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RESEARCH

Clinical application of fly-thru in diagnosis of biliary obstructive diseases: feasibility, reproducibility, and diagnostic value

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Abstract

Purpose To evaluate the feasibility, reproducibility, and diagnostic value in biliary obstructive diseases using Fly-Thru (FT) technique.

Methods In this single-center prospective study, patients with biliary obstruction who underwent both abdominal ultrasound and FT examinations were recruited between January 2013 and January 2023. 3D FT images (3D-FT) were reconstructed with FT volumetric data. Image quality was subjectively assessed by two radiologists independently. 3D-FT was used to determine the degree of biliary obstruction and compared with ultrasound-guided percutaneous transhepatic cholangiography (PTC). Diagnostic confidence level, diagnostic accuracy and diagnostic duration of the two radiologists using 2D-ultrasound (2D-US) alone and 2D-US combined with 3D-FT were recorded respectively and compared.

Results 100 consecutive patients were enrolled (mean age: 59.6 ± 13.2 years; 52 men). All 3D-FT images were successfully reconstructed and most (75% and 66%) 3D-FT images were considered clear and highly useful for diagnosis with a good agreement (*Kappa* = 0.653). Benign lesions and malignancies presented differently in both 2D-US and 3D-FT imaging. 3D-FT was not inferior to PTC in determining the degree of biliary obstruction ($p = 0.101$), with the sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, positive predictive value, and positive predictive value as 90.5%, 26.7%, 1.23, 0.36, 77.6%, 50.0% respectively. Combined with 2D-US, 3D-FT significantly increased the diagnostic confidence level and diagnostic accuracy of biliary obstructive diseases (all $p < 0.01$), especially for radiologists with less experience.

Conclusion Application of 3D-FT in diagnosis of biliary obstructive diseases was considered feasible and reproducible, with satisfactory diagnostic value and clinical importance.

Keywords Virtual endoscopy · Biliary obstruction · Ultrasound imaging · Feasibility · Diagnostic value

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Abbreviations

2D-US	two-dimensional ultrasound imaging
3D-FT	three-dimensional Fly-Thru imaging
CA19-9	carbohydrate antigen 19 – 9
DBIL	serum direct bilirubin
ERCP	endoscopic retrograde cholangiopancreatography
EUS	endoscopic ultrasound
FT	Fly-Thru virtual endoscopy technique
MRCP	magnetic resonance cholangiopancreatography
OR	odd ratio
PTC	percutaneous transhepatic cholangiography
PTCD	percutaneous transhepatic cholangial drainage
PUSC	percutaneous ultrasound cholangiography
TBIL	serum total bilirubin

Introduction

Biliary obstruction, whose etiology varies from benign lesions to malignancies, is a common situation that can lead to cholestatic disorders, infections, and abnormalities in liver function, and precise diagnosis is pivotal to subsequent treatment decisions [1, 2]. Fundamental imaging modalities including transabdominal ultrasound, endoscopic ultrasound (EUS), computed tomography (CT), and magnetic resonance imaging (MRI) are available for diagnosis of biliary disease, among which 2D transabdominal ultrasound scan (2D-US) is widely applied as the first choice with its non-invasive, non-radiative, repeatable and inexpensive advantages [1, 3] but relatively low sensitivity and accuracy [4–6]. Furthermore, percutaneous transhepatic cholangiography (PTC), magnetic resonance cholangiopancreatography (MRCP), and endoscopic retrograde cholangiopancreatography (ERCP) have been proven competent in presenting the overall structure and the degree of obstruction for sensitive diagnosis of diverse abnormalities of biliary tracts [2, 7–11]. Nevertheless, PTC and ERCP are invasive with the potential to cause hemorrhage or biliary infection and pancreatitis [8, 12, 13]. Although MRCP is non-invasive, it cannot provide a clear visualization of the intraluminal surface of biliary tracts with risk for contrast agent allergy. More importantly, MRI resources are quite expensive and scarce, especially in underdeveloped rural regions [14]. Therefore, novel imaging techniques with higher accessibility are still needed for biliary obstructive diseases.

Fly-Thru (FT), a novel ultrasonic virtual endoscopy technique, has been utilized in intraluminal visualization of hollow viscera or vascular lumens and detection of lesions in vessels, uterine, bladder, and intestine, due to its capacity to reconstruct intraluminal features and auto-navigate in potential lacunar spaces according to echoic differences [15–20]. Similarly, this technique has been combined with CT scan to simulate laryngoscopy [21]. Previously, CT- or MRI-based virtual endoscopy for biliary tracts has aroused great interest [22–25], but radiation, expensiveness and long examination duration remain natural shortcomings of CT or MRI. To date, research on application of FT technique combined with ultrasound scan in biliary diseases is still quite limited.

Consequently, this study aims to evaluate the feasibility and reproducibility of FT and investigate its diagnostic value in diagnosis of biliary obstructive diseases, expecting a more accessible diagnostic tool in clinical practice.

