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A clinical pilot study of Resection Process Map: A novel virtual hepatectomy software to visualize the resection process, case series

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ABSTRACT

Background: Preoperative simulation of liver resection to visualize the intraoperative cutting process, including liver deformation, may help surgeons to more accurately implement hepatectomy. We developed a novel simulation software called Resection Process Map (RPM). The present study was performed to evaluate the feasibility and efficacy of RPM as a tool for preoperative simulation and surgical education for liver surgery.
Materials and methods: Twenty-four patients who underwent anatomical hepatic resection at our institute from February 2017 to May 2018 were enrolled in this study. The time needed to prepare RPM for each patient was recorded. The imaging similarity between the image provided by RPM and the intraoperative photograph was evaluated with the Dice similarity coefficient and locational displacement of the vessels of interest. The surgeons completed questionnaires. The educational effect was assessed by a survey administered to medical students who attended clinical clerkship at our department from October 2017 to December 2018.
Results: The time required to prepare the dataset for RPM was 199 ± 20 s after completion of operative planning in SYNAPSE VINCENT. The Dice similarity coefficient for surface similarity was 0.85 ± 0.06, where 1.00 indicates perfect concordance. The mean positional displacement of the vessels of interest was 8.7 ± 6.7 mm. Medical students' application of RPM significantly improved their survey score (use vs. non-use of RPM, 6.5 vs, 4.6, respectively; $p < 0.001$).
Conclusion: RPM allows for preoperative simulation of hepatectomy and might be helpful for many surgeons. RPM is also useful for education of medical students.

1. Introduction

Precise preoperative planning based on patient-specific anatomical information is crucial to achieve safe and accurate hepatectomy. Three-dimensional reconstruction software is helpful to understand the anatomy of individual patients and perform operative planning [1–4]. Although the planned cutting path and virtual organ images created by this software are useful for intraoperative cutting guidance, the software provides only static liver images [2–6]. During hepatic resection, the liver is considerably deformed by mobilization and parenchymal transection. To implement the planned liver resection, careful transection is required while checking the reference vascular structures partially revealed on the resection surface. Recognizing vascular structures on the resection surface is sometimes difficult because of deformation of the liver and uncertainty of the accuracy of the actual cutting path derived from the planned cutting line. A misunderstanding of the exposed vessels may lead to an inaccurate resection path, which can result in an insufficient surgical margin or division of essential vascular structures that actually need to be preserved. These issues might be more important in the increasing number of surgeries being performed using laparoscopy, which provides a magnified but limited field of view [6]. Preoperative simulation that allows for visualization of the intraoperative cutting process, including liver deformation, may help surgeons implement accurate resection [1,7]. Several investigators have described deformation models that simulate intraoperative deformation of the liver. However, few of these models were clinically evaluated [8–11]. We have developed a novel simulation software called Resection Process Map (RPM). RPM simulates individual patients' liver deformation, which reflects the three-dimensional anatomy, including the vascular morphology and tumor location. RPM also contains information regarding the planned resection line and allows operators to divide the liver in a step-by-step manner, demonstrating

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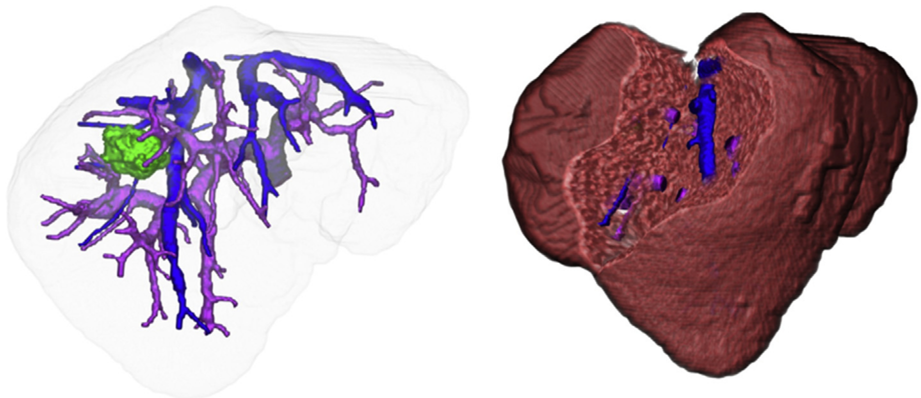

