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INTERVENTIONAL RADIOLOGY

ORIGINAL ARTICLE

Preoperative simulation results and intraoperative image fusion guidance for transjugular intrahepatic portosystemic shunt placement: a feasibility study of nineteen patients

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PURPOSE

The purpose is to evaluate the feasibility and efficacy of preoperative simulation results and intraoperative image fusion guidance during transjugular intrahepatic portosystemic shunt (TIPS) creation.

METHODS

Nineteen patients were enrolled in the present study. The three-dimensional (3D) structures of the bone, liver, portal vein, inferior vena cava, and hepatic vein in the contrast-enhanced computed tomography (CT) scanning area were reconstructed in the Mimics software. The virtual Rosch–Uchida liver access set and the VIATORR stent model were established in the 3D Max software. The puncture path from the hepatic vein to the portal vein and the release position of the stent were simulated in the Mimics and 3D Max software, respectively. The simulation results were exported to Photoshop software, and the 3D reconstructed top of the liver diaphragm was used as the registration point to fuse with the liver diaphragmatic surface of the intraoperative fluoroscopy image. The selected portal vein system fusion image was overlaid on the reference display screen to provide image guidance during the operation. As a control, the last 19 consecutive cases of portal vein puncture under the guidance of conventional fluoroscopy were analyzed retrospectively, including the number of puncture attempts, puncture time, total procedure time, total fluoroscopy time, and total exposure dose (dose area product).

RESULTS

The average time of preoperative simulation was about 61.26 ± 6.98 minutes. The average time of intraoperative image fusion was 6.05 ± 1.13 minutes. The median number of puncture attempts was not significantly different between the study group (n = 3) and the control group (n = 3; *P* = 0.175). The mean puncture time in the study group (17.74 ± 12.78 min) was significantly lower than that in the control group (58.32 ± 47.11 min; *P* = 0.002). The mean total fluoroscopy time was not significantly different between the study group (26.63 ± 12.84 min) and the control group (40.00 ± 23.44 min; *P* = 0.083). The mean total procedure time was significantly lower in the study group (79.74 ± 37.39 min) compared with the control group (121.70 ± 62.24 min; *P* = 0.019). The dose area product of the study group (220.60 ± 128.4 Gy. cm^2) was not significantly different from that of the control group (228.5 ± 137.3 Gy. cm^2; *P* = 0.773). There were no image guidance-related complications.

CONCLUSION

The use of preoperative simulation results and intraoperative image fusion to guide a portal vein puncture is feasible, safe, and effective when creating a TIPS. The method is cheap and may improve portal vein puncture, which may be valuable for hospitals lacking intravascular ultrasound and digital subtraction angiography (DSA) equipment equipped with a CT-angiography function.

KEYWORDS

Cirrhosis, portal hypertension, transjugular intrahepatic portosystemic shunt, three-dimensional reconstruction, simulation, image fusion guidance

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A transjugular intrahepatic portosystemic shunt (TIPS) has been widely used to treat some complications associated with portal hypertension.[1-3] With the increasing experience of surgeons and the continuous development of imaging methods, the incidence of major complications related to a TIPS has decreased significantly in the past few decades.[4,5] Puncturing the portal vein during a TIPS procedure is no longer a challenge for experienced doctors in large and medium-sized medical centers. However, in developing countries and underdeveloped regions, for medical institutions that are about to carry out a TIPS treatment (or the initial stages of the treatment), the puncture from the hepatic vein to the portal vein is still difficult, and doctors will face potentially fatal puncture-related complications.[6] Therefore, effective and cheap intraoperative guidance methods may have a significant reference value for these interventional doctors in underdeveloped areas.

The preoperative simulation of a TIPS on a personal computer may provide some useful parameters. The fusion of the simulation results with intraoperative fluoroscopy may be helpful for the portal vein puncture. The purpose of this study is to evaluate the feasibility and effectiveness of carrying out a TIPS procedure under the guidance of fusion images in terms of the number of puncture attempts, puncture time, total procedure time, total fluoroscopy time, and dose area product, and to compare this with a conventional fluoroscopy group.

Methods

Patients

Nineteen consecutive patients who underwent a TIPS procedure because of complications resulting from cirrhosis-related portal hypertension were enrolled in the study between January 2021 and March 2022. The indication for TIPS creation was recurrent variceal bleeding refractory to endoscopic treatment and drug therapy. According to the Child–Pugh classification, chronic liver disease was categorized as class A in two patients, class B in 16 patients, and class C in one patient. Written informed consent was obtained from all patients before inclusion in this study. The study was approved by the Medical Ethics Committee of Nanchong Central Hospital [approval number: 2021, annual review (048), date: August 24, 2021]. As a control, the last 19 consecutive cases of the TIPS procedure were performed under the guidance of conventional fluoroscopy and analyzed retrospectively, including the number of puncture attempts, puncture time, total procedure time, total fluoroscopy time, and dose area product.

Main points

- Compared with traditional methods, using preoperative simulation results and intraoperative image fusion to guide portal vein puncture in transjugular intrahepatic portosystemic shunt creation is feasible, safe, and effective.
- The results show that the study group's puncture time and total procedure time were significantly lower than those in the control group guided by fluoroscopy. This method is cheap and may improve portal vein puncture.
- To assess the impact of respiratory movement and the introduction of a stiff puncture needle and sheath on the position and direction of the liver, further study is required to try to find new image-matching reference points.

Methods of preoperative simulation

The portal vein phase data of preoperative abdominal-enhanced computed tomography (CT) were imported into the Mimics 10.0 software (Materialise NV, Leuven, Belgium) in Digital Imaging and Communications in Medicine format. The three-dimensional (3D) reconstruction models of the bone, portal vein, hepatic vein, inferior vena cava, and liver were extracted by setting the threshold and combining the functions of "region growing" and "dynamic region growing".

