UltraFast Doppler ultrasonography for hepatic vessels of liver recipients: preliminary experiences

ULTRA SONO GRAPHY

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Purpose: The purpose of this study was to investigate the value of UltraFast Doppler ultrasonography (US) for evaluating hepatic vessels in liver recipients.

Methods: Thirty-nine liver Doppler US sessions were conducted in 20 liver recipients. Each session consisted of UltraFast and conventional liver Doppler US in a random order. We compared the velocities and phasicities of the hepatic vessels, duration of each Doppler study, occurrence of technical failures, and differences in clinical decisions.

Results: The velocities and resistive index values of hepatic vessels showed a strong positive correlation between the two Doppler studies (mean R=0.806; range, 0.710 to 0.924). The phasicities of the hepatic vessels were the same in both Doppler US exams. With respect to the duration of the Doppler US exam, there was no significant difference between the UltraFast (251±99 seconds) and conventional (231±117 seconds) Doppler studies (P=0.306). In five poor breath-holders, in whom the duration of conventional Doppler US was longer, UltraFast Doppler US (272±157 seconds) required a shorter time than conventional Doppler US (381±133 seconds; P=0.005). There was no difference between the two techniques with respect to technical failures and clinical decisions.

Conclusion: UltraFast Doppler US is clinically equivalent to conventional Doppler US with advantages for poor breath-holders during the post-liver transplantation work-up.

Keywords: Doppler ultrasonography; Liver; Liver transplantation

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Introduction

Liver transplantation is now frequently used in the treatment of end-stage liver disease and acute liver failure [1–7]. Liver transplant recipients are followed-up closely after surgery to evaluate acute complications and rejection. Despite technical advances and improvements in postoperative care, vascular complications are among the major causes of morbidity and mortality after liver transplantation [8–11]. Therefore, the early detection and treatment of vascular complications are essential to reduce the associated morbidity and mortality. The clinical signs of vascular complications are usually nonspecific; therefore, a radiologic diagnosis is required. Doppler ultrasonography (US) is

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a well-established radiologic method for initial screening to detect vascular complications and is sometimes the only available modality in perioperative care [2,8,9,12–23].

Recently, UltraFast Doppler US has been introduced into medical practice; it differs from conventional Doppler US in that UltraFast Doppler US uses sequential insonation of focused beams, plane-wave insonation to allow the computation of a full image from a single transmission, and increased frame rates of up to the maximum level achievable by a US system [24,25]. In UltraFast Doppler US, Doppler information is continuously and simultaneously acquired across the full image, and all pixels are sampled at a high Doppler pulse repetition frequency. Thus, UltraFast Doppler US may offer improvements in color flow imaging in terms of temporal resolution and sensitivity without compromising the field of view [25,26]. More importantly, a full-spectral wave analysis at every pixel within the region of interest (ROI) can be achieved with the movie clips obtained during color Doppler studies, which can be captured during a few-second acquisition without repeating the Doppler exam to perform the spectral Doppler study. Therefore, enhanced Doppler study throughput and quality can be achieved, particularly in poor breath-holders and patients who do not cooperate.

To date, only a few studies have been published on the utility of UltraFast Doppler US. However, these studies have examined the flow phantom model and the neck and lower extremity vessels [25–27]. To the best of our knowledge, the value of the UltraFast Doppler technique for evaluating the hepatic vasculature has not yet been reported. Therefore, the purpose of our study was to investigate the value of UltraFast Doppler US in the evaluation of hepatic vessels.

Materials and Methods

Patients

The Institutional Review Board of our institute approved this retrospective study, and the requirement for patient informed consent was waived. We searched our radiology database in March 2013 by using the search terms SONO Doppler Liver and found 138 Doppler US liver studies. Liver recipients who underwent UltraFast (SuperSonic Imagine, Aix-en-Provence, France) and conventional Doppler US exams in the same session were included in our study. Thirty-nine Doppler US sessions from 20 patients (four sessions in three patients, three sessions in two patients, two sessions in six patients, and one session in nine patients) were ultimately considered in our study (patients, 12 men and 8 women; mean age, 49 years; age range, 13 to 64 years). Thirteen of these patients were inpatients, and seven were outpatients. Four of these patients underwent deceased donor liver transplantation, and the remaining patients underwent living donor liver transplantation using the right hepatic lobe (n=14) or the left hepatic lobe (n=2). Indications for liver transplantation included liver cirrhosis associated with hepatitis B (n=9), hepatocellular carcinoma (n=6), alcoholic liver cirrhosis (n=2), cryptogenic liver cirrhosis (n=1), Alagille syndrome (n=1), and Wilson disease (n=1). The mean interval between the liver transplantation and the Doppler US of all the patients was 243±716 days (range, 3 to 3,105 days), that of the inpatients was 9±5 days (range, 3 to 21 days), and that of the outpatients was 1,315±1,272 days (range, 36 to 3,105 days).

