in 23% of cases and in 77% of cases it has interjacent type of branching (23). In case of interjacent type of branching mesenteric vein goes to superior mesenteric vein between right colonic and jejuna veins. The inferior mesenteric vein of the magistral type goes to the splenic vein in most cases (as it is shown on Fig. 3), or it is independent afflux of portal vein. Its diameter is significantly shorter than the diameter of the superior mesenteric vein, and makes 4.5 (2.0; 6.5) mm. Length measures are still variant depending on branching features, but statistically they are not different from the analogous measure of the superior mesenteric vein. The formation corner in the case of influx to upper or splenic vein is in a range from 135 to 151°. Lineal patterns and formation corners of affluxes of the inferior mesenteric vein do not have statistically significant differences (Table 2).

In comparison with systems of superior and inferior mesenteric veins, the splenic vein (Fig. 4) always has magistral type of branching. The vena lienalis has an intermediary diameter of 7.5 (5.5; 8.5) mm, a maximum length of 125.0 (97.5; 129.5) mm, and goes to the portal vein under a less corner (100.0° (95.0; 111.0) towards the analogous measures of the superior and inferior mesenteric veins. Affluxes of splenic vein are numerous; measures of lineal patterns are statistically not different. Average measures of length, diameter and angle of convergence of the left gastroepiploic vein make 20.0 (13.5; 29.5)

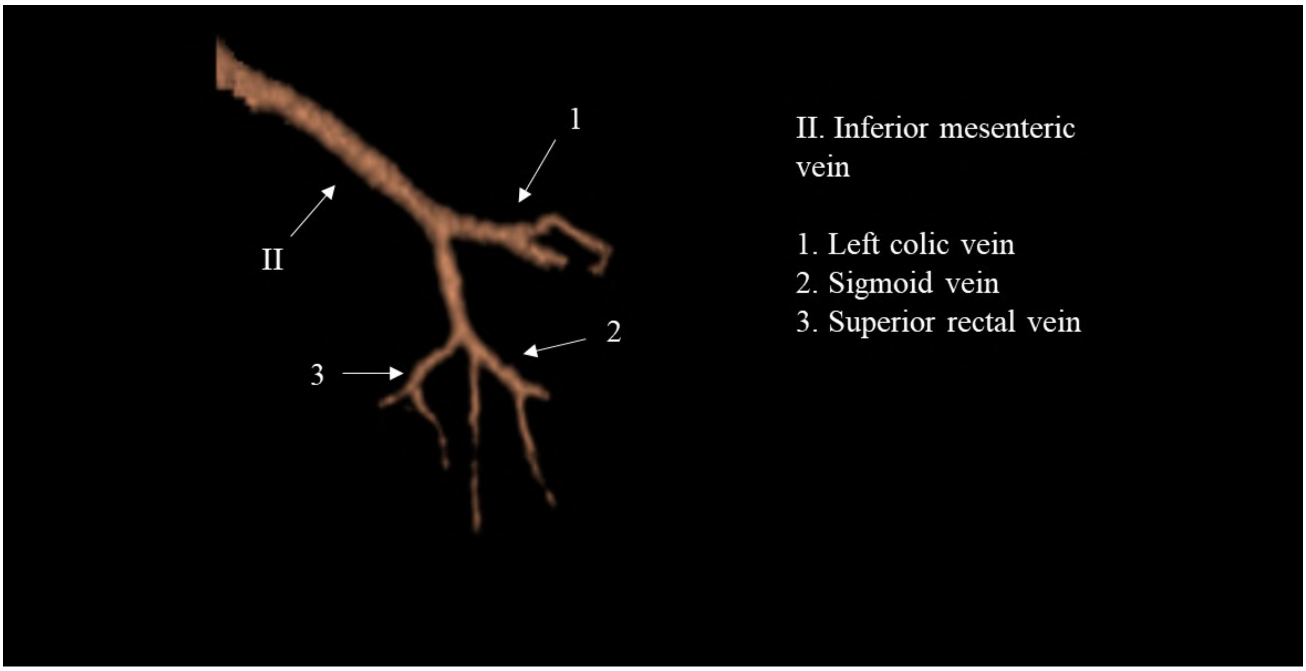

Fig. 2.- 3D model of human inferior mesenteric vein.

mm; 5.0 (4.0; 6.0) mm and 130.0° (120.0; 135.0). The short veins of the gaster go to splenic vein under the straight corner (90.0° (90.0; 95.0), and average measures of length and diameter make 12.0 (7.0; 18.5) mm and 4.0 (3.0; 4.5) mm.