The above 3D models of the patient were saved in an STL format file and then imported into the 3D Studio Max 7.0 software (Autodesk, San Rafael, California, USA). In the system settings of the software, the modeling unit was set to mm. According to the dimensions in the Rosch–Uchida transjugular liver access set (RUPS-100; Cook Medical Inc., Bloomington, Indiana, USA) and the VIATORR (W.L. Gore & Associates, Inc., Flagstaff, Arizona, USA) stent instructions, the liver access set, and stent models were established, respectively, by using the functions of line drawing, bending, alignment, and lofting (Figure 1). The liver access set and stent models were incorporated into the patient's 3D model scene. The planning of the puncture path from the hepatic vein to the portal vein, the shaping angle of the puncture needle end, and the simulation operation of the position of the stent in the portal vein were carried out (Figures 2, 3). The liver access set and stent model could also be saved in STL format and imported into the Mimics software for puncture and stent position simulation (Figure 4).

Methods of intraoperative image fusion

In the 3D Studio Max software, the inferior vena cava, portal vein, bone, and liver top models were rendered and saved in the anterior and lateral positions, respectively (image resolution: 1200 × 1200). In the Photoshop software, a transparent background image was established (image resolution: 1200 × 1200). The above-rendered images were imported into the transparent background image to become different layers. In each layer, the blank part was selected and deleted, which formed a combined image containing each part (Figure 5). During the operation, the X-ray fluoroscopy image of the anteroposterior position operation area was collected and saved in BMP or JPG format and then imported into the combined image. The X-ray fluoroscopy layer was scaled, and the ribs and vertebral bodies were overlapped and aligned with the 3D reconstructed bone image. Then, the reconstructed liver top lay-

Figure 1. This image shows three-dimensional (3D) models of the Rups-100 liver access set and the VIATORR stents. In the 3D Max software, the angle of the front end of the liver access set and the bending direction of the VIATORR stent can be adjusted according to the simulated path of the portal vein puncture.

er was associated with the portal vein layer and moved together so that the upper edge of the liver top overlapped with the liver top position of the X-ray fluoroscopy image to form a fusion image (Figure 6); this was the output to the reference display screen in the operation room.

TIPS procedure

The 19 TIPS procedures were performed by the angiography system (Artis Zeego, Siemens Healthcare) and a team of five interventional radiologists (two of whom have more than three years of experience with a total of 76 TIPS procedures). Percutaneous access was achieved by puncture of the right internal jugular vein. A 10-French introducer was inserted, and the operator catheterized the hepatic vein. After introducing the liver access set into the hepatic vein, the intrahepatic puncture was performed according to the fusion image on the reference display screen. The lateral position of the C-arm was adjusted if necessary, and the lateral position fusion image was established. The initial angle of the puncture needle was not shaped in all cases during the first puncture. When the puncture was not successful after three attempts, it was considered that the bending angle of the puncture needle was not appropriate. At this point, the puncture needle was shaped according to the simulated angle. Once access to the intrahepatic portal branches was confirmed, a portogram was acquired, and the portal pressure gradient was measured. In each patient, the parenchymal tract was initially dilated using an 8 mm-diameter angioplasty balloon. A VIATORR stent was deployed to cover the entire length of the shunt up to the junction of the hepatic vein and the inferior vena cava. A final portal venogram was acquired, and the portal pressure gradient was measured again after the TIPS procedure.

Analysis methods and definitions

The time required for modeling and simulating puncture and stent release and acquisition of X-ray fluoroscopy images to the completion of the image fusion in each patient were recorded. For each procedure, parameters such as technical success, the number of needle passes, radiographic fluoroscopy time, total procedure time, radiation exposure, and procedural complications were recorded for data analysis. The system automatically recorded the total fluoroscopy time and the dose area product relating to the whole procedure. During the TIPS procedure, digital subtraction angiography (DSA) technicians usually

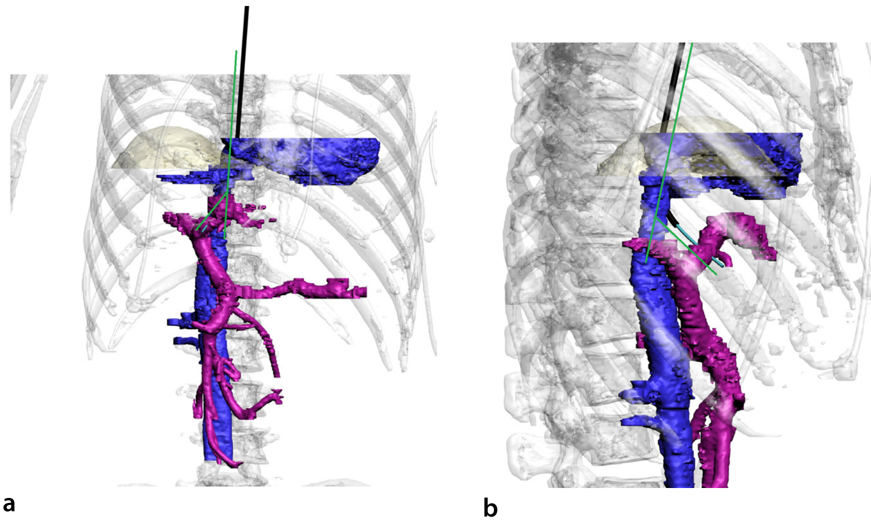

Figure 2. (a, b) The left portal vein puncture was simulated in the three-dimensional Max software. In the rendered anteroposterior position, the image shows the spatial relationship between the puncture needle and the portal vein and the angle of the puncture needle pointing to the portal vein **(a)**. The rendered lateral position image shows the bending angle of the front end of the puncture needle **(b)**. The yellow part of the picture is the liver dome. The additional green line indicates an angle that can be measured.