Imaging Techniques and Methods

All liver Doppler US examinations were performed by one of two radiologists (BYH and AJC) with four years of clinical experience in Doppler US of liver transplant recipients, using an Aixplorer (SuperSonic Imagine) with a 1–6-MHz wideband convex probe. The patients were examined in a supine position with the right arm abducted, and examinations were performed by oblique intercostal scanning of the right hepatic lobe and transverse and sagittal subcostal scanning of the left hepatic lobe. After the localization of the hepatic vessels on the grayscale US, the machine settings, such as depth, focal zone, and time-gain compensation, were optimized. A single focal zone was located at the center of the hepatic hilum. The conventional color Doppler US mode was then applied, and the size of the ROI was adjusted to contain the targeted hepatic vessels: the hepatic artery (HA), portal vein (PV), and hepatic vein (HV). The standard Doppler parameters were adjusted for maximal gain without background noise and the lowest pulse-repetition frequency without aliasing artifacts.

The spectral Doppler US mode was applied to the conventional color Doppler US mode, and a 2–5-mm Doppler sample gate was adjusted in real-time for optimal signal detection from the target vessel. Angle correction was done for the Doppler angle in parallel with the flow direction of the target vessel. The waveform was obtained for at least three consecutive heartbeats. For the UltraFast Doppler study, an UltraFast Doppler movie clip was acquired with a mechanically fixed duration (2–4 seconds) after initiating UltraFast Doppler acquisition on the conventional color Doppler US. Then, the UltraFast Doppler movie clip was reviewed, the frame offering the best visualization of the flow properties was selected, and the sample gate was located in the target vessel with an angle in parallel to the flow direction of the vessel. Then, a spectral wave analysis was performed for flow quantification without any additional images.

UltraFast and conventional Doppler studies were performed in one session in a random order, according to the last digit (odd or even) of the patients' identification number of this hospital. Thus, in 17 of the 39 Doppler exams, the UltraFast Doppler study was

performed prior to the conventional study, and the remaining 22 exams were performed with the conventional Doppler study first. For living donor right liver grafts, the right HA, right PV, and right HV were measured and calculated; for living donor left liver grafts, the left HA, left PV, and left HV were measured; and for deceased donor total liver grafts, the right and left HAs, right and left PVs, and the right, middle, and left HVs were examined.

Image Analysis

To evaluate the difference in blood flow between the UltraFast and the conventional Doppler studies, peak systolic velocity (PSV), end diastolic velocity (EDV), and resistive index (RI) of HA and the peak PV and HV velocities obtained in both exams were compared. The phasicity of hepatic vessels (monophasic, biphasic, or triphasic) was also compared. The time taken to finish each UltraFast and conventional Doppler study, whether the patient was a good breath-holder or a poor breath-holder, the presence and cause of technical failures, and the difference in clinical decisions were evaluated using recorded imaging data and radiologist reports. The time taken for each Doppler study was defined as the duration from the time when the last grayscale image or the last counterpart Doppler image was stored just before the first Doppler image to the time when the last Doppler image was stored. Poor breath-holders were defined as patients who did not cooperate with the operator's comments and could not hold their breath, such that three or more trials were needed to obtain an optimal spectral waveform of each target vessel. Technical failure was defined as an ill-defined spectral Doppler waveform and/or a condition in which the peak velocity could not be measured. A case in which the measured value was uncertain on the radiologic report was also considered a technical failure. The clinical decision was defined by the following abnormal findings: the presence of thrombus, absence of a Doppler signal of the hepatic vessels, pulsus parvus et tardus flow pattern of the HA, or a decreased RI value (<0.5) of the HA [12].

