Hepatic Arterial Stenosis Assessed with Doppler US after Liver Transplantation: Frequent False-Positive Diagnoses with Tardus Parvus Waveform and Value of Adding Optimal Peak Systolic Velocity Cutoff

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**Purpose:** To evaluate the utility of the tardus parvus waveform of the hepatic artery at Doppler ultrasonography (US) in the diagnosis of hepatic arterial stenosis in liver transplant (LT) recipients and determine whether the accuracy of such a diagnosis is enhanced by including an optimal peak systolic velocity (PSV) cutoff.

**Materials and Methods:** This retrospective study was institutional review board approved; the requirement for informed consent was waived. The authors identified 361 LT recipients (267 male, 94 female) who underwent Doppler US and either computed tomography (CT) or angiography, with an interval between these examinations of less than 1 week. At Doppler US, tardus parvus pattern was defined as a waveform with a resistive index (RI) of less than 0.5 and a systolic acceleration time longer than 0.08 second. At CT or angiography, patients were assigned to the hepatic arterial stenosis (≥50% vessel narrowing) or nonstenosis group. The capability of the tardus parvus pattern to facilitate the diagnosis of hepatic arterial stenosis was calculated. The difference in PSV between the true- and false-positive tardus parvus patterns was evaluated. Receiver operating characteristic (ROC) analysis was performed to determine the optimal cutoff PSV for diagnosing hepatic arterial stenosis. The capability of the tardus parvus pattern and an optimal PSV cutoff in the diagnosis of hepatic arterial stenosis was determined.

**Results:** Sixty transplant recipients had the tardus parvus pattern at Doppler US. The sensitivity, specificity, and positive predictive value (PPV) of the tardus parvus pattern were 72% (23 of 32 LT recipients), 88.8% (292 of 329 LT recipients), and 38% (23 of 60 LT recipients), respectively. The false-positive rate was 11.2% (37 of 329 LT recipients). ROC analysis revealed an optimal PSV cutoff of less than or equal to 48 cm/sec for diagnosing hepatic arterial stenosis. The capability of the tardus parvus pattern and an optimal PSV cutoff in the diagnosis of hepatic arterial stenosis was determined.

**Conclusion:** Use of the tardus parvus waveform of the hepatic artery resulted in a low PPV and a high false-positive rate. However, the combination of the tardus parvus pattern and an optimal PSV cutoff greatly improved the PPV and reduced the false-positive rate in the diagnosis of hepatic arterial stenosis.
hepatic artery complications are the most threatening complications that occur after liver transplantation (1,2). Significant hepatic arterial stenosis or hepatic arterial thrombosis can progress to early graft failure or acute bile duct necrosis–biliary sepsis (3–5). Although such events are more infrequent after living-donor liver transplantation than after deceased-donor liver transplantation and urgent surgical revascularization is less commonly required after the living-donor procedure, low-grade hepatic arterial stenosis can cause nonanastomotic biliary stricture (6). Hepatic arterial stenosis may be successfully treated by using stents, and early detection is crucial for successful treatment—with surgical reconstruction, balloon angioplasty, or stent placement (7,8).

Doppler ultrasonography (US) is the established method for initial screening of vascular abnormalities after liver transplantation. Doppler waveforms of the postanastomotic hepatic artery are indirect indicators of anastomosis (2,9,10). The Doppler US criteria for hepatic arterial thrombosis and significant hepatic arterial stenosis include no Doppler signal or a tardus parvus waveform (with a resistive index [RI] < 0.5 and systolic acceleration time > 0.08 second) (9,11). A tardus parvus waveform, however, may result in frequent false-positive diagnoses of hepatic arterial thrombosis and hepatic arterial stenosis. Although the causes of these false-positive diagnoses have been investigated (12), little is known about the methods of differentiating between true- and false-positive diagnoses based on tardus parvus waveforms. Therefore, our purpose was to evaluate the utility of the tardus parvus waveform of the hepatic artery at Doppler US in the diagnosis of hepatic arterial stenosis in liver transplant recipients and determine whether the accuracy of such a diagnosis is enhanced by including an optimal cutoff value for peak systolic velocity (PSV).