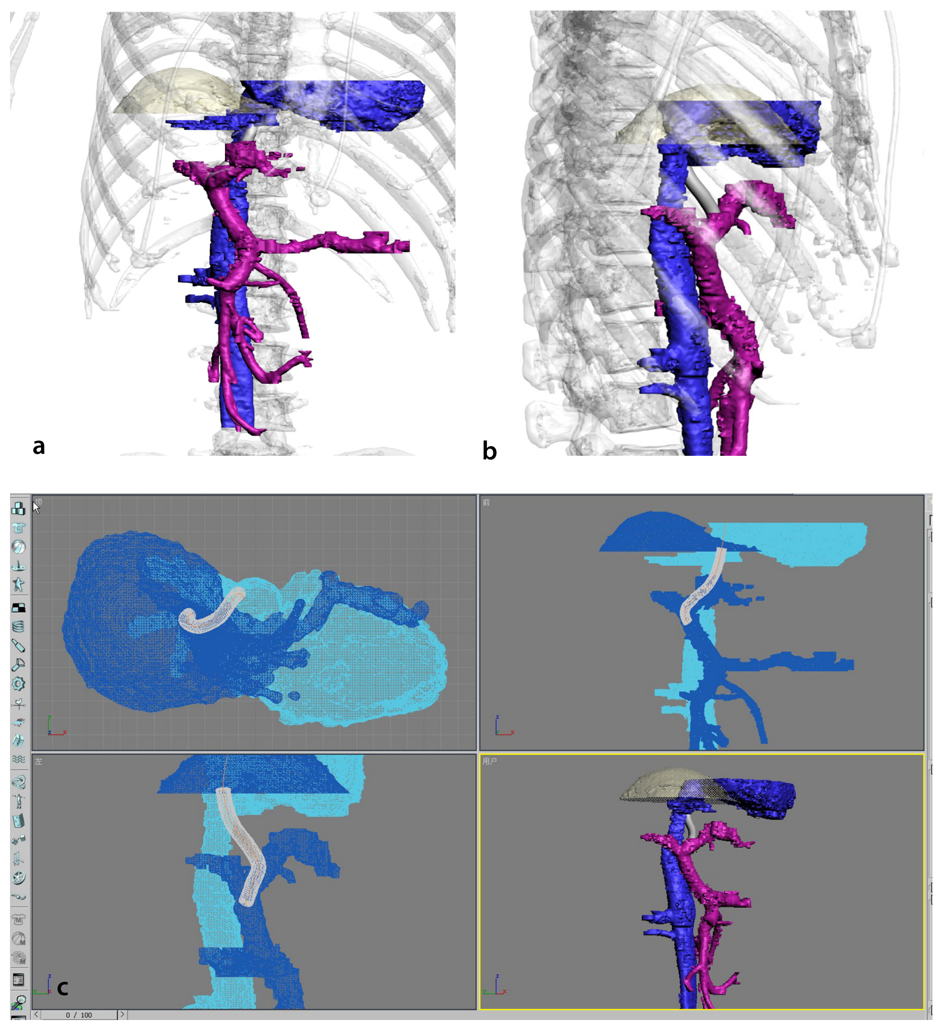

Figure 3. (a-c) The stent release simulation was performed in the three-dimensional (3D) Max software. The 3D rendering results show the relationship between the stent and the blood vessel in the anteroposterior position **(a)** and the lateral position **(b)**, respectively. The morphology of the intravascular stent is clearly displayed on the 3D Max software interface **(c)**.

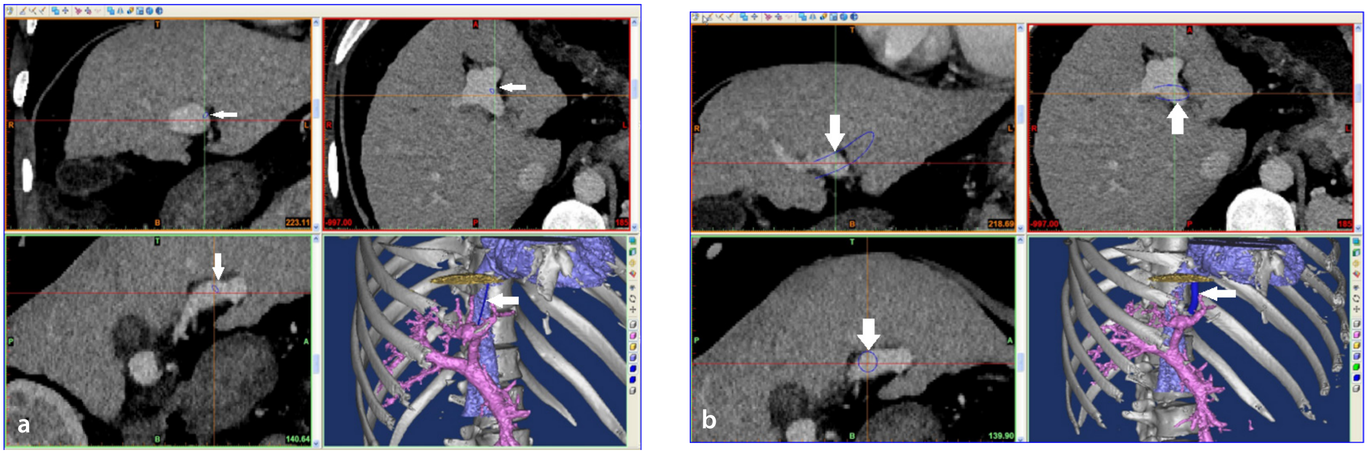

Figure 4. (a, b) Simulated portal vein puncture and stent release were performed in the Mimics software. The software can automatically display the path of the puncture needle (arrows) **(a)** and the path of the stent (arrows) **(b)** in transverse, coronal, and sagittal positions.

