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Original Article

Comparative sonographic assessment of spleen dimensions and quantitative parenchymal echotexture in children with sickle cell disease at a Tertiary Hospital in Nigeria

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Abstract

Background: Sickle cell disease (SCD) causes progressive splenic injury due to recurrent vaso-occlusion and infarction, leading to functional asplenia. In African children's population, comprehensive sonographic assessments combining spleen biometry with objective echotexture analysis remain underexplored. **Objective:** The study compared spleen linear dimensions, calculated volume, and quantitative parenchymal echotexture between children with SCD in steady state and age/sex matched healthy controls. **Methodology:** This hospital-based cross-sectional comparative study included 45 children with SCD (HbSS) and 45 healthy controls (HbAA), aged 1-14 years. Spleen length, width, and height were measured sonographically, and volume was calculated using the prolate ellipsoid formula. Parenchymal echotexture was quantified as Mean Pixel Intensity (MPI) using a validated in-house MATLAB algorithm applied to standardised regions of interest. Group comparisons were performed using independent samples *t*-test and Mann-Whitney U test as appropriate. **Results:** Children with SCD had significantly smaller spleens than controls in terms of length (6.6 ± 1.4 cm and 7.2 ± 1.4 cm, p=0.03), width (3.3 ± 0.7 cm and 4.5 ± 0.9 cm, p<0.001), and volume (70.9 ± 47.1 cm^3 and 100.1 ± 55.7 cm^3, p=0.008), while splenic height showed no significant difference (p=0.98). Mean Pixel Intensity was significantly higher in the SCD group (63.47 ± 14.67 and 30.9 ± 12.9, p=0.002), indicating markedly increased parenchymal echotexture. **Conclusion:** Children with SCD demonstrate significant splenic regression and objectively increased parenchymal echogenicity compared with healthy controls. The integration of standard sonographic biometry with quantitative echotexture analysis provides a more comprehensive and objective approach for evaluating splenic involvement in children with SCD.

Keywords: *Children, Echotexture, Mean pixel intensity, Sickle Cell Disease, Spleen, Ultrasonography.*

Introduction

One of the most prevalent inherited hemoglobinopathies in the world is sickle cell disease (SCD), with higher occurrence in sub-Saharan Africa.[1] Recurrent Vaso-occlusive episodes and chronic hemolysis associated with SCD result in progressive multiple organ damage, with the spleen being among the earliest and most severely affected organs.[2,3] In children with SCD, repeated splenic infarctions lead to architectural distortion, fibrosis, and eventual functional asplenia or autosplenectomy, increasing susceptibility to severe infections and contributing significantly to morbidity and mortality.[4,5]

Ultrasonography remains the most accessible and widely used imaging modality for evaluating splenic

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pathology in pediatric populations due to its safety, affordability, and real-time capability.[6,7] Conventional sonographic assessment of the spleen in SCD is based on linear dimensions, calculated volume, and subjective evaluation of echogenicity.[8,9] While splenic size reduction is a recognised marker of disease progression, qualitative assessment of echotexture is inherently operator-dependent and may fail to detect subtle parenchymal changes that preceded gross morphological alterations.

Quantitative ultrasound echotexture analysis has emerged as an objective imaging approach capable of characterising tissue microstructural changes by analysing grayscale pixel distribution within ultrasound images.[10-12] Parameters such as mean pixel intensity provide reproducible measures of parenchymal echogenicity and have been explored in the evaluation of hepatic, renal, and testicular pathology.[13] However, the application of quantitative echotexture analysis to splenic assessment in children with sickle cell disease remains limited, particularly in African settings where disease burden is highest and access to advanced diagnostic tools is restricted.

There is currently a scarcity of data comparing conventional splenic biometry with objectively quantified parenchymal echotextures in children with SCD. Establishing such comparisons will improve understanding of splenic involvement and enhance early detection of parenchymal compromise before irreversible autosplenectomy occurs. This study therefore aimed to compare splenic linear dimensions, volume, and quantitative parenchymal echotexture between children with sickle cell disease and age/sex matched healthy controls using an in-house ultrasound image analysis algorithm.