Materials and methods

Study participants

This prospective single-center study was approved by the First Affiliated Hospital of Sun Yat-sen University and received written informed consent from all participants. Between 2013 and 2023, patients with biliary obstruction who agreed to undergo both abdominal ultrasound and FT examinations were included in this study, with the definite diagnosis confirmed by either postoperative pathological hematoxylin-eosin sections or clinical follow-ups combined with other imaging modalities including CT and MRCP. Patients received ultrasound-guided PTC voluntarily based on clinical needs. Exclusion criteria were patients with unstable vital signs, inability to cooperate by postural adjustment or breath-holding, and lack of subsequent pathological diagnosis or clinical follow-up.

Ultrasound examinations

Ultrasound examinations were performed by a board-certified radiologist with over 15 years of experience in abdominal diagnostic and interventional ultrasound using a TOSHIBA Aplio i500 diagnostic ultrasound system (Toshiba Co., Tokyo, Japan) with a 3.5-5 MHz 3D volumetric 6CV1 probe. The location, size, echogenicity compared to adjacent liver tissue, border, and nature of the lesions and lumen of biliary tracts were preliminarily determined by 2D ultrasound imaging (2D-US). FT volumetric data were collected in FT mode and stored as "RAWDATA" followed by switching to a 3D ultrasonic probe and necessary adjustment of relevant parameters (gain, contrast, depth, focus, acquisition angle 30°- 60°) to ensure the highest resolution of images. Ultrasound-guided PTC (also known as percutaneous ultrasound cholangiography, PUSC) was also performed for some patients as needed with Sonovue (Braco Co., Italy) as the contrast injected into the biliary tree by a process similar to percutaneous transhepatic cholangial drainage (PTCD) as previously reported [26], and the degree of biliary obstruction was recorded during the examination.

Image analysis

All "RAWDATA" was copied to the Toshiba workstation software (Toshiba Virtea v7.0) for offline analysis with the reconstruction parameters as G = 50, DR = 50, Threshold 40–90, Filter = 3 to obtain reconstructed 3D FT images (3D-FT). 2D-US and 3D-FT images were then analyzed independently by a junior board-certified radiologist (noted as Doctor A, with over 3 years of experience in abdominal diagnostic and interventional ultrasound) and a senior

board-certified radiologist (noted as Doctor B, with over 10 years of experience in abdominal diagnostic and interventional ultrasound), whose rating of 3D-FT image quality and diagnostic confidence level based on either 2D-US or 2D-US combined with 3D-FT (2D-US + 3D-FT) was recorded. The rating standard of 3D-FT image quality was: 3 points for clearly reconstructed biliary tract lumen providing adequate information for observation (highly useful for diagnosis), 2 points for the reconstructed lumen with minor artifacts causing no possible misleading during observation (useful for diagnosis), 1 point for apparent artifacts or failure in image reconstruction (useless for diagnosis). The diagnostic confidence level of each observer was classified as: grade 1 for surely benign lesions, grade 2 for possibly benign lesions, grade 3 for unsure nature of the lesions, grade 4 for possibly malignant lesions, and grade 5 for surely malignant lesions. Diagnostic accuracy was calculated hereby showing the ratio of the amount of cases with correctly identified lesion nature to the amount of all cases. As for whether the biliary tract was completely obstructed or incompletely obstructed, two radiologists negotiated and reached a consensus according to 2D-US + 3D-FT. The findings in PTC were considered the gold standard due to the high accuracy of PTC, which is in line with previous research [27, 28]. Also, the time for radiologists to review 2D-US with or without 3D-FT and draw a conclusion on the lesion nature as well as the degree of obstruction was recorded as diagnostic duration. Both radiologists were blinded to the definite diagnosis, clinical information and PTC findings.

Clinical data

Patients' characteristics and laboratory test results, including sex, age, serum total bilirubin level (TBIL), serum direct bilirubin level (DBIL), and serum CA19-9 level were collected from their medical records.

Statistical analysis

According to our previous exploration data, the sensitivity of 2D-US + 3D-FT was about 0.90 and the specificity was about 0.85 in judging lesion nature, and the sample size was estimated using PASS 21.0 software (NCSS Co., USA) with $\alpha = 0.05$, power = 0.9 before the beginning of the study. Subsequent statistical analysis was performed using SPSS 25.0 software (IBM Co., USA) and MedCalc 10.1 software (Reachsoft Co., China). Results are expressed in the form of mean ± standard deviation and analyzed with Student's t test or Wilcoxon's rank sum test if needed for continuous variables. For categorical variables, the χ^2 test, and the Fisher's exact test if needed are performed. $p < 0.05$ is considered a statistically significant difference. The Kappa test was used for the consistency of image quality between observations. A Kappa value of 0.01 to 0.20 suggests very poor agreement, 0.21 to 0.40 for relatively poor agreement, 0.41 to 0.60 for moderate agreement, 0.61 to 0.80 for good agreement, and 0.81 to 0.99 for very good agreement. When assessing the capacity of 3D-FT to judge the degree of biliary obstruction, sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, positive predictive value, and negative predictive value were calculated (formulas listed in supplementary statistics).