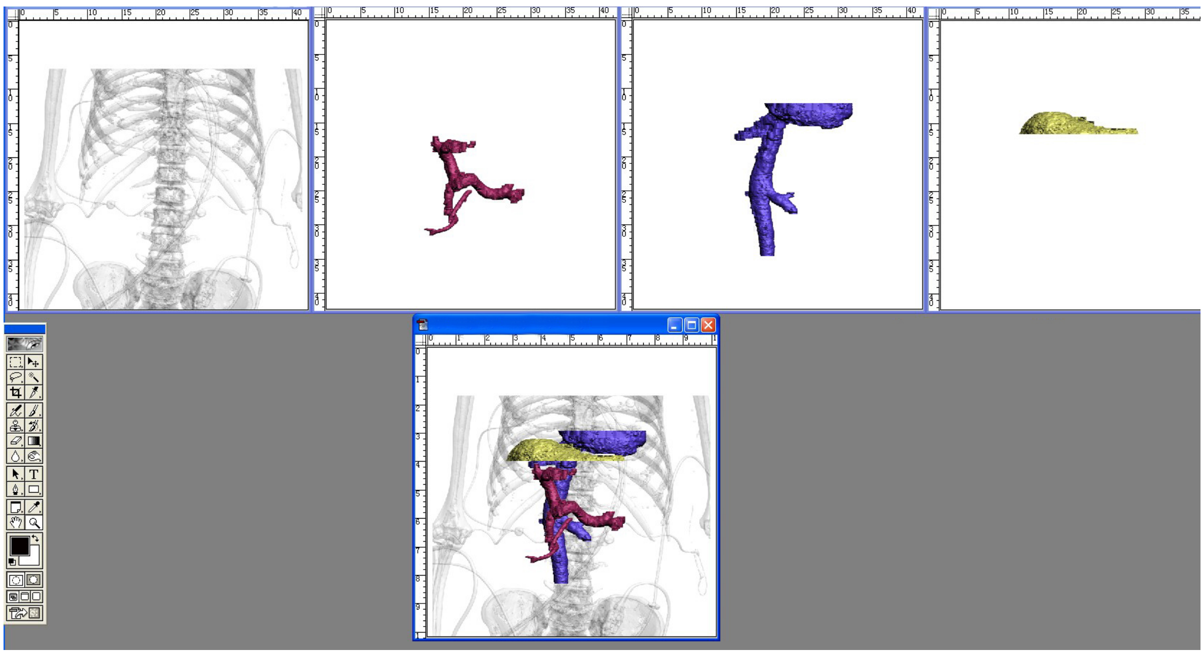

Figure 5. In the Photoshop software, the four images in the upper row show the models of the inferior vena cava, portal vein, bone, and the top of the liver diaphragm rendered in three-dimensional Max software. The following figure shows the combined image after merging the layers of four images.

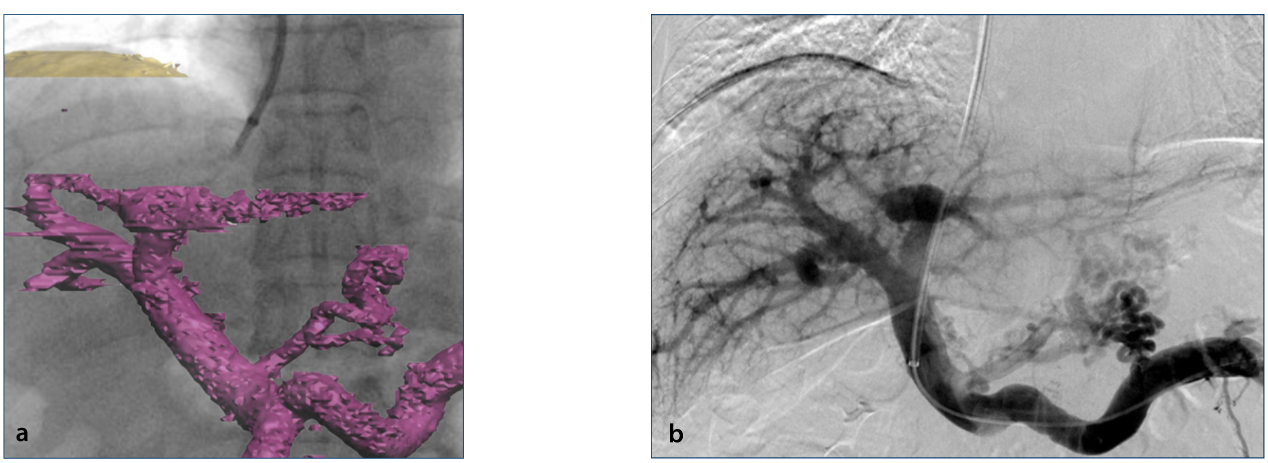

Figure 6. (a, b) A 44-year-old man with liver cirrhosis undergoing intraoperative image fusion guidance assisted transjugular intrahepatic portosystemic shunt to prevent variceal rebleeding. This is an example of relatively good registration accuracy. The yellow part of the picture is the three-dimensional (3D) reconstructed liver dome, which is registered and fused with the diaphragmatic surface of the liver in the intraoperative fluoroscopy **(a)**. The left branch of the portal vein was successfully punctured after one puncture. Portal venography showed that the position and shape of the main portal vein and its left and right branches were consistent with the preoperative 3D reconstruction model **(b)**.

saved the fluoroscopy images for each puncture operation. The portal vein puncture time of the patients in the control group was reconstructed as the time interval from the first image to the recorded image showing successful portal vein puncture. The total procedure time in the control group was reconstructed as the interval from the first to the last documented image. The number of puncture attempts was reconstructed as the number of puncture images saved at different time points before entering the portal vein. This possibly underestimated counting method did not exaggerate the significant difference between the two groups.

Technical success was defined as the successful creation of a shunt between the hepatic vein and the intrahepatic branch of the portal vein. The number of needle passes refers to the number of attempted punctures of the portal vein. Radiographic fluoroscopy time was defined as the period during which the X-ray fluoroscopy was used to guide the whole TIPS procedure. The total radiation dose associated with the whole procedure was automatically recorded by the system. Procedural complications were recorded during hospitalization, including intraabdominal hemorrhage, hepatic artery injury, hemobilia, and stent malposition.

Statistical analysis

All statistical analyses were performed with commercially available software (SPSS 22.0, IBM Corp., Armonk, New York, USA). Graphics were created with GraphPad Prism v.5 (GraphPad Software, San Diego, California, USA). Median and interquartile ranges were given for categorical data. Continuous variables were shown with mean and standard deviation. The Wilcoxon signed-rank test for non-normal distributed data was applied to assess the level of significance. Comparisons between intraoperative image fusion guidance and conventional fluoroscopy guidance were analyzed using the two-sided Mann–Whitney U test for continuous variables and Fisher's exact test for categorical variables. A P value lower than 0.005 was accepted as a significant difference.

Results

All software operations of preoperative simulation and image fusion were completed by an interventional radiologist in the study group. Nineteen patients with a mean age of 49.74 ± 10.93 years (range: 26–66 years) were included in the study. There were 17 men (89.5%) and two women (10.5%). The establishment of the virtual RUPS-100 liver access set and the VIATORR stent models was completed in the preliminary study, which took about 180 minutes. In this study, the model only needed to be copied and imported into the simulation scene. The average time of preoperative simulation in 19 patients was about 61.26 ± 6.98 (range: 50–75 minutes) minutes (Table 1), including the establishment of an individualized patient model, the simulation of the portal vein puncture, and the stent release in the 3D Studio Max and Mimics software. The operation convenience and the 3D display effect of the simulation process in the 3D Studio Max software were better than those in the Mimics software; the Mimics software had the advantage of observing the relationship between the puncture needle path and the artery and bile duct. Table 2 shows the patients' data in the control group.