Materials and methods

Study design and participants.

This was a cross-sectional comparative study conducted at the Tertiary Referral Health Centre in Northeastern Nigeria. A total of 90 children were enrolled in the study: 45 with homozygous SCD (HbSS) in a clinically steady state (no crisis or transfusion in the preceding 3 months), and 45 age and sex comparable healthy controls with HbAA genotype. Children with a history of splenectomy, acute febrile illness, or other chronic conditions affecting the spleen were excluded. Ethical approval was obtained from the facility's review board with approval code number (NREC/040/11/19B/2021/020), and informed consent/assent was secured. The study commenced in January 2025 and was completed by July 2025.

Inclusion criteria

After providing agreement or assent, children with homozygous SCD who were healthy in steady state, verified by Hb electrophoresis, were enrolled in the study. Both males and females who have been attending the clinic for follow-up were included. Children diagnosed with SCD in a stable condition at the time of data collection. Age-matched controls, normal Hb genotype children, who were obtained from their hospital medical record also included in the study.

Exclusion criteria

To rule out any past or present disorders that might affect the size and shape of the spleen, the subjects underwent a medical examination and were asked a series of brief, standardised interview questions. The exclusion criteria for the control group were taken from their medical records and included a history of splenic trauma, non-traumatic benign splenic lesions, infarctions, lobulations, cysts, accessory spleen, hemangioma, sickle cell anaemia, lymphadenopathy, and anyone who had a fever at the time of the examination or within the four weeks before that could have affected splenic morphology. Additionally, sickle cell disease subjects with absent spleen (auto-splenectomy) were excluded from the study. Children whose parents declined consent.

Sample Size calculation.

The minimum number (n) of subjects needed for the study was calculated using Cochran's formula [14].

$n = Z^2 P (1-P) / d^2$

Therefore,

Z = is the standard normal variant, which is 1.96 at 5% type 1 error ($p \leq 0.05$) and 2.58 at 1% type 1 error ($p \leq 0.01$).

This study uses 1.96 because, as in most other studies, the p-value was deemed significant below 0.05.

P = is the predicted percentage in the population derived from pilot or prior research. However, SCD within the states in Nigeria ranges from 1%-3% [15]. In this study, 3% considered as the prevalence of SCD in Nigeria.

d = Absolute error or precision - the fixed percentage in this study is 5 per cent.

The smallest sample size is thus, $n= 1.96^2 \times 0.03 (1-0.03) / 0.05^2 = 44.69 \approx 45$

Therefore, 45 sickle cell disease subjects were recruited from the paediatrics clinic, and 45 non-sickle cell children were enrolled as the control group.

Sonographic Examination

All scans were performed by a qualified sonographer and a radiologist using a DP10 ultrasound system

with a curvilinear transducer (3.5-5 MHz). For the ultrasound examination of the spleen, the subject did not need prior preparation. To provide the best possible energy transfer between the patient and the probe, coupling gel was first applied to the abdominal wall in the left hypochondriac region while the patient was in a supine position. The individual was now instructed to elevate their left side while lying in the right lateral posture. The 3.5 MHz transducer was then positioned between the eighth and ninth ribs at a right angle to the skin, and contact compound scanning was carried out parallel to the ribs from the rear to the front. To reduce lung masking, a splenic measurement was made during deep inhalation. As the upper part of the spleen was partly masked by air in the lung, the margin between the lung and the spleen served as a limit of transverse and longitudinal diameter. Every measurement was made at least three times to assess reproducibility, and the most repeated value was noted. A single representative longitudinal image of each subject was saved in DICOM format for echotexture analysis. However, the following measurements were taken as shown in Figure 1:

Splenic Length (L): The maximum distance between the superomedial and inferolateral poles in a longitudinal section.

Splenic Width (W): The maximum anteroposterior diameter in a transverse section.

Splenic Height (H): The maximum mediolateral distance from the hilum to the capsule.

