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Retrospective Study

# Topological approach of liver segmentation based on 3D visualization technology in surgical planning for split liver transplantation

Dong Zhao, Kang-Jun Zhang, Tai-Shi Fang, Xu Yan, Xin Jin, Zi-Ming Liang, Jian-Xin Tang, Lin-Jie Xie

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## Abstract

### BACKGROUND

Split liver transplantation (SLT) is a complex procedure. The left-lateral and right tri-segment splits are the most common surgical approaches and are based on the Couinaud liver segmentation theory. Notably, the liver surface following right tri-segment splits may exhibit different degrees of ischemic changes related to the destruction of the local portal vein blood flow topology. There is currently no consensus on preoperative evaluation and predictive strategy for hepatic segmental necrosis after SLT.

### AIM

To investigate the application of the topological approach in liver segmentation based on 3D visualization technology in the surgical planning of SLT.

### METHODS

Clinical data of 10 recipients and 5 donors who underwent SLT at Shenzhen Third People's Hospital from January 2020 to January 2021 were retrospectively analyzed. Before surgery, all the donors were subjected to 3D modeling and evaluation. Based on the 3D-reconstructed models, the liver splitting procedure was simulated using the liver segmentation system described by Couinaud and a blood flow topology liver segmentation (BFTLS) method. In addition, the volume of the liver was also quantified. Statistical indexes mainly included the hepatic vasculature and expected volume of split grafts evaluated by 3D models, the

actual liver volume, and the ischemia state of the hepatic segments during the actual surgery.

## RESULTS

Among the 5 cases of split liver surgery, the liver was split into a left-lateral segment and right tri-segment in 4 cases, while 1 case was split using the left and right half liver splitting. All operations were successfully implemented according to the preoperative plan. According to Couinaud liver segmentation system and BFTLS methods, the volume of the left lateral segment was  $359.00 \pm 101.57$  mL and  $367.75 \pm 99.73$  mL, respectively, while that measured during the actual surgery was  $397.50 \pm 37.97$  mL. The volume of segment IV (the portion of ischemic liver lobes) allocated to the right tri-segment was  $136.31 \pm 86.10$  mL, as determined using the topological approach to liver segmentation. However, during the actual surgical intervention, ischemia of the right tri-segment section was observed in 4 cases, including 1 case of necrosis and bile leakage, with an ischemic liver volume of 238.7 mL.

## CONCLUSION

3D visualization technology can guide the preoperative planning of SLT and improve accuracy during the intervention. The simulated operation based on 3D visualization of blood flow topology may be useful to predict the degree of ischemia in the liver segment and provide a reference for determining whether the ischemic liver tissue should be removed during the surgery.

**Key Words:** Three-dimensional visualization; Couinaud liver segmentation; Blood flow topology liver segmentation; Split liver transplantation; Surgical planning

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**Core Tip:** This is the first study to explore the application of the topological approach of liver segmentation based on 3D visualization technology in surgical planning of split liver transplantation. Clinical data of 10 recipients and 5 donors were analyzed. Couinaud liver segmentation and blood flow topology liver segmentation (BFTLS) methods were used to simulate operation, respectively. The volume of segment IV (the portion of ischemic liver lobes) allocated to the right tri-segment was  $136.31 \pm 86.10$  mL as determined using BFTLS. Results showed that the approach of BFTLS may be useful to predict the range of ischemia in the liver section.

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## INTRODUCTION

The Couinaud liver segmentation is based on the distribution of the Glisson system in the liver and the division of the hepatic vein system. Three hepatic veins are used as vertical planes to form the main longitudinal fissure, and the liver is divided into different liver segments by the left and right branches of the portal vein. This segmentation method provides an anatomical basis for the clinical imaging diagnosis of liver diseases and has been widely used in clinical practice[1-3]. However, only 30%-50% of the segmented results are consistent with the actual anatomy of the liver as the segmented results are derived from the cast liver specimen *ex vivo*, and the variation in hepatic blood vessels is not taken into account[4,5]. The blood flow topology segmentation method is based on the blood flow topology of the hepatic portal vein[6,7]. Therefore, this method can truly reflect the anatomical structure of the liver and is the theoretical basis of anatomical hepatectomy *via* indocyanine green fluorescence imaging[8-10].

