Original Article

The Efficiency of Gray-Level Ultrasound Histogram Analysis in Patients with Supraspinatus Tendinopathy

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Abstract

Background: Musculoskeletal ultrasonography is a viable substitute for magnetic resonance imaging (MRI) that offers advantages in terms of time efficiency and cost-effectiveness. The gray-level histogram is a tool used to depict the distribution of pixel gray levels that provide quantitative data. **Aim:** The objective of our research was to establish a threshold value for ultrasonography-measured supraspinatus tendon gray-level values by comparing patients with tendinopathy to those without. **Materials and Methods:** This study comprised a cohort of 271 individuals, consisting of 124 patients diagnosed with supraspinatus tendinopathy and 147 cases without the aforementioned condition who underwent shoulder MRI and ultrasound examinations. Two radiologists independently conducted the gray-level histogram analyses. The histogram parameters were determined, including the mean, minimum, median, maximum, fifth, 10th, 25th, 50th, 75th, 90th, and 95th percentiles, as well as skewness, kurtosis, and variance. The interobserver agreement was evaluated using the interclass correlation coefficient. **Results:** The supraspinatus tendinopathy group's all gray-level values were lower than those of the control group, and the difference was statistically significant ($P < .05$). The supraspinatus tendinopathy group exhibited greater values of skewness and kurtosis in comparison to the control group ($P < .05$). The area under the curve of the 95th percentile of the gray-level value was the highest (area under the curve = 0.960; cut-off value = 82.5; sensitivity = 96.7%; specificity = 88.2%). **Conclusion:** The analysis of the histogram of gray-level values has the potential to be a promising method for the monitoring of patients with supraspinatus tendinopathy. This approach could be considered a feasible alternative to MRI.

Keywords: *Gray-level histogram, magnetic resonance imaging, supraspinatus tendon, tendinopathy*

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Introduction

Rotator cuff disorders are a leading cause of shoulder pain, accounting for approximately 75% of cases. Notably, the supraspinatus tendon is involved in 95% of rotator cuff tears. With great sensitivity and specificity rates, musculoskeletal ultrasonography has been found to be trustworthy and helpful in the diagnosis of rotator cuff tears.[1-4] It is a more time-efficient and cost-effective alternative to magnetic resonance imaging (MRI).[5,6]

The gray-level histogram is used to depict the distribution of pixel gray levels within a designated region of interest (ROI). The technique is employed for the purpose of assessing and quantifying the echogenicity of ultrasound tissue characterization that is displayed on the B-mode image.[7] The stability and value of this technique have been reported in the characterization of fetal lung maturation and in distinguishing malignant tumors in various organs such as the myometrium, breast, placenta, parotid gland,

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ovarian stroma index, childhood neuromuscular disease, and hepatic parenchymal echotexture. This is achieved through the analysis of the distribution of gray-scale pixels in a ROI set on the B-mode image.[8-13]

Tendinopathy is characterized by an inflammatory reaction of a tendon, accompanied by the clinical triad of pain, swelling, and reduced activity. This pathology may arise due to degeneration associated with aging, excessive use, or external impingement.[14] Ultrasound examination may reveal changes in tendon thickness, contour, echotexture, and fibrillar pattern, as well as the presence of hypoechoic heterogeneity. The alterations may exhibit either a focal or diffuse pattern.[15] Numerous investigations have effectively identified supraspinatus tendinopathy through quantitative ultrasound techniques.[16-18] Nonetheless, there is a dearth of research on gray-level histogram analysis.

The aim of our study was to conduct a comparison of the gray-level value of the supraspinatus tendon as measured by ultrasonography in cases with and without supraspinatus tendinopathy and to establish a threshold value. We used MRI as the gold standard for tendinopathy detection.

Materials and Methods

Study population

The present study was conducted with the approval of the Ethics Committee of our university (approval number: 2022/414) on September 25, 2022. The participants included individuals diagnosed with supraspinatus tendinopathy, as confirmed by MRI examination, as well as those without the condition. The study was conducted between May 2022 and February 2023. The research encompassed individuals who underwent both MRI and ultrasound examinations of the shoulder. The participants were divided into two groups: those with supraspinatus tendinopathy and those without.

The study excluded patients who did not undergo MRI or ultrasound examinations, as well as those whose image quality was not suitable due to artifacts. The research involved a sample size of 124 patients diagnosed with supraspinatus tendinopathy, consisting of 50 male and 74 female participants, as well as 132 cases without supraspinatus tendinopathy, consisting of 52 male and 80 female participants. The interval between the MRI and the ultrasound examinations varied between 6 and 16 days.

