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Inter-transducer Variability of Ultrasound Image Quality in Obese Adults: Qualitative and Quantitative Comparisons

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Short Title: Qualitative and Quantitative Comparisons of Ultrasound Image Qualities
Abstract

**Purpose:** Acquiring high-quality ultrasound images of deep abdominal organs and vasculatures in obese adults (BMI >30 kg/cm$^2$) is considered challenging. The aim of the study was to assess the inter-transducer variability in B-mode and color Doppler image quality from four commercial ultrasound transducers through qualitative and quantitative analyses.

**Methods:** Four curvilinear transducers on three ultrasound scanners were used to acquire B-mode and color Doppler images of deep abdominal structures in 15 obesity ≥ class II (BMI >35 kg/cm$^2$) adults. Using visual-qualitative assessment and an offline image processing software, visual-qualitative score and quantitative mean pixel values of B-mode images, and color area ratios of color Doppler images were calculated. Differences in these values among the transducers were analyzed using one-way ANOVA. The intra- and inter-observer reliability of visual-qualitative assessment and offline image processing was tested using the intraclass correlation coefficient (ICC).

**Results:** Differences in visual-qualitative score, mean pixel value of B-mode images, and color area ratio of color Doppler images among the four transducers were significant (p <0.001). Transducer -4 produced the highest quality of B-mode (45-53% improvement) and color Doppler (22-73% improvement) images among the transducers. Intra-observer repeatability and inter-observer reproducibility were higher with performing offline image processing than visual-qualitative assessment (ICC: 0.97-0.99 versus ICC: 0.76-0.97).

**Conclusion:** There was significant image quality variability between different transducers. Transducer -4, a transducer designed specifically for high BMI patients, had the highest quality
B-mode and color Doppler images compared to the other transducers lending to improved ultrasonographic visualization in obese patients.

**Keywords:** Color Doppler imaging, image quality, transducer, pixel-intensity, ultrasound

1. **Introduction**

Image quality of abdominal ultrasound based on resolution and penetration greatly influences the diagnostic interpretation of pathology and performance of ultrasound-guided interventional procedures [1]. Currently, commercially available ultrasound transducers have limitations in acquiring high quality images of deep abdominal organs and vasculatures. Abdominal image quality further decreases as patients' body mass indexes (BMI) increase [2]. It is considered technically challenging to acquire high quality ultrasound images while visualizing deep abdominal structures in obese populations (BMI > 30 kg/cm²) due to increased ultrasound attenuation following increased tissue depth. Challenging abdominal structures to visualize include the abdominal aorta and the liver near the diaphragm, which both lie deep in the abdomen. The vasculature of the kidney is difficult to assess using Doppler technique due to slow flow through the microvasculature in the kidney cortex and deep location of the renal artery [3, 4]. Additionally, thickened subcutaneous fat along the abdominal wall results in ultrasound sound wave distortion and scattering, as well as subsequent loss of contrast and image sharpness. These obtainable images are qualitatively described as “limited” or “degraded” [5, 6]. As such, additional uses of magnetic resonance imaging (MRI) and/or computed tomography (CT) become necessary to have optimal and adequate images of deeply located structures for
diagnostic interpretation in these populations [7]. This leads to increased healthcare cost, radiation exposure, and inefficient use of time.

Although qualitative assessments are useful in determining optimization of anatomic structures, quantitative comparisons may clearly establish standards of imaging quality across various equipment and patient demographics. For instance, image quality can be quantified by measuring the ability of the transducer to detect reflected ultrasound waves as an emulation of the variability in refraction, such as the tissue echogenicity in B-mode image and depiction of slow flow with color Doppler technique. Pixel counting analysis measures backscatter that is useful for determining the echo-intensity of grayscale images. Color area ratio measures the percentage of color pixels representing Doppler signals (flow in vessels) in a total region of interest [8]. Most recently reported studies focused on comparison of shear wave elastography using scanners made by various ultrasound manufacturers. Yet, differences in quality of B-mode and color Doppler images in patients with high BMI have not been investigated between transducers [9].