Split liver transplantation (SLT) is complex, and the commonly used surgical technique is the left-lateral segment and right tri-segment splits, which are implemented based on the theory of Couinaud liver segmentation. Previous studies uncovered that the right tri-segment liver surface might show different degrees of ischemic changes related to the destruction of the local portal vein blood flow topology following the intervention[11-13].

However, opinions diverge on the management of ischemia found on the surface tissues of the liver segment following SLT, as well as liver tissue necrosis, infection, and bile leakage[11,14]. Some experts postulate that the direct resection of segment IV of the ischemic liver tissue is necessary, while others

believe no treatment is needed. This difference in opinion is due to a lack of preoperative evaluation and predictive strategy for hepatic segmental necrosis after SLT and a dearth of relevant publications worldwide. Therefore, this study aimed to investigate the application value of 3D visualization technology in the surgical planning of SLTs.

## MATERIALS AND METHODS

### General clinical data

A retrospective analysis was performed on 10 patients who underwent SLT in the Third People's Hospital of Shenzhen from January 2020 to January 2021 and the corresponding data of 5 donors. All cases in this study were performed after the approval of the Hospital Ethics Committee. The livers were donated after the death of the donors.

### Pre-operation evaluation

For each organ donor, preoperative blood routine, liver function, kidney function, coagulation function, tumor markers, and infection-related tests, as well as abdominal Doppler ultrasound and liver computed tomography (CT) angiography examination, were performed. A preoperative 3D visualization model of the liver was constructed for each case. The model was acquired by importing high-quality THIN-layer enhanced CT DICOM data into the medical 3D reconstruction software: (1) For organ reconstruction: The region-growing method was used to perform a 3D reconstruction of the liver, tumor, pancreas and spleen; and (2) For vascular reconstruction: The segmentation based on threshold method was used to perform a 3D reconstruction of the portal vein, hepatic artery and hepatic vein[15]. The model was utilized to evaluate the vascular pattern and hepatectomy simulation.

### Simulated surgery

(1) The SLT procedure was simulated on a 3D visualization model and included a segment of the hepatic artery, portal vein, and hepatic vein and the disconnection of the liver parenchyma; and (2) The SLT procedure was simulated according to the Couinaud liver segmentation and blood flow topology liver segmentation (BFTLS) methods. The volume of the two liver segments and the ischemic volume were also quantified (Figure 1).

### Actual operation

The combination of *in-situ* and *ex vivo* splitting was used for liver splitting. The surgical methods included left-lateral and right tri-segment splits, and left and right hepatic splits. During the operation, Doppler ultrasound was employed to identify and mark the shape of the middle hepatic vein, and a cavitron ultrasonic surgical aspirator and an ultrasonic knife were used to separate the liver parenchyma.