Statistical Analysis

To determine the correlation between the two Doppler US studies with respect to the velocity and phasicity of the hepatic vessels, Pearson's correlation coefficient was used for the statistical analysis. The two-tailed paired t-test was performed to determine which Doppler US required less time. With respect to the time required for Doppler US, a subgroup analysis was performed according to whether the patient was a good or a poor breath-holder. All statistical analyses were performed with the commercially available software (IBM SPSS ver. 21.0, IBM Co., Armonk, NY, USA). A P-value of less than 0.05 was considered statistically significant.

Results

The PSV, EDV, and RI values of the HAs and the peak velocities of the PVs and HVs showed a statistically strong positive correlation between the two Doppler US studies (mean R, 0.806; range, 0.710 to 0.924). The velocities and RI values of the hepatic vessels are summarized in Table 1. Fig. 1 shows scatterplots of conventional and UltraFast measurements with several parameters. The phasicities of the hepatic vessels were the same in both Doppler US exams (Table 2), and all the evaluated hepatic vessels showed a normal flow pattern.

In terms of the time required for the Doppler US study, the UltraFast Doppler US (251±99 seconds) took slightly longer than the conventional Doppler US (231±117 seconds). However, the difference was not significant (P=0.306). In seven poor breath-holders, the time taken for UltraFast Doppler US (294±141 seconds) was slightly shorter than that for the conventional Doppler US (331±141 seconds). In particular, in five of the seven poor breath-holders, the UltraFast Doppler US (272±157 seconds) took less time than the conventional Doppler US (381±133 seconds; P=0.005) (Fig. 2). In nine of the 32 sessions in the good breath-holder subgroup, the time taken by the UltraFast Doppler US was shorter.

In two patients, the spectral Doppler waveform of the left HA could not be obtained due to cardiac interference and superimposed

Table 1. Correlation of velocity and resistive index value between UltraFast and conventional Doppler ultrasound studies

Variable		Number	UltraFast	Conventional	R[a)]
Right hepatic artery	PSV	34	45.9±27.8	56.0±24.9	0.778
	EDV	34	16.3±12.6	16.3±10.7	0.807
	RI	34	0.65±0.12	0.71±0.11	0.875
Left hepatic artery	PSV	10	28.7±6.60	31.9±9.90	0.890
	EDV	10	11.9±3.63	10.8±4.60	0.747
	RI	10	0.58±0.09	0.66±0.09	0.722
Right portal vein	Peak velocity	34	61.8±36.1	60.7±27.7	0.776
Left portal vein	Peak velocity	12	38.6±31.5	40.2±36.8	0.924
Right hepatic vein	Peak velocity	34	40.1±19.5	43.6±20.9	0.710
Middle hepatic vein	Peak velocity	8	29.3±16.5	25.8±5.76	0.906
Left hepatic vein	Peak velocity	11	30.4±11.9	33.4±13.4	0.811

Values are presented as mean±SD (cm/sec).

PSV, peak systolic velocity; EDV, end diastolic velocity; RI, resistive index.

[a)] Pearson correlation coefficient between the UltraFast and the conventional Doppler studies.

Table 2. Phasicities of hepatic vessels

Variable	Total	UltraFast			Conventional		
		Monophasic	Biphasic	Triphasic	Monophasic	Biphasic	Triphasic
Right hepatic artery[a)]	34	0	34	0	0	34	0
Left hepatic artery[a)]	10	0	10	0	0	10	0
Right portal vein	34	21	13	0	21	13	0
Left portal vein	12	5	7	0	5	7	0
Right hepatic vein	34	6	17	11	6	17	11
Middle hepatic vein	8	1	4	3	1	4	3
Left hepatic vein	11	0	6	5	0	6	5

Values are presented as the number of cases. All evaluated hepatic vessels showed a normal flow direction.
[a)] Hepatic arteries showed a typical normal pulsatile waveform.