Using the time of the disinfection and the laying of the surgical towel, the rendered images of each reconstructed part of the model were imported into the Photoshop software, and the merged images with different layers were established. When the operator had

Table 1. Data pertaining to preoperative simulation, intraoperative image fusion, and the transjugular intrahepatic portosystemic shunt procedure

Patient no.	Preoperative simulation time (min)	Intraoperative image fusion time (min)	Puncture time (min)	Overall procedure time (min)	No. of needle passes	Radiographic fluoroscopy time (min)		Radiation dose (Gy·cm²) of whole procedure	No. of stents placed
						Portal vein entry	Whole procedure		
1	57	8	22	90	4	7	30	466.79	1
2	65	6	19	99	2	6	33	151.91	1
3	56	5	34	99	4	11	33	87.99	1
4	64	7	6	42	1	2	14	95.47	1
5	72	8	12	108	2	4	36	391.43	1
6	52	7	36	147	3	12	49	408.53	1
7	68	6	4	30	1	2	10	100.79	1
8	58	7	21	48	4	7	16	106.97	1
9	75	6	5	75	1	2	25	108.71	1
10	64	5	36	162	3	12	54	387.30	1
11	60	5	13	87	3	4	29	300.65	1
12	55	5	4	75	1	2	25	182.65	1
13	63	6	47	87	4	11	29	340.17	1
14	57	5	6	22	1	2	5	126.00	1
15	50	5	16	42	3	5	20	77.84	1
16	72	8	14	116	3	6	42	275.60	2
17	63	6	17	69	3	5	21	269.91	1
18	58	5	22	65	3	4	21	176.33	1
19	55	5	3	52	1	1	14	136.55	1

completed the internal jugular vein puncture, inserted the guide wire and catheter, and introduced the stiff puncture needle and sheath in the hepatic vein for X-ray fluoroscopy, the time required for the image fusion was calculated. The total time was about 6.05 ± 1.13 minutes (range: 5–8 minutes), including saving the X-ray fluoroscopy image, copying the image from the workstation, and importing it into the Photoshop software to form a fusion image.

Technical success in TIPS creation was achieved in all 19 patients in the study group, of which 17 patients received variceal embolization at the same time. Each patient had a 3D reconstruction image of the portal venous system overlaid on the X-ray fluoroscopy to form a fusion image. One case used the preoperative simulated puncture needle as the registration reference point for image fusion to guide the portal vein puncture (Figure 7). Under the guidance of the intraoperative fusion map on the reference screen, the interventional radiologist adjusted the angle pointing to the left or right portal vein branch for puncture and successfully performed the operation on 15 patients without adjusting the bending angle of the front end of the liver access set. Four patients underwent portal vein puncture three times according to the original bending angle of the front end of the liver access set, but all were unsuccessful. Then, according to the simulation results of the bending angle of the liver access set, the bending angle of the puncture needle was increased, and all four cases were successful at the fourth puncture. Intraoperative puncture of the bifurcation of the left and right branches of the portal vein was achieved in two cases, the left branch in 10 cases, and the right branch in seven cases (preoperative simulated puncture of the left branch in 12 cases and the right branch in seven cases). The overall coincidence rate was 89.47% (17/19).

The median number of puncture attempts was not significantly different between the study group (n = 3) and the control group (n = 3; P = 0.175; Figure 8). The mean puncture time in the study group (17.74 ± 12.78 min) was significantly lower than that in the control group (58.32 ± 47.11 min; P = 0.002; Figure 9). The mean total fluoroscopy time was not significantly different between the study group (26.63 ± 12.84 min) and the control group (40.00 ± 23.44 min; P = 0.083; Figure 10). The mean total procedure time was significantly lower in the study group (79.74 ± 37.39 min) compared to the control group (121.70 ± 62.24 min; P = 0.019; Figure 11). The dose area product of the study group (220.60 ± 128.4 Gy. cm^2) was not significantly different from that of the control group (228.5 ± 137.3 Gy. cm^2; P = 0.773; Figure 12). For details, refer to Table 2.

Two patients were punctured at the bifurcation of the left and right branches of the portal vein. The method of releasing the VIATORR stent first and then expanding the balloon in the stent was implemented. No contrast agent extravasation was observed on the portal vein angiography. The condition of these patients remained hemodynamically stable without transfusion. No other major complications or in-hospital deaths were observed in the present study.

Table 2. Data relating to the study group (image fusion guided transjugular intrahepatic portosystemic shunt) and the control group (conventional transjugular intrahepatic portosystemic shunt)

	Study group (n=19)	Control group (n=19)	*P* value
Gender (male/female)	17/2	12/7	0.124
Age (years)	49.74 ± 10.93	53.58 ± 8.43	0.447
Child–Pugh grade			0.539
A	2	4	
B	16	13	
C	1	2	
Ascites [n (%)]	15 (78.95%)	12 (63.16%)	0.476
Portal vein thrombosis [n (%)]	3 (15.79%)	1 (5.26%)	0.604
Location of portal vein puncture			0.342
Left branch of portal vein	10	15	
Right branch of portal vein	7	3	
Bifurcation of portal vein	2	1	
Variceal embolization [n (%)]	17 (89.47%)	14 (73.68%)	0.405
Assist other guidance methods [n (%)]	0	4 (21.05%)*	0.105
Number of puncture attempts	2.47 ± 1.17	3.74 ± 2.40	0.175
Puncture time (min)	17.74 ± 12.78	58.32 ± 47.11	0.002
Total fluoroscopy time (min)	26.63 ± 12.84	40.00 ± 23.44	0.083
Total procedure time (min)	79.74 ± 37.39	121.70 ± 62.24	0.019
Dose area product (Gy × cm^2)	220.60 ± 128.4	228.5 ± 137.3	0.773

*Among the four cases requiring other guidance methods, two cases were assisted with indirect portal vein angiography, and two cases were assisted with percutaneous transhepatic portal vein angiography.

