УДК 616.36-006-079.2-073.756.8-089.87:004.94
https://doi.org: 10.20538/1682-0363-2021-1-39-44

Segmentation of focal liver lesions and virtual resection based on computed tomography data

Zelter P.M., Kolsanov A.V., Pyshkina Yu.S.

Samara State Medical University (SamSMU)
89, Chapayevskaya Str., Samara, 443099, Russian Federation

ABSTRACT

The aim of the study was to test the work of plugins for segmentation and virtual resection of focal liver lesions based on CT data.

Materials and methods. Analysis of CT data of the abdominal organs with bolus contrast enhancement in 80 patients with focal liver lesions was carried out. Segmentation and 3D-modeling of the CT data was carried out by radiologists and the surgeon in the 'Autoplan' system.

Results. The nosological structure of the liver in patients was determined (the most common were hemangiomas in 21.25% of 80 patients, cysts in 20%, parasitic cysts in 20%, etc.), according to the computed tomography results. The segmentation of the liver, its focal lesions, arteries, and veins was carried out using the 'Autoplan' system. The surgeon determined the volume of the parenchyma and focal liver formations using the standard function 'volume of segmentation', chose the optimal treatment tactics, and performed a virtual liver resection. In some cases, the use of segmentation and preoperative planning made it possible to avoid an inefficient surgery. The effectiveness of modeling changed the treatment tactics of 42 patients.

Conclusion. The obtained results indicate that the use of the 'Autoplan' system plugins for planning an abdominal surgery allows doctors: 1) to carry out segmentation of the liver, focal lesions, and blood vessels; 2) to determine the location of a focal formation in a particular segment, their combinations; 3) to perform a virtual resection, evaluate the structures passing through it; 4) to choose the optimal tactics of intervention or abandon it due to objective anatomical reasons.

Key words: computed tomography, preoperative 3D-modeling, segmentation, liver resection, 'Autoplan' system.

Conflict of interest. The authors declare the absence of obvious or potential conflict of interest related to the publication of this article.

Source of financing. The authors state that they received no funding for the study.

Conformity with the principles of ethics. All patients signed an informed consent to participate in the study. The study was approved by the local Ethics Committee at Samara State Medical University (Protocol No. 205 of 19.02.2020).

For citation: Zelter P.M., Kolsanov A.V., Pyshkina Yu.S. Segmentation of focal liver lesions and virtual resection based on computed tomography data. *Bulletin of Siberian Medicine.* 2021; 20 (1): 39–44. https://doi.org: 10.20538/1682-0363-2021-1-39-44.

✉ *Pyshkina Yuliya S.,* e-mail: yu.pyshkina@yandex.ru.

Сегментация очаговых образований печени и виртуальная резекция на основе данных компьютерной томографии

Зельтер П.М., Колсанов А.В., Пышкина Ю.С.

Самарский государственный медицинский университет (СамГМУ)
Россия, 443099, г. Самара, ул. Чапаевская, 89

РЕЗЮМЕ

Цель работы – протестировать работу плагинов по сегментации и виртуальной резекции очаговых образований печени на основе данных компьютерной томографии.

Материалы и методы. Проведен анализ данных компьютерной томографии органов брюшной полости с болюсным контрастированием 80 пациентов с очаговыми образованиями печени. Сегментация и 3D-моделирование томограмм проводилось в системе «Автоплан» врачами-рентгенологами при непосредственном участии врача-хирурга.

Результаты. Определена структура нозологий печени у пациентов (наиболее часто встречались гемангиомы у 21,25% из 80 пациентов, кисты у 20% обследуемых, паразитарные кисты у 20% больных и т.д.) по данным компьютерной томографии. Затем проводилась сегментация печени, ее очаговых образований, артерий и вен с помощью системы «Автоплан». Хирург определял объем паренхимы и очаговых образований печени с помощью стандартной функции «объем сегментации», выбирал оптимальную тактику лечения и проводил виртуальную резекцию. В ряде случаев применение сегментации и предоперационного планирования позволило отказаться от заведомо неэффективной операции. В результате результативность моделирования в информировании хирурга изменила тактику ведения 42 пациентов.