Materials and Methods

Patients

This study was approved by our institutional review board (Asan Medical Center). The requirement for informed patient consent for this retrospective review was waived. A total of 374 patients had undergone liver transplantation at our institution between January 2009 and January 2010. A patient’s data were included if he or she underwent postoperative Doppler US during hospitalization and a correlated computed tomography (CT) or angiographic examination within 7 days after US. The 374 patients underwent 3298 Doppler US (mean of 9.1 examinations per patient ± 2.8 [standard deviation]) and 1389 CT (mean of 3.8 examinations per patient ± 1.7) examinations before being discharged. Angiography was performed in 23 patients. All Doppler US results were reviewed by one radiologist (S.J.L., 3 years experience in liver transplant imaging), who determined whether there was a tardus parvus pattern (RI < 0.5 and systolic acceleration time > 0.08 second) of the hepatic artery at Doppler US. In the presence of a tardus parvus waveform episode at Doppler US, the CT or angiographic examination was matched nearest to each Doppler US examination as a reference standard. In the absence of a tardus parvus waveform episode at Doppler US, the CT or angiographic examination and the Doppler US examination performed at the shortest interval were selected. If there were multiple pairs of examinations, an earliest one was selected. Patients who did not undergo CT or angiography within 7 days after US (n = 10) and patients with no detectable flow signal of the hepatic artery (n = 3) at Doppler US were excluded.

The remaining 361 patients (mean age, 50.7 years ± 9.2 [standard deviation]; age range, 16–68 years) were included in this study. They included 267 male patients (mean age, 51 years ± 9; age range, 16–68 years) and 94 female patients (mean age, 50.3 years ± 9; age range, 16–68 years). All Doppler US examinations were performed at the Asan Medical Center between January 2009 and January 2010.

Implication for Patient Care

Introduction of an optimal PSV cutoff to the tardus parvus pattern may facilitate a more accurate diagnosis of hepatic arterial stenosis at Doppler US by considerably decreasing the high false-positive rate of the tardus parvus waveform.
range, 21–67 years). Eighty-six of these patients underwent deceased-donor liver transplantation, and the remaining patients underwent living-donor liver transplantation by using modified right-lobe (n = 255), left-lobe (n = 6), or dual-lobe (n = 14) grafts. Indications for liver transplantation included liver cirrhosis associated with hepatitis B or hepatitis C virus (n = 188), hepatocellular carcinoma (n = 124), acute fulminant hepatitis (n = 39), autoimmune hepatitis (n = 3), cryptogenic liver cirrhosis (n = 2), primary biliary cirrhosis (n = 2), chronic rejection after previous transplantation (n = 2), and primary sclerosing cholangitis (n = 1).

During surgery, hepatic artery reconstruction was performed after reconstruction of the hepatic and portal veins and before reconstruction of the bile duct. In those patients who underwent living-donor liver transplantation, the graft hepatic arteries were anastomosed in an end-to-end fashion to the right hepatic artery or distal branches in the recipient for size matching. For deceased-donor liver transplantation, the hepatic arterial anastomoses consisted of end-to-end fish-mouth anastomoses between the graft celiac axis and either the bifurcation of the right and left hepatic arteries or the branch point of the gastroduodenal artery from the proper hepatic artery. On the Doppler waveform, the RI and systolic acceleration time were evaluated for evidence of a tardus parvus pattern, which was defined as a waveform with a RI lower than 0.5 and a systolic acceleration time longer than 0.08 second. In addition, the PSV was measured with manual angle correction. All measurements were acquired on waveforms that could be reproduced for at least three consecutive heart beats. If review of the RI, systolic acceleration time, and PSV of the hepatic artery revealed a tardus parvus waveform, the prevalence and time of onset of this finding were evaluated. Moreover, we attempted to determine the cause of any false-positive tardus parvus waveform.

Angiographic Methods
An experienced interventional radiologist performed the angiographic examinations by using a standard transfemoral approach with a 5-F Cobra catheter (Cook, Bloomington, Ind). Selective catheterization of the hepatic artery was performed by injecting contrast material (iohexol, Omnipaque 350; GE Healthcare, Cork, Ireland) at 8 mL/sec (total volume, 40 mL) to delineate the hepatic artery.