Ultrasound examination

Measurements were performed with an Aplio 500 Platinum (Toshiba, Tokyo, Japan) ultrasound device with a 10-MHz linear array transducer. The supraspinatus muscle was evaluated longitudinally using ultrasonography by positioning the probe in the transverse plane while externally rotating and flexing the forearm. The mean gain was 52 and the mean dynamic range was 54 for all ultrasound examinations.

MRI examination

The examination was conducted using a 3.0-T MR unit (Verio; Siemens Medical Solutions, Erlangen, Germany) equipped with a 16-channel phased array surface coil for signal reception. The imaging sequences included fat-saturation (fatsat) T2-weighted Turbo Spin Echo (TSE) sequences in the sagittal and coronal planes (20 slices; thickness: 4 mm with no intersection gap; TR/TE: 3070/85 ms; number of signals acquired: 2; voxel size: 0.5 × 0.5 × 4 mm), fatsat proton-density (PD) TSE images in the axial plane (24 slices; thickness: 4 mm with no intersection gap; TR/TE: 2.560/43 ms; number of signals acquired: 2; voxel size: 0.5 × 0.5 × 4 mm), and T1-weighted TSE sequences in the sagittal plane (21 slices; thickness: 4 mm with no intersection gap; TR/TE: 514/9.9 ms; number of signals acquired: 2; voxel size: 0.6 × 0.6 × 4 mm).

Image analysis

The raw data were transferred from the picture archiving and communication system to a personal computer for processing using the open-source LIFE × 7.2.0 voxel program (https://lifesoft.org). Two radiologists, possessing a range of eight to 16 years of experience in interpreting musculoskeletal imaging, conducted an independent evaluation of MRI and ultrasound images.

The ROI, which encompasses the supraspinatus tendon, was manually delineated. Subsequently, the gray-level values corresponding to the fifth, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th} percentiles were computed. Additionally, the minimum, mean, median, and maximum values were determined, along with the skewness, kurtosis, and variance. The point at which n% of the voxel values from the histogram were detected on the left is referred to as the nth percentile. A distribution exhibiting positive skewness is characterized by a longer or flatter right tail compared to the left tail. The presence of positive skewness in a distribution indicates that the median of the distribution is shifted away from its mean value. Kurtosis is a statistical measure that indicates the degree of peakedness of a histogram distribution. A high kurtosis value is indicative of a distribution that exhibits a prominent peak in the vicinity of the mean, a rapid decrease in frequency thereafter, and heavy tails.

Statistical analysis

Statistical analysis was performed using IBM SPSS 23.0 software (Chicago, IL, the United States). Histograms

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were generated from the combined gray-level measurements of patients in both the groups with and without supraspinatus tendinopathy, as established by the dataset. The histograms indicated that the measurements exhibited varying distributions. Based on the measurements obtained, descriptive statistics were computed for each patient group, including mean, minimum, median, maximum, standard deviation, skewness, kurtosis, and percentiles. These descriptive statistics were then visually represented to illustrate the variations observed. The statistics presented were generated on an individual basis within a group context. The *t*-test for independent samples was employed to ascertain whether there were significant differences in the statistics obtained from individuals across various groups. Receiver operating characteristic curves were generated based on individual statistics, and the threshold value for the acquired statistics was calculated. The sensitivity and specificity metrics were computed for various threshold values.

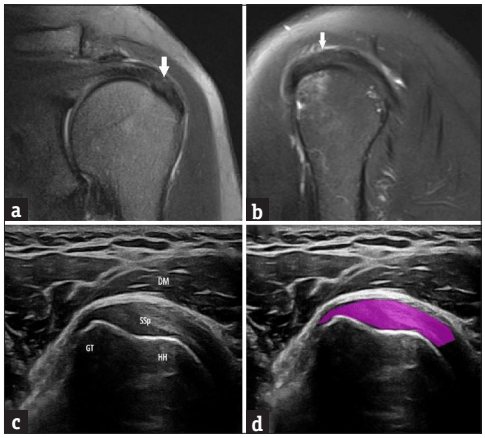

Figure 1: DM, Deltoid Muscle; SSp, Supraspinatus Muscle; GT, Greater Tubercule; HH, Humeral Head. In the supraspinatus tendon, evident thickening and hyperintensity indicative of tendinopathy are seen on coronal (a) and sagittal (b) T2-weighted sequences. Ultrasound images provide gray-level histograms (c, d)