Estimating the length, diameter and formation corners of the portal vein and its affluent vessels, we have come to a conclusion that in order to study the system of the portal vein at different levels of its structure organization, it is needed to use modern methods of X-ray diagnostics with help of contrast stuff and what is more important with bolus contrasting.

With the use of created three-dimensional computer model, the blood flow in the portal vein at various variants of its structure was simulated. It was obtained that, in the presence of the main type of structure with predominance of blood flow along the splenic vein, the blood flow turbulence and risk of thrombosis development are higher. At the same time, with virtual thrombosis of the portal vein trunk, the pressure gradient is 1.4 times higher than with the bulk type, which is more favorable for the proposed reconstruction. Thus, these data can be used for preoperative planning in surgical treatment of portal vein thrombosis in liver transplantation (Fig. 5).

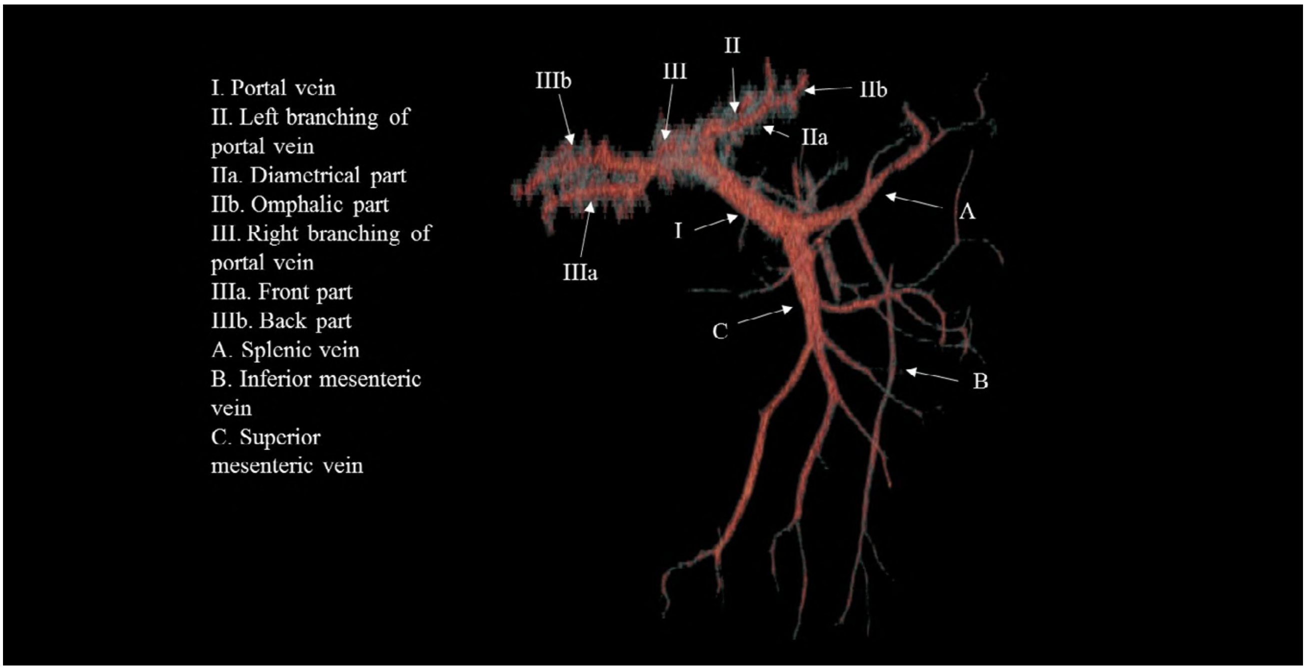

Fig. 3.- 3D model of human portal vein system.

Table 2. Morphometric measures of portal vein roots found by X-ray.