CT Methods
The mean interval between CT and Doppler US was 2.5 days ± 2.5 (range, 0–7 days). CT was performed by using a 16-detector CT scanner (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany [n = 339] or LightSpeed 16; GE Healthcare, Milwaukee, Wis [n = 18]). After nonenhanced CT scans were obtained, each patient received 130 mL of iopromide (Ultravist 370; Bayer Schering, Berlin, Germany), which was administered at a flow rate of 3 mL/sec by using a mechanical injector (Percupump II; E-Z-Em, Westbury, NY). Biplanar CT was performed during the hepatic arterial and venous phases. With use of bolus-tracking methods (SmartPrep; GE Healthcare or CARE-Bolus; Siemens Medical Solutions), hepatic arterial phase scanning was initiated when 10 seconds had elapsed after the attenuation of the descending aorta reached 100 HU. The parameters used for hepatic arterial phase CT scanning included a detector configuration of 0.75 mm × 16, a table feed of 12 mm per rotation, a gantry rotation time of 0.5 second, 200 mAs (effective), and 120 kVp for the Somatom Sensation 16 scanner, and a detector configuration of 1.25 mm × 16, a table feed of 20 mm per rotation, a gantry rotation time of 0.6 second, 220 mAs (effective), and 120 kVp for the LightSpeed 16 scanner.

The images obtained by using the Somatom Sensation 16 machine were reconstructed with section thicknesses and intervals of 3 mm for the axial images and 5 mm for the coronal images. The images obtained by using the LightSpeed 16 machine were reconstructed with section thicknesses and intervals of 2.5 mm for the axial images and 5 mm for the coronal images. All images were downloaded to a picture archiving and communication system workstation (Petalvision; Hyundai Information Technology, Seoul, Korea). In addition, the images obtained with the Somatom Sensation 16 system were reconstructed at 1-mm section thicknesses and 0.70-mm intervals, and those obtained with the LightSpeed 16 system were reconstructed at 1.25-mm section thicknesses and intervals and were downloaded to a workstation (Advantage Windows, version 4.0; GE Medical Systems) for three-dimensional reconstruction of the hepatic arteries. Volume-rendering and maximum intensity projection techniques were used as standard algorithms.

CT or Angiogram Analysis
The CT images were retrospectively reviewed in consensus by abdominal
radiologists (K.W.K., Y.S.P., 9 and 2 years experience, respectively, in hepatic transplant imaging) who were unaware of the clinical, laboratory, and Doppler US findings.

After the location of the hepatic arterial anastomotic site was identified from surgical records and on the three-dimensional maximum intensity projections, the luminal diameters of the hepatic arterial anastomosis and the postanastomotic (graft) hepatic artery were measured on axial or coronal multiplanar reformatted images at a magnification of 4/3 to minimize potential measurement errors. The percentage of hepatic arterial stenosis at the anastomosis site was calculated as 

\[ \frac{(D_{\text{postHA}} - D_{\text{anastHA}})}{D_{\text{postHA}}} \times 100 \]

where \( D_{\text{postHA}} \) is the diameter of the postanastomotic hepatic artery and \( D_{\text{anastHA}} \) is the diameter of the hepatic arterial anastomosis. Significant hepatic arterial stenosis was defined as 50% or greater stenosis at the anastomosis or the case in which the anastomotic site was invisible, with faint opacification of the postanastomotic hepatic artery, regardless of hepatic parenchymal infarction or ischemia. A hepatic artery was considered to be patent when it was enhancing and could be continuously traced from the anastomotic site to the intrahepatic branches, with less than 50% stenosis. Angiograms were evaluated by using methods similar to those used for CT analysis. Accordingly, patients were assigned to the hepatic arterial stenosis group or nonstenosis group. The cause of hepatic arterial stenosis was subjectively evaluated and was presumed to be (a) anastomotic strictures if there was short segmental or focal luminal narrowing of the hepatic artery near the surgical clips of the anastomosis, (b) hepatic arterial dissection if there was long segmental, smoothly narrowed opacification of the hepatic artery (ie, assumed true lumen) surrounded by a thick low-attenuating cuff (presumably, a thrombosed false lumen), or (c) thrombosis if there was abrupt termination of the hepatic artery and either an absence of opacification or a filling defect of the anastomotic hepatic artery and the intrahepatic branches. For patients assigned to the hepatic arterial stenosis group, follow-up imaging studies and electronic medical records were reviewed to assess the patients’ clinical management and outcomes.