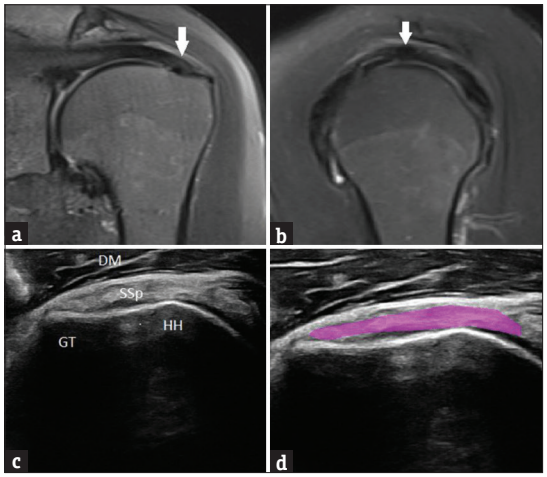

Figure 3: DM, Deltoid Muscle; SSp, Supraspinatus Muscle; GT, Greater Tubercule; HH, Humeral Head. The supraspinatus tendon without pathology is hypointense on coronal (a) and sagittal (b) T2-weighted sequences. The analysis of gray-level histograms is observable in ultrasound images (c, d)

Results

One hundred twenty four patients were diagnosed with supraspinatus tendinopathy, and 132 cases were included in the control group. There were a total of 102 men and 154 women included in the study. There was no statistically significant difference in gender (P = .879) or age (P = .582) between the two groups [Table 1].

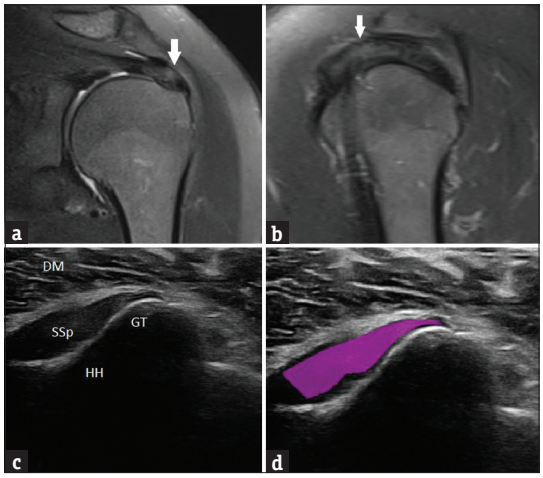

Figure 2: DM, Deltoid Muscle; SSp, Supraspinatus Muscle; GT, Greater Tubercule; HH, Humeral Head. Coronal (a) and sagittal (b) T2-weighted sequences reveal thickening and hyperintensity in the supraspinatus tendon, indicative of tendinopathy. Gray-level histogram analysis can be seen in ultrasound images (c, d)

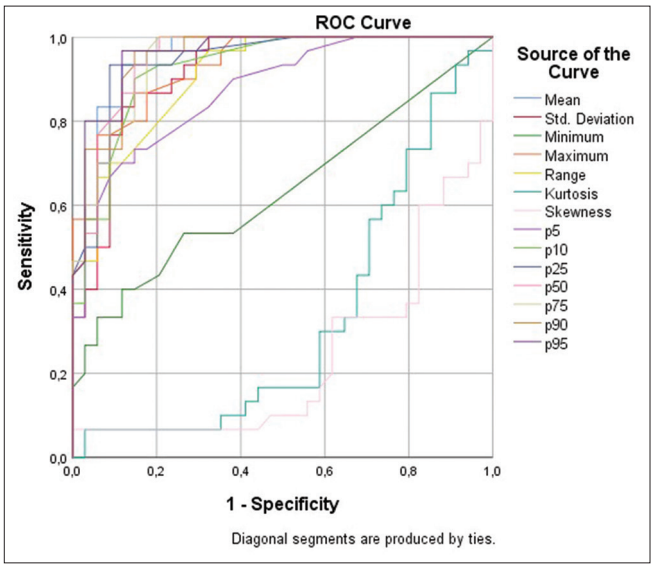

Figure 4: Receiver operating characteristic (ROC) curve of all parameters. The area under the curve (AUC) was higher with the 95th percentile (0.960), the mean (AUC = 0.955), the 90th percentile (0.954), and the median (0.951) gray-level values

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Interobserver agreement

The evaluation of the agreement between the two observers was conducted through the utilization of the interclass correlation coefficient. All parameters exhibited interclass correlation coefficient values more than 0.8, suggesting almost perfect agreement.