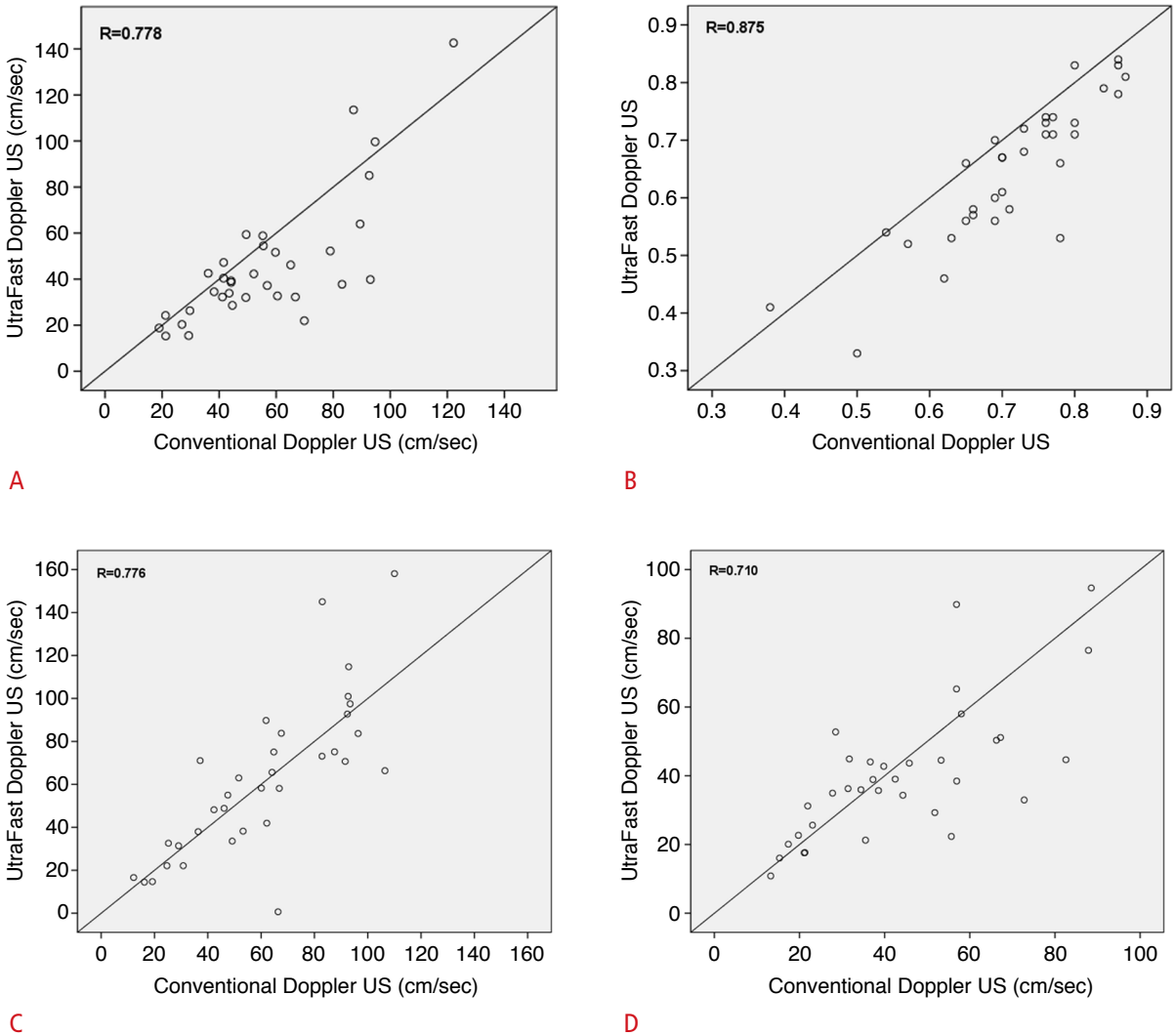


Fig. 1. Scatterplot of conventional and UltraFast measurements for several representative parameters.
Pearson's correlation coefficient (R) of the peak systolic velocity of the right hepatic artery is 0.778 (A), that of the resistive index of the right hepatic artery is 0.875 (B), that of the velocity of the right portal vein is 0.776 (C), and that of the velocity of the right hepatic vein is 0.710 (D). These high R-values imply a strong positive correlation between the two Doppler US studies, as shown in the scatterplots. US, ultrasonography.