Results

Baseline characteristics of participants

From April 2013 to February 2023, 100 consecutive patients (mean age: 59.6 ± 13.2 years, range 18–83 years; 52 men) with biliary obstruction were enrolled in this study according to the inclusion and exclusion criteria (Fig. 1; Table 1). 77 patients were found to have malignant lesions (21 cases of hilar cholangiocarcinoma, 13 carcinoma of the common bile duct, 9 intrahepatic cholangiocarcinoma, 8 pancreatic ductal adenocarcinoma, 7 ampullary cancer, 5 carcinoma of the duodenum papilla, 4 hepatocellular carcinoma, 3 gallbladder cancer, 3 gastric cancer, 2 colon cancer, 1 lymphoma, and 1 malignant mesenchymal neoplasm) while other 23 patients were found to have benign lesions (14 cases of gallstones, 3 IgG4-associated diseases, 3 cholangitis, 2 Caroli's disease, and 1 postoperative stenosis).

2D-US and 3D-FT characteristics of lesions in biliary tracts

For benign intraluminal lesions, a single hyperechoic lesion with clear border was commonly seen in 2D-US, and 3D-FT reconstructed a single well-demarcated protruding lesion with smooth surface without altering the peripheral bile duct wall (Figs. 2 and 3). For malignant lesions, 2D-US mainly revealed a poorly demarcated, hypo- to moderate echoic appearance, and 3D-FT presented an isolated or diffusely infiltrative lesion with rugged, uneven surface and unclear border, and an uneven intraluminal wall of surrounding regions (Figs. 3, 4 and 5).

Application of 3D-FT in determining the degree of biliary obstruction

Among 100 patients, 57 patients subsequently received PTC to further evaluate the degree of biliary obstruction with 42 (73.7%) patients were confirmed complete biliary obstruction and 15 (26.3%) incomplete obstruction. Malignant lesions were more prone to cause complete obstruction

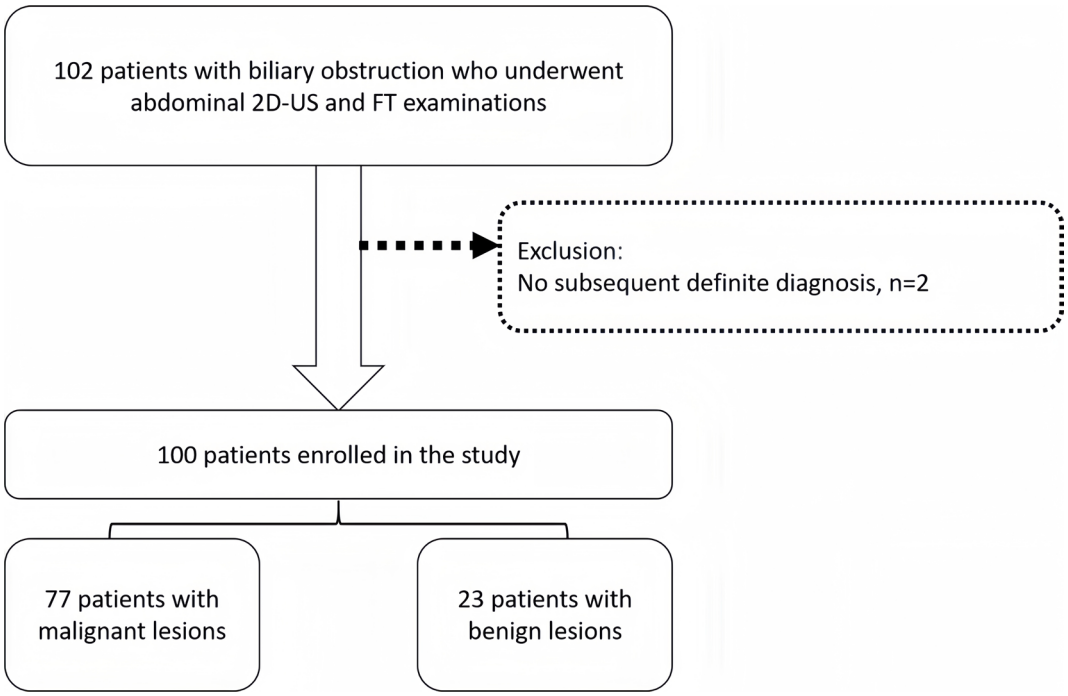

Fig. 1 Flow chart of participant enrollment

Table 1 100 patients' baseline characteristics

Characteristics	Lesion Nature	Value	*p*
Men	Benign	11 (47.8%)	0.648
	Malignant	41 (53.2%)	
Age (years)	Benign	55.5 ± 17.1	0.096
	Malignant	60.8 ± 11.7	
TBIL (μmol/L)	Benign	62.0 ± 67.5	< 0.001*
	Malignant	195.0 ± 138.4	
DBIL (μmol/L)	Benign	42.0 ± 52.8	< 0.001*
	Maligant	136.6 ± 103.9	
CA19-9 (kU/L)	Benign	1642.4 ± 3555.3	0.220
	Malignant	3083.9 ± 4357.5	

*Statistically significant

Image quality of 3D-FT virtual endoscopy

All (100%) FT volumetric data was successfully reconstructed into 3D-FT images. Most 3D-FT images were clear, with 75% and 66% of images rated 3 points by two observers respectively (Table 2). The Kappa value is 0.653 [95%CI: 0.500-0.806], indicating a good agreement on the stable image quality of 3D-FT between observers

