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Impact of Respiratory Motion on the Quantification of Pediatric Hepatic Steatosis Using Two Different Ultrasonography Machines

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Purpose: This study aimed to investigate the effect of respiratory motion on hepatic steatosis quantification using ultrasound attenuation imaging (ATI) or ultrasound-guided attenuation parameter (UGAP) in pediatric patients.
Materials and Methods: Pediatric patients (aged ≤18 years) who underwent liver ultrasonography (US) with ATI or UGAP between May 2022 and February 2023 were included retrospectively. Median, interquartile range (IQR), and IQR/median values were calculated in both free-breathing (FB) and breath-holding (BH) states. Subjects were divided into normal and fatty liver groups according to grayscale US. Wilcoxon signed rank test, intraclass correlation coefficient (ICC), and linear regression test were used.
Results: A total of 83 patients (M:F=46:37, median age 10 years, range 6–17 years) was included, with 55 patients in the ATI group and 28 patients in the UGAP group. The measured values of ATI and UGAP were not significantly different between FB and BH. The ICC values between FB and BH states were 0.950 [95% confidence interval (CI) 0.916–0.971] for median ATI and 0.786 (95% CI 0.591–0.894) for median UGAP. FB and BH status did not significantly affect the median ATI and UGAP (p=0.852, 0.531, respectively). The IQR/median value showed a significant association with age only in the FB status of the normal group using ATI (β=-0.014, p=0.042).
Conclusion: Respiratory motion does not significantly affect the measurement of ATI or UGAP. Median ATI value showed excellent agreement in FB and BH status, while UGAP showed good agreement. Younger age may affect measurement variability in FB status of the normal group using ATI.

Key Words: Child, fatty liver, ultrasonography, diagnostic imaging, retrospective study

INTRODUCTION

Nonalcoholic fatty liver disease (NAFLD) is a wide-ranging entity of chronic liver disease encompassing simple steatosis, nonalcoholic steatohepatitis, and liver cirrhosis, and can lead to hepatocellular carcinoma.[1,2] The incidence of NAFLD is increasing rapidly for both adults and pediatric populations, and NAFLD is the most common liver disease worldwide. The global prevalence of NAFLD is 25% in the general population, 8% in the pediatric population, and 34% in children with obesity.[3,4] Current guidelines advise screening of children at risk for early intervention and lifestyle modification to prevent com-

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plications from NAFLD.[4] Early diagnosis and accurate monitoring of hepatic steatosis may help lead to positive long-term outcome. Due to the invasiveness of liver biopsy, imaging modalities are preferred as an effective diagnostic tool for quantifying hepatic steatosis.

Magnetic resonance imaging (MRI) with proton density fat fraction (PDFF) is considered as a gold standard and substitute for liver biopsy in both adults and children, demonstrating high diagnostic performance.[4] However, since MRI needs a long scan time, has a high cost, and requires sedation for children, ultrasonography (US) has been the preferred modality, especially for screening hepatic steatosis. Quantification of hepatic steatosis using US was recently introduced and attracted attention due to its easy accessibility and relative accuracy with quantitative results. As the degree of hepatic steatosis increases, greater attenuation of the US beam occurs according to the depth, and the attenuation coefficient can be quantified using the slope.[5] The most widely used method is controlled attenuation parameter from transient elastography (Fibroscan), but 2D attenuation imaging, called attenuation imaging (ATI) or ultrasound-guided attenuation parameter (UGAP), is possible.[1,6] This approach has benefits from incorporating B-mode imaging during acquisition, leading to accurate selection of the measurable area.

Many studies in adult patients demonstrated the usefulness of ATI and UGAP and of preset acquisition guidelines for adults.[5,7-10] While there is currently no consensus guideline for measurement in children, most of the recommendations for adults can be applied for children, except for one guideline regarding the breathing method.[7] Recent recommendations advise patients to hold their breath during acquisition for reliable results; however, holding the breath can be difficult for young children.[6] For this reason, different breathing methods were applied for children in recent studies using this technique.[1,6,11] Use of this technique in children is important with proper understanding of the effects of respiratory motion and establishing a unifying measurement protocol.

Therefore, the purpose of this study was to investigate the effect of respiratory motion on hepatic steatosis quantification using ATI or UGAP in pediatric patients.