Заключение. Полученные результаты свидетельствуют о том, что использование плагинов системы «Автоплан» для планирования абдоминальной хирургии позволяет: 1) провести сегментацию печени, очаговых образований и сосудов; 2) определить расположение очагового образования в том или ином сегменте, их комбинации; 3) провести виртуальную плоскость резекции, оценить структуры, проходящие через нее; 4) выбрать оптимальную тактику вмешательства или отказаться от него вследствие объективных анатомических причин.

Ключевые слова: компьютерная томография, предоперационное 3D-моделирование, сегментация, резекция печени, система «Автоплан».

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источник финансирования. Авторы заявляют об отсутствии финансирования при проведении исследования.

Соответствие принципам этики. Все лица, участвующие в исследовании, подписали информированное согласие на участие в исследовании. Исследование одобрено локальным этическим комитетом Самарского государственного медицинского университета (протокол № 205 от 19.02.2020).

Для цитирования: Зельтер П.М., Колсанов А.В., Пышкина Ю.С. Сегментация очаговых образований печени и виртуальная резекция на основе данных компьютерной томографии. *Бюллетень сибирской медицины.* 2021; 20 (1): 39–44. https://doi.org: 10.20538/1682-0363-2021-1-39-44.

INTRODUCTION

Surgery planning is an important and integral step, especially in abdominal surgery. This process determines features of a clinical case and identifies possible problems during the operation. Planning includes standard physical examination of a patient, laboratory data analysis, and imaging techniques. For a comprehensive assessment of computed and magnetic resonance tomography imaging, modeling with constructing a polygonal model is used. This technique makes it possible not only to supplement a standard study with visual three-dimensional images with pathology mapping, but also to obtain important numerical parameters. Modeling is based on the segmentation process [1, 2]. Segmentation is division of an image into areas for which a certain criterion of uniformity is met [3].

Segmentation tasks can be divided into two classes: search and selection of areas in the image, the characteristics of which are reliably known, and automatic search for areas with some similar char- acteristics. Segmentation, preoperative planning and preparing for intraoperative navigation are possible with the help of the 'Autoplan' system, which includes a workstation for a radiologist. This system was developed at the Center for Breakthrough Research of SamSMU 'Information Technologies in Medicine'.

The aim of the research is to test the work of plugins for segmentation and virtual resection of liver lesions based on the computed tomography data.

MATERIALS AND METHODS

The data of abdominal CT with contrast enhancement of 80 patients with focal liver lesions were analyzed. Studies were carried out on Toshiba Aqullion 32 CT (Japan). Then images in DICOM format were loaded into the 'Autoplan' hardware and software complex (registration certificate 2019/8153 of 27.02.2019) [4]. Segmentation and 3D-modeling were carried out by radiologists with the direct participation of the surgeon. The surgeon drew a virtual line of resection and set points of interest (relationship with branches of the portal vein, sufficiency of blood flow in the preserved part, etc.). The processing of one study took from 15 to 30 minutes, depending on the complexity of pathology and tasks.

RESULTS AND DISCUSSION

The following types of automatic segmentation are known: 1) thresholding; 2) region growing; 3) border detection; 4) texture segmentation methods.

The 'Autoplan' system uses the first three types of automatic segmentation in the segmentation system. Thresholding is the simplest segmentation method. It implies selection of areas homogeneous in brightness according to a threshold, which is determined automatically. Growing regions is a method that is based on joining regions closest in brightness. The idea behind the method is to analyze a pixel and grow the area to which it belongs based on most of its neighbors. Border detection is a method that is used to detect abrupt changes in image brightness and find borders and contours [5]. To solve the most frequent tasks, plugins for automatic segmentation based on "average models" have been developed in the 'Autoplan' system: 1) automatic segmentation of the body surface; 2) automatic segmentation of organs (liver, kidneys, spleen, lungs and trachea).