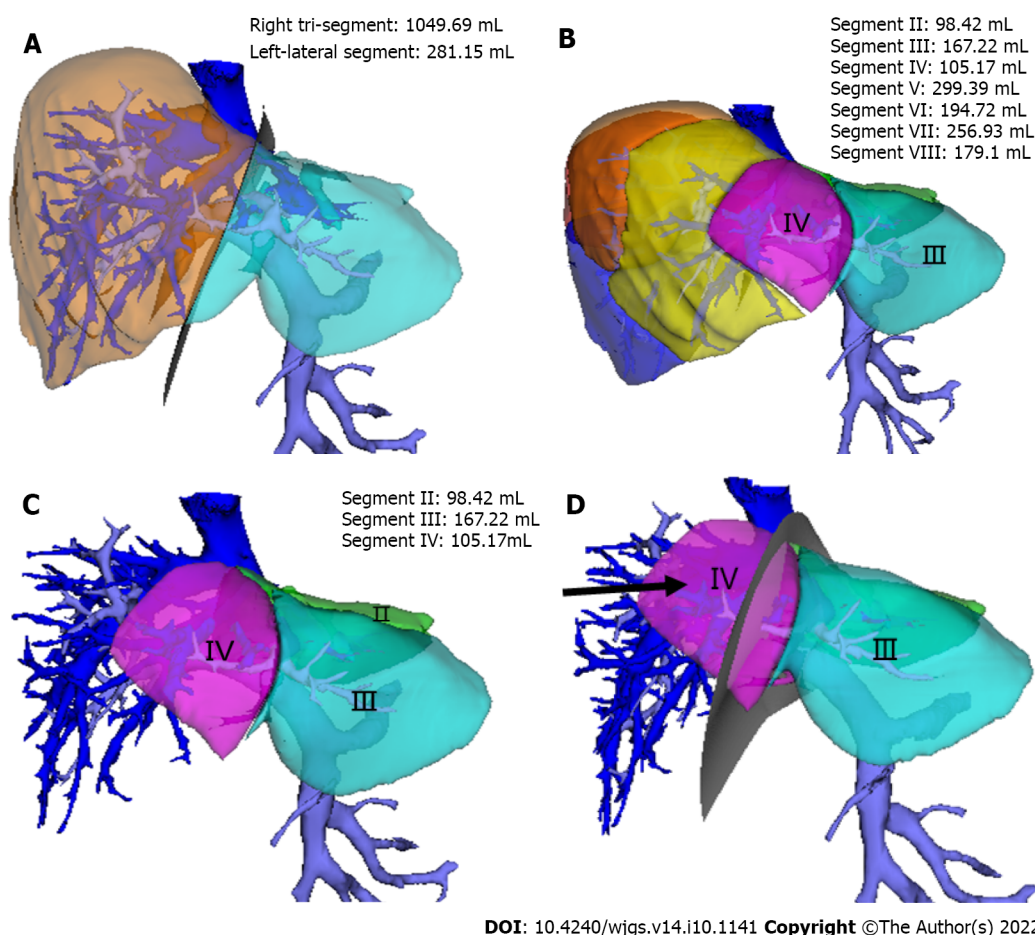
### Main statistical indicators

The classification of hepatic vasculatures was based on 3D visualization technology, the hepatic and ischemic volume was estimated using simulated surgery, and hepatic ischemia was measured during the actual surgery.

## RESULTS

Preoperative hepatic vascular evaluation and simulated surgical results. The preoperative 3D visualization model revealed that all the donor hepatic portal veins were Cheng *et al*'s type I[16], the hepatic arteries were Michels[17] type I, the middle hepatic vein and left hepatic vein shared trunk in 5 cases, and a single hepatic vein of segment IV directly flowed into the inferior vena cava in 1 case. Among the 5 simulated operations, 4 cases were split into left-lateral segment and right tri-segment; 1 case was split into left and right half liver, and the middle hepatic vein was split by median segmentation.

The results revealed that the resection plane simulated by the Couinaud liver segmentation method or BFTLS method was inconsistent, the former was flat, while the latter was irregularly shaped. 4 cases were simulated using left-lateral and right tri-segment splits. As measured by the above two liver segmentation methods, the volumes of the left-lateral segments were  $359.00 \pm 101.57$  mL and  $367.75 \pm 99.73$  mL, respectively. According to the BFTLS method, the volume of segment IV (*i.e.*, the ischemic part of the liver) cleaving to the right tri-segment was  $136.31 \pm 86.10$  mL. 1 case of left and right liver splitting was simulated, and median segmentation of the middle hepatic vein was performed after strictly evaluating two adult recipients with low body weight. The operation was simulated according to the above two segmentation methods. 99.95 mL of tissues in segment IV was assigned to the left half of the liver according to Couinaud classification; if splitting was carried out according to this method, 99.95 mL of liver tissues might experience postoperative ischemia or even necrosis.



**Figure 1** The range of hepatic ischemia was calculated by simulating the left-lateral segment and right tri-segment splitting. A: The simulated operation based on Couinaud liver segmentation; B: The liver segments constructed via the topological structural relationship of portal vein blood flow; C: The calculated liver volume of the II/III/IV segments based on the blood flow topology liver segmentation method; D: The volume of ischemic range in the hepatic segment of the right tri-segment after split liver transplantation (black arrow).

### Actual surgical results

In practice, *in-situ* and *ex vivo* splits were performed successfully according to the preoperative plan. According to the Couinaud liver segmentation method, left-lateral and right tri-segment splitting was performed in 4 cases. The left branch of the portal vein, the main trunk of the left hepatic artery, and the left branch of the hepatic vein were distributed to the left-lateral segment. The hepatic artery and portal vein branches entering segment IV of the liver were severed. The actual volume of the left-lateral segment was  $397.50 \pm 37.97$  mL. The liver sections of the 4 cases exhibited ischemic changes after the operation (Figure 2). 1 case experienced necrosis of the liver section and bile leakage and underwent reoperation to remove the necrotic tissues. The volume of the ischemic liver calculated before the operation was 238.7 mL.