MATERIALS AND METHODS

Subjects

The institutional review board (IRB) approved this retrospective study, and the requirement for informed consent was waived due to the retrospective nature of the study. The research was conducted in accordance with the Declaration of Helsinki and was approved by the IRB of Yongin Severance Hospital (IRB No. 9-2022-0071). The study was conducted according to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Pediatric patients (aged ≤18 years) who underwent liver US with ATI or UGAP between May 2022 and February 2023 were included retrospectively. In our institution, US with UGAP was performed since December 2022. Liver US was performed according to the clinical demand for patients with suspected fatty liver when they had abnormalities in body mass index (BMI) or liver function test. No one had underlying disease, such as biliary atresia or metabolic liver disease, to cause liver fibrosis. We included patients who had ATI or UGAP results in both free-breathing (FB) and breath-holding (BH) status. Patients who could not cooperate with US at the first attempt or had US results only for FB or BH were excluded from the study. Since this study was conducted retrospectively during routine examinations, we did not insist on forcing measurements with repeated trial if the patient was unable to stand for the assessment. Patients with liver MRI results, including a PDFF sequence within 1 month of the US examination, were included for additional analysis. For the included patients, age, sex, height, weight, and BMI percentage were retrospectively reviewed using electronic medical records. Based on the grayscale US results, the patients were categorized into normal and fatty liver groups using the conventional semi-quantitative method regarding liver parenchymal echogenicity when the liver parenchyma showed relatively increased echogenicity compared with the renal cortex.[5]

ATI and UGAP acquisition

ATI and UGAP were measured by one pediatric radiologist with 13 years of experience. ATI was obtained using a convex transducer of C1–8 MHz in the Aplio i800 (Canon Medical Systems, Otawara, Japan), and UGAP was performed using a convex transducer of C1–6 MHz in the LOGIQ E10 (GE Healthcare, Wauwatosa, WI, USA). The patients underwent at least 4 h of fasting before the examination. ATI or UGAP was obtained after routine grayscale US examination of the liver in patients in a supine position with their arm elevated for liver exposure. The transducer was placed perpendicular to the skin in the right intercostal space.[1] Patients were in a comfortable FB status for measurement of ATI or UGAP results. Patients were then asked to hold their breath without Valsalva maneuver or forced breath-holding to measure the values in a BH status.

For ATI, when the color appeared homogeneously within a fan-shaped color-coded box in the liver parenchyma, a smaller, 3×4 cm-sized fan-shaped region-of-interest (ROI) was placed at a depth of 4–10 cm to avoid large vessels or artifacts to obtain an R^2 value equal to or greater than 0.8 for reliable measurement. Five ATI measurements in repeated short intervals were performed in each FB and BH status, and the median value with interquartile range (IQR) and IQR/median values were recorded (Fig. 1).

For UGAP, the automatically preset depth of the fan-shaped ROI was 4–8 cm. When the blue color-coded box on the quality map appeared homogeneously, a smaller, 1×4 cm-sized elongated fan-shaped ROI was placed in the liver parenchyma.