**Statistical Analyses**

Statistical analyses were performed by using MedCalc, version 9.3.6.0, software (Frank Schoonjans, Mariakerke, Belgium). To avoid potential confounders in the classification of the stenosis and nonstenosis groups, the independent \( t \) test and the Fisher exact test were used. Using CT or angiographic findings as the reference standard, we calculated values of the capability of the tardus parvus pattern in the diagnosis of hepatic arterial stenosis, including sensitivity, specificity, positive predictive value (PPV), negative predictive value, and accuracy, as well as 95% confidence intervals (CIs) for each of these parameters. The independent \( t \) test and the Fisher exact test were performed to evaluate differences in onset time and contributing factors between the patients with true-positive tardus parvus patterns and those with false-positive patterns.

Differences in PSV between the hepatic arterial stenosis and nonstenosis groups were evaluated by using independent \( t \) tests. We constructed receiver operating characteristic curves for PSV. The optimal PSV cutoff was correlated with the highest accuracy resulting from the maximal Youden index. We also evaluated the diagnostic accuracy of the combination of optimal PSV cutoff and tardus parvus pattern.

**Results**

Of the 361 patients, 60 (16.6%) had the tardus parvus waveform at Doppler US, with a mean RI of 0.46 ± 0.10 (standard deviation) (range, 0.29–0.49) and a mean systolic acceleration time of 112.1 cm/sec ± 26.3 (range, 83–200 cm/sec). These patients had a first documented tardus parvus waveform a mean of 18.9 days ± 22.6 (range, 1–65 days) after liver transplantation. The mean interval between Doppler US and either CT or angiography was 0.5 day ± 1 (range, 0–4 days).

At CT, 17 patients had anastomotic strictures, 14 had hepatic arterial dissections, and one had hepatic arterial thrombosis. These 32 (8.9%) patients were assigned to the hepatic arterial stenosis group; their mean percentage of stenosis was 64.0% ± 9.7 (range, 50%–79%). The mean interval between Doppler US and either CT or angiography was 0.7 day ± 1 (range, 0–4 days). There was no interval treatment between the two examinations. The remaining 329 (91.1%) patients were assigned to the nonstenosis group. The mean interval between Doppler US and either CT or angiography was 2.7 days ± 2.5 (range, 0–7 days). There were no significant differences between the stenosis and nonstenosis groups in terms of age (32.6 years ± 8.7 and 50.6 years ± 9.0, respectively; \( P = .73 \)), sex (81 men, 13 women and 248 men, 19 women, respectively; \( P = .58 \)), or liver transplant type (\( P = .17 \)). The sensitivity, specificity, PPV, negative predictive value, and accuracy of the tardus parvus pattern for the diagnosis of hepatic arterial stenosis were 72% (23 of 32 liver transplant recipients; 95% CI: 53.3%, 86.2%), 88.8% (292 of 329 transplant recipients; 95% CI: 84.8%, 92.0%), 38% (23 of 60 transplant recipients; 95% CI: 26.1%, 51.8%), 97.0% (292 of 301 transplant recipients; 95% CI: 94.4%, 98.6%), and 87.3% (315 of 361 transplant recipients; 95% CI: 83.3%, 90.5%), respectively. The false-positive rate was 11.2% (37 of 329 transplant recipients). The results of the subanalyses of anastomotic stricture, dissection, and thrombosis are shown in Table 1. Of the 301 patients with normal hepatic arterial waveforms, two had anastomotic strictures and seven had hepatic arterial dissections.

The mean time of onset of the true-positive tardus parvus patterns (Fig 1) was 14.7 days ± 14.0 after liver transplantation, and the mean time of onset of the false-positive tardus parvus patterns was 21.4 days ± 26.3 after liver transplantation (\( P = .20 \)). The possible causes of the false-positive tardus parvus waveforms (Fig 2) included an early postoperative period (\(< 48 \) hours after liver transplantation) (\( n = 13 \),...
celiac trunk stenosis \( (n = 11) \), portal venous stenosis or thrombosis \( (n = 5) \), hepatic venous stenosis \( (n = 3) \), and arterioportal fistula \( (n = 1) \). In the remaining 12 (32%) of 37 false-positive cases, however, we found no causes of the false-positive tardus parvus waveforms. However, an early postoperative period \( (n = 5) \), celiac trunk stenosis \( (n = 3) \), portal venous stenosis or thrombosis \( (n = 3) \), and hepatic venous stenosis \( (n = 3) \) were also noted in the true-positive tardus parvus waveform cases. There was no significantly meaningful factor in the false-positive diagnoses (Table 2).

