Estimation of Resected Liver Regions Using a Tumor Domination Ratio

Masanori Hariyama[1], Moe Okada[1], Mitsugi Shimoda[2], Keiichi Kubota[2]
[1]Graduate School of Information Sciences, Tohoku University, Japan
[2] Second Department of Surgery, Dokkyo Medical University

Abstract— *This article presents an automatic approach to estimate optimal resected-liver regions for oncologic surgery planning. Usually, resected liver regions are determined by selecting cut points on the portal vessels on 3D simulation software. Since the liver has complex vessel structure, it is difficult for human to find optimal resected liver regions. To solve this problem, a tumor domination ratio is proposed to find all portal vessels related to tumors. The tumor domination ratio allows us to compute the ideal resected region, that is, all the perfusion territories related to the tumor. Moreover, some types of conditions such as the size of vessels are considered for practical surgical use. The experimental results demonstrate that the resected liver regions of the proposed approach are much smaller than those of the conventional approach in most cases.*

Keywords: Medical imaging, 3D simulation analysis, anatomic hepatectomys

1. Introduction

3D simulation, recently, plays an important role in surgical planning for hepatectomy since the liver has a complex structure, that is, some different vessels are arranged complexly as shown in Fig. 1. The estimation of regions perfused by the portal vein is especially one important task in anatomical hepatectomy, since the hepatocellular carcinoma(HCC) tends to metastasize via the portal vein [1], [2]. Figure 2 explains how the perfused region is estimated. The tumor affects the nearest parts of the portal vein; from the nearest parts, the HCC metastasize in the downstream direction via the portal vein. The overestimate of the perfused region tends to prevent the metastases, but it increases the possibility of the postoperative liver failure. Therefore, the volume of perfused region should be minimized while including all the perfused regions of the portal vein feeding the tumor.[2]

Some practical software programs for 3D simulation and preoperative planning have been developed like Hepavision (MeVis Medical Solutions AG, Bremen, Germany)[3] , OVA (Hitachi, Tokyo, Japan)[4], and Synapse VINCENT (Fujifilm Medical, Tokyo, Japan)[5]. In preoperative planning, surgeons search for the combination of the cut points on the portal vein in a trial-and-error way until the tumor is covered by the perfused regions of the portal cut points. However, it is difficult and time-consuming for surgeons to find optimal or near-optimal combination since the portals vein has complex structure, that is, it has many branches. Surgeons select simple combinations, and this results in overestimation of the perfused region.

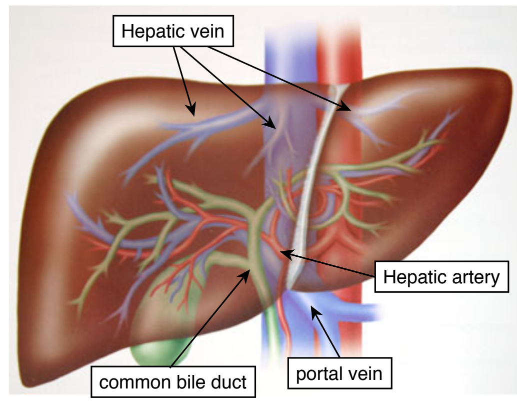


Fig. 1: Vascular system of the liver.

To solve this problem, this paper presents the method to compute the optimal perfused regions, where the volume is minimized while including all the perfused region of the tumor-related portal vein. In order to find the tumor-related part of the portal vein accurately, the tumor domination ratio is defined which reflects how much volume of the tumor a part of the portal vein feeds. The tumor domination ratio allows to pick up all the tumor-related parts of the portal vein, and the total of the regions perfused by them is determined to be the resected region.

The rest of this paper is organized as follows. In Section 2, the basic method to find the ideal resected region is explained where practical conditions used in the real surgeries are not considered. In Section 3, its extension is explained where practical conditions such as the branch points and the radiuses of the vessels are considered. Section 4 is conclusion.