Table 2 Image quality rating of two observers

Observer	1 point	2 points	3 points	Kappa
Doctor A	1 (1%)	24 (24%)	75 (75%)	0.653 [0.500,0.806] [a]
Doctor B	4 (4%)	30 (30%)	66 (66%)	

[a] The Kappa coefficient is expressed in value [95%CI]

($p = 0.030$, OR = 4.75, Supplementary Table 1). In 3D-FT images, interruption of the auto-navigation process, or access to adjacent bile ducts could suggest complete obstruction of the observed bile duct (Fig. 3). Compared with PTC, 3D-FT images diagnosed 49 (86.0%) complete biliary obstruction and 8 (14.0%) incomplete biliary obstruction, showing no statistically significant difference ($p = 0.101$, Table 3). The sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, positive predictive value, and negative predictive value of 3D-FT in differentiating the degree of biliary obstruction are 90.5%, 26.7%, 1.23, 0.36, 77.6%, and 50.0% respectively.

The diagnostic confidence level of both observers was significantly different between 2D-US alone and 2D-US combined with 3D-FT (both $p < 0.001$, Table 4), with greatly less grade 3 (unsure nature) lesions and more grade 5 (surely malignant) lesions when diagnosis was made by 2D-US combined with 3D-FT. The diagnostic accuracy of both observers was significantly increased using 2D-US combined with 3D-FT ($p < 0.001$ and $p = 0.006$ respectively, Table 5; Fig. 4). Wherein, the diagnostic accuracy was increased from 34.8% and 43.5–52.2% and 65.2% respectively for benign lesions; for malignant lesions, it was increased from 51.9% and 77.9–89.6% and 88.3% respectively. Meanwhile, the duration for diagnosis was relatively longer using 2D-US combined with 3D-FT (both $p < 0.001$, Supplementary Table 2).

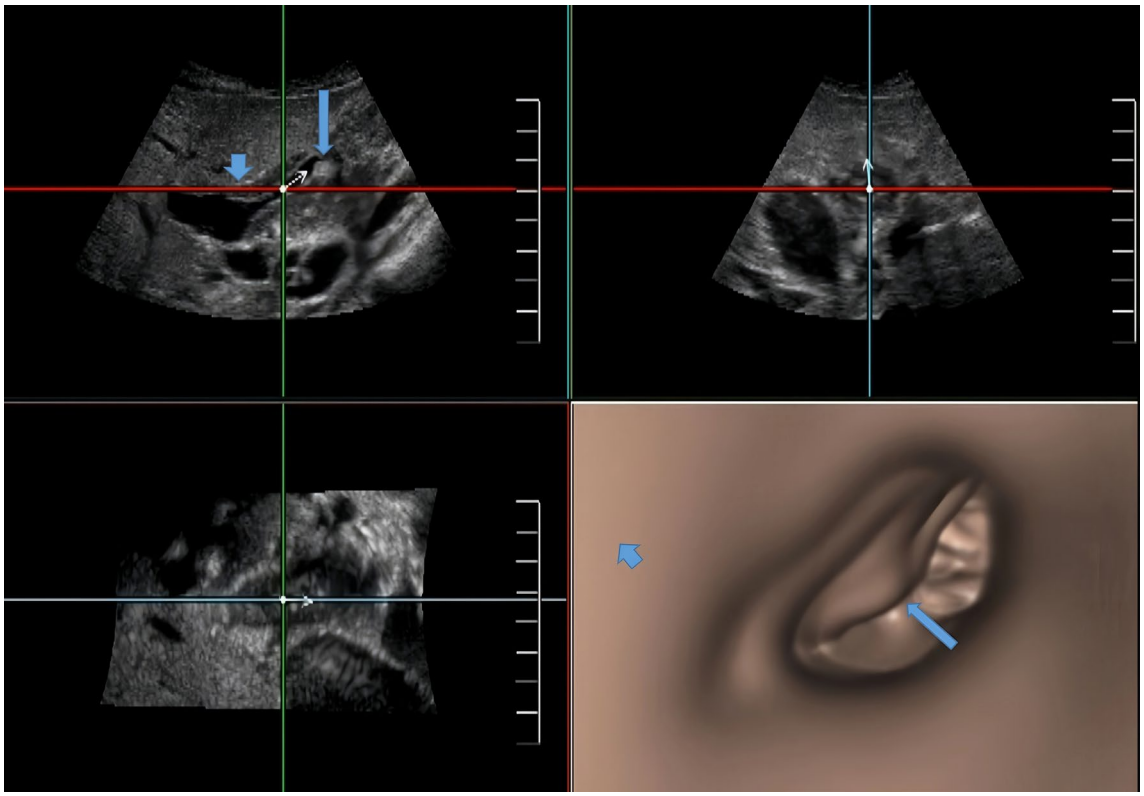

Fig. 2 IgG4-associated cholangitis with gallstone of a 51-year-old man. The first section of 2D-US showed obviously dilated bile duct with thickened wall (short arrow) and an intrahepatic gallstone (long arrow). In 3D-FT, the surface of the bile duct wall was smooth without malignant features and a smooth protruding lesion was shown (detailed video clip in supplementary video 1)

Discussion

In the present study, we report feasible and reproducible clinical application of FT technique to provide stable, clear, real-time 3D images of biliary tracts and additional valuable information for diagnosis of biliary obstruction non-invasively simulating cholangioscope. 3D-FT images were applied to diagnose the degree of biliary obstruction, showing non-inferiority compared to PTC with a high sensitivity. More importantly, the diagnostic confidence level, as well as diagnostic accuracy of radiologists were significantly increased when 3D-FT was combined with 2D-US, especially for those with less experience.