The mean PSV was significantly lower in the hepatic arterial stenosis group than in the nonstenosis group \( (46.1 \text{ cm/sec} \pm 27.2 \text{ vs } 83.8 \text{ cm/sec} \pm 39.4, P < .0001) \) (Fig 3). In the 60 patients with tardus parvus patterns, the mean PSV was significantly lower in the true-positive cases than in the false-positive cases \( (33.8 \text{ cm/sec} \pm 10.1 \text{ vs } 94.9 \text{ cm/sec} \pm 41.5, P < .0001) \).

Receiver operating characteristic analysis of PSVs revealed that the area under the curve was 0.834 (95% CI: 0.791, 0.871). The optimal cutoff PSV of the hepatic artery was less than or equal to 48 cm/sec, and this value had a sensitivity of 75% (24 of 32 transplant recipients) and a specificity of 86.9% (286 of 329 transplant recipients) (Fig 4). The combination of the tardus parvus pattern and a PSV cutoff of less than or equal to 48 cm/sec resulted in a sensitivity of 69% (22 of 32 liver transplant recipients; 95% CI: 50.0%, 83.9%), a specificity of 99.1% (326 of 329 transplant recipients; 95% CI: 97.4%, 99.8%), a PPV of 88% (22 of 25 transplant recipients; 95% CI: 68.8%, 97.3%), a negative predictive value of 97.0% (326 of 336 transplant recipients; 95% CI: 94.6%, 98.6%), and an accuracy of 96.4% (348 of 361 transplant recipients; 95% CI: 93.9%, 98.1%). The false-positive rate was 1.0% (three of 329 transplant recipients).

Patients in the hepatic arterial stenosis group were followed up for a mean of 244 days \( \pm 143 \) (range, 9–525 days). Of these 32 patients, only one, who had an anastomotic stricture, underwent repeat transplantation with hepatic artery reconstruction from an aortic jump graft. The condition of this patient improved, with no further adverse events. Six patients died: two owing to graft failure—two with an anastomotic stricture, one with a hepatic arterial dissection, and one with hepatic arterial thrombosis. These patients could not be treated surgically because of their poor general condition. The remaining patients with anastomotic strictures and hepatic arterial dissections were treated with systemic heparinization and anticoagulation because they had minor elevations in liver enzymes, and, thus, the clinicians did not consider their findings to be clinically important. During follow-up, the condition of 20 patients improved, with minimal residual stenosis on the follow-up CT scans; four of these patients had a mild degree of biliary stricture. In five patients, the hepatic arterial

**Table 1**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Accuracy</th>
<th>False-Positive Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatic arterial stricture ( (n = 17) )</td>
<td>88 (15/17)</td>
<td>86.9 (299/344)</td>
<td>25 (15/60)</td>
<td>99.3 (299/301)</td>
<td>87.0 (314/361)</td>
<td>13.1 (45/344)</td>
</tr>
<tr>
<td>Hepatic arterial dissection ( (n = 14) )</td>
<td>50 (7/14)</td>
<td>84.7 (294/347)</td>
<td>12 (7/60)</td>
<td>97.7 (294/301)</td>
<td>83.4 (301/361)</td>
<td>15.3 (53/347)</td>
</tr>
<tr>
<td>Hepatic arterial thrombosis ( (n = 1) )</td>
<td>100 (1/1)</td>
<td>83.6 (301/360)</td>
<td>2 (1/60)</td>
<td>100 (301/301)</td>
<td>83.7 (302/361)</td>
<td>16.4 (59/360)</td>
</tr>
</tbody>
</table>

Note.—Data are percentages, with the numbers of liver transplant recipients used to calculate the percentages in parentheses and 95% CIs of the percentages in brackets. NPV = negative predictive value.