2. Estimating an ideal resected region using the tumor donation ratio

The region perfumed by a point on the portal vein is estimated by using a Voronoi diagram[2]. Figure 3 shows a Voronoi diagram. A Voronoi diagram is a way of dividing

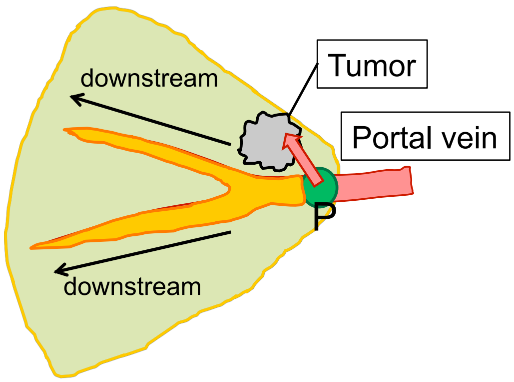


Fig. 2: Region perfused by the portal point P and its downstream.

space into a number of regions. A set of points (called seeds) is specified beforehand and for each seed there will be a corresponding region consisting of all points closer to that seed than to any other. The regions are called Voronoi cells. A seed and Voronoi cell in a Voronoi diagram correspond to a point on a portal vein and a region perfumed by the portal point.

The tumor domination ratio TDR of a portal point P is defined as follows.

$$TDR = \frac{\text{[Volume of the region perfused by } P\text{]}}{\text{[Volume of the tumor]}} \times 100 \quad [\%] \tag{1}$$

Given a tumor location, let us compute an ideal resected region by using the tumor donation ratio, where the ideal resected region means a minimum region including all sub-regions perfused by tumor-related portal points. All tumor-related portal points are found by using the tumor donation ratio; all the portal point with TDR larger than 0 are picked up as tumor-related portal points as shown in Fig. 4. The ideal resected region is given as the union of all the regions perfused by the tumor-related portal points.

Let us compare the proposed method with the manual approach by the conventional 3D simulation software program(Synapse VINCENT ver.2). Figure 5 shows the sample date used for evaluation. The samples 1 and 2 are the cases where the small tumor exists near the liver surface; the sample 3 is the case where the large tumor exists near the main stem of the portal vein. For each sample, the liver, vessels, and a tumor are extracted in advance by the other software programs. Tables 1-3 summarize the results for sample 1-3, respectively. From Tables 1 and 2, the proposed optimization method is very useful compared to the manual approach, that is, the volume of the estimated resected region by the proposed method is much smaller than that of the manual approach. This is because the degree of freedom of cut-point selection is high and the effect of optimization is large when the case where the small tumor exists near the liver surface. On the other hand, from Table 3, the

Fig. 3: Voronoi diagram.

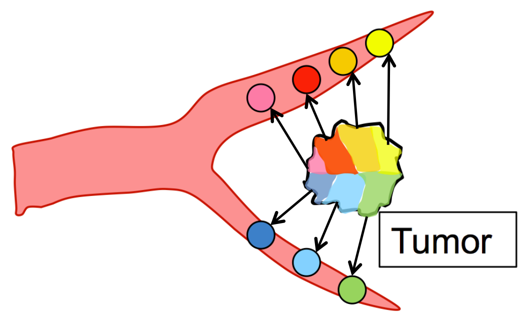
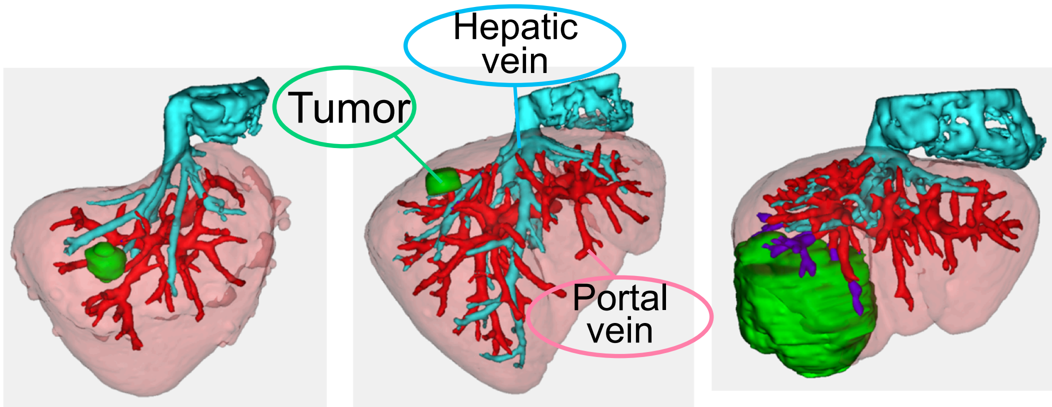


Fig. 4: Tumor-related portal points.

optimization is not very effective when the tumor exists near the main stem of the portal vein since the degree of freedom of cut-point selection is low.