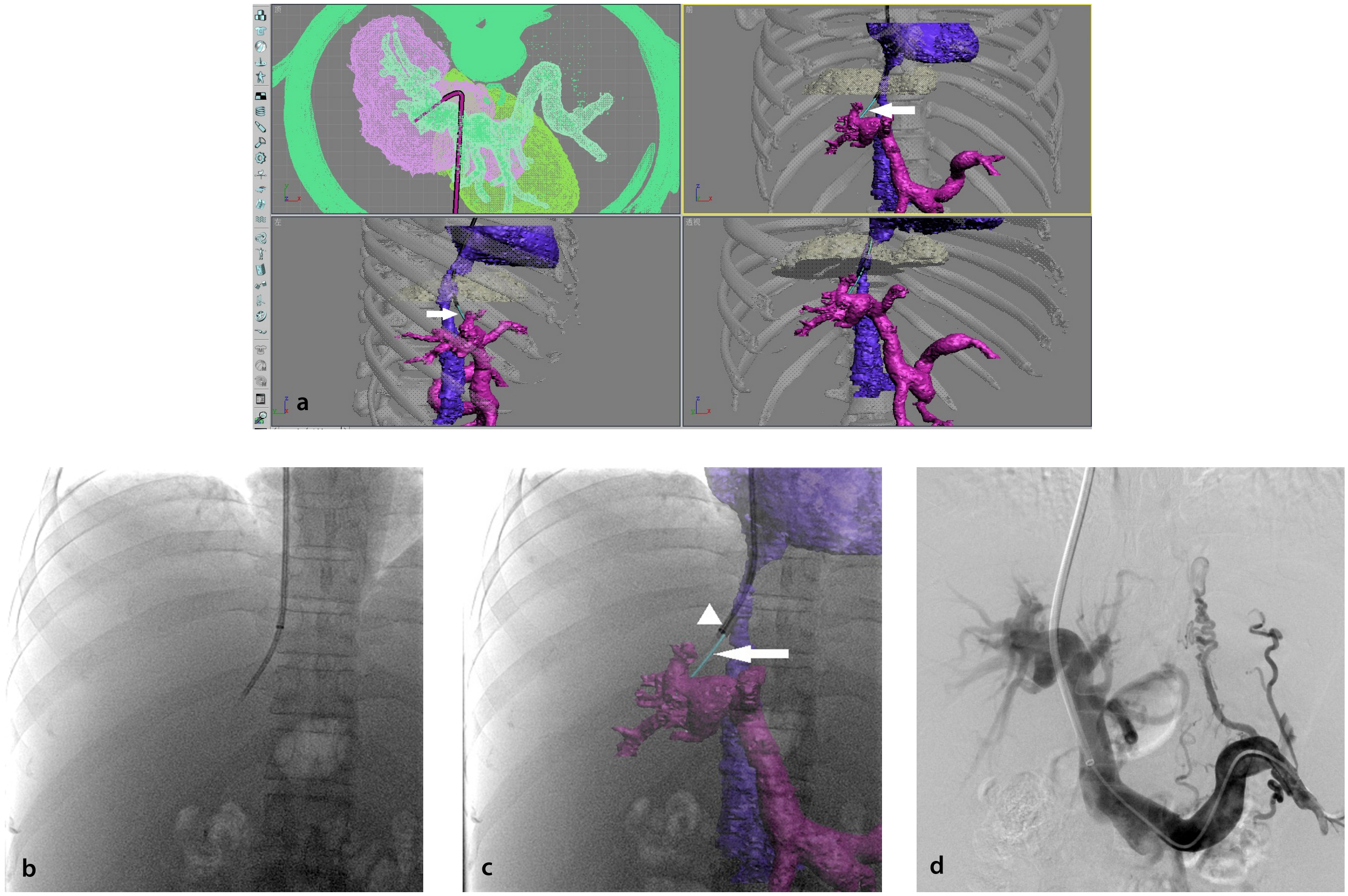

Figure 7. (a-d) An example of better registration accuracy. A 50-year-old man with liver cirrhosis undergoing intraoperative image fusion guidance assisted transjugular intrahepatic portosystemic shunt to prevent variceal rebleeding. The preoperative simulation provided the path for the puncture needle (arrow) to enter the portal vein **(a)**. However, the intraoperative fluoroscopy found that the ascites increased significantly, and the liver diaphragmatic surface originally planned for registration was not clearly displayed **(b)**. Therefore, the simulated puncture needle (arrow) was used as the registration reference point for image fusion with the hard puncture needle (arrowhead) in the fluoroscopy **(c)**. After two punctures, the right branch of the portal vein was successfully punctured. The portogram showed that the position and shape of the main portal vein and its left and right branches were consistent with the preoperative three-dimensional reconstruction model **(d)**.

Discussion

Numerous strategies have been proposed to localize the portal vein during a TIPS procedure, such as the placement of a coil, wire, or snare in or near the portal vein as a target, using a CO_2 wedged hepatic vein portography, and utilizing an image fusion of a preoperative CT and an intraoperative cone beam CT (CBCT) image, including 3D ultrasound (US) and intravascular ultrasound (IVUS).[7-22] The use of IVUS in these strategies seems to be more effective than any other cross-sectional imaging procedure. Most punctures only need to be made once or twice, but they involve special tools, professional skills, and expensive costs,[20,21] which may be difficult to procure in developing countries and underdeveloped areas. The new generation of fluoroscopy suites that have CT-angiography capability allows a fused image to move along with a fluoroscopy panel detector, creating a live image as obliquity changes, which avoids any preoperative planning and

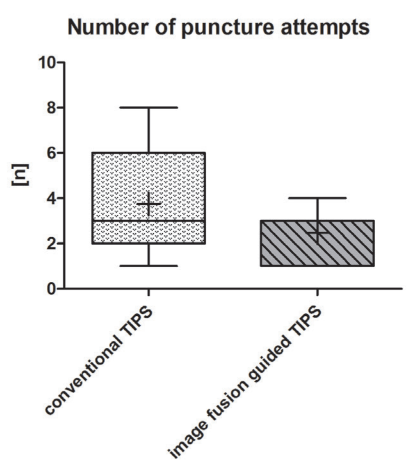

Figure 8. Number of puncture attempts. The median number of puncture attempts was not significantly different between the group of image fusion-guided transjugular intrahepatic portosystemic shunt (TIPS) (n = 3) and the group of conventional TIPS (n = 3; $P = 0.175$).