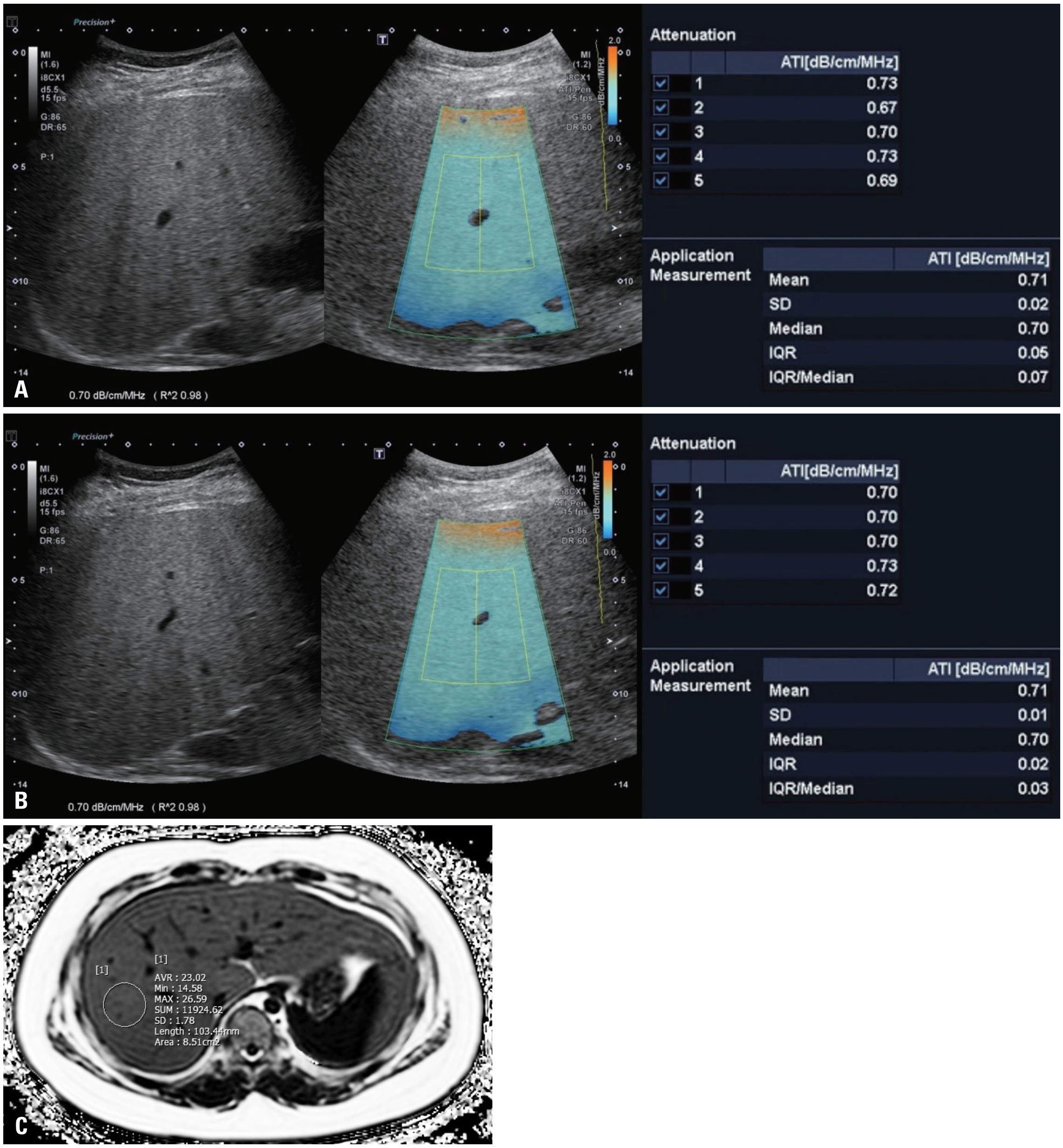

Fig. 1. A 10-year-old boy in the fatty liver group. The median ATI value was 0.7 dB/cm/MHz for FB (A) and BH (B). (C) The mean fat signal percentage of the liver was 23% on MRI. ATI, attenuation imaging; FB, free-breathing; BH, breath-holding; MRI, magnetic resonance imaging; IQR, interquartile range.

When the value was unreliable, the margin of the smaller ROI appeared red and no value was presented. However, when we placed the ROI in a reliable area with a homogeneous blue background color on the quality map, the value appeared successfully with an ROI margin of white lines. Therefore, using a quality map for obtaining reliable results, 12 UGAP measurements in repeated short intervals were conducted in each FB and BH status, and the median value with IQR and IQR/median values were recorded (Fig. 2). For the number of measurements and the size of ROIs, we employed measurement methods recommended by the vendors to ensure the acquisition of reliable results on each machine. For ATI, five measurements were recommended, and for UGAP, 12 measurements were advised, as shown in Figs. 1 and 2. Furthermore, the size of ROIs adhered to the recommended preset shape and dimensions specific to each machine. There was no overlap when setting the ROIs. The goal was to minimize the influence of factors other than motion on the reliability of this study. Therefore, we made an effort to adhere to the recommended guidelines of each machine to obtain reliable outcomes when evaluating the effects of respiratory motion.

MRI PDFF acquisition

When the patient had liver MRI with PDFF sequence within 1 month of the US examination, the results of the fat signal percentage of the liver were recorded. MRI was performed using a