3. Estimating an optimal resected region under the practical conditions in surgery

Although the method described in the previous section greatly reduces the volume of the estimated resected region, it is difficult for surgeons to use the results directly in the real surgery since the number of cut points is larger than the that of manual approach, and since cut points are sometimes set on such tiny vessels that surgeons cannot identify in the real surgery. In order to solve this problem, the the method described in the previous section is improved considering the practical conditions as follows. In this paper, branch points and the radius of the vessels are considered as the practical conditions. The optimization procedure starts with obtaining the ideal cut by the method in the previous section shown in Figure 6(a). These ideal cut points are refined considering the practical conditions as shown in 6(b). Each cut point is moved towards the upstream direction in such a way that the cut point is set on a branch and the radius of the vessel



(a) sample1 (b) sample2 (c) sample3

Fig. 5: Samples for evaluation.

Table 1: Comparison results for sample 1

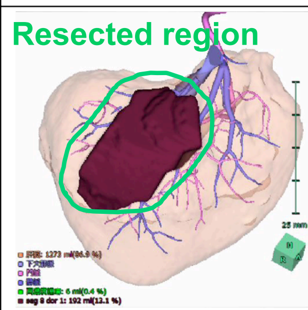
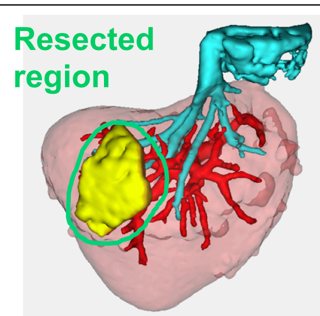
sample1	Manual approach by a surgeon	Proposed
Resected volume (cc)	192	66
The number of cut points	1	2
Results		

Table 2: Comparison results for sample 2

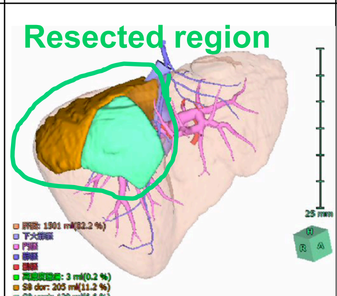
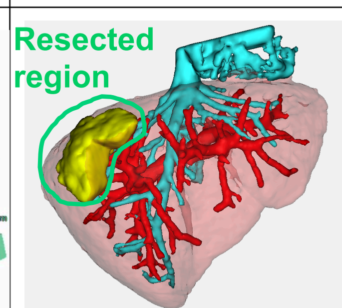
sample2	Manual approach by a surgeon	Proposed
Resected volume (cc)	325	42
The number of cut points	2	4
Results		

Table 3: Comparison results for sample 3

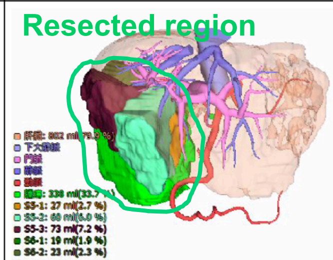
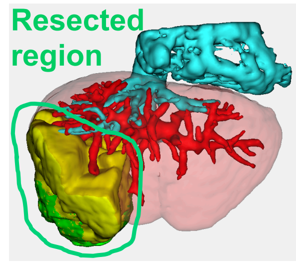
sample3	Manual approach by a surgeon	Proposed
Resected volume (cc)	550	476
The number of cut points	5	10
Results		

Table 4: Results of the optimization considering the practical conditions for sample 1.