**Figure 1**

True-positive diagnosis of tardus parvus waveform in 27-year-old woman with hepatic arterial stenosis after deceased-donor liver transplantation. (a) Doppler sonogram shows dampened flow and tardus parvus waveform of graft hepatic artery. RI is 0.40, and systolic acceleration time is 117 msec. \( P/S \) = systolic-to-diastolic ratio, \( V_1 \) = minimal diastolic velocity, \( V_2 \) = PSV. (b) Coronal maximal intensity projection shows luminal narrowing (arrow) of anastomotic hepatic artery.
on the tardus parvus waveform has been reported to be more frequent during the early postoperative period (<48 hours after transplantation) possibly because of surgical edema, with the tardus parvus waveform occasionally returning to normal within a few days (9). Among the 60 patients with the tardus parvus waveform in our series, the pattern appeared during the early postoperative period (<48 hours) in 18 transplant recipients, and 13 of these cases were false-positive. However, the false-positive diagnoses also occurred frequently at later periods, and the time of onset of the tardus parvus waveform did not differ significantly between the patients with true-positive and those with false-positive diagnoses (P = .20). False-positive diagnoses may also be due to conditions other than hepatic arterial stenosis, including severe aortoiliac atherosclerotic disease, arteriovenous or arterial-biliary fistula formation, and hepatic venous or portal venous thrombosis (2,9–11,13–15).

We observed false-positive diagnoses based on the tardus parvus pattern frequently (in 11 [30%] of 37 cases) in patients with celiac trunk stenosis and occasionally in patients with arterioportal fistula after hepatic parenchymal biopsy, portal venous stenosis or thrombosis, or hepatic venous stenosis. In approximately 30% of the patients with a false-positive diagnosis based on the tardus parvus pattern, however, we could not identify any cause.

Although a jet flow with a PSV greater than 200 cm/sec at the hepatic arterial anastomosis or the juxtaanastomotic part is suggestive of hepatic arterial stenosis (2,9,16,17), it is often difficult to obtain a Doppler signal from a hepatic arterial anastomosis, or it may be difficult to identify an anastomosis during the early postoperative period because of a poor sonic window (2,9,18). In contrast, while the blood flow velocity must increase initially to maintain the continuity of volume flow as the diameter of the stenotic vessel decreases, once a critical stenosis is reached, any further decrease in stenotic diameter will rapidly reduce the blood flow velocity as well as the blood volume flow (19). For this reason, a low PSV at the hepatic artery distal

**Table 2**

<table>
<thead>
<tr>
<th>Possible Cause</th>
<th>No. of False-Positive Cases*</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early postoperative period</td>
<td>13/18 (72)</td>
<td>.387</td>
</tr>
<tr>
<td>Celiac trunk stenosis</td>
<td>11/14 (79)</td>
<td>.211</td>
</tr>
<tr>
<td>Portal venous stenosis or thrombosis</td>
<td>5/8 (62)</td>
<td>&gt;.99</td>
</tr>
<tr>
<td>Hepatic venous stenosis</td>
<td>3/3 (100)</td>
<td>.279</td>
</tr>
<tr>
<td>Arterioportal fistula</td>
<td>1/1 (100)</td>
<td>&gt;.99</td>
</tr>
</tbody>
</table>

* Numerator is number of possible causes for the false-positive diagnosis of the tardus parvus pattern (as compared with the true-positive diagnosis), and denominator is number of possible causes for the sum of true-positive and false-positive diagnoses. Numbers in parentheses are resultant percentages.

lesions did not change during follow-up; however, these liver transplant recipients remained clinically stable.

**Discussion**

We found that use of the traditional criterion of a tardus parvus waveform—that involving the RI and the systolic acceleration time—had an accuracy of 87.3% for the diagnosis of hepatic arterial stenosis. Although this method had a sensitivity of 72% and a specificity of 88.8%, the false-positive rate was relatively high (11.2%). A false-positive diagnosis of hepatic arterial stenosis based

![Figure 2](image-url)
to the anastomosis may suggest hepatic arterial stenosis. Although a hepatic artery PSV lower than 31 cm/sec at intraoperative Doppler US in 40 pediatric liver transplant recipients was reported to reflect significant hepatic arterial stenosis (20), this diagnostic criterion may not be valid in adult liver transplant recipients during the postoperative period.