Fig. 1. RPM simulates intraoperative deformation during hepatectomy
(A) Three-dimensional reconstruction of patient's liver by Resection Process Map. Vessels (hepatic vein: blue, portal system: purple) and tumors (green) are indicated. This patient had a tumor on the boundary between segments 7 and 8. Sub-segmentectomy of S7 + S8 dorsal was planned.
(B) Parenchymal dissection and liver deformation were reproduced (the movie of the simulation is shown in Supplemental Video 1). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the entire path of hepatic parenchymal resection on the computer screen [12,13] (Fig. 1, Supplemental Video 1). We developed RPM software to assist in preoperative planning and implementation of the planned resection as well as to supplement surgical education. The present study was performed to evaluate the feasibility and efficacy of RPM as a tool for preoperative simulation and surgical education for liver surgery. We performed both objective and subjective assessments of RPM software using imaging analysis and a questionnaire. We also assessed the effect of RPM on the education of medical students.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ijsu.2019.09.002.

2. Methods

2.1. Patients

Patients who underwent hepatic resection at our institute from February 2017 to May 2018 were enrolled in this study. The study was approved by our institutional ethics review board, and written informed consent was obtained from all participants. The inclusion criterion was the need for anatomical resection (lobectomy, segmentectomy or sub-segmentectomy). Patients who were scheduled to undergo non-anatomical resection (partial hepatectomy) were excluded. This study is registered to UMIN Clinical Trials Registry and reported in line with the PROCESS 2018 criteria [14].

2.2. Preparation of preoperative simulation by RPM

The detailed RPM system has been previously described [12,13]. First, the Digital Imaging and Communications in Medicine (DICOM) data of a computed tomography scan of each patient were transferred to a workstation and processed by SYNAPSE VINCENT (Fujifilm Medical Co., Ltd., Tokyo, Japan). Magnetic resonance imaging data were not used in the preparation of RPM. The liver, inferior vena cava, portal vein, hepatic veins, and tumors were extracted, and the operative plan (i.e., the regions to be resected during the operation) was designed. The DICOM data of each component were exported to another workstation and processed by Plissimo XV (Konica Minolta, Inc., Tokyo, Japan) to generate the dataset for RPM. The translation from the DICOM image to the dataset for RPM was automatically processed, and the time needed for the data translation was recorded.

2.3. Preoperative evaluation and operative procedures

Preoperative computed tomography images were used to create three-dimensional images of the liver for all patients using SYNAPS VINCENT, and these images were used to plan the operative procedure. Preoperative simulation using RPM was performed after the operative procedure was determined. The operative procedure was performed as previously described [15,16]. Briefly, intraoperative ultrasonography was performed to detect intrahepatic vessels and to mark the transection plane. Transection of the liver parenchyma was mostly performed under laparotomy using a Cavitron ultrasonic surgical aspirator (CUSA; Valleylab, Boulder, NY) and bipolar cautery with a saline irrigation system.

2.4. Questionnaire for surgeons

The operators and assistants for each patient were requested to perform a preoperative simulation by RPM and complete a questionnaire. The questionnaire comprised the following three questions: (1) How easily could you operate the RPM? (simplicity), (2) How similar was the RPM imaging to the hepatectomy actually done? (similarity), and (3) How useful was the RPM imaging as a guidance for the operation? (usefulness). Each question was scored from 0 to 4 points using a Likert scale, with 4 indicating the highest effectiveness. Surgeons were categorized according to their surgical experience (veteran: experience with > 100 hepatectomies as the operator, trainee: experience with < 100 cases).

2.5. Objective evaluation for similarity of imaging

We quantitatively evaluated the similarity between the RPM imaging and the intraoperative scene. We recorded an intraoperative photograph when the root of the venous branch of segment 5 (right inferior anterior segment) draining into the middle hepatic vein (V5) was exposed during right or left hemi-hepatectomy. Patients who did not undergo hemi-hepatectomy and patients who underwent hemi-hepatectomy without exposure of the root of V5 were excluded from the analysis. The corresponding RPM image was manually selected, and the RPM image and intraoperative photograph were overlaid.