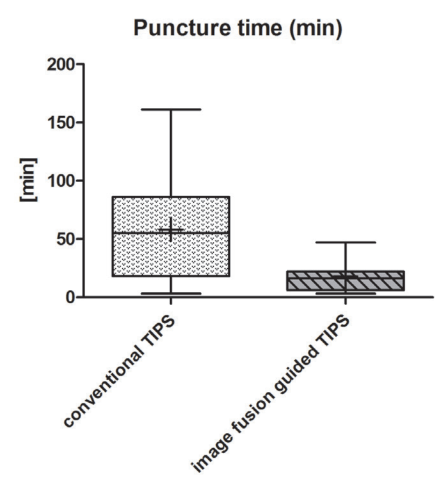

Figure 9. Puncture time. The mean puncture time was significantly different between the group of image fusion-guided transjugular intrahepatic portosystemic shunt (TIPS) (17.74 ± 12.78 min) and the group of conventional TIPS (58.32 ± 47.11 min; $P = 0.002$).

3D image production.[11,12] The promotion of this excellent method is also limited by the need for expensive equipment in underdeveloped areas. Transabdominal US guidance has proved to be an effective, relatively simple, and non-invasive portal vein puncture guidance method. Its disadvantages include the need for additional equipment and a second clinician familiar with the TIPS procedure and US, leading to additional staff radiation exposure, increased costs, and limitations in personnel planning.[18,22] Other guidance methods also have some shortcomings, such as indirect portal venography, CO_2 wedge hepatic vein portal venography, and percutaneous liver puncture portal venography, which increase both the operation and material costs.[7-9,11,19] Additionally, CBCT increases the X-ray irradiation dose[13-15] and requires a special workstation and software.[11-15,18] However, the guidance method designed in this study, which integrates preoperative simulation results and intraoperative images to guide portal vein puncture, tries to avoid the shortcomings of the above methods.

Image registration was the difficulty in the fusion of the preoperative CT 3D reconstruction and intraoperative fluoroscopy. In many studies, manual adjustment was performed according to the vertebral body and rib standards.[11,12,14,15,17,18] Due to the significant difference in the body position and respiratory state between preoperative CT scanning and intraoperative fluoroscopy, it is difficult to register the position of the liver and portal vein with reference to the bone position in the image fusion, but the relative position of the top of the liver diaphragm and portal vein changes little. In this study, the upper and lower positions of image registration are based on the position of the top of the liver diaphragm, with the left and right positions based on the rib boundary.

Compared with the control group guided by fluoroscopy, the portal vein puncture time and the total procedure time in the study group were significantly lower than those in the control group. In terms of the number of puncture attempts, although the study group avoided assisting other invasive guidance methods, and the quartile Q3 (n = 3) was lower than the control group (n = 6), there was no significant difference between the two groups. There was also no significant difference between the two groups in total fluoroscopy time and dose product, which may be related to the fact that some cases received variceal embolization at the same time–17 cases in the study group (89.47%) and 14 cases in the control group (73.68%).

Although the present study was designed to evaluate the feasibility and safety of intraoperative image fusion guidance with the use of preoperative simulation results, initial comparisons with the TIPS procedures performed with the use of other imaging modalities could be made regarding the number of needle passes, the radiographic fluoroscopy time, the time required for the whole procedure, and the dose area product. A previous study assessed the usefulness of 3D US during the creation of TIPS. The mean number of needle passes required for portal vein entry was 4.6 in the 3D US group and 10.4 in the conventional TIPS group.[23] Fewer median number of intrahepatic needle passes were required in the IVUS-guided TIPS creation group compared with the conventional TIPS group (two passes compared with six passes).[24] The results of the present study showed that when intraoperative image fusion guidance based on preoperative simulation results was used, the mean number of needle passes could be reduced to 2.47.

The time required for radiographic fluoroscopy during a TIPS procedure ranged from 3.5 to 153.1 minutes, with a mean of 38.7 minutes noted for 135 cases from a previous study.[25] Kee et al.[26] showed that the mean fluoroscopy time was reduced to 22.3 minutes when hybrid guidance with fluoroscopy and magnetic resonance imaging was used. In comparison, the initial results of the present study showed that preoperative simulation results and intraoperative image fusion guidance required a mean fluoroscopy time of 5.5 minutes for portal vein entry. Seventeen of the 19 cases underwent variceal vein embolization at the same time, so the operation time and exposure dose should be more than in a conventional TIPS. The mean radiographic fluoroscopy time was 26.63 ± 12.84 minutes for the whole TIPS procedure, and the mean radiation dose associated with the entire procedure was 220.60 ± 128.4 Gy.cm^2. Compared with previous studies,[11,12,14,15,17,18] this result is at a medium level. However, the above literature does not report the simultaneous implementation of variceal embolization. For details, refer to Table 3.

In two patients in whom it was planned to puncture the left portal vein, the bifurcation of the left and right portal vein was punctured. This may be related to the lower start-

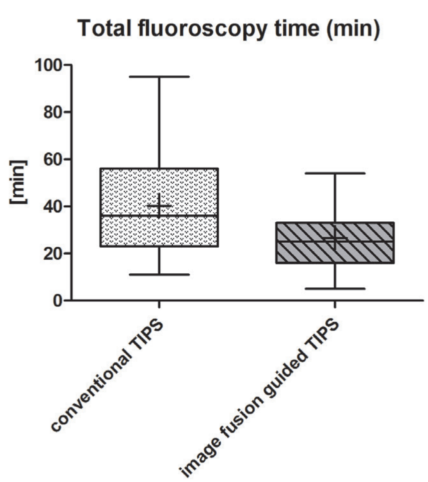

Figure 10. Total fluoroscopy time. The mean total fluoroscopy time was not significantly different between the group of image fusion-guided transjugular intrahepatic portosystemic shunt (TIPS) (26.63 ± 12.84 min) and the group of conventional TIPS (40.00 ± 23.44 min; P = 0.083).