Furthermore, ultrasound probe selection greatly varies in the visibility and image quality for deep organs and structures. It is estimated that up to 30% of variation can occur when comparing tissue Doppler imaging between different machines, thus affecting clinical results and repeatability [10]. Even with adequately acquired images, systemic variability occurs when comparing image quality, artifacts, and Doppler sensitivity among vendors, transducers, and image processing software [11]. It is important to identify clinically useful transducers that adequately visualize anatomic details and depict blood flow in high BMI populations for improving diagnostic accuracy and repeatability between users. This is especially true when
patients require ongoing monitoring, follow-ups, or second opinions. It may also improve outcomes of ultrasound-guided procedures in patients with high BMI.

This study aimed to compare the ability to acquire high-quality B-mode and color Doppler images of deep abdominal structures in obese populations (BMI >35 kg/cm²), among four different commercial ultrasound transducers using visual-qualitative assessment and quantitative analysis.

2. Material and Methods

2.1. Participants

The Institutional Review Board of the University approved the study (IRB# 2020-0007) and all participants provided written informed consent prior to ultrasound scanning. Inclusion criteria: Age of 20y or older; able to understand and sign on written informed consent; body mass index (BMI) >35 kg/cm²; no major surgeries in the liver, kidney, and abdominal aorta; medically stable without cardiac, renal, or hepatic failure; tolerant to ultrasound.

2.2. Ultrasound Image Acquisition

All participants fasted for 6 hours prior to ultrasound scanning. During scanning, subjects were positioned in lateral decubitus or supine position to best view deep abdominal structures. We used four commercial curvilinear transducers on three ultrasound scanners (transducer-1 on ultrasound scanner A; transducer-2 on scanner B; transducer-3 and transducer-4 on scanner C) in the study. The scanning protocol and machine settings (scanning frequency [3.0 MHz for B-mode and 2.5 MHz for color Doppler], grayscale gain: 0 dB, single image focus, dynamic range:
65, time gain compensation, color gain, pulse repetition frequency, harmonic imaging) were standardized and preset.

Commercialized four curvilinear transducers on three ultrasound scanners were used to acquire the following images. One of the transducers was designed with advanced Multi-D beam forming technique specifically for high BMI patients (Table 1).

1. B-mode images of the liver/diaphragm and proximal abdominal aorta (coronal view);

2. Color Doppler images of the portal vein, entire right renal artery (proximal to distal, from abdominal aorta to kidney hilus), and kidney cortical perfusion (near and mid portion of the kidney in sagittal plane).

The listed images were acquired from all participants for each of the four transducers. Ultrasound images (B-mode and color Doppler) with Digital Imaging and Communication in Medicine (DICOM) format were transferred from ultrasound scanners to a desktop computer for offline visual-qualitative assessment and image processing.

A single ultrasound expert with 30 years of experience in abdominal ultrasound performed all ultrasound scans to prevent inter-observer variations in image acquisition.

2.3. Visual-qualitative Assessment of Ultrasound Images

Visual-qualitative assessment of ultrasound images of deep organ (the right lobe of the liver/diaphragm) and vasculature (coronal view of the proximal abdominal aorta) was conducted using a modified Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET) method [12]. Modified B-QUIET method included eight components of visual-quantitative assessment: anatomy identification, resolution, depth, gain, near field, far field,
receding edge (right side of image), and leading edge (left side of image). Because our study used de-identified ultrasound images, the original B-QUIET score was modified to exclude subscale for date/time, body marker, and patient’s information. Based on the modified B-QUIET scores, we assessed B-mode image quality of the proximal abdominal aorta (coronal view) and liver/diaphragm. The image quality was scored as 1: unacceptable; 2: needs improvement; 3: acceptable; and 4: optimal for interpretation [12]. The average of all scores in eight components was used for analysis. Each of two operators (M.M. and J.L.) performed visual-qualitative assessment on the same ultrasound images recorded from 15 participants two times (7 days apart). The two operators conducted all visual-qualitative assessments separately.