To evaluate the morphological similarity between the intraoperative photograph and the corresponding RPM image, the Dice similarity coefficient (DSC) [17] was used to calculate the ratio of overlap between the resection surface of RPM and that of the intraoperative view.

The numbers of pixels in the following areas were counted using GIMP (free software available at https://www.gimp.org/):

- D(RPM): area included in the resection surface of the RPM image
- D(intraoperative picture): area included in the resection surface of the intraoperative picture
- D(RPM)∩D(intraoperative picture): area included in the resection surface of both the RPM and intraoperative pictures

The DSC was then calculated as follows:

DSC = 2 × D(RPM)∩D(intraoperative picture)/D(RPM) + D(intraoperative picture).

The positional displacement of V5 was measured as the distance

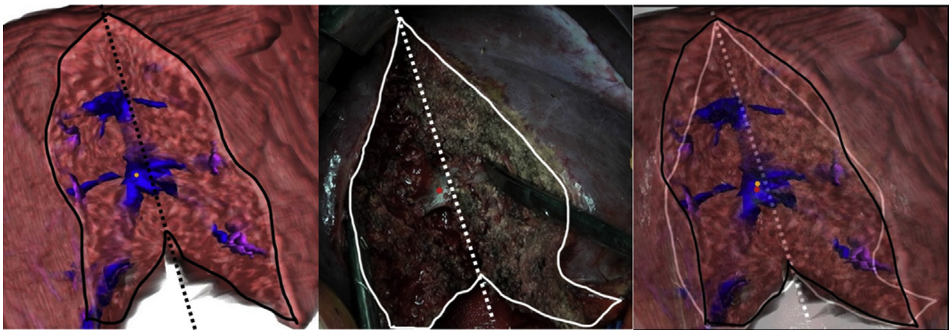

Fig. 2. Similarity evaluation by the Dice similarity coefficient (DSC) and locational displacement of vessels
(A) Resection surface on Resection Process Map (RPM). The shape of the resection surface is outlined in black, and the root of V5 is indicated by the yellow dot.
(B) Resection surface in the intraoperative photograph. The shape of the resection surface is outlined by the solid white line, and the root of V5 is indicated by the red dot. The center line of the resection surface is indicated by the dashed white line.
(C) The picture of RPM and the intraoperative photograph are overlaid. The distance between the yellow dot and red dot was measured as the locational displacement. The DSC in this case was 0.86, and the locational displacement was 3.6 mm. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

between the center of the root of V5 on each overlaid picture (Fig. 2).

2.6. Education of medical students using RPM

Medical students who attended clinical clerkship at our department from October 2017 to December 2018 were encouraged to participate in the evaluation of RPM. The students were randomly allocated to two groups: those were lectured on liver resection using RPM (RPM + group) and those who were lectured on liver resection without RPM (RPM− group). After the lecture, the students underwent the quiz regarding their understanding of hepatectomy, and the results were compared between the RPM+ and RPM− groups. The students in the RPM− group were allowed to perform RPM after the quiz. All students completed a questionnaire regarding surgical education after using RPM. The questionnaire comprised the following three questions: (1) How much did the RPM interest you? (interest in RPM), (2) How useful was the RPM as teaching material? (usefulness as teaching material), and (3) How did you become interested in being a surgeon? (interest in becoming a surgeon). The responses were based on a visual analog scale from 0 to 100%, with 100% indicating the highest effectiveness. Written informed consent was obtained from all participants.

2.7. Statistical analysis

Continuous variables are presented as mean (± standard deviation). Comparisons between two groups were made using the Mann–Whitney *U* test or chi-square test where appropriate. JMP 12.0 software (SAS Institute, Inc., Cary, NC, USA) was used for analysis. Categorical variables in analyses of small sample sizes were compared using Fisher's exact test. Correlations between two continuous variables were evaluated by Spearman's correlation coefficient. Values of $p < 0.05$ were considered statistically significant.

3. Results

3.1. Preoperative simulation by RPM

Twenty-four patients were enrolled. The patients' characteristics are shown in Table 1. The time required to prepare the dataset for RPM after completion of the operative planning in Synapse Vincent was 199 ± 20 s. A representative case of simulation by RPM (segmentectomy of S7 + S8 dorsal) is shown in Fig. 1 and Supplementary Video 1.