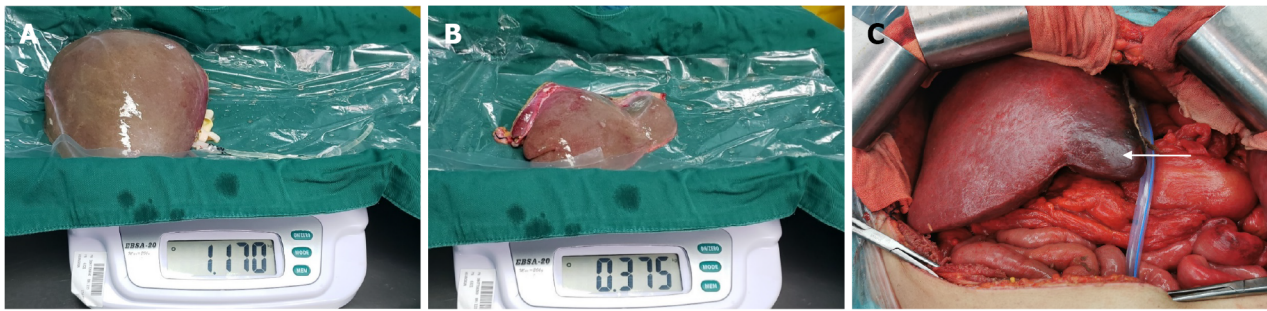
In the other case, the operation was performed by left and right half liver splitting based on the portal vein BFTLS method. The middle hepatic vein was segmented in the middle, and the donor's external iliac vein was used to reconstruct the middle hepatic vein of the left and right halves of the liver. No apparent changes in hepatic sectional ischemia were detected post-surgery (Figure 3).

### Post-transplant outcomes

The operation was successfully completed in all 10 patients corresponding to the split livers, and postoperative biliary leakage occurred in 1 case without small-for-size syndrome. During the perioperative period, 1 patient who underwent a right tri-segment split suffered from a sudden intracerebral hemorrhage on the 7<sup>th</sup> postoperative day and died on the 18<sup>th</sup> postoperative day.