For vessels, an automatic segmentation plugin is also implemented in the presence of images of the corresponding phase of contrast enhancement: arterial for segmentation of arteries, venous for segmentation of veins. This plugin software module is used to visualize individual anatomy of the organ blood supply system, aortic pathologies (aneurysms, wall dissection, occlusion), and sites of tumor invasion into vascular structures in abdominal surgery. Automatic vessel segmentation is performed by establishing a point within the lumen. In this case, complex Fast Marching and Geodesic Active Contours algorithms are used [6].

Two approaches are used to highlight the structure within the created segmentation, for example, a focal lesion within the liver parenchyma. The first one is manual contouring on several sections with further modeling based on the boundary interpolation on raw sections. The second (which is more efficient) one is using the incremental segmentation plugin.

The 'Incremental segmentation' plugin is designed for segmentation by gradual region growing from a given point, based on density and contours of the surrounding tissues. This type of segmentation is the fastest and most convenient of all semi-automatic tools due to the 'spread' of segmentation simultaneously in all three coordinates and due to passing around contrasted tissues.

As a result of computer segmentation, the doctor receives a polygonal model of internal organs with marked areas of pathology.

The structure of liver nosologies identified by CT data is presented in Table. 1.

Segmentation of the liver, focal lesions, arteries, and veins was performed. Further, the function 'dividing liver into segments' was used. In order to do this, standard points were identified on the surface of the liver, after which planes were automatically drawn (Fig. 1), dividing the liver into 8 segments according to the Couinaud classification [7].

Table 1

The structure of liver lesions identified in patients according to the computed tomography

Nosology	Number of patients
Hemangioma	17
Cyst	16
Parasitic cyst	16
Hepatocellular cancer	11
Abscess	10
Metastasis	8
Adenoma	2

The distribution of focal lesions by liver segments is shown in Table. 2.

Afterwards, if it was necessary to perform a surgical intervention, the surgeon determined the volume of focal lesions and liver parenchyma using the standard function 'Segmentation volume'. When the lesion was located in one segment, segmentectomy was chosen as the tactics of treatment; when it was located in several segments, hemihepatectomy or atypical resection was selected.