The feasibility and the reproducibility of FT were first assessed. Similar to Azuma's work on MR virtual endoscopy [23], we collected subjective judgments of different observers to evaluate image quality and agreement. To ensure optimal 2D-US image quality and control confounding factors for subsequent reconstruction of 3D-FT images, patients were asked to cooperate by postural adjustment and breath holding during ultrasound examination, and 18 patients were asked to drink small amount of water to reduce the impact of gas in the gastrointestinal tract. According to our data, the successful rate of 3D reconstruction was 100%, and most (66% and 75%) of 3D-FT images were considered clear and highly useful for diagnosis, with a good agreement of judgments between two radiologists with different years of experience (*Kappa* = 0.653). The agreement on image quality guaranteed different radiologists with various years of experience to analyze the 3D reconstructed images for diagnosis, and thus contributed to its reproducibility in clinical application. Compared with vascular imaging in a previous study [16], less motion artifacts were observed in our reconstructed 3D-FT images of biliary tracts since there was no vascular pulsation, which may interpret the reason for better image quality. Images rated 1 or 2 points in quality were mostly collected from overweight patients with a higher BMI whose abdominal wall was thick or with severe fatty liver. Besides, this technique is inexpensive and maintains a relatively high cost-effectiveness owing to the characteristics of ultrasound examinations [29]. Together, our data suggests satisfactory feasibility and promising reproducibility of FT technique in clinical application.

The characteristics of lesions in 3D-FT images were then summarized. In short, reconstructed malignant lesions usually present an irregular, invasive morphology with infiltrated intraluminal wall of peripheral regions in 3D-FT while regular shape, clear border, and unaffected