2.4. Offline Image Processing

There are various factors influencing the resolution and brightness of displayed ultrasound images. Technical variations in transducers and machine design of signal processing contribute to differences in brightness on B-mode images and color signals on color Doppler images. Raw radiofrequency (RF) ultrasound data are scanner-independent and can provide the most accurate ultrasound data to quantify backscatter coefficient and attenuation coefficient of the tissue. However, RF data is currently not available for radiologists to interpret clinical ultrasound examinations. In clinical patient care, radiologists view B-mode and color Doppler ultrasound images transferred from commercialized ultrasound scanners to the picture archiving communication system (PACS). Therefore, we used standardized machine settings to acquire ultrasound images and the corresponding off-line software and protocol to process all ultrasound images [13].

We used an offline image processing software, GetColorPixels (Shanghai Jiaotong University, Shanghai, China) to quantify all B-mode and color Doppler images [8, 13]. A
standardized size of the region of interest (ROI) to assess mean pixel counts representing backscatter (echo-intensity) of B-mode images (Fig. 1) and color area ratio (area of color/total area of ROI) of color Doppler images (Fig. 2). ROIs were maintained for each anatomical landmark throughout the study. The size of a rectangular ROI to calculate the color area ratio in the kidney cortex was 0.25 cm². The ROIs for all other landmarks (liver-subcostal, liver-intercostal, proximal abdominal aorta, main portal vein, right renal artery, and kidney cortical perfusion) were set to 0.5 cm².

Finally, the thickness of the subcutaneous fat was measured using B-mode images (DICOM format) of the proximal abdominal aorta and right lobe of the liver/diaphragm.

2.5. Statistical analysis

Modified B-QUIET scores, mean pixel values, and color area ratios were collected using Microsoft Excel (Microsoft Inc.). All variables were expressed by the mean and standard deviation (SD). Differences in subcutaneous fat thickness, visual-qualitative assessment scores, and mean pixel value of B-mode images, color area ratio of color Doppler images were compared using one-way analysis of variance (ANOVA) and post-hoc to determine differences among four transducers and each paired transducer. Results of the echo-intensity of proximal abdominal aorta and color area ratios of renal cortex were also displayed with box-and-whisker plots (Fig. 3 and Fig. 4). To test intra- and inter-observer reliability in performing visual-qualitative assessment and offline image processing, single operator processed visual-qualitative assessment and B-mode and color Doppler images two times in 15 participants and two observers independently performed visual-qualitative assessment and image processing on the same 15 participants. Intra-observer repeatability and inter-observer reproducibility were analyzed using the intraclass correlation coefficient (ICC). A p-value of less than 0.05 was
considered statistically significant. All statistical analyses were conducted using commercial software of SPSS (SPSS, 28.0 version, IBM) and Excel (Microsoft, Pota Lato, CA).

3. Results

From November 2020 to May 2021, we successfully performed B-mode and color Doppler ultrasonography of the abdomen on 15 adult volunteers (9 men, 6 women; mean age 54y, age range 25y to 73y) who were classified into class II and III obesity (mean BMI 38.34 kg/cm², BMI range 35-46.2 kg/cm²). The material and technology used for designing four transducers are listed in Table 1. The subcutaneous fat thickness on liver/diaphragm and proximal abdominal aorta images was not significantly different across the four transducers (Table 2). However, the differences in visual-qualitative assessment score of the B-mode ultrasound images were statistically significant across the four transducers (Table 3).