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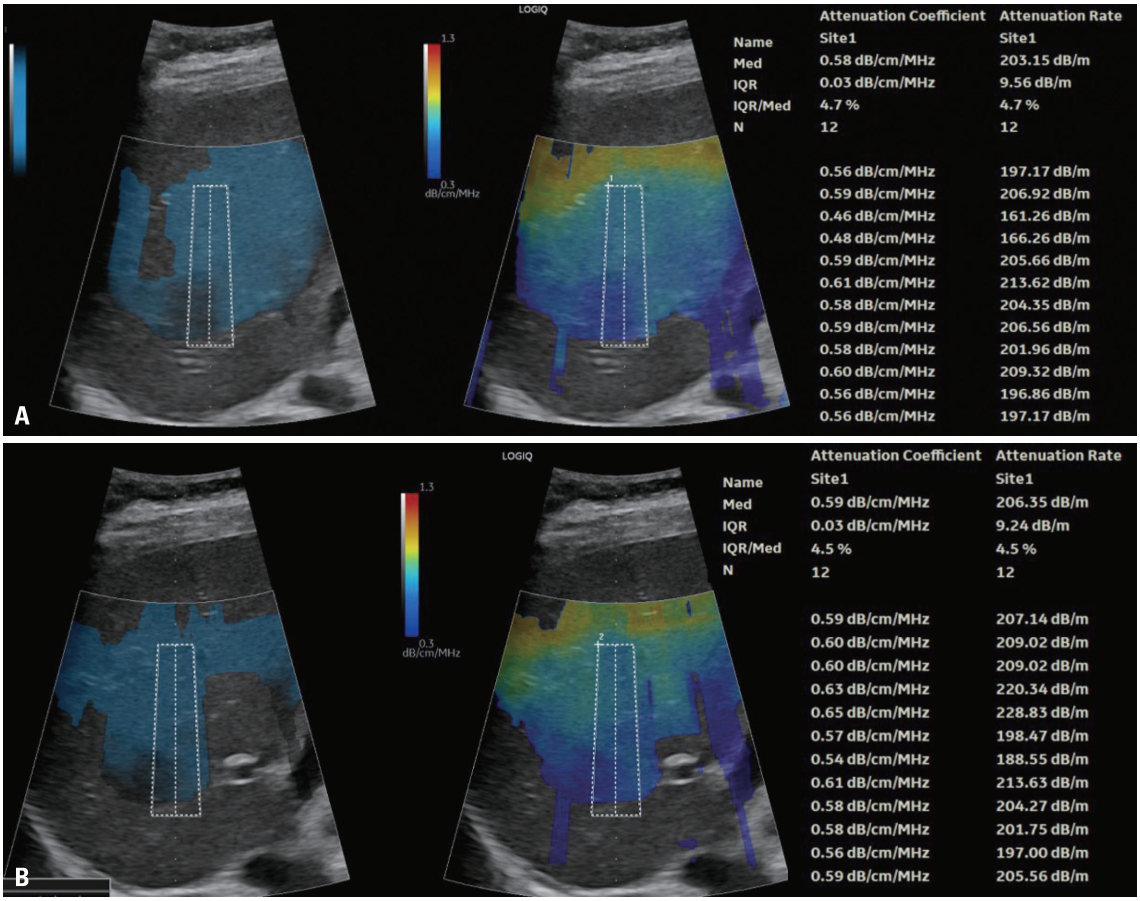

Fig. 2. An 8-year-old girl in the normal group. The median UGAP values were 0.58–0.59 dB/cm/MHz for FB (A) and BH (B). UGAP, ultrasound-guided attenuation parameter; FB, free-breathing; BH, breath-holding; IQR, interquartile range.

3 T system (Ingenia Elition X, Philips Medical Systems, Veenpluis, Best, Netherlands). An axial 3D volumetric multi-echo gradient sequence for PDFF was acquired in addition to the routine liver MRI sequences. The MRI parameter for PDFF was the same as in previous studies.[1] In the fat map automatically generated from PDFF sequence, round ROIs were placed in the right lobe of the liver, avoiding large vessels and fissures in four contiguous axial slices using a picture archiving communication system by the same pediatric radiologist (Fig. 1C). The mean fat signal percentage of the liver was recorded from four measurements.[11,12]

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and R program (4.2.3, Foundation for Statistical Computing, Vienna, Austria). After the normality test using the Kolmogorov–Smirnov test, values were presented as median with range. The Wilcoxon signed-rank test and Spearman correlation test were used to compare ATI or UGAP values in FB and BH status. The Mann–Whitney U test and chi-square test were used to compare values according to group. The intraclass correlation coefficient (ICC) in a two-way analysis of variance model was used to determine the reliability of values in FB and BH status. The ICC values were interpreted as follows; 0.00–0.20 poor agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 good agreement, and 0.81–1.00 excellent agreement. When the patients had MRI results, the linear regression test was performed to determine the relationship between US and MRI values in FB and BH status. In addition, the linear regression test was used to determine whether breathing method, age, and BMI percentage affected the ATI or UGAP results. To determine the effect of age on measurement variability, a linear regression test was performed for age and IQR/median values of ATI and UGAP, as larger IQR/median values represent increased variability of the measured values. In addition, we conducted a significance test of β between the FB and BH status to examine whether there were differences in the effects of age based on each group. *P*-values less than 0.05 were considered statistically significant.