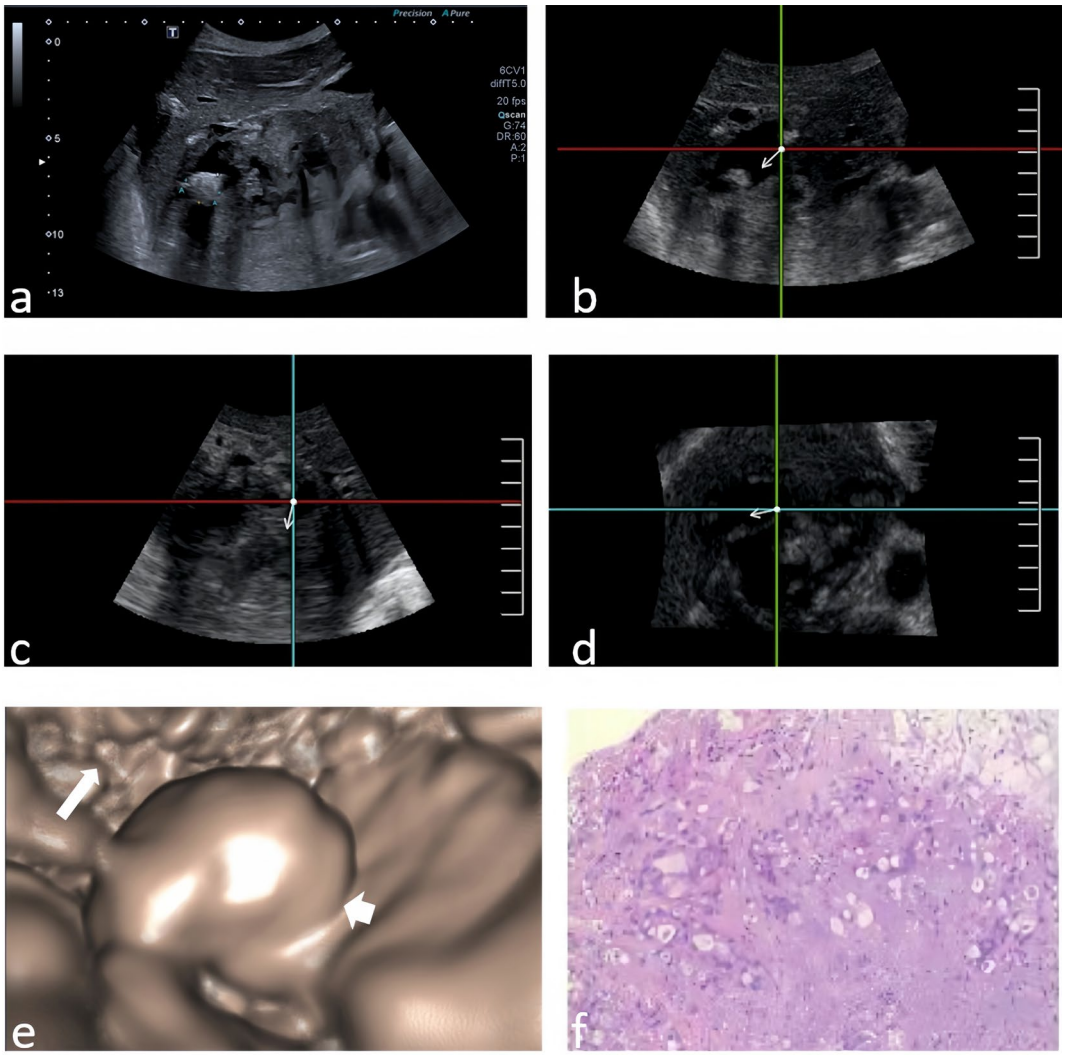

Fig. 3 Intrahepatic cholangiocarcinoma with gallstone of a 70-year-old woman. (**a**)2D-US showed a mixed echoic mass in the liver, with a hyperechoic stone found in surrounding dilated intrahepatic bile duct. (**b-d**) Here shows the reconstruction process of FT volumetric data of 3 different sections of the affected bile duct for reconstruction and real-time auto-navigation. (**e**)3D-FT image was reconstructed to reveal the intraluminal lesions in the affected bile duct. A single protruding lesion was shown with smooth surface and smooth surrounding intraluminal wall, indicating a gallstone (short arrow). The intraluminal wall was rugged and uneven with a diffusely affected, poorly demarcated lesion, reflecting the infiltrative growth of malignant tumor (long arrow). (f) Pathological HE observation (200×) confirmed the diagnosis of intrahepatic cholangiocarcinoma with gallstone

surrounding tissue usually characterize benign lesions, which is in line with biological behaviors of lesions [7, 30, 31]. FT allows radiologists to observe growing patterns of abnormal lesions and peripheral lumen morphology of the interested bile duct 3-dimensionally based on any selected sections in US scan. Previous research has shown that intraductal ultrasound examination is conducive to diagnosis of biliary diseases but drawbacks including invasiveness and limited penetration depth still exist [32–34], and that 3D ultrasound examination possesses a higher diagnostic accuracy in biliary malignancies [35, 36]. In our study, 3D-FT images exhibited the strengths of both intraductal and 3D ultrasound scan and were rid of possible shortcomings through virtual endoscopic reconstruction.

Simultaneously, auto-navigation of FT traces potential lacunar regions to form the reconstructed images of bile duct lumen (supplementary video 2), during which interrupted auto-navigation process or incorrect tracing into adjacent bile ducts indirectly reflects complete biliary obstruction of the bile duct being reconstructed. As a result, we hypothesized that 3D-FT could determine the degree of biliary obstruction based on this principle. Compared with PTC, 3D-FT is not significantly inferior in determining the degree of biliary obstruction, with a promising sensitivity over 90% and no invasiveness. However, the specificity is