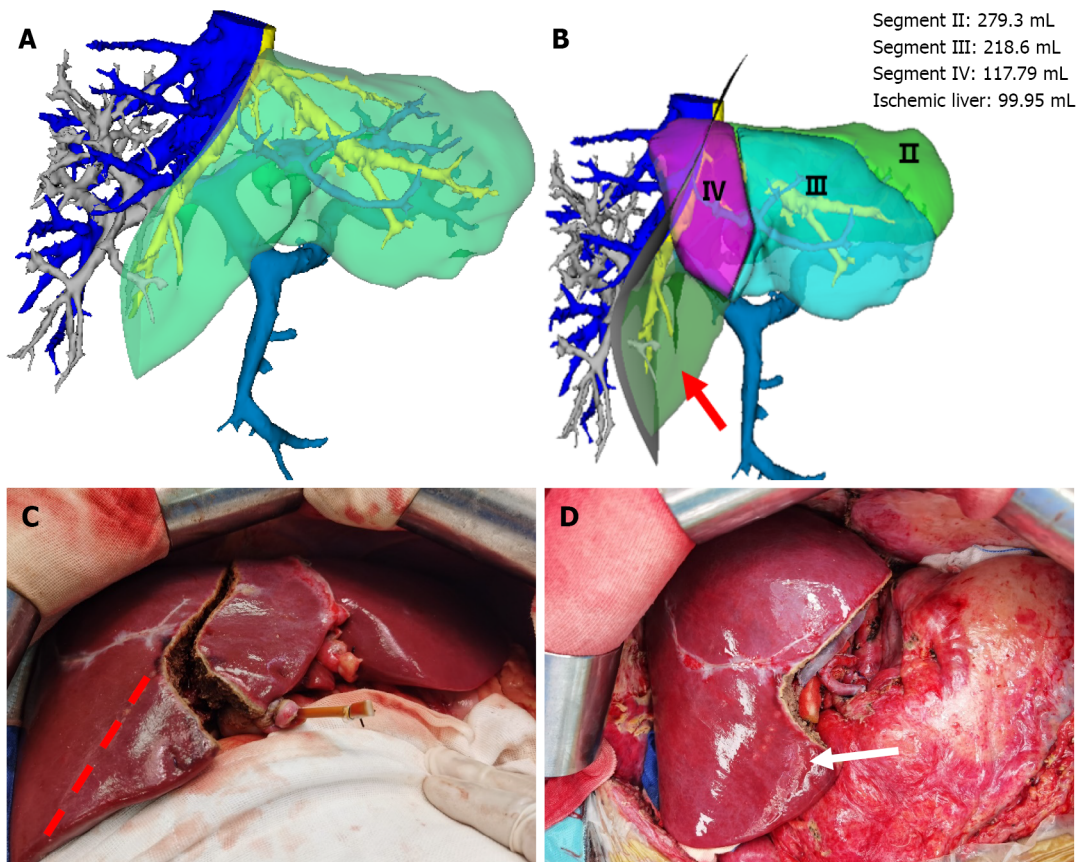
## DISCUSSION

Couinaud liver segmentation is an artificial segmentation method based on anatomical markers of the liver. Moreover, its segmentation plane limits the drainage area of the hepatic vein and does not



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**Figure 2** Based on the Couinaud liver segmentation method, left-lateral segment and right tri-segment splits were performed. During the operation, obvious ischemic changes in the cross-section of the right tri-segment were observed. A: The right tri-segment graft; B: The left-lateral segment graft; C: Cleaved right tri-segment with distinct ischemia in the hepatic segment after hepatic reflow (white arrow).



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**Figure 3** Left and right half-split liver transplantation was performed according to the portal vein blood flow topology liver segmentation method. There was no ischemic change in the liver segment after reflow. A: Left and right half liver splitting were simulated based on the Couinaud liver segmentation method, while the middle hepatic vein was split in the middle; B: The simulation of left and right half liver splitting based on the portal vein blood flow topology liver segmentation method. It can be seen that a portion of segment V liver tissues (99.95 mL) is partitioned into the left liver (arrow); C: Surgery based on the portal vein blood flow topology liver segmentation method was implemented for left and right half liver splitting instead of the Couinaud liver segmentation method (red dotted line); D: No ischemic changes in the hepatic segment after reflow (white arrow).

consider the topology of portal vein branches in the liver[6,7,18]. For instance, when a vascular variation occurs in the liver, multiple portal or hepatic vein branches may co-exist within the same Couinaud liver segment. However, the BFTLS approach used herein was based on the topological structural relationship of the hepatic portal vein, which can truly display anatomical structural relationships in the liver[6,7]. Indeed, this concept is also widely used in clinical practice[19-21].

The initial aim of SLT is to save two lives with a single liver. However, inappropriate preoperative evaluation of the liver donor or splitting method may bring a well-functional liver into 2 marginal donors, which may delay the recovery of graft function and even lead to graft failure or recipient death

[22,23]. Therefore, compared with other hepatobiliary surgeries, adequate preoperative evaluation of SLT is monumental. At the time of preoperative donor evaluation, enhanced CT of the liver must be performed, with initial vascular and biliary evaluation followed by re-evaluation based on the 3D visual model. If the donor has significant portal vein variation, SLT is not recommended to ensure the safety of both recipients. Herein, only donors with good liver function and no significant anatomical variation were included in the SLT cohort. All the patients undergoing SLT in our center underwent an initial simulation using the 3D visualization model, and the portal vein, hepatic vein, and hepatic artery were segmented accordingly. Furthermore, the liver volume was also calculated so that a detailed preoperative plan could be drawn up.

In this study, all patients underwent simulated surgeries using the Couinaud liver segmentation method and BFTLS method, and the measured volumes of the left-lateral segment were  $359.00 \pm 101.57$  mL and  $367.75 \pm 99.73$  mL, respectively. Moreover, according to the above two methods, the volume of the segment IV (the portion of the ischemic liver lobe) allocated to the right tri-segment was  $136.31 \pm 86.10$  mL, obtained by adding the volume of segments II/III/IV minus the volume of the left-lateral segment. Based on these data, we can obtain a detailed evaluation of the surgery, predict the degree of ischemic tissue changes and necrosis in the liver segments, as well as assess the need to remove ischemic segments during liver transplantation.