Mean pixel value representing echo-intensity was used for determining amplitude of backscatter indicating the quality (resolution and penetration) of B-mode images. The color area ratio, a quantitative assessment of the sensitivity of color Doppler in depicting Doppler flow signals, was used for determining the quality of color Doppler images. Differences in echo-intensity of B-mode images and color area ratio of color Doppler images among the four ultrasound transducers were highly significant (p <0.001, Table 3). Of note, Transducer-4 produced the highest quality of B-mode and color Doppler images among the transducers and consistently yielded higher grayscale pixel intensity (45-53% improvement) and color area ratios (22-73% improvement) when compared to Transducer 1, 2, and 3. In comparison to Transducer 1-3, the improvement rate (%) of mean gray pixel for Transducer-4 was 45.55%, 53.02%,
52.81%, respectively, and the improvement rate (%) of mean color area ratio for Transducer-4 was 73.14%, 37.71%, 22.29%, respectively (Table 3). Mean pixel value of the proximal abdominal aorta tabulated for Transducer-4 (Fig. 1a-d) demonstrated higher image resolution and penetration when compared to Transducers 1-3. In depicting kidney cortical microvasculature using color Doppler, the sensitivity of Transducer-4 was also significantly higher compared to Transducer 1-3 (Fig. 2a-d). Intra-observer repeatability and inter-observer reproducibility in performing visual-qualitative assessment and offline image processing were moderate to excellent (ICC: 0.76-0.97) and excellent (ICC: 0.97-0.95) (Table 4), respectively.

4. Discussion

We have observed that Transducer 4 possessed the highest quality of B-mode grayscale and color Doppler images when compared to the other three transducers. This transducer was specifically designed to image deep structures in patients with high BMI (>30 kg/cm²) and has proven to produce superior B-mode image penetration and color Doppler sensitivity among the tested transducers with 45-55% improvement in mean pixel value and 22-73% improvement in mean color area ratio. Through image processing, mean pixel value quantifies the amplitude of backscatter from highly attenuated deep tissues. Color area ratio represents the ability of color Doppler in depicting weak Doppler signals produced by slow flow within the kidney cortical microvasculature [8]. Both are effective means of comparable quantification of image quality across transducers. We have also demonstrated excellent intra-observer repeatability and inter-observer reproducibility in performing offline image processing for quantifying grayscale pixels in B-mode images and color signals in color Doppler images, which proved to be superior to visual-quantitative assessment of image quality.
In clinical ultrasonography, common factors affecting ultrasound image quality are the experience of the operator, the body habitus of the patient, and software/hardware designed for image processing and production (scanner/transducer) made by manufacturers [14]. In this study, one experienced operator scanned all participants to avoid inter-observer variation in ultrasound image acquisition. As a result, the difference in the subcutaneous fat thickness on acquired ultrasound images among the four transducers was not significant. To test the ability of the transducers to acquire high quality images in technically challenging populations, we recruited participants with obesity classes II and III as increased thicknesses of subcutaneous tissue and intraperitoneal fat in obesity result in high ultrasound attenuation and poor beam penetration [15, 16]. Previously suggested solutions to imaging obese subjects included the use of lower frequency transducer to improve ultrasound penetration [16]. However, using low frequency transducers to image deep organ structures incurs the tradeoff of decreased resolution of B-mode image and sensitivity of color Doppler [15, 16]. The subcutaneous tissue thickness reflects the distribution of adipose tissue, which directly affects ultrasound image quality due to strong beam distortion and phase aberration in the subcutaneous fat and subsequent decrease in the penetration of the sound beam to internal organs [17]. Therefore, we quantitatively compared the image quality acquired from participants with similar thickness of subcutaneous fat (Table 2). Our study provides strong evidence that Transducer-4, which was designed for the high BMI population, can generate high quality images in ultrasound resolution and penetration. As obesity continues to rise worldwide, using the specialized transducer may reduce the burden of additional imaging (CT and/or MRI) in this population.