RESULTS

Patients

During the study period, a total of 86 patients underwent ATI or UGAP examination. Three patients were excluded due to poor cooperation. Therefore, a total of 83 patients were included in this study. The patient group included 55 patients with ATI (median age 10 years, with an age range of 6–17 years) and 28 patients with UGAP results (median 11 years, with an age range of 7–17 years). The demographics of the study population are presented in Table 1. Based on the grayscale US findings, 34 patients (34/55, 61.8%) with ATI and 18 patients (18/28, 64.3%) with UGAP results were classified in the fatty liver groups. Among them, six patients with ATI results and one patient with UGAP result had undergone MRI within 1 month of US examination. All seven patients who underwent MRI were classified into the fatty liver group based on grayscale US.

Comparison of ATI or UGAP results in FB and BH

The median ATI and UGAP values showed no significant differences between FB and BH in all subjects (median 0.64 vs. 0.67, p=0.585 for ATI, median 0.68 vs. 0.66, p=0.052 for UGAP). The results were the same in normal and fatty liver groups. The median ATI and UGAP values were significantly increased in the fatty liver group compared to the normal group in both FB and BH (median 0.77 vs. 0.54–0.55, p<0.001 for ATI, median 0.72 vs. 0.57, p<0.001 for UGAP). The median values in FB and BH showed significant positive correlations with both ATI and UGAP, except for the normal group with UGAP result.

The median ATI value showed excellent agreement between FB and BH status in all patients [ICC 0.950, 95% confidence interval (CI) 0.916–0.971] and in the fatty liver group (ICC 0.926, 95% CI 0.859–0.962). In the normal group, median ATI value showed good agreement between FB and BH (ICC 0.720, 95% CI 0.423–0.876). The median UGAP value showed good agreement between FB and BH in all patients (ICC 0.786, 95% CI 0.591–0.894) and in the fatty liver group (ICC 0.616, 95% CI 0.225–0.836). However, in the normal group, the median UGAP value showed poor agreement between FB and BH (ICC 0.047, 95% CI -0.515–0.618). All results, including IQR and IQR/median values, are presented in Table 2.

In six patients with both ATI and MRI results, the median ATI value showed significant association with MRI-PDFF value in both FB (β=73.683, p=0.023) and BH (β=83.237, p=0.03).

Effects of breathing, age, and BMI percentage on ATI and UGAP results

In univariate and multivariate linear regression tests (Tables 3 and 4), breathing methods showed no significant association with median ATI or UGAP results. The IQR and IQR/median values were not significantly affected by the breathing method. For ATI, age and BMI percentage showed significant associations with the median, IQR, and IQR/median values in multivariate linear regression analysis. For UGAP, BMI percentage showed significant associations with the median and IQR/median values.

When we considered the effects of age on IQR/median values (Table 5), a significant association with IQR/median value of ATI in FB status was noted in all patients (β=-0.007, p=0.033) and in the normal group (β=-0.014, p=0.042), but not in the BH or in fatty liver group. UGAP showed no significant association between age and IQR/median value. When we compared β between the FB and BH status, there was no significant differences in all groups.

DISCUSSION

This study evaluated whether breathing methods affected the measurement of ATI and UGAP values in a pediatric population. Median ATI and UGAP values were not significantly affected by the breathing method, and this result was the same when we divided the subjects into normal and fatty liver groups. Regarding the agreement between FB and BH, the median ATI values in all and fatty liver groups showed excellent agreement, while the median ATI value in the normal group and UGAP value in all and fatty liver groups showed good agreement. However, the median UGAP value in the normal group showed poor agreement. In the linear regression test, breathing method did

Table 1. Demographics of Subjects with ATI and UGAP Results

	ATI				UGAP				
	All (n=55)	Normal (n=21)	Fatty liver (n=34)	p value*	All (n=28)	Normal (n=10)	Fatty liver (n=18)	p value*	p value†
Age (yr)	10 (6–17)	8 (6–15)	10.5 (6–17)	0.005	11 (7–17)	12 (9–17)	10.5 (7–16)	0.082	0.204
Sex (M:F)	30:25	12:9	18:16	0.041	16:12	7:3	9:9	0.314	0.823
Height (cm)	144.5 (115.3–186.1)	136.7 (115.3–170.0)	152.5 (120.8–186.1)	0.001	154.5 (121.6–175.0)	152.8 (121.6–171.7)	154.5 (123.2–175.0)	0.962	0.287
Weight (kg)	52 (22.9–167.1)	43 (22.9–65.9)	68.0 (26.0–167.1)	<0.001	55.3 (22.1–82.0)	55 (22.1–75.6)	56.6 (25.3–82.0)	0.549	0.919
BMI percentage (%)	99.6 (50–100)	98.5 (50–100)	99.9 (78.1–100)	0.009	96.7 (26–100)	93.8 (30–99.5)	96.7 (26–100)	0.020	0.002
MRI fat signal percentage (%)			27.3 (8–36.3) (n=6)				16 (n=1)		