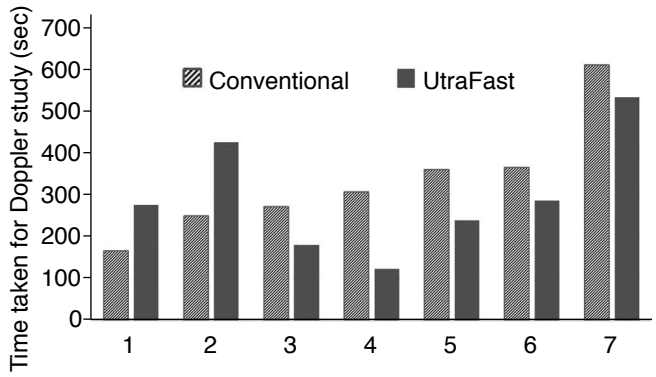
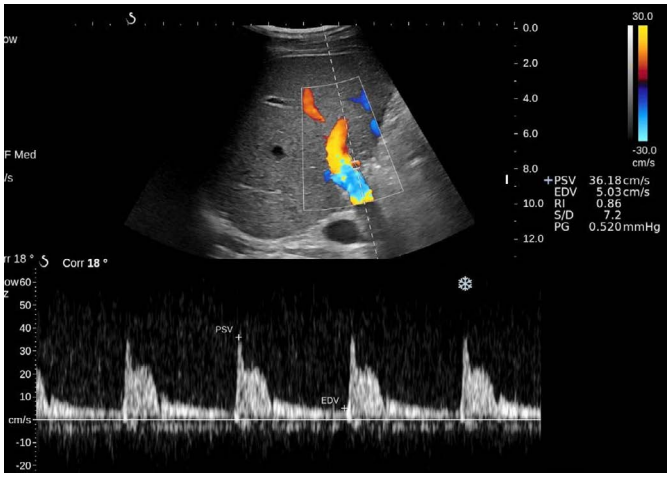
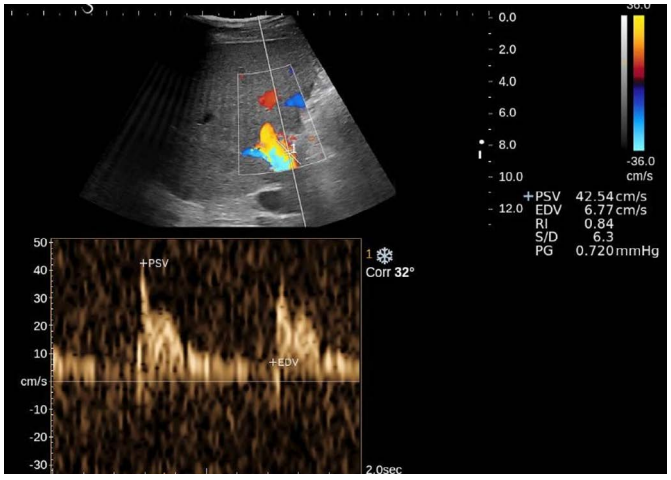


Fig. 2. Duration of Doppler studies in seven poor breath-holders. In five out of seven sessions, conventional Doppler ultrasonography took longer than 270 seconds. From numbers 3 to 7, the UltraFast Doppler ultrasonography (272±157 seconds) is faster than the conventional Doppler ultrasonography (381±133 seconds) (P=0.005).