Based on quantitative comparisons, Transducer-4 showed significantly higher quality in both B-mode and color Doppler images while the other transducers demonstrated relatively
lower image quality to varying degrees. For example, Transducer-1 had similar values of grayscale pixel counts compared to Transducer-2 and Transducer-3; however, the quality of color Doppler imaging was comparatively much lower as assessed by the differences of color area ratio. Transducer-4 consistently demonstrated higher quality results in all quantitative parameters, making it a simple and easy option when imaging obese populations. The major advantage of such probes, like Transducer-4, results in the possibility of reducing the scanning time and complications.

There were several limitations in the study. First, the sample size of the study was small. Second, we performed B-mode and color Doppler on participants with class II and III obesity based on classification of BMI. BMI has been useful in classifying the degree of obesity in clinic, information related to patient waist circumference/absolute weight and distribution of adipose tissue may help the operator to select the proper transducer for obtaining high quality ultrasound images [15]. Third, the same operator performed all scans in the study to reduce the variability in scanning skills between operators. Further studies to test inter-observer reproducibility in ultrasound scanning are warranted. Finally, the variation in transducer design, image processing, and hardware development related to ultrasound imaging made by different vendors may contribute to results of significant differences in image quality among the four transducers, even with standardized machine settings, scanning protocol, and offline image processing in the study. Future assessments of differences in image quality in relations to clinical outcome, scanning time, imaging cost, technical pitfalls, and/or incident findings among variable transducers are warranted.

5. Conclusion
It is important to select a transducer that produces high quality B-mode and color Doppler images in clinical patient care. It is particularly challenging and valuable when performing ultrasound on high BMI individuals. The study results suggest that Transducer-4, which is specially designed with high element density allowing dynamic elevation aperture control for the obese population, shows the highest B-mode image quality and color Doppler sensitivity in imaging deep organs and depicting microvasculature compared with the other three transducers in high BMI participants. With the increasing incidence of obesity, the improved image quality of Transducer-4 demonstrates the benefit for the general use of specialized transducers to overcome the limitation of the conventional abdominal transducer in imaging deep organs and vasculatures in obese patients. Our results also demonstrate that the quality of ultrasound images significantly varies from one transducer to another. Therefore, it is encouraged the operator to try different ultrasound transducers and/or machines to acquire higher quality ultrasound images in clinical patient care, particularly in the context of challenging obese populations and imaging deep organs and vasculatures.

Acknowledgment: Authors thank Siemens Healthineers for research grant and equipment to support the study.
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Figures and figure legends

**Figure 1a-b.** Grayscale image of the proximal abdominal aorta in coronal view (aorta). Using offline image processing software, mean pixel in the region of interest (0.25 cm²) is 19.11 (a), 38.33 (b), 35.5 (c), and 70.59 (d) using transducer-1 (a), -2 (b), -3 (c), and -4 (d), respectively. The highest mean pixel value is in the image obtained using Transducer-4 (d).

**Figure 2a-b.** To assess color Doppler sensitivity in depicting small vessels in the kidney cortex, we measured color area ratio (color area / area in total region of interest) in color Doppler image of the longitudinal right kidney. The region of interest for measuring color area ratio is place in near/mid portion of the kidney cortex. Color area ratio calculations were 0.19 (a), 0.35 (b), 0.38 (c), and 0.56 (d) using Transducer-1, -2, -3, and -4, respectively.

**Figure 3.** Box-and-whisker plots show a significant difference in grayscale pixel value across Transducer 1-3 and Transducer-4 in one-way ANOVA and paired groups (post-hoc test) analysis. No significant difference was found between Transducer-1 and Transducer-2 or between Transducer-2 and Transducer-3 in post-hoc testing. The mean and standard deviation (SD) of mean pixel value of the proximal aorta (coronal view) imaged using Transducer-1 (blue box), -2 (orange box), -3 (gray box), and -4 (yellow box) measures 27.99±19.56, 28.03±12.58, 30.61±13.47, and 69.02±22.24, respectively. **Note:** ns, non-significant; ***, P < 0.001.