Table 1: Demographic data of patients

		Supraspinatus tendinopathy group	Control group	*P*
		n (%)/mean±SD	*n* (%)/mean±SD	
Age		40.79±14.58	39.92±14.54	0.582[a]
Sex	Male	50 (40.3)	52 (39.4)	0.879[b]
	Female	74 (59.7)	80 (60.6)	

[a]Mann Whitney U Test, [b]Chi-squared test

Results of gray-level histogram parameters

The supraspinatus tendinopathy group's [Figures 1 and 2] minimum, median, mean, maximum, fifth, 10th, 25th, 50th, 75th, 90th, and 95th percentiles were all less than those of the control group [Figure 3], and the difference was statistically significant ($P < .05$) [Table 2].

The supraspinatus tendinopathy group exhibited greater values of skewness and kurtosis in comparison to the control group. However, the variance was larger in the control group. There was a statistically significant difference among these parameters ($P < .05$) [Table 2].

Diagnostic performance

The receiver operating characteristic curve illustrated the effectiveness of gray-level histogram parameters

Table 2: Comparisons of gray-level histogram parameters between supraspinatus tendinopathy and control groups

Gray-level histogram parameters	Supraspinatus tendinopathy group	Control group	*P*	Significance Level
Mean	27.52±15.31	72.09±26.19	<0.001	99%
Std. Deviation	14.51±6.78	27.07±5.31	<0.001	99%
Median	25.23±15.3	70.3±27.52	<0.001	99%
Minimum	1.91±4.1	8.4±12.71	0.045	95%
Maximum	93.97±37.25	169.77±33.4	<0.001	99%
Skewness	0.88±0.47	0.4±0.55	<0.001	99%
Kurtosis	1.18±1.66	0.43±1.49	0.018	95%
Fifth	8.41±7.62	30.33±19.81	<0.001	99%
10th	10.73±8.57	38.47±22.48	<0.001	99%
25th	16.2±11.36	52.87±25.17	<0.001	99%
50th	25.23±15.30	70.30±27.52	<0.001	99%
75th	36.59±19.81	89.83±29.73	<0.001	99%
90th	47.18±23.48	107.73±29.3	<0.001	99%
95th	54.08±25.6	118.63±29.19	<0.001	99%

Table 3: ROC results of histogram parameters

Test Result Variable (s)	AUC	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval		Cut-off	Sensitivity	Specificity
				Lower Bound	Upper Bound			
Mean	0.955	0.024	0.000	0.908	1.000	44.59	0.933	0.882
Std. Deviation	0.919	0.034	0.000	0.852	0.985	21.08	0867	0.853
Median	0.951	0.025	0.000	0.903	1.000	39.5	0.933	0.853
Minimum	0.634	0.071	0.066	0.494	0.774	1.5	0.533	0.735
Maximum	0.931	0.029	0.000	0.875	0.988	130.5	0.867	0.824
Skewness	0.238	0.062	0.000	0.117	0.359	0.61	0.333	0.382
Kurtosis	0.327	0.069	0.018	0.192	0.463	0.01	0.567	0.294
Fifth	0.877	0.042	0.000	0.795	0.959	15.0	0.733	0.853
10th	0.927	0.031	0000	0.866	0.989	17.0	0.900	0.853
25th	0.945	0.027	0.000	0.891	0.998	29.5	0.933	0.912
50th	0.951	0.025	0.000	0.903	1.000	39.5	0.933	0.853
75th	0.948	0.025	0.000	0.898	0.997	51.0	0.967	0.824
90th	0.954	0.024	0.000	0.908	1.000	71.5	0.967	0.853
95th	0.960	0.022	0.000	0.917	1.000	82.5	0.967	0.882

AUC=area under the curve, a. Under the nonparametric assumption, b. Null hypothesis: true area=0.5

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in diagnosing the supraspinatus tendinopathy group [Figure 4]. The 95th percentile of the gray-level value had the highest area under the curve (AUC) at 0.960. When the cut-off value for gray-level was set at 82.5, the sensitivity and specificity were 96.7% and 88.2%, respectively. Diagnostic efficacy was followed by the mean gray-level value (AUC = 0.955). Under the threshold of 44.59, the sensitivity and specificity were 93.3% and 88.2%, respectively. The AUC was also higher at the 90th percentile (0.954) and median (0.951) gray-level values. Under the threshold values of 71.5 and 39.5, the sensitivity and specificity were 96.7% and 85.3% and 93.3% and 85.3%, respectively [Table 3].

Discussion

Prior research has indicated that elastography may provide valuable insights into the diagnosis of supraspinatus tendinopathy.[19] This technique may encounter obstacles such as operator dependence as well as limitations in terms of artifacts and reliability. In the process of elastographic evaluation, it is crucial to specify pertinent details such as the subject's age, gender, muscle segment, shoulder position, and the magnitude of tension exerted on the tendon or muscle.