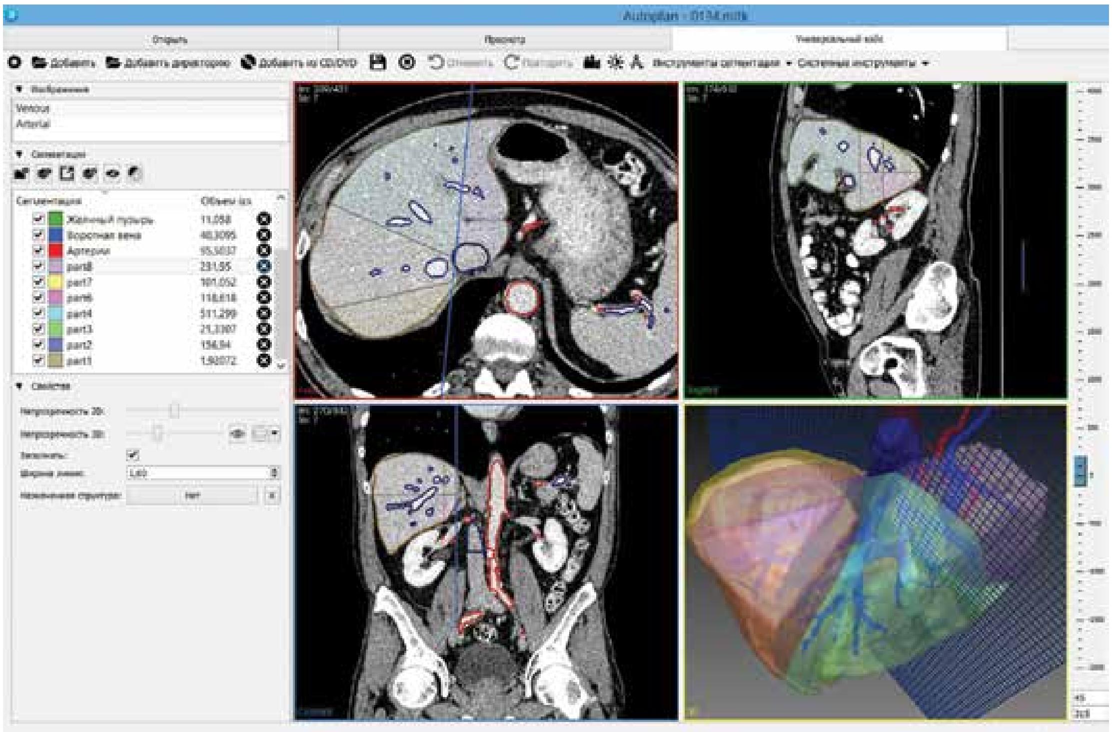

Fig. 1. Segmentation of the liver, arteries, and veins. Dividing the liver into segments using the 'Autoplan' system

Table 2

Distribution of focal lesions by liver segments

Segment	S1	S2	S3	S4	S5	S6	S7	S8	Multiple segments
Number of patients	5	7	8	7	9	7	11	8	18

A virtual resection was carried out, which consisted in constructing a line of any shape, cutting off the volume that the surgeon plans to remove from the bulk of the resulting segmentation (in this case, an organ model). The advantage of performing virtual resection is preoperative informing of the surgeon about possible complications, as the branches of portal vein and hepatic veins are visible in the resection plane [8]. It gives the surgeon the opportunity to choose an optimal resection method based as well on the residual parenchyma volume. The volume of any segmentation, both removed and remaining part of the liver, is displayed automatically [9]. Planning of a right-sided hemihepatectomy in a patient with multiple hydatid cysts is shown in Fig. 2.

In some cases, the use of segmentation and preoperative planning made it possible to abandon the obviously ineffective operation. Here is a clinical example of patient I., 32 years old. The patient went to the hospital with complaints of pain and heaviness in the right hypochondrium, general weakness, loss of appetite, and stool disorder. Computed tomography of the abdominal organs with bolus contrast enhancement was performed according to the standard protocol. The results are shown in Fig. 3.

In the right lobe of the liver, a large lesion with an inhomogeneous structure was found, and in the central parts, a formation with pronounced calcification and hypovascular periphery was detected. Compression of the inferior vena cava and signs of invasion in the branches of the portal and right hepatic veins were observed. Impression: liver alveococcosis.

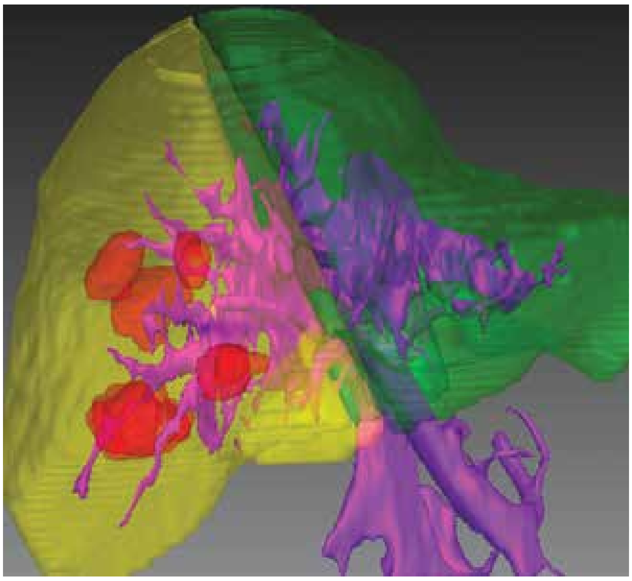

Fig. 2. 3D-model of the liver of the patient K. Green color indicates the preserved part, yellow – the resected part. Hydatid cysts are highlighted with red color, branches of the portal and hepatic veins are highlighted with purple color