**Figure 4.** Box-and-whisker plots show significant differences in color area ratio between Transducer-1 and Transducer-2, between Transducer-3 and Transducer-4 in one-way ANOVA and paired groups (post-hoc test) analysis. No significant difference was found between Transducer-2 and Transducer-3 in post-hoc testing. The mean and standard deviation (SD) of color area ratio of the kidney cortex imaged using Transducer-1 (blue box), -2 (orange box), -3 (gray box), and -4 (yellow box) measures 0.16±0.13, 0.37±0.26, 0.46±0.21, and 0.59±0.16, respectively. **Note:** Color area ratio = color area/total area in the region of interest. ns, non-significant; **, P < 0.01; ***, P < 0.001.
Highlights

1. The quality of ultrasound images varies among different transducers and scanners
2. Ultrasound images can be quantitatively assessed
3. Satisfied ultrasound B-mode and color Doppler images can be acquired in high BMI patients using the specially designed transducer
Table 1. Material and Technology of four curvilinear transducers

<table>
<thead>
<tr>
<th>Transducer</th>
<th>Material</th>
<th>Elements</th>
<th>Bandwidth</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single crystal piezoelectric</td>
<td>192</td>
<td>1.0-6.0 MHz</td>
<td>Wider bandwidth transducer has better harmonic imaging, axial resolution, and higher sensitivity, which improves penetration and contrast resolution.</td>
</tr>
<tr>
<td>2</td>
<td>Hanafy lens</td>
<td>192</td>
<td>1.5-6.0 MHz</td>
<td>The transducer has a uniform slice thickness throughout the depth, therefore maintains image uniformity and contrast resolution in both near and far field.</td>
</tr>
<tr>
<td>3</td>
<td>Single crystal piezoelectric</td>
<td>180</td>
<td>1.0-5.7 MHz</td>
<td>Wider bandwidth transducer has better harmonic imaging, axial resolution, and higher sensitivity, which improves penetration and contrast resolution.</td>
</tr>
<tr>
<td>4</td>
<td>Multi-D array</td>
<td>288</td>
<td>1.0-3.5 MHz</td>
<td>Advanced Multi-D beam forming transducer controls the beam thickness, beam formation in both transmission and receive phases to enable deep penetration. High element density transducer allows dynamic elevation aperture control as needed.</td>
</tr>
</tbody>
</table>
**Table 2.** Thickness of subcutaneous fat and visual-qualitative assessment of ultrasound images

<table>
<thead>
<tr>
<th>Transducer</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>(p)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subcutaneous Fat Thickness (cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver/diaphragm</td>
<td>1.5±0.41</td>
<td>1.5±0.42</td>
<td>1.53±0.4</td>
<td>1.55±0.4</td>
<td>0.98</td>
</tr>
<tr>
<td>Proximal abdominal aorta</td>
<td>1.5±0.41</td>
<td>1.51±0.41</td>
<td>1.54±0.38</td>
<td>1.54±0.4</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>§Visual Quality Assessment score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver/Diaphragm</td>
<td>2.02±0.56</td>
<td>1.95±0.76</td>
<td>2.23±0.61</td>
<td>3.29±0.47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Proximal abdominal aorta</td>
<td>1.87±0.61</td>
<td>2.08±0.65</td>
<td>2.50±0.65</td>
<td>3.23±0.69</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Note:** * p values are based on one-way analysis of variance (ANOVA). §Visual-qualitative assessments were conducted using a modified B-QUIET method [12]. The method uses a 4-point Likert scale for each of the eight components (anatomy identification, resolution, depth, gain, near field, far field, receding edge [image right side], leading edge [image left side]). 4-point scale is defined as 1: unacceptable; 2: needs improvement; 3: acceptable; and 4: optimal. Each operator scored the individual ultrasound image using the modified B-QUIET method. The average of eight components of visual-qualitative assessment scores was used for analysis.
### Table 3. Comparison of mean pixel value and color area ratio among the four ultrasound transducers