ATI, attenuation imaging; UGAP, ultrasound-guided attenuation parameter; BMI, body mass index.
Values are presented as median (min–max).
*p-values between the normal and fatty liver groups; †p-values between the ATI and UGAP groups, using the Mann-Whitney U test or chi-square test.

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Table 2. Comparison of ATI and UGAP Values According to Breathing Method

Methods	Groups	Values	FB	BH	*p* value*	Correlation coefficient	*p* value†	ICC	95% CI
ATI	All (n=55)	Median	0.64 (0.41–1.00)	0.67 (0.46–0.98)	0.585	0.938	<0.001	0.950	0.916–0.971
		IQR	0.06 (0.01–0.16)	0.06 (0.01–0.15)	0.437	0.180	0.193	0.180	-0.093–0.427
		IQR/median	0.07 (0.02–0.31)	0.08 (0.01–0.31)	0.492	0.317	0.019	0.417	0.167–0.615
	Normal (n=21)	Median	0.55 (0.41–0.64)	0.54 (0.46–0.70)	0.948	0.789	<0.001	0.720	0.423–0.876
		IQR	0.08 (0.02–0.16)	0.06 (0.02–0.15)	0.867	0.283	0.214	0.371	-0.077–0.690
		IQR/median	0.16 (0.05–0.31)	0.12 (0.03–0.31)	0.672	0.384	0.086	0.433	-0.001–0.726
	Fatty liver (n=34)	Median	0.77 (0.5–1.0)	0.77 (0.53–0.98)	0.553	0.951	<0.001	0.926	0.859–0.962
		p value‡	<0.001	<0.001					
		IQR	0.05 (0.01–0.16)	0.05 (0.01–0.14)	0.353	0.008	0.965	-0.073	-0.409–0.274
		p value‡	0.093	0.054					
		IQR/median	0.07 (0.02–0.22)	0.05 (0.01–0.23)	0.530	-0.049	0.785	0.004	-0.343–0.343
		p value‡	0.001	0.001					
UGAP	All (n=28)	Median	0.68 (0.52–0.87)	0.66 (0.43–0.92)	0.052	0.845	<0.001	0.786	0.591–0.894
		IQR	0.07 (0.02–0.13)	0.05 (0.02–0.20)	0.146	0.525	0.004	0.390	0.028–0.662
		IQR/median	0.09 (0.02–0.18)	0.08 (0.03–0.43)	0.118	0.638	<0.001	0.485	0.137–0.725
	Normal (n=10)	Median	0.57 (0.52–0.66)	0.57 (0.43–0.60)	0.240	0.098	0.789	0.047	-0.515–0.618
		IQR	0.06 (0.04–0.09)	0.06 (0.03–0.20)	0.797	0.408	0.241	0.328	-0.360–0.779
		IQR/median	0.11 (0.06–0.18)	0.11 (0.05–0.43)	0.646	0.450	0.192	0.389	-0.257–0.801
	Fatty liver (n=18)	Median	0.72 (0.61–0.87)	0.72 (0.53–0.92)	0.097	0.655	0.003	0.616	0.225–0.836
		p value‡	<0.001	<0.001					
		IQR	0.07 (0.02–0.13)	0.05 (0.02–0.08)	0.017	0.661	0.003	0.507	0.071–0.782
		p value‡	0.796	0.494					
		IQR/median	0.09 (0.02–0.18)	0.06 (0.03–0.14)	0.010	0.735	0.001	0.606	0.146–0.840
		p value‡	0.356	0.027					

FB, free-breathing; BH, breath holding; ICC, intraclass correlation coefficient; CI, confidence interval; ATI, attenuation imaging; UGAP, ultrasound-guided attenuation parameter; IQR, interquartile range.
Values are presented as median (min–max).
*Wilcoxon signed rank test; †Spearman correlation test; ‡*p*-value in comparison with normal group using Mann–Whitney test.