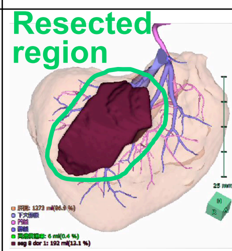
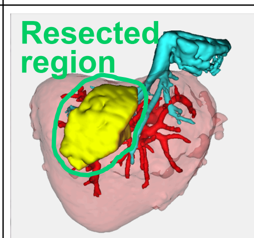
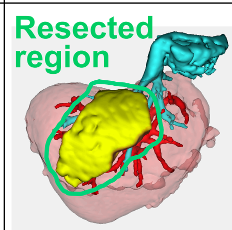
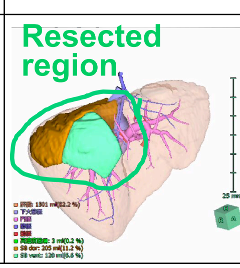
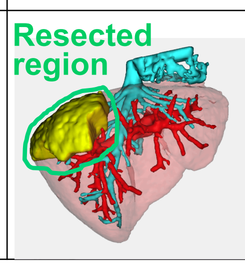
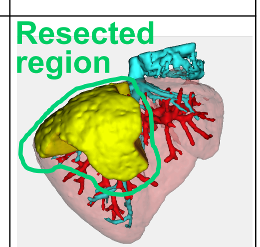
sample1	Manual approach by a surgeon	Proposed (Radius: 6mm)	Proposed (Radius: 8mm)
Resected volume (cc)	192	112	178
The number of cut points	1	2	1
Results			

Table 5: Results of the optimization considering the practical conditions for sample 2.

sample2	Manual approach by a surgeon	Proposed (Radius 6mm)	Proposed (Radius 8mm)
Resected volume (cc)	325	170	346
The number of cut points	2	3	2
Results			

is larger than the pre-determined condition.

Figures 4 and 5 summarize the results of the optimization considering the practical conditions for samples 1 and 2, respectively. The radius of the vessel is set to 6 mm and

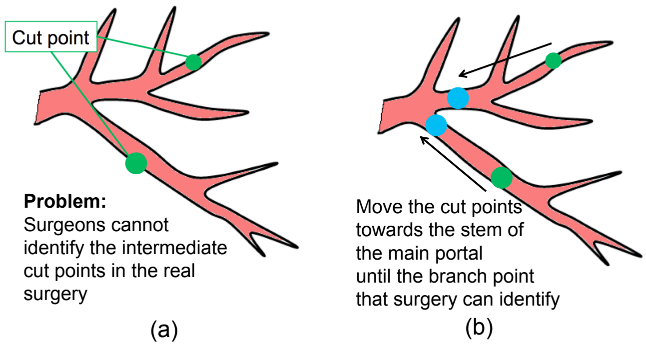


Fig. 6: Refining the cut points considering the practical conditions.

8 mm. These results shows that the estimated resected region is minimized keeping the number of cut points small appropriately for real surgery

4. Conclusion

In order to minimize the resected volume while preventing metastases, the automatic method that finds the optimal combination of cut points is proposed.

The domination ratio is key to success to find such optimal combination in a systematic way.

Recently, the integration of 3D simulation and ultrasonography is progressing to support the surgical operations in the real surgery. Such navigation technology makes it easier that surgeons resects the liver according to the optimal resected regions computed from our method.

References

[1] M. Makuuchi, H. Hasegawa, S. Yamazaki, “Ultrasonically guided subsegmentectomy“, Surg. Gynecol. Obstet., Vol.161,pp.346-50 (1985).
[2] T. Takamoto, T. Hashimoto, S. Ogata, K. Inoue, Y. Maruyama, A. Miyazaki, M. Makuuchi, “Planning of anatomical liver segmentectomy and subsegmentechtomy with 3-dimensional simulation software”, The American Journal of Surgery Vol. 206, Issue 4, pp. 530-538 (2003)
[3] D. Selle, B. Preim, A. Schenk, et al., “Analysis of vasculature for liver surgical planning“, IEEE Trans. Med. Imaging, Vol. 21, pp.1344-57 (2002).
[4] S. Saito, J. Yamanaka J,K. Miura, et al., “A novel 3D hepatectomy simulation based on liver circulation: application to liver resection and transplantation“, Hepatology, Vol. 41, pp.1297-1304, (2005)
[5] S. Ohshima, “Volume analyzer SYNAPSE VINCENT for liver analysis“, Journal of Hepato-Biliary-Pancreatic Sciences, Vol. 21, Issue 4, pp. 235-238(2014)