Pattern	**Length** Me [P_{25}; P_{75}] mm	**Diameter** Me [P_{25}; P_{75}] mm	**Formation corner**, degree
1	2	3	4
Superior mesenteric vein - middle colonic vein - jejunal vein - suprailiac vein - suprailiac – jejunal vein - right colonic vein - right gastroepiploic vein	93.5 [78.5; 119.5] 60.0 [58.5; 63.5] 40.0 [38.5; 46.5] 50.0 [48.5; 53.5] 70.0 [68.5; 78.5] 115.0 [108.5; 120.5] 45.0 [38.5; 53.5]	9.5 [6.5; 12.0] 9.0 [6.0; 11.0] 4.0 [3.5; 6.0] 5.5 [5.0; 7.0] 5.0 [3.5; 6.5] 6.0 [6.5; 9.0] 4.0 [3.5; 6.0]	170.0 [160.0; 175.0] 120.0 [110.0; 131.0] 70.0 [60.0; 81.0] 160.0 [155.0; 171.0] 160.0 [150.0; 171.0] 140.0 [130.0; 145.0] 85.0 [80.0; 91.0]
Low mesenteric vein - left colonic vein - vein of sigmoid bowel - upper rectal vein	108.5 [104.0; 111.5] 40.0 [33.5; 49.5] 50.0 [27.0; 53.5] 30.0 [20.0; 50.0]	4.5 [2.0; 6.5] 3.5 [2.0; 4.5] 3.0 [2.0; 3.5] 3.0 [2.0; 4.0]	140.0 [135.0; 151.0] 175.0 [170.0; 179.0] 165.0 [160.0; 170.0] 160.0 [155.0; 165.0]
Splenic vein - left gastroepiploic vein - short gaster veins (n=6-12)	125.0 [97.5; 129.5] 20.0 [13.5; 29.5] 12.0 [7.0; 18.5]	7.5 [5.5; 8.5] 5.0 [4.0; 6.0] 4.0 [3.0; 4.5]	100.0 [95.0; 111.0] 130.0 [120.0; 135.0] 90.0 [90.0; 95.0]

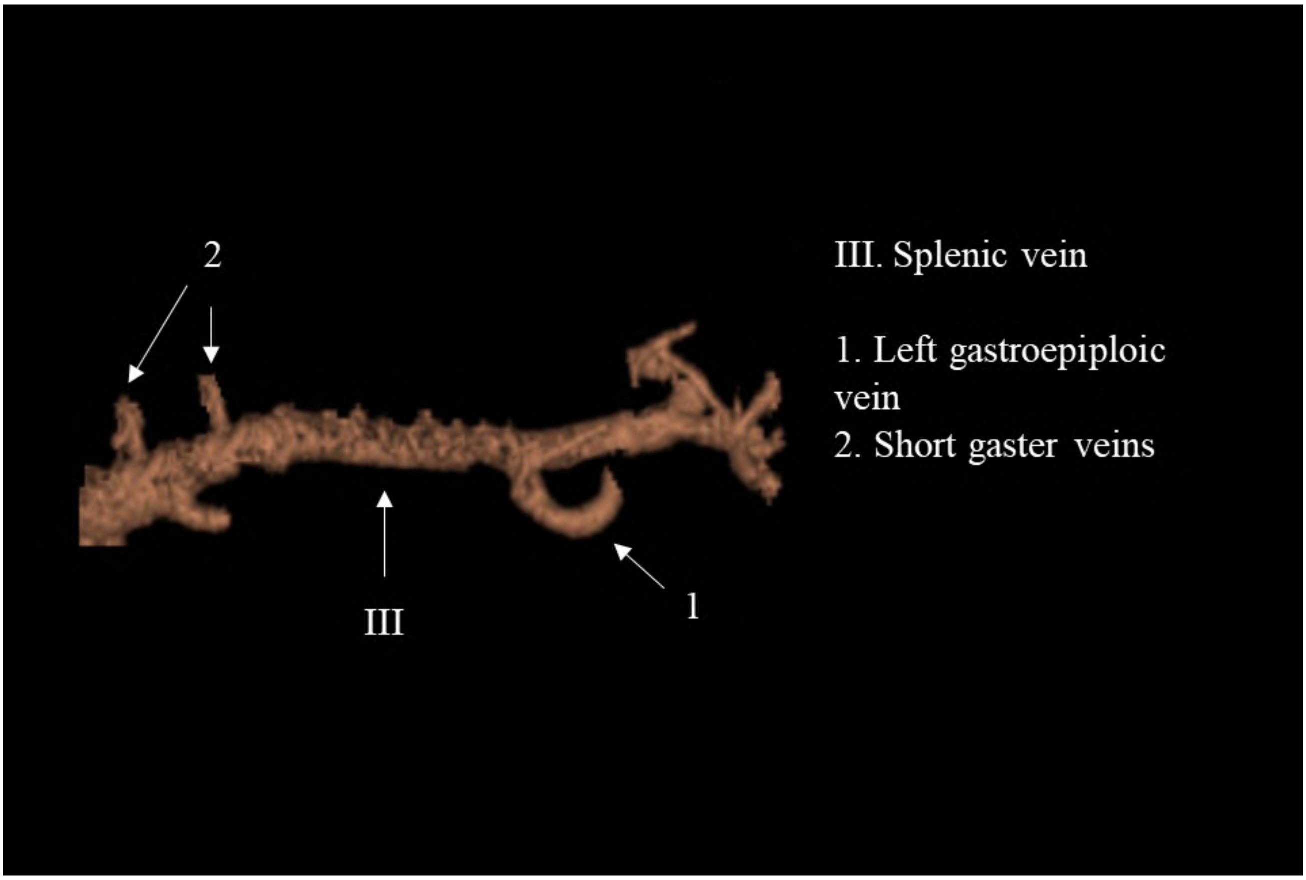

Fig. 4.- 3D model of human splenic vein.