The utilization of gray-level histogram analysis in ultrasound imaging is considered a more objective approach. This method allows for the quantitative provision of echogenicity information pertaining to lesions based on the echo intensity level within the gray range of 0 to 255. Consequently, certain subjective or operator-dependent characteristics present in conventional ultrasound assessments can be efficiently eradicated.[20-22] Numerous studies have reported that the utilization of gray-level ultrasound histograms is beneficial in the assessment of various lesions.[21-24] As an illustration, Sezer *et al*.[21] employed gray-level ultrasound histogram analysis to examine the parotid glands of individuals diagnosed with Sjögren's syndrome. The study revealed that the employment of the quantitative histogram ratio method resulted in a greater positivity rate in detecting abnormal parotid glands as compared to subjective evaluations of ultrasound images. Beyazal *et al*.[23] conducted a study that found that patients with chronic hepatitis B had significantly increased mean value, variance, 50th percentile value, and 90th percentile value of gray-level ultrasound histogram analysis compared to a healthy control group. Additionally, the skewness and kurtosis values were significantly decreased in the chronic hepatitis B group. The aforementioned results underscored the prospective role of gray-level ultrasound histogram analysis in distinguishing tendinopathy. Nonetheless, this method is infrequently used in the musculoskeletal area of clinical practice.[25-28]

The supraspinatus tendon in individuals with subacromial bursitis, bicipital tendonitis, and rotator cuff tendinopathy typically exhibits a varied hypoechoic appearance and a notable reduction in the average gray-level value on imaging. The degree of attenuation and tendon echogenicity are likely to be impacted to a greater extent by the attenuation coefficient of the soft tissues that overlay them, including the skin, subcutaneous fat, and surrounding musculature.[26] An attempt was made to mitigate the impact of anisotropy by orienting the transducer perpendicular to the shoulder. This was done to optimize the production of the supraspinatus tendon's maximum mean gray-level values.

Certain studies used a superficial reference muscle adjacent to the supraspinatus or biceps tendon to establish the echogenicity ratio between the tendon and reference muscle. Huang *et al*.[26] found that the supraspinatus tendons exhibit a thickened and hypoechogenic appearance with advancing age, rendering them more susceptible to tearing. Chang *et al*.[27] determined the thresholds for the transverse and longitudinal perspectives of the ROI measurements at 26.85 and 21.25, respectively. The sensitivity and specificity values for the transverse view were 68% and 90%, while the sensitivity and specificity values for the longitudinal view were 81% and 73%, respectively. They concluded that the utilization of sonographic gray-level pixels of the ROI in both transverse and longitudinal views of the biceps tendon can serve as quantitative measures in the identification of biceps tendinitis. In their study, Hsu *et al*.[28] used two distinct ultrasound devices to assess the ratio of echogenicity between symptomatic and asymptomatic tendons. The results obtained in the transverse plane were 0.919 ± 0.090 and 0.899 ± 0.113, while those obtained in the longitudinal plane were 0.937 ± 0.081 and 0.940 ± 0.113. Consistent with prior research, our study revealed significantly reduced values in individuals with supraspinatus tendinopathy. In contrast to prior research, this study conducted a more comprehensive evaluation of gray-level parameters and established threshold values.

This study had certain strengths and limitations. MRI was used to conduct a comparative analysis of its precision in contrast to ultrasound and a greater number of parameters were assessed in the gray-level ultrasound histogram analysis. There may be variations in the accuracy of the manually contoured circumscribed region, in depicting the authentic circumference of the supraspinatus tendon among individuals. The infraspinatus tendon's point of insertion exhibited an anterior extension that covered a portion of the supraspinatus tendon, extending over its superior

facet. A potential misinterpretation of supraspinatus tendinopathy could be a distal anterior infraspinatus tendon tear. Therefore, it is imperative to focus on scrutinizing the hypoechoic lines that exist between the supraspinatus and infraspinatus tendons' boundaries.

In conclusion, the findings of this research indicate that the ultrasonographic gray-level histogram exhibits potential as a means of identifying the hypoechogenic manifestation of supraspinatus tendinopathy. A potential sonographic indicator of rotator cuff tendinopathy could be a reduction in the average gray-level value on the affected side. The utilization of the gray-level histogram in ultrasound presents a convenient and auspicious approach for the quantitative evaluation of supraspinatus tendinopathy. This method shows potential as a cost-effective and noninvasive means of assessing tendinopathies. Gray-level value histogram analysis is a potentially promising approach for monitoring patients with supraspinatus tendinopathy and may serve as a viable alternative to MRI.

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Ethical approval

The present study was conducted with the approval of the Ethics Committee of our university (approval number: 2022/414) on September 25, 2022.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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