Table 3. Effects of Breathing Method, Age, and BMI Percentage for ATI and UGAP Results Using Univariate Linear Regression

Factors	Values	Breathing	ATI			UGAP		
			β	SE	*p* value	β	SE	*p* value
FB or BH	Median		0.005	0.027	0.852	-0.018	0.029	0.531
	IQR		-0.003	0.007	0.670	-0.006	0.009	0.487
	IQR/median		-0.003	0.013	0.816	-0.003	0.017	0.856
Age	Median	FB	0.013	0.007	0.061	-0.010	0.007	0.169
		BH	0.015	0.007	0.031	-0.012	0.008	0.156
	IQR	FB	-0.003	0.002	0.071	-0.0001	0.002	0.949
		BH	-0.002	0.002	0.280	-0.0004	0.003	0.876
	IQR/median	FB	-0.007	0.003	0.033	0.001	0.003	0.837
		BH	-0.007	0.003	0.052	0.002	0.006	0.748
BMI percentage	Median	FB	0.003	0.002	0.078	0.003	0.001	0.003
		BH	0.004	0.002	0.029	0.003	0.001	0.004
	IQR	FB	-0.001	0.001	0.126	-0.0007	0.0003	0.784
		BH	-0.001	0.001	0.141	-0.001	0.0003	0.038
	IQR/median	FB	-0.002	0.001	0.028	-0.001	0.0004	0.143
		BH	-0.002	0.001	0.051	-0.002	0.001	0.004

FB, free-breathing; BH, breath holding; SE, standard error; BMI, body mass index; ATI, attenuation imaging; UGAP, ultrasound-guided attenuation parameter; IQR, interquartile range.

Table 4. Effects of Breathing Method, Age, and BMI Percentage on ATI and UGAP Results Using Multivariate Linear Regression Test

Values	Factors	ATI			UGAP		
		β	SE	*p* value	β	SE	*p* value
Median	Age	0.014	0.005	0.004	-0.004	0.005	0.437
	BMI percentage	0.003	0.001	0.005	0.003	0.001	<0.001
	FB or BH	0.005	0.025	0.842	-0.018	0.025	0.467
IQR	Age	-0.002	0.001	0.044	-0.002	0.002	0.394
	BMI percentage	-0.001	0.000	0.035	-0.0004	0.0002	0.050
	FB or BH	-0.003	0.007	0.660	-0.006	0.009	0.479
IQR/median	Age	-0.007	0.002	0.004	-0.003	0.003	0.421
	BMI percentage	-0.002	0.001	0.003	-0.001	0.0003	0.001
	FB or BH	-0.003	0.012	0.803	-0.003	0.015	0.844

FB, free-breathing; BH, breath holding; SE, standard error; BMI, body mass index; ATI, attenuation imaging; UGAP, ultrasound-guided attenuation parameter; IQR, interquartile range.

Table 5. Effect of Age on the IQR/Median Values of ATI and UGAP Measurement

	Groups	Breathing	β	SE	*p* value	βBH-βFB (95% CI)	*p* value
ATI	All	FB	-0.007	0.003	0.033	0 (-0.009–0.009)	0.997
		BH	-0.007	0.003	0.052		
	Normal	FB	-0.014	0.006	0.042	0.009 (-0.011–0.029)	0.370
		BH	-0.005	0.008	0.542		
	Fatty liver	FB	0.002	0.003	0.562	-0.004 (-0.013–0.005)	0.416
		BH	-0.002	0.003	0.569		
UGAP	All	FB	0.001	0.003	0.837	0.001 (-0.012–0.014)	0.856
		BH	0.002	0.006	0.748		
	Normal	FB	-0.003	0.006	0.593	0.001 (-0.033–0.035)	0.947
		BH	-0.002	0.015	0.885		
	Fatty liver	FB	0.001	0.004	0.805	-0.004 (-0.015–0.007)	0.459
		BH	-0.003	0.003	0.391		

FB, free-breathing; BH, breath holding; SE, standard error; CI, confidence interval; ATI, attenuation imaging; UGAP, ultrasound-guided attenuation parameter.

not affect the results, while younger age was associated with larger variability only in FB of ATI for all and normal groups.

For adults, suspending breath during acquisition is a general recommendation for ATI.[7,13] Holding the breath at the end of expiration is advised to obtain reliable and stable values.[5,7,13] However, for pediatric patients, different approaches have been used. For example, Kim, et al.[11] used ATI and asked children to hold their breath during the examination if possible. Another ATI study by Song, et al.[1] allowed participants to be in FB since the authors thought that asking children to hold their breath could worsen artifacts from poor cooperation, and that avoiding forced breath-hold would be necessary as in shear wave elastography (SWE). Similarly, Yoon, et al.[6] used UGAP and asked the patients to breathe freely. The effect of respiratory motion on measurement values is not fully understood and is critical to explore.