3.2. Quantitative analysis for imaging similarities

Of 20 patients who underwent lobectomies, 13 patients whose V5 was exposed at the junction to the middle hepatic vein were analysed. The surface similarity of RPM imaging was 0.85 ± 0.06, where a score of 1 indicates perfect concordance. The positional displacement of V5 was 8.7 ± 6.7 mm. The results of the similarity analysis in representative cases are shown in Fig. 2.

Table 1
Patients' characteristics.

Patients' characteristics	N = 24
Sex	male: 9, female: 15
Age, years	62.5 (29–86)
Primary diseases LDLT donor	13
HCC	7
Metastatic tumor	1
Others	3
Operation type Right lobectomy	13
Left lobectomy	7
Segmentectomy	2
Subsegmentectomy	2
Operation time, minutes	388(288–618)
Blood loss, ml	460(65–1415)
Blood transfusion	1
Albumin, g/dl	4.2(3.4–5)
Total bilirubin, mg/dl	0.75(0.4–1.2)
Platelet count, 10^7/ml	21.7(10.3–37.0)
Prothrombin activity, %	103(57–130)

LDLT: living-donor liver transplantation, HCC: hepatocellular carcinoma. Liver parenchymal dissection was mostly performed by laparotomy (except one patient who underwent laparoscopic right lobectomy).

3.3. Questionnaire for surgeons

In total, 49 questionnaires were collected from 16 surgeons (10 trainees and six veterans) who participated in the surgery. The average scores (± standard deviation) for each question were as follows; simplicity, 3.28 ± 0.35, similarity, 2.71 ± 0.76, usefulness, 3.00 ± 0.65. The responses were similar between trainee and veterans (Supplemental Fig. 1).

3.4. Correlations between quantitative analysis and questionnaire for surgeons

The correlation between the DSC or locational displacement of vessels and the result of the questionnaires (similarity) was investigated (Supplemental Fig. 2). The correlation coefficients were 0.405 (p = 0.17) for the DSC and −0.16 (p = 0.61) for locational displacement of vessels.

3.5. Usefulness of RPM for surgical education

Sixty students completed the quiz and the questionnaire. Although the proportion of students who wished to be a surgeon were not

Table 2
Survey for medical students.

	RPM + (N = 30)	RPM- (N = 30)	P
Wish to be a surgeon	53%	43%	0.44
Anatomy (0–3)	2.4(± 0.1)	1.4(± 0.2)	< 0.001
Surgical procedure (0–5)	4.1(± 0.2)	3.3(± 0.2)	0.013
Total score (0–8)	6.5(± 0.3)	4.6(± 0.4)	< 0.001

RPM, Resection Process Map The score on survey was described as mean (± Standard deviation).

different between the RPM+ and RPM− groups, the students in the RPM + group scored significantly higher regarding their understanding of hepatectomy than those in the RPM− group (6.5 vs. 4.6, respectively; $p < 0.001$) (Table 2). In total, 46 (77%) students were highly interested in RPM, and 49 (82%) students felt that RPM was very useful as a teaching tool (score of ≥70%) (Supplemental Fig. 3).

4. Discussion

In this study, we evaluated the feasibility and usefulness of RPM for preoperative simulation and educational material for liver resection.

The most useful feature of RPM is that it enables visualization of the entire cutting path of liver resection. Lamata et al. [18] described software that simulated the cutting path during liver resection, but the software did not reflect the parenchymal deformation; therefore, the image had the potential to be largely different from the intraoperative image. The fact that RPM that can reflect the parenchymal deformation represents a substantial advantage in the operative setting.

According to the questionnaire results, many surgeons felt that the preoperative simulation by RPM was useful for hepatectomy. Although previous studies have shown that preoperative simulation is useful especially for trainees [8,18], RPM in this study was widely accepted among various surgeons, which might have reflected the ability of RPM to reveal the critical point of the procedure. The score about the similarity of RPM imaging to the intraoperative scene was not high compared with that about the simplicity or usefulness of RPM, which suggests that RPM still requires improvement.