<table>
<thead>
<tr>
<th>Transducer</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>(p)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gray mean pixel value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver-Subcostal</td>
<td>52.20±28.39</td>
<td>36.93±24.19</td>
<td>37.12±18.65</td>
<td>86.35±19.56</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Liver-Intercostal</td>
<td>55.76±26.01</td>
<td>52.33±28.64</td>
<td>50.08±17.56</td>
<td>94.30±18.92</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Proximal abdominal aorta</td>
<td>27.99±19.56</td>
<td>28.03±12.58</td>
<td>30.6 ±13.47</td>
<td>69.02±22.34</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>% difference (pixel value)#1</td>
<td>-45.55%</td>
<td>-53.02%</td>
<td>-52.81%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Color area ratio§</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main portal vein</td>
<td>0.12±0.10</td>
<td>0.31±0.16</td>
<td>0.37±0.19</td>
<td>0.50±0.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Right renal artery</td>
<td>0.19±0.15</td>
<td>0.41±0.18</td>
<td>0.53±0.23</td>
<td>0.66±0.18</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Kidney cortical perfusion</td>
<td>0.16±0.13</td>
<td>0.37±0.26</td>
<td>0.46±0.21</td>
<td>0.59±0.16</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>% difference (color area ratio)#2</td>
<td>-73.14%</td>
<td>-37.71%</td>
<td>-22.29%</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** * p value is based on one-way analysis of variance. §Color area ratio = color area/total area in the region of interest. #1 represents total increase (%) in mean pixel value in 3 B-mode images obtained by Transducer-4 compared with the respective probe; #2 represents lower (%) color area ratio in 3 color Doppler images obtained by 3 transducers compared with that obtained by the Transducer-4. % difference (pixel value#1 or color area ratio#2) = (transducer x – transducer-4)/transducer-4 x 100%
Table 4. Repeatability and reproducibility of off-line image processing and visual-qualitative assessment

<table>
<thead>
<tr>
<th>Average Measures</th>
<th>ICC*</th>
<th>95% Confidence Interval</th>
<th>F Test with True Value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower bound</td>
<td>Upper bound</td>
<td>Value</td>
</tr>
<tr>
<td>Quantitative image processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator-1:Operator-1:pixel count</td>
<td>.99</td>
<td>.98</td>
<td>.99</td>
<td>76.26</td>
</tr>
<tr>
<td>Operator-2:Operator-2:pixel count</td>
<td>.98</td>
<td>.97</td>
<td>.99</td>
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<td>Operator-1:Operator-2:pixel count</td>
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<td>.95</td>
<td>.98</td>
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<td>Operator-1:Operator-1:Color ratio</td>
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<td>Operator-1:Operator-1 (AO)</td>
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<td>.95</td>
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<td>.94</td>
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<td>.96</td>
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<td>Operator-1:Operator-2 (AO)</td>
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<td>Operator-1:Operator-1 (liver)</td>
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<td>Operator-1:Operator-2 (liver)</td>
<td>.84</td>
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<td>.90</td>
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Note: *ICC, intraclass correlation coefficient using a consistency definition; Inter-observer reliability test: measurements performed by operator-1 to measurements performed by operator-2 on the same images independently; intra-observer reliability tests: measurement 1 to measurement 2 on the same images obtained by the operator-1 (operator-2). Pixel count, gray mean pixel value in B-mode ultrasound image; Color ratio, color area ratio = color area/ total area in the region of interest on color Doppler image. Visual image quality assessment is based ultrasound image quality score using a modified Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET). AO, proximal abdominal aorta; liver, the area of liver right lobe/diaphragm.
Figure 1A
Figure 1C
Figure 1D
Figure 2B
Figure 2C
Figure 2D