Several studies have investigated the effect of motion on the measurement of SWE.[14-16] However, regarding attenuation imaging, only one study demonstrated the effect of motion using UGAP for adults.[17] The study found no significant differences in UGAP results during FB, BH, deep inspiration, and expiration status of supine and decubitus positions.[17] Our study showed similar results, and we suggest that increased venous flow in the liver in BH would have no significant effect on the degree of US beam attenuation, different from the velocity of US beam using the SWE technique. Our study is meaningful as we measured values in the same children with two breathing methods and also presented values using two machines. Even though the values were not repeated with ATI and UGAP in this retrospective study, knowing the effect in different machines could increase the clinical utility since these two techniques are widely used for attenuation imaging in adults and children. In addition, knowing the effect of motion is important for treating adults with difficulty in regulating respiration from underlying cardiopulmonary or neurologic diseases. This could enhance the utility of the attenuation technique in real clinical situations.

Although the agreement was influenced by breathing in the normal group using UGAP, as this technique is mainly used for patients with fatty liver, the influence on normal subjects would not be a serious problem. Regarding the relatively poor agreement in the normal group, liver size could influence the results, as an increased BMI percentage exhibited a negative associa-

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tion with the IQR/median value, indicating reduced variability. The underlying reasons for this association could be diverse, with one possible explanation being the increased size of the liver. However, concerns persist, as measurable depth is present and cannot be adjusted according to the patients. Moreover, if the measurable depth and area were insufficient according to the ROIs, then the values did not appear, and the color map and R^2 values would raise alarms about the results. Therefore, further evaluation is warranted, with a focus on liver size and the reliability of measurements in subsequent investigations. In addition, while the measurement variability increased as age decreased when using ATI, this did not significantly affect the measurement agreement between FB and BH. Therefore, we conclude that breathing did not significantly affect ATI or UGAP measurements, especially for fatty liver patients. Further studies with a larger number of patients and investigating the effect of respiration according to steatosis grade are necessary.

Even though the measured values of ATI and UGAP were not significantly different between FB and BH, the ICC values were lower in UGAP. The ICC value may be influenced by factors such as data variability, the number of subjects, and measurement methods, including acquisition numbers or ROI size. The relatively smaller number of patients in the UGAP group, attributed to the delayed implementation in our hospital, and the recommendation of 12 acquisitions by vendors could contribute to the relatively lower ICC values for UGAP. We made efforts to adhere to all the vendor recommendations for reliable measurements to understand the effect of motion. Given that this study was retrospective, further investigation is warranted, regulating detailed measurement methods. This study had several limitations. First, we did not obtain histologic confirmation of hepatic steatosis in the pediatric patients. Instead, we assessed fatty liver and steatosis grade with the generally acknowledged method of using grayscale US. While the sensitivity of grayscale US to differentiate mild fatty liver from no steatosis may be reduced, we thought diagnosing moderate to severe hepatic steatosis from normal liver could have low argument even when using grayscale US. Grayscale US has a sensitivity of 90% for detecting steatosis and is excellent for diagnosing moderate and severe fatty liver not associated with fibrosis.[5,7] Second, this study included a relatively small number of patients, and there was asymmetry in the number of ATI and UGAP results. This is because UGAP was installed in our hospital relatively recently, and the difference in patient number was inevitable in this retrospective study design. Although age, sex, height, and weight were not statistically different between the ATI and UGAP groups, the disparity in the number of subjects and BMI percentage could potentially influence the results. Third, one radiologist performed the US exams, and inter- and intra-observer variability was not assessed in this retrospective study. However, the radiologist is a specialist in pediatric radiology with extensive experience and has published research for quantitative liver US, including SWE and attenuation imaging, of children. Therefore, this may lower the concern about operator issue on the measurement technique. Finally, the number of acquisitions as well as the size and depth of ROIs were different in ATI and UGAP. We measured ATI five times and UGAP 12 times and used preset displays, as it was in accordance with the respective manufacturer's policy, as shown in Figs. 1 and 2. Several studies have focused on the number of attenuation images for measurement,[18] but this was not an issue of our study. Therefore, further studies investigating the effect of respiration and minimum image acquisition number are necessary.

In conclusion, ATI and UGAP values were not significantly affected by the breathing method in a pediatric population. While younger age and normal group influence the measurement variability, good to excellent agreement was observed in FB and BH of the fatty liver group when using ATI and UGAP.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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