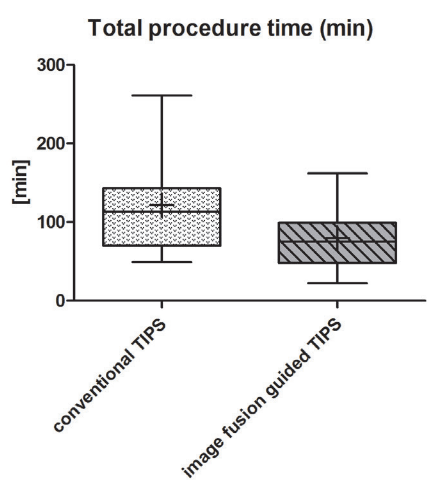

Figure 11. Total procedure time. The mean total procedure time was significantly different between the group of image fusion-guided transjugular intrahepatic portosystemic shunt (TIPS) (79.74 ± 37.39 min) and the group of conventional TIPS (121.70 ± 62.24 min; P = 0.019).

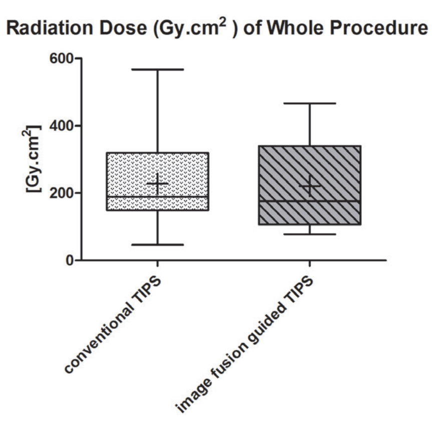

Figure 12. Radiation dose of the whole procedure. The mean radiation dose of the whole procedure was not significantly different between the group of image fusion-guided transjugular intrahepatic portosystemic shunt (TIPS) (220.60 ± 128.4 Gy·cm^2) and the group of conventional TIPS (228.5 ± 137.3 Gy·cm^2; P = 0.773).

Table 3. Procedural characteristics and comparison to the literature

Procedural characteristics	The present study	Meine et al.[12] (2020)	Böning et al.[18] (2018)	Luo et al.[11] (2018)	Luo et al.[15] (2017)	Rouabah et al.[17] (2016)	Ketelsen et al.[14] (2016)
Number of patients	19	27	21	15	20	18	12
Puncture time (min)	17 ± 12	14 ± 6	32 ± 45	n.a.	n.a.	17 ± 9	14 ± 8
Overall procedure time (min)	79±37*	64±29	115±52	60±13	n.a.	n.a.	66 ± 29
Fluoroscopy time (min)	26 ± 12*	21 ± 12	n.a.	14 ± 4	11 ± 2	n.a.	18 ± 9
Dose area product (Gy x cm^2)	220.60 ± 128.42*	107.48 ± 93.84	563.00 ± 289.00	152.11 ± 86.63	295.50 ± 66.60	258.53 ± 161.41	188.16 ± 121.18

*Among the 19 TIPS patients, 17 patients received variceal embolization at the same time. n.a., not applicable.

ing point of the hepatic vein puncture due to the patient's respiratory movement and the vertical distribution of the left portal vein. This series of cases shows that the VIATORR stent is valuable in avoiding extrahepatic portal vein puncture bleeding.

Using preoperative simulation results and intraoperative image fusion guidance as an auxiliary means of fluoroscopy to create a TIPS has the following characteristics. First, the tools of this study are three common commercial software packages, which are easy to obtain at low cost. No additional surgery and material consumption is needed, and there are no requirements for the configuration parameters of DSA equipment. Although it lacks accuracy compared with IVUS guidance and operability compared with DSA equipment accompanied with CT-angiography function, the method of this study may be more valuable for developing countries and underdeveloped regions.

Second, preoperative simulation can provide the angle of the puncture needle pointing to the portal vein in the anteroposterior position and its lateral bending angle. Because the vertical distance between the hepatic and portal vein is shorter or longer in a few patients, it is necessary to increase or reduce the original bending angle of the front end of the puncture needle before a successful puncture. The preoperative simulation can show this angle, which helps adjust the original bending angle of the front end of the puncture needle during the operation. In this group, four cases were successfully punctured after increasing the bending angle of the puncture needle.

Third, there are many choices of reference points for intraoperative image fusion, such as the rib edge, the vertebral body, the costophrenic angle, the right cardiac margin, and the top of the liver diaphragm. This study used the top of the liver diaphragm as the reference point for image fusion. The image fusion registration of eight cases was perfect (Table 1), and the number of needle passes required to access the portal branch was one or two. In four cases, although the image fusion registration was also accurate in the anteroposterior position, the puncture was successful only after increasing the original bending angle of the puncture needle. The possible causes of registration deviation in the remaining seven cases include the translation and torsion of the liver after the use of a hard puncture needle and sheath, shortness of breath, and a significant increase or decrease of ascites.

Fourth, for elective surgery, preoperative simulation can simulate the puncture path of the right and middle hepatic veins, which depends on the patient's vascular anatomical characteristics and the needs of the surgeon. In emergency cases, there may not be time to complete the preoperative simulation process, and only the portal vein images in CT data can be extracted for intraoperative image fusion guidance. This process is similar to the method of Rouabah et al.[17]

The limitations of this study include the small sample size and the fact that the assessment involves a single institution. The retrospective analysis of the fluoroscopic-guided group resulted in a lack of data concerning the number of puncture attempts, puncture time, and total procedure time. The method of reconstructing the total procedure time and the number of puncture attempts of this group of patients introduced potential inaccuracies, which were accepted due to underestimation. In addition, the preoperative simulation results and the accuracy of intraoperative image fusion guidance technology were not quantitatively analyzed. To account for the impact of respiratory movement and the introduction of a stiff puncture needle and sheath on the position and direction of the liver, attempts to find new image-matching reference points should be made in the future. As with most guidance methods, in this study, it was difficult to replicate guidance effects for patients with chronic portal vein obstruction, while IVUS guidance is effective for patients with completely occluded portal veins with or without cavernous transformation of the portal vein.[20]

In conclusion, compared with traditional methods, using preoperative simulation results and intraoperative image fusion to guide portal vein puncture in TIPS creation is feasible, safe, and effective. The preoperative simulation method has potential value in TIPS training.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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