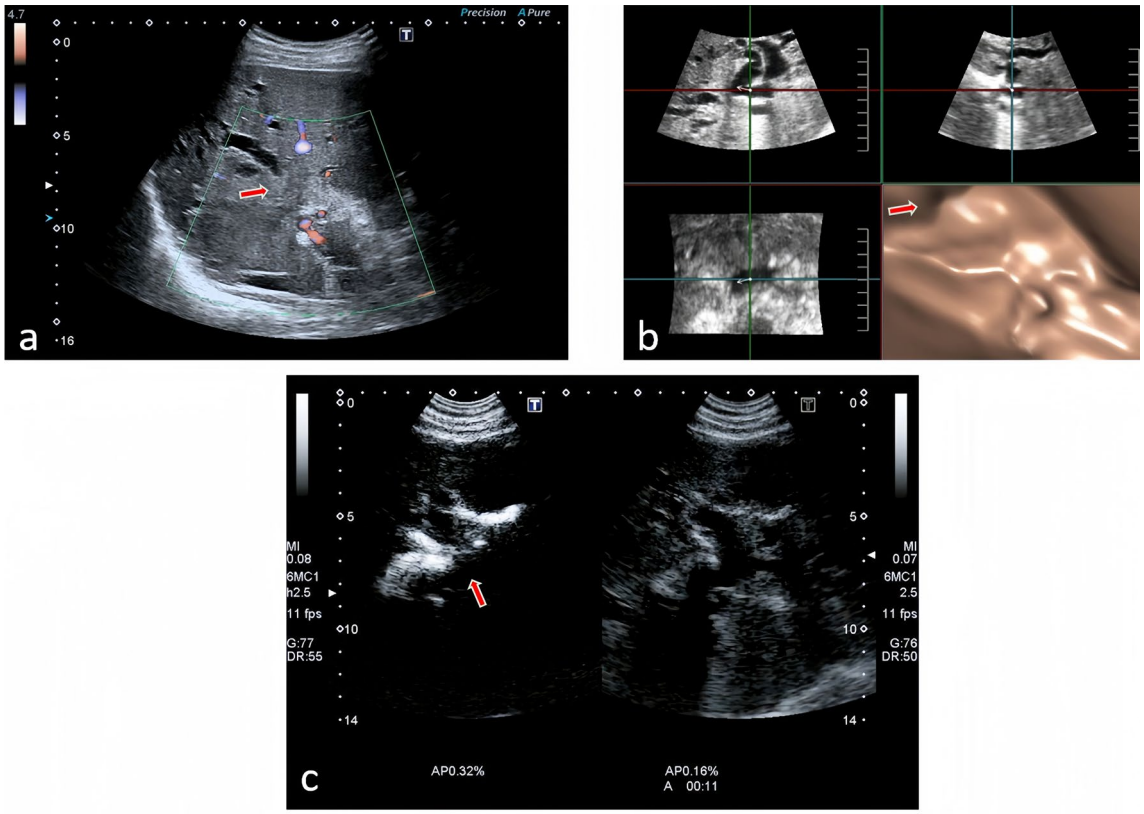

Fig. 4 Complete biliary obstruction caused by hilar cholangiocarcinoma of a 48-year-old man. (**a**) 2D-US showed an isoechoic lesion with dilated bile duct. (**b**) Reconstructed 3D-FT images from 3 different sections of the lesion showed that the bile duct was obstructed by a diffusely infiltrative, poor-demarcated neoplasm and the auto-navigation process was interrupted (detailed video clip in supplementary video 2). (**c**) Ultrasound-guided PTC confirmed the diagnosis of complete biliary obstruction. Contrast could not flow down to downstream biliary tracts

relatively low and 3D-FT tends to misdiagnose complete obstruction when its diagnosis differs from PTC. Possible mechanisms include: (1) Lesions near the porta hepatis usually result in stricture and dilatation of multiple branched bile ducts, but FT mainly focuses on local changes of only a single interested bile duct at a time rather than every duct. On the contrary, microbubbles can flow through adjacent bypass bile ducts and therefore confirm incomplete obstruction; (2) More importantly, the remnant lumen with a diameter less than the resolution power of 3D-FT images can also result in a misidentification. In these cases, microbubbles pass through the narrow remnant slit while the auto-navigation process cannot proceed. In our study, we noticed that patients found to have biliary malignancies were more prone to suffer from complete obstruction (OR = 4.75) and a significantly higher serum bilirubin level, which is consistent with our clinical experience as well as previous literature [11, 37–39]. It is noteworthy that MRCP also shows the biliary tract clearly, but its accessibility is insufficient in developing areas especially those rural areas due to its expansiveness and long checking time so US examination serves as the first choice of diagnosis. Taking these data into account, 3D-FT can serve as a preliminary screening method for the degree of biliary obstruction as it is non-invasive with less cost and duration, and no imaging contrast agent is needed during the process, which also avoids potential allergic reactions. Complete biliary obstruction diagnosed by 3D-FT needs further confirmation by PTC or MRCP if available which are more competent in showing the overall structure of biliary tree [38].

Combined with 2D-US, 3D-FT significantly boosts the diagnostic confidence level of radiologists and increases diagnostic accuracy in differentiating the lesion nature, especially for those with less experience (accuracy raised from 48 to 81%). Far less (from 37% and 17–8% and 7% respectively) unsure lesions and more surely malignant lesions (from 0 and 2–1% and 14% respectively) were classified using 2D-US + 3D-FT, making US examinations more helpful for definite diagnosis. Interestingly, for doctors with less experience, the diagnostic accuracy with 2D-US + 3D-FT is close to the senior doctor's, possibly owing to a deeper understanding of lesion morphology provided by reconstructed 3D images than 2D sectional appearance, which may offer a potential way for more effective future medical

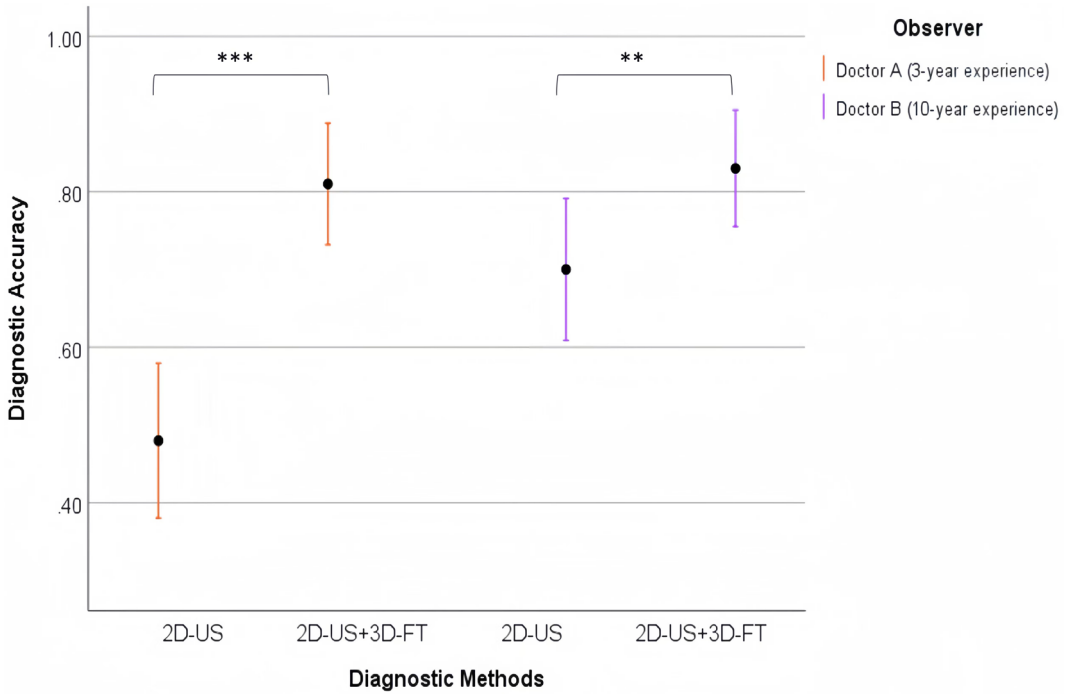

Fig. 5 Diagnostic accuracy of observers with 2D-US and 2D-US combined with 3D-FT. ** represents $p < 0.01$ and *** represents $p < 0.001$. Horizontal lines indicate 95%CI of diagnostic accuracy