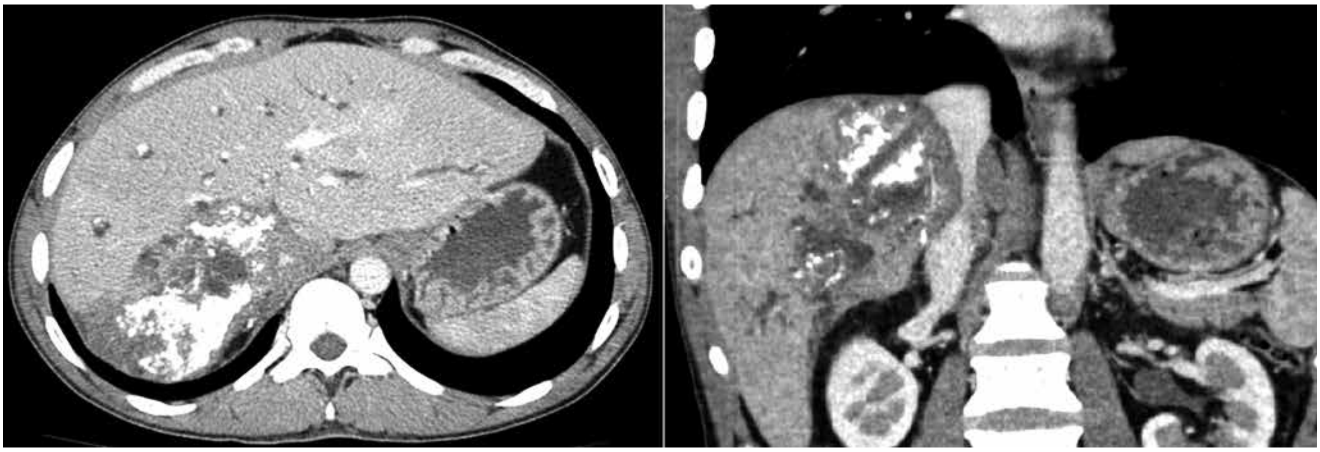

Fig. 3. Computed tomography of the abdominal organs of patient I., axial and coronal reconstruction, venous phase. In the right lobe of the liver, there is a massive heterogeneous zone with calcification

To assess the resectability of the lesion, reconstruction in the ‘Autoplan’ system was performed. The result is shown in Fig. 4.

Modeling made it possible to detect an extensive arterial and venous invasion of the alveococcus, which did not allow its resection as it could lead to massive intraoperative blood loss. The patient was consulted by a transplant doctor and his data were added to the waiting list for a liver transplant [10].

The effectiveness of modeling in informing the surgeon and changing the tactics in 42 patients is shown in Table 3.

Table 3

The effectiveness of modeling in informing the surgeon and changing the tactics

Performance indicator	Number of patients
The choice of tactics in the form of segmentectomy	9
The choice of tactics in the form of atypical resection	6
The choice of tactics in the form of hemihepatectomy	8
Changing the initial tactics after analyzing planar images	8
Refusal from resection due to the small volume of preserved parenchyma	5
Refusal from intervention due to vascular anatomy	3
Refusal from intervention due to vascular invasion	3

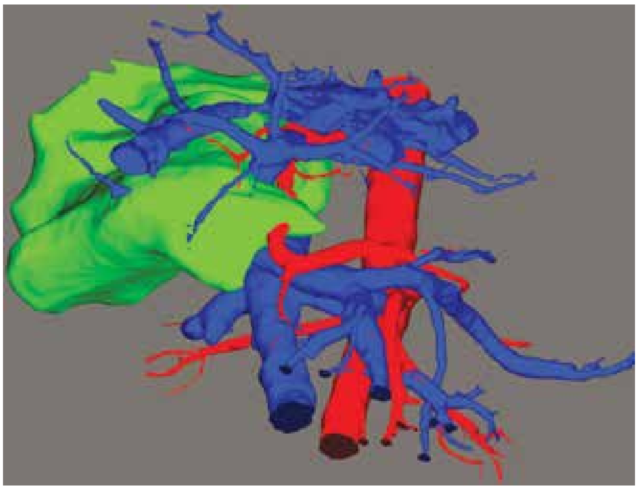

Fig. 4. 3D-model of liver alveococcosis. The zone of alveococcosis is highlighted with green color, invasion of the portal vein, inferior vena cava, and common hepatic artery are clearly shown

CONCLUSION

Thus, the use of the ‘Autoplan’ system plugins for planning an abdominal surgery allows doctors: 1) to carry out the segmentation of liver, focal lesions and blood vessels; 2) to determine the location of a focal formation in a particular segment, their combination; 3) to perform a virtual resection, evaluate the structures passing through it; 4) to choose the optimal tactics of intervention or abandon it due to objective anatomical reasons.