We found that among 60 patients with the tardus parvus pattern, the mean PSV was significantly lower in the true-positive cases than in the false-positive cases (33.8 cm/sec ± 10.1 vs 94.9 cm/sec ± 41.5, P < .0001), suggesting that false-positive diagnoses tend to occur in patients with higher PSVs of the hepatic artery. At receiver operating characteristic analysis, we found that the optimal PSV threshold for the postoperative diagnosis of hepatic arterial stenosis was less than or equal to 48 cm/sec. Although the specificity, PPV, accuracy, and false-positive rate of the tardus parvus pattern were 88.8% (292 of 329 liver transplant recipients), 38% (23 of 60 recipients), 87.3% (315 of 361 transplant recipients), and 11.2% (37 of 329 transplant recipients), respectively, in the diagnosis of hepatic arterial stenosis, the combination of an optimal PSV of the hepatic artery and the tardus parvus pattern improved the specificity, PPV, accuracy, and false-positive rate to 99.1% (326 of 329 transplant recipients), 88% (22 of 25 transplant recipients), 96.4% (348 of 361 transplant recipients), and 1.0% (three of 329 transplant recipients), respectively; however, the sensitivity decreased slightly, from 72% (23 of 32 transplant recipients) to 69% (22 of 32 transplant recipients).

Our study had several limitations. First, because our study was retrospective in design, there was an inherent limitation in terms of the adjusted analysis that could be expected with a randomized controlled study. Instead, we compared age, sex, and liver transplant type between the hepatic arterial stenosis and nonstenosis groups as potential confounders. There were no significant differences between the stenosis and nonstenosis groups in terms of age (P = .73), sex (P = .058), or liver transplant type (P = .17). Second, the PPV can change according to disease prevalence. This is important if the prevalence or incidence of hepatic arterial stenosis in this study (anastomotic stenosis in 17 [4.7%] of 361 liver transplant recipients, dissection in 14 [3.9%] transplant recipients, thrombosis in one [0.3%] of 361 transplant recipients) was representative of that in the general population. However, we think that there is an inherent limitation in this type of study in that the prevalence of surgical complications is difficult to generalize because it is highly dependent on the surgeon’s skill and experience. The prevalences of anastomotic stricture and thrombosis were 5%–11% and 4%–12%, respectively, according to old reports from the earlier days of liver transplantation (1–4,6,9,18,21). Currently, however, general prevalences are likely to be lower owing to improvements in surgical technique and greater experience. This should be validated with further studies.

Third, the performance of Doppler US tends to be dependent on the operator’s skill and the machine used. In our study, all Doppler US examinations were performed by radiologists and by using one US machine and a strict protocol that was already established for clinical purposes and included measurements of the RI, systolic acceleration time, and PSV at the postanastomotic hepatic artery near the right portal vein, with accurate manual angle correction. Every radiologist was trained with use of the spectral waveform and measurement were recorded. Fourth, we used CT angiography rather than conventional angiography as...
the reference standard in most cases. Compared with angiography, CT is a relatively imperfect reference standard for determining hepatic arterial stenosis, although several researchers have reported that CT angiography is well correlated with conventional angiography in the diagnosis of hepatic arterial stenosis (2,21), and three-dimensional multidetector CT with thin-section reconstruction usually has sufficed for diagnosing hepatic artery complications after liver transplantation (6,22–24). However, at our institution, angiography is not commonly performed for the confirmative diagnosis of hepatic arterial stenosis because of its invasiveness. Therefore, only a small portion of the patients in the hepatic arterial stenosis group (five of 32) underwent angiography in our study population. Fifth, measurements of the diameter of the hepatic artery anastomosis depicted on CT scans may be affected by beam hardening artifacts due to surgical clips. To maximize accuracy and minimize potential measurement errors, we first identified the location of the hepatic artery anastomosis from the surgical record and on the three-dimensional maximum intensity projection images. Only after locating the anastomotic site did we measure the diameters of the hepatic arterial lumens on axial or coronal multiplanar reformatted images with magnification.

In conclusion, the tardus parvus waveform of the hepatic artery had a poor PPV, 38% (23 of 60 liver transplant recipients), and a high false-positive rate, 11.2% (37 of 329 liver transplant recipients), in the diagnosis of hepatic arterial stenosis. Adding a PSV cutoff of less than or equal to 48 cm/sec to the tardus parvus pattern greatly improved the PPV—to 88% (22 of 25 liver transplant recipients)—and reduced the false-positive rate to 1% (three of 329 liver transplant recipients).

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References