A

B



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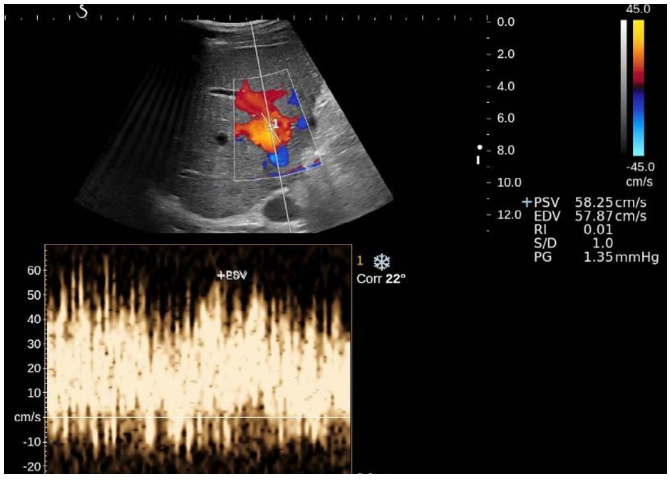
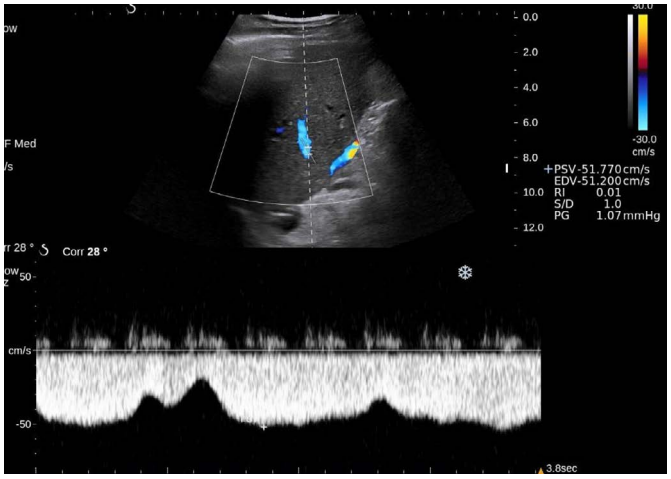
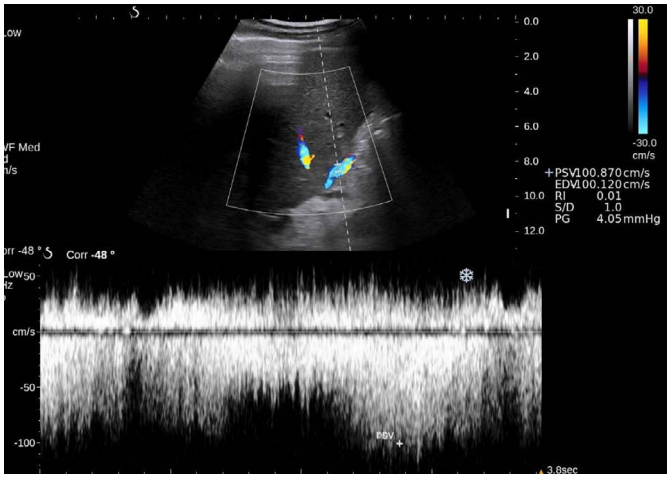


D

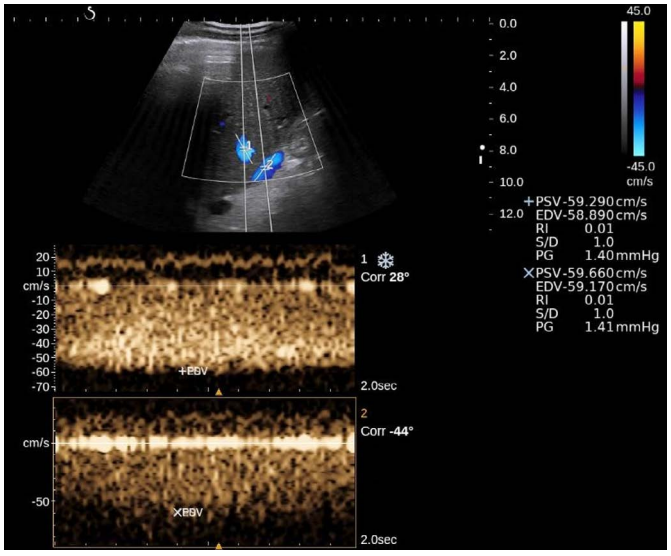
Fig. 3. Conventional and UltraFast Doppler images in a good breath-holder, a 58-year-old male who underwent living donor liver transplantation four days prior to ultrasonography imaging.
Conventional Doppler images (A, right hepatic artery; B, right portal vein) and UltraFast Doppler images (C, right hepatic artery; D, right portal vein) show that the velocities and spectral waveforms of the hepatic vessels are well-correlated between the two Doppler studies. The duration of the conventional Doppler exam was 1 minute 59 seconds; the duration was 2 minutes 44 seconds for the UltraFast Doppler exam.