REFERENCES

1. Shishkin V.B., Golubev V.G. Preoperative planning in traumatology and orthopedics with the use of three-dimensional computer reconstruction and modeling technology. *Modern problems of science and education.* 2015; (5): 47 (in Russ.).
2. Karmazanovsky G.G., Nerestyuk Ya.I., Kriger A.G., Khayrieva A.V. Diagnostic value of three-dimensional reconstructions of CT images in patients with ductal pancreas adenocarcinoma. *Russian Electronic Journal of Radiology*. 2017; 7 (1): 69–76 (in Russ.). DOI: 10.21569/2222-7415-2017-7-1-69-76.
3. Senyukova O.V., Galanin V.E. Highlighting areas of interest based on the classification of contours. *Software & Systems.* 2012; (1): 52–55 (in Russ.).
4. Kolsanov A.V., Manukyan A.A., Zelter P.M., Chaplygin S.S, Kapishnikov A.V. Preoperative virtual modeling of liver based on computerized tomography data. *Annals of HPB Surgery.* 2016; 21 (4): 16–22 (in Russ.).
5. Doronicheva A.V., Savin S.Z. Method of segmentation of medical images. *Fundamental research*. 2015; (5-2): 294–298 (in Russ.).
6. Goldenberg R., Kimmel R., Rivlin E., Rudzsky M. Fast geodesic active contours. *IEEE Trans. Image Process.* 2001; 10 (10): 1467–1475. DOI: 10.1109/83.951533.
7. Dirisamer A., Friedrich K., Schima W. Anatomy and variants of hepatic segments, vessels, and bile ducts. *Radiology*. 2005; 45 (1): 8–14. DOI: 10.1007/s00117-004-1150-5.
8. Hansen C., Zidowitz S., Preim B., Stavrou G., Oldhafer K.J., Hahn H.K. Impact of model-based risk analysis for liver surgery planning. *Int J Comput Assist Radiol Surg.* 2014; 9 (3): 473–480. DOI: 10,1007 / s11548-013-0937-0.
9. Högemann D., Stamm G., Shin H., Oldhafer K.J., Schlitt H.J., Selle D., Peitgen H.O. Individual planning of liver surgery interventions with a virtual model of the liver and its associated structures. *Radiology.* 2000; 40 (3): 267–273. DOI: 10.1007/s001170050668.
10. He Y.B., Bai L., Aji T., Jiang Y., Zhao J.M., Zhang J.H., Shao Y.M., Liu W.Y., Wen H. Application of 3D reconstruction for surgical treatment of hepatic alveolar echinococcosis. *World J. Gastroenterol.* 2015; 21 (35): 10200–10207. DOI: 10.3748/wjg.v21.i35.10200.

Authors information

Zelter Pavel M., Cand. Sci. (Med.), Assistant, Department of Radiology and Radiation Therapy with a Course of Medical Computer Science, SamSMU, Samara, Russian Federation. ORCID 0000-0003-1346-5942.

Kolsanov Alexander V., Dr. Sci. (Med.), Professor, Professor of the RAS, Rector of SamSMU, Samara, Russian Federation. ORCID 0000-0002-4144-7090.

Pyshkina Yuliya S., Cand. Sci. (Med.), Associate Professor, Department of Radiology and Radiation Therapy with a Course of Medical Computer Science, SamSMU, Samara, Russian Federation. ORCID 0000-0002-7241-6828.

(✉) **Pyshkina Yuliya S.,** e-mail: yu.pyshkina@yandex.ru.

Received: 16.03.2020
Accepted: 29.09.2020