The similarity between the software images and the actual intraoperative scene may be one of the most crucial aspects of virtual hepatectomy software. Because there is the lack of standardized methods for quantitative evaluation of imaging similarity, we attempted to approach this issue through calculation of the DSC. The DSC is an indicator of the overlap of two different figures [19]. Using the DSC, we partly succeeded in digitalizing the similarity of the surface shape. Notably, not only the surface shape but also the landmark vessels are important for appropriate simulation. Therefore, we quantitatively measured the positional displacement of the vessels of interest. We found that the DSC scores varied from case to case and that some dislocations of vessels were present between the RPM images and intraoperative pictures and these differences might affect the satisfaction for similarity. However, there were poor correlations between these quantitative analyses and the surgeons' impressions. More appropriate methods for evaluation should be investigated in the future.

Simplicity and convenience in preparing RPM is another potential advantage of this software. Oshiro et al. [8]. reported the use of software for virtual hepatectomy, but creation of detailed images took 1–2 h. In the present study, virtual hepatectomy by RPM was ready within a few minutes (median, 199 s) after operative planning with SYNAPSE VINCENT. Easy and rapid preparation is important in daily clinical practice.

Surgical education using RPM was significantly more effective for medical students than that using conventional lectures and textbooks. Although the hepatectomy procedure might be difficult to understand, many students felt that RPM was interesting regardless of whether they wished to become a surgeon. Comparison with static imaging studies or simulations showed that the direct imaging of hepatectomy provided by RPM can provide an interactive experience of the surgical procedure, potentially contributing to efficient education.

We acknowledge several limitations in this study. As this was an observational study performed to evaluate the accuracy of RPM, further investigations are needed to elucidate whether the use of RPM had a positive clinical impact. Although RPM can simulate any type of hepatectomy, we validated RPM only for anatomical liver resection because non-anatomical liver resection sometimes lacks anatomical landmarks and is considered unsuitable for judgment of the efficacy of RPM. The quantitative imaging analysis was performed only using lobectomy. The efficacy of RPM in different types of hepatectomy should be further validated. The efficacy of RPM might be enhanced during laparoscopic surgery, which sometimes causes disorientation due to the limited field of view; however, we could not assess the efficacy of RPM specifically in laparoscopic surgery because only one patient underwent laparoscopic parenchymal transection. Considering that many surgeons were satisfied with RPM in living donor surgeries, RPM may be applicable in laparoscopic living donor surgeries in future.

In conclusion, RPM software is feasible for preoperative simulation of hepatectomy and might be helpful for many surgeons. RPM was also useful for the education of medical students.

Ethical approval

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee (approval number R0841) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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This study was not funded.

Author contribution

Study design: Y. Uchida, K Taura, S. Uemoto.
Data collections: Y. Uchida, K. Taura.
Data analysis: Y. Uchida, M. Nakao.
Writing: Y. Uchida, K Taura.

Conflicts of interest

The authors declare that they have no conflict of interest.

Trial registry number

This study is registered to UMIN Clinical Trials Registry. (UMIN000036629).
Registration LINK: https://www.umin.ac.jp/ctr/index.htm.

Guarantor

Y. Uchdia, K. Taura, M. Nakao, S. Uemoto.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Data statement

The datasets generated during and analysed during the current study are available from the corresponding author on reasonable request.

This study is registered to UMIN Clinical Trials Registry.

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CRediT authorship contribution statement

Yuichiro Uchida: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Kojiro Taura:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing, Supervision. **Megumi Nakao:** Software, Data curation, Formal analysis, Validation. **Shinji Uemoto:** Conceptualization, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijsu.2019.09.002.