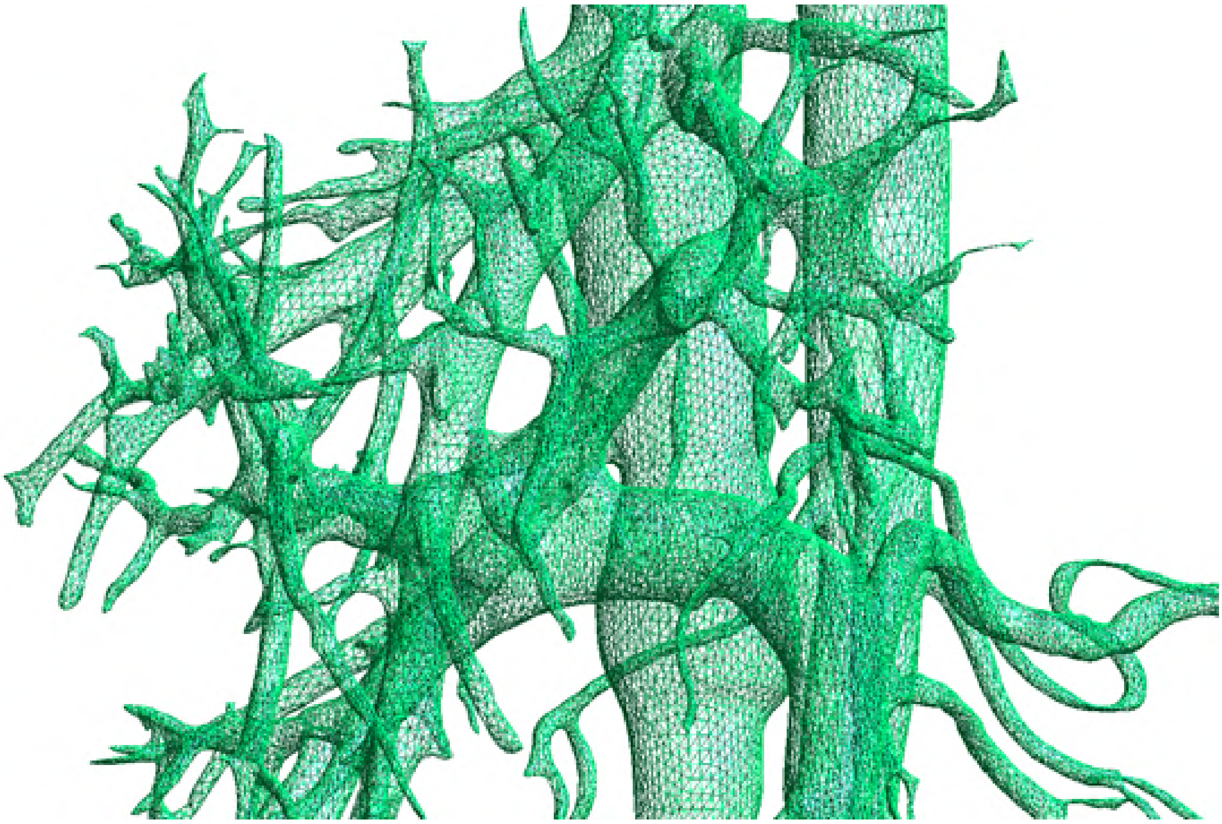

Fig. 5.- 3-dimensional model of portal system (mesh model).

DISCUSSION

The current research gives quantitative orienting points for main vein structures of portal vein system. The research results have allowed adding science materials about types of branching and morphological patterns of the portal vein and its branching. The results of the current research reflecting morphometric characteristics of superior, inferior mesenteric vein and splenic vein prove the variability of veins system v. portae, wide range of its structure anatomy, and can be used for solving questions of surgery interference for abdominal organs. Variations common for every system are preferably being used for regulation of the discussed subject in terms of tactic patients' curing with syndrome of portal hypertension or at the step of pre surgical preparation.

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