A



B



C

Fig. 4. **Conventional and UltraFast Doppler images in a poor breath-holder, a 56-year-old male who underwent living donor liver transplantation eleven days prior to ultrasonography imaging.**
Conventional Doppler images (A, right hepatic vein; B, middle hepatic venous graft) and UltraFast Doppler image of the right hepatic vein, and the middle hepatic venous graft (C) show that the multi-location spectral analysis was possible with the UltraFast Doppler exam, which resulted in a reduction of the exam duration. The duration of the conventional Doppler exam was 5 minutes 5 seconds; the duration was 2 minutes 4 seconds for the UltraFast Doppler exam.

left PV signals. In one case, the failure could be attributed to difficulties measuring the peak velocity of the left HV, also due to cardiac interference. These technical failures occurred in both Doppler studies. With respect to the clinical decision, there were no discrepancies between the Doppler studies. Figs. 3 and 4 show representative cases for conventional and UltraFast Doppler US studies in the good and poor breath-holder subgroups, respectively.

Discussion

Doppler-based blood flow analysis and quantification are well-established in clinical practice and have become indispensable in the evaluation of cardiovascular disease, including vascular complications after liver transplantation. From the perspective of Doppler US studies of abdominal organs such as the liver or kidney, which move with respiration, breath-holding is essential to obtain optimal spectral Doppler waveforms of the target vessel and to quantify the flow characteristics. Conventionally, spectral Doppler studies are performed in real time, and therefore, the Doppler sample gate is placed within the target vessels while the patients hold their breath. Little effort and time are required to complete the spectral Doppler study when patients hold their breath according to the operator's comments. However, in the case of poor breath-holders, multiple trials are needed to obtain optimal spectral Doppler waveforms from each target vessel because the targeted vessels almost always escape from the Doppler sample gate with respiration. Therefore, the total time taken to complete a Doppler US exam increases in the case of poor breath-holders, and operators feel more fatigued.

In this study, the flow velocities and RI values of UltraFast Doppler

US were strongly correlated with those of conventional US. In addition, there was no difference between the two Doppler studies with respect to the clinical decision. Based on the results of our study, UltraFast Doppler US can be applied to visualize abdominal organs, such as hepatic vessels, and is equivalent to conventional Doppler US.

Overall, there was no significant difference between the two Doppler studies in terms of the duration of the exam. This may be primarily due to the large proportion (32/39, 82%) of good breath-holders. However, in the poor breath-holder subgroup, five of seven exams showed a significantly shorter exam time with the UltraFast Doppler US than the conventional Doppler US. The reduction in the duration of the UltraFast Doppler US test in the case of poor breath-holders is most likely related to the placement of the Doppler sample gate, which eliminates the need for repeated trials for flow quantification. Therefore, we expect UltraFast Doppler US to have the potential of reducing the number of trials and amount of effort in the case of poor breath-holders.

Our study has some limitations. First, the sample size is small; only seven poor breath-holders were included. However, considering that UltraFast Doppler US is a fairly new technology and has just begun to be applied to real clinical settings, this study could be a meaningful preliminary experience. Second, the degree of expertise differed between the two Doppler studies. The operators had little experience using the UltraFast Doppler US before this study, while they had four years of clinical experience using the conventional Doppler US. This difference in expertise may have negatively affected the exam time. However, this effect seems to be inevitable with the introduction of a new method. Another limitation is that many sessions were conducted in a given patient (four sessions in three, three in two, two in six, and one in nine patients). This situation could have biased some of the results. Next, the study population consisted of liver recipients who were clinically stable. Therefore, further investigation is needed to determine the value of the UltraFast Doppler US for complicated liver recipients. Lastly, UltraFast Doppler US uses plane-wave transmits as mentioned above, and therefore, a high frame rate acquisition is achievable while the transmit focus is sacrificed. This would clearly affect the penetration and the resolution of the ultrasound signal as well as the sensitivity of the Doppler frequency shift estimation. These limitations need to be properly studied and quantified under more controlled conditions as opposed to a clinical setting. Therefore, a more systematic further comparison is needed to better understand the advantages and limitations of the UltraFast Doppler US as compared to the conventional Doppler US.

In this study, the values of velocities and the RI of the hepatic vessels in the case of UltraFast Doppler US showed a strong positive correlation with those obtained in the case of conventional Doppler US. Further, there was no significant difference between the two techniques with respect to the exam duration, technical failures, and clinical decisions. In conclusion, UltraFast Doppler US is clinically equivalent to conventional Doppler US during the post-liver transplantation work-up.

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Conflict of Interest

Byung Ihn Choi received a grant from Samsung Electronics Company in the past. For the remaining authors, no conflicts of interests have been declared.

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