Table 3 Diagnosis of the degree of biliary obstruction by 3D-FT and gold standards

		PTC		Total	*p*
		Complete Obstruction	Incomplete Obstruction		
3D-FT	Complete Obstruction	38	11	49	0.101
	Incomplete Obstruction	4	4	8	
Total		42	15	57	

No statistically significant difference was found

Comparison of diagnostic value of 2D-US and 2D-US + 3D-FT in biliary obstructive diseases

Table 5 Diagnostic accuracy of observers with 2D-US and 2D-US + 3D-FT

Observer	Method	Lesion Nature	Accuracy	Overall Accuracy	*p*
Doctor A	2D-US	Benign	34.8%	48%	< 0.001*
		Malignant	51.9%		
	2D-US + 3D-FT	Benign	52.2%	81%	
		Malignant	89.6%		
Doctor B	2D-US	Benign	43.5%	70%	0.006*
		Malignant	77.9%		
	2D-US + 3D-FT	Benign	65.2%	83%	
		Malignant	88.3%		

*Statistically Different

education for radiologists. As shown in our data, the diagnostic accuracy for benign biliary lesions remains relatively low using 2D-US alone, and the combination of 3D-FT greatly improves that in both benign lesions and malignancies. Additionally, although the duration for diagnosis using combined imaging was significantly increased, it took only 8.9 ± 3.3 and 7.5 ± 2.7 min respectively to make a diagnosis based on the images on average. We believe this prolonged time is acceptable considering the improvement in diagnostic confidence level and diagnostic accuracy. In clinical practice, MRCP resources are scarce compared to a large

Table 4 Diagnostic confidence level of observers with 2D-US and 2D-US + 3D-FT

Observer	Method	Diagnostic Confidence Level					*p*
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	
Doctor A	2D-US	2 (2%)	13 (13%)	37 (37%)	48 (48%)	0	< 0.001*
	2D-US + 3D-FT	3 (3%)	12 (12%)	8 (8%)	76 (76%)	1 (1%)	
Doctor B	2D-US	6 (6%)	9 (9%)	17 (17%)	66 (66%)	2 (2%)	< 0.001*
	2D-US + 3D-FT	5 (5%)	15 (15%)	7 (7%)	55 (55%)	14 (14%)	

*Statistically significant

population, and this improved accuracy of 2D-US + 3D-FT results in enhanced confidence especially in confirming a benign lesion and thus spares patients from subsequent MRCP examinations.

There are some limitations in our study. First, this is a single-center study with a relatively small sample size, as it is, to the best of our knowledge, the first exploration of the clinical application of ultrasound-based FT virtual endoscopy in the diagnosis of biliary diseases. Second, as a tertiary referral center, our participants are mainly those with malignancies, and potential bias may occur. So further investigations on benign lesions with a larger sample size is still necessary. Third, more objective quantitative imaging characteristics of 3D-FT in biliary diseases are to be identified and precise diagnostic models incorporating clinical data including laboratory tests are to be developed in future research. Last but not least, limitations of FT technique still need to be resolved. 1) BMI does affect the image quality of 3D-FT as an intrinsic shortcoming of ultrasound scan, and increasing the penetrability of ultrasound may be conducive to improving this technique for overweight patients. 2)As is mentioned, the specificity of judging the degree of obstruction is relatively low because of the resolution power, so current high-resolution or super-resolution techniques may be applied to optimize FT technique in future research [40]. 3)For regions where diagnostic and interventional ultrasound is not so prevalent, it may take time for training of radiologists, but performing FT technique is not difficult as it is based on ultrasound scan.

In conclusion, considering the image quality, increased diagnostic accuracy, and improved diagnostic confidence of radiologists, clinical application of 3D-FT in diagnosis of biliary obstructive diseases is feasible and reproducible, which can serve as a preliminary screening method for biliary obstruction in routine clinical practice especially when MRCP is not reachable for various reasons.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00261-024-04672-3.

Author contributions All author contributed to the study conception and design. Investigation and data collection were mainly done by Tongyi Huang and Xiaoer Zhang. Data analysis and interpretation were mainly performed by Zebang Yang and Xiaoer Zhang. The first draft of the manuscript was written by Zebang Yang and carefully revised by Zebang Yang and Ming Xu. All authors reviewed and approved the present version of manuscript. Ming Xu was the project supervisor. Tongyi Huang and Zebang Yang Contributed equally in this study and should be regarded as co-first authors. Ming Xu and Xiaoer Zhang contributed equally in this study and should be regarded as co-corresponding authors.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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