Hepatic segmental ischemic necrosis is extremely common following SLT, mainly because the branches of the portal vein[13] and hepatic artery[14,24,25] entering this part of the liver are not connected, and the corresponding hepatic vein[26-28] may also be cut off in some cases. Therefore, this part of the liver may undergo pathological changes such as hepatocyte ischemia, necrosis, fibrosis, and atrophy, and in some cases, tissue necrosis and bile leakage. Indeed, one of the 5 cases in this study suffered from ischemic tissue necrosis and bile leakage on the surface of the right tri-segment. The necrotic tissue was eventually resected by reoperation in that particular case, with a preoperative ischemic liver volume of 238.7 mL. The ischemic areas of the right tri-segment in the other 3 cases, calculated preoperatively, were 76.9 mL, 54.4 mL, and 175.3 mL, respectively. Therefore, we postulate that if the scope of hepatic segmental ischemia can be accurately determined before the operation, hepatic segmental tissue necrosis can be predicted in advance, avoiding reoperation and alleviating the pain and economic burden of patients.

## CONCLUSION

In conclusion, in the case of the left-lateral segment and right tri-segment splits, preoperative evaluation based on three-dimensional visualization technology could calculate the ischemic range of the right tri-segment. Judging by the results, the operator could predict the postoperative ischemic range and make clinical judgments accordingly. For instance, when the branches of the hepatic artery and portal vein of segment IV supplying the right tri-segment are disconnected, and the calculated ischemic range is large, the operator can directly remove this section during the operation to avoid further damage to the body due to tissue necrosis, infection or bile leakage. Nevertheless, due to the small number of cases, it was not possible to determine a specific cut-off value to predict the likelihood of postoperative hepatic ischemic necrosis. Therefore, it is imperative to include a large number of cases for future clinical or multi-center research.

## ARTICLE HIGHLIGHTS

### Research background

Split liver transplantation (SLT) is complex, and the commonly used surgical technique is the left-lateral segment and right tri-segment splits, which is implemented based on Couinaud liver segmentation. The right tri-segment liver surface may have different degrees of ischemic changes after SLT, which was related to the destruction of the local portal vein blood flow topology.

### Research motivation

To our best knowledge, opinions diverge on the management of ischemia in surface tissues of the liver segment following SLT and there was no a consensus of pre-operative evaluation and predictive strategy for hepatic segmental necrosis after SLT worldwide.

### Research objectives

Herein, we sought to investigate the application of the topological approach of liver segmentation based on 3D visualization technology in the surgical planning of SLT.

### Research methods

A retrospective analysis was performed on 10 recipients and 5 donors who underwent SLT from January 2020 to January 2021. All the donor livers were subjected to 3D modeling and evaluation before surgery, based on which the liver splitting procedure was simulated by the Couinaud liver segmentation and blood flow topology liver segmentation (BFTLS) methods respectively, and the volume of the liver was calculated. Clinical data were analyzed, including the hepatic vasculature and expected volume of split grafts evaluated by 3D models, the actual liver volume, and the ischemia state of hepatic section in actual surgery.

### Research results

The donor liver was split into a left-lateral segment and right tri-segment in 4 cases, while 1 case was split by left and right half liver splitting. According to Couinaud liver segmentation and BFTLS methods, the volume of the left lateral segment was  $359.00 \pm 101.57$  mL and  $367.75 \pm 99.73$  mL, respectively. The volume of segment IV (the portion of ischemic liver lobes) allocated to the right tri-segment was  $136.31 \pm 86.10$  mL as determined using the topological approach to liver segmentation. Yet, during the actual operations, ischemia of the right tri-segment section was observed in 4 cases, including 1 case of necrosis of the surfaces cut and bile leakage.

### Research conclusions

The application of the topological approach of liver segmentation based on 3D visualization technology may be useful to predict the range of ischemia in the liver section and provide a basis for determining whether the ischemic liver tissue should be removed during the surgery.

### Research perspectives

However, the follow-up studies with large samples are still warranted due to the relatively small number of cases.

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## FOOTNOTES

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