References

[1] J. Hallet, B. Gayet, A. Tsung, G. Wakabayashi, P. Pessaux, Systematic review of the use of pre-operative simulation and navigation for hepatectomy: current status and future perspectives, J Hepatobiliary Pancreat Sci 22 (2015) 353–362.
[2] T. Takamoto, T. Hashimoto, S. Ogata, K. Inoue, Y. Maruyama, A. Miyazaki, et al., Planning of anatomical liver segmentectomy and subsegmentectomy with 3-dimensional simulation software, Am. J. Surg. 206 (2013) 530–538.
[3] Y. Wang, Y. Zhang, H.-O. Peitgen, A. Schenk, L. Yuan, G. Wei, et al., Precise local resection for hepatocellular carcinoma based on tumor-surrounding vascular anatomy revealed by 3D analysis, Dig. Surg. 29 (2012) 99–106.
[4] I. Endo, H. Shimada, M. Sugita, Y. Fujii, D. Morioka, K. Takeda, et al., Role of three-dimensional imaging in operative planning for hilar cholangiocarcinoma, Surgery 142 (2007) 666–675.
[5] S. Saito, J. Yamanaka, K. Miura, N. Nakao, T. Nagao, T. Sugimoto, et al., A novel 3D hepatectomy simulation based on liver circulation: application to liver resection and transplantation, Hepatology 41 (2005) 1297–1304.
[6] J. Yamanaka, T. Okada, S. Saito, Y. Kondo, Y. Yoshida, K. Suzumura, et al., Minimally invasive laparoscopic liver resection: 3D MDCT simulation for pre-operative planning, J Hepatobiliary Pancreat Surg 16 (2009) 808–815.
[7] R. Tang, L.F. Ma, Z.X. Rong, M.D. Li, J.P. Zeng, X.D. Wang, et al., Augmented reality technology for preoperative planning and intraoperative navigation during hepatobiliary surgery: a review of current methods, Hepatobiliary Pancreat. Dis. Int. 17 (2018) 101–112.
[8] Y. Oshiro, H. Yano, J. Mitani, S. Kim, J. Kim, K. Fukunaga, et al., Novel 3-dimensional virtual hepatectomy simulation combined with real-time deformation, World J. Gastroenterol. 21 (2015) 9982–9992.
[9] Y. Zou, P.X. Liu, Q. Cheng, P. Lai, C. Li, A new deformation model of biological tissue for surgery simulation, IEEE Trans. Cybern. 47 (2017) 3494–3503.
[10] A. Idkaidek, I. Jasiuk, Toward high-speed 3D nonlinear soft tissue deformation simulations using Abaqus software, J. Robotic Surg. 9 (2015) 299–310.
[11] M.R. Dehghan, A. Rahimi, H.A. Talebi, M. Zareinejad, A three-dimensional large deformation model for soft tissue using meshless method, Int. J. Med. Robot. 12 (2016) 241–253.
[12] M. Nakao, Y. Oda, K. Taura, K. Minato, Direct volume manipulation for visualizing intraoperative liver resection process, Comput. Methods Progr. Biomed. 113 (2014) 725–735.
[13] M. Nakao, K. Taura, T. Maeda, Deformable resection process map for intraoperative cutting guides, Conf. Proc. Eng. Med. Biol. Soc. (2016) 2554–2557.
[14] R.A. Agha, M.R. Borrelli, R. Farwana, K. Koshy, A. Fowler, D.P. Orgill, For the PROCESS group. The PROCESS 2018 statement: updating consensus preferred reporting of CasE series in surgery (PROCESS) guidelines, Int. J. Surg. 60 (2018) 279–282.
[15] T. Nishio, K. Taura, Y. Koyama, K. Tanabe, G. Yamamoto, Y. Okuda, et al., Prediction of posthepatectomy liver failure based on liver stiffness measurement in patients with hepatocellular carcinoma, Surgery 159 (2016) 399–408.
[16] K. Yoshino, K. Taura, Y. Ikeno, Y. Okuda, T. Nishio, G. Yamamoto, et al., Low preoperative platelet count predicts risk of subclinical posthepatectomy liver failure in right lobe donors for liver transplantation, Liver Transplant. 24 (2018) 1178–1185.
[17] L.R. Dice, Measures of the amount of ecologic association between species, Ecology 26 (1945) 297–302.
[18] P. Lamata, F. Lamata, V. Sojar, P. Makowski, L. Massoptier, S. Casciaro, et al., Use of the Resection Map system as guidance during hepatectomy, Surg. Endosc. 24 (2010) 2327–2337.
[19] C. Li, B. Jing, L. Ke, B. Li, W. Xia, C. He, et al., Development and validation of an endoscopic images-based deep learning model for detection with nasopharyngeal malignancies, Cancer Commun. 38 (2018) 59.