Splenic Volume (V): Calculated using the prolate ellipsoid formula: $V = L \times W \times H \times 0.523$.[16]

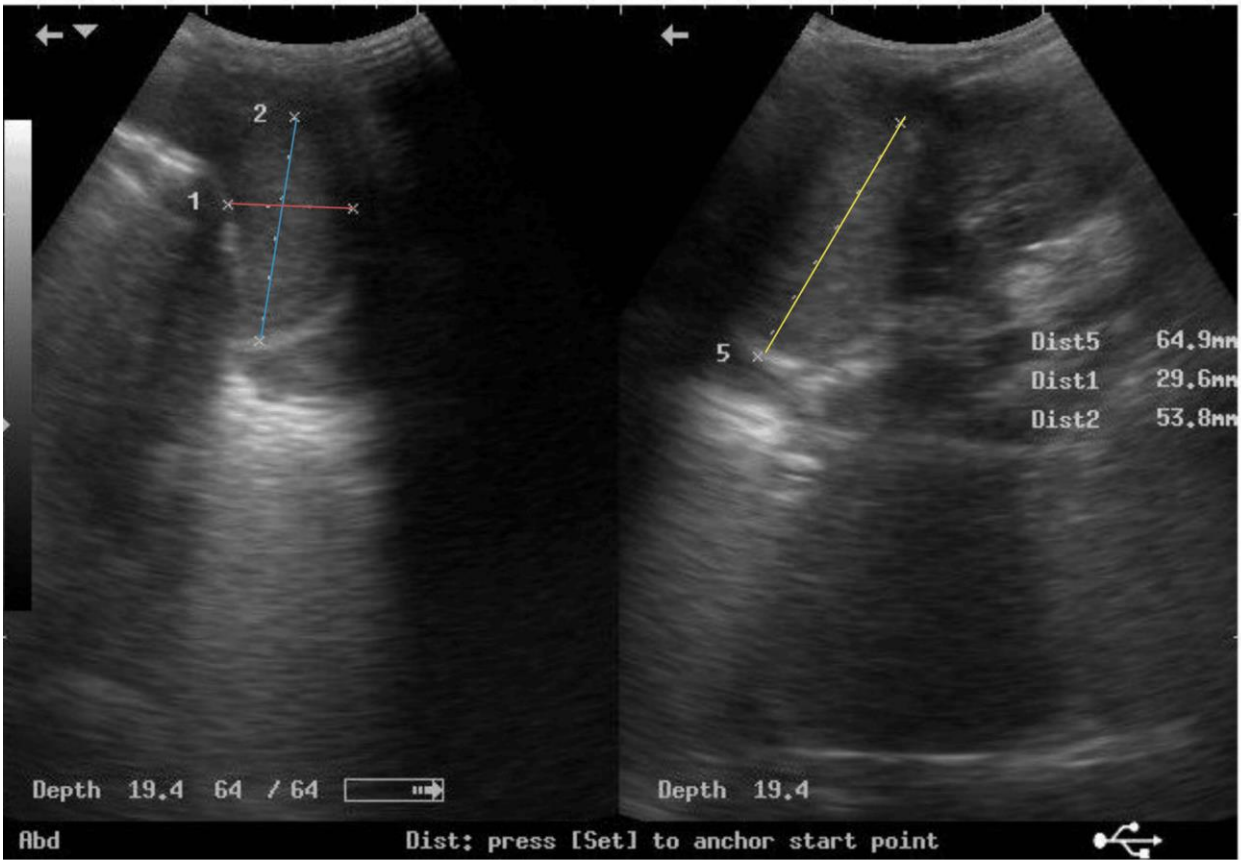

Figure 1: Image illustration of spleen dimensions measurement
Yellow line annotation shows maximum spleen length measured.
Blue line annotation shows spleen height measurement.
Red line annotation shows spleen width measurement.

Quantitative Echotexture Analysis

Echotexture was quantified using a previously developed and validated in-house algorithm in MATLAB. The following consecutive steps made up the algorithm's workflow, which is depicted in Figure 2: after the DICOM image was imported using the "dicomread" function. A graphical user interface (GUI) was developed to enable the operator to manually design a rectangular ROI within the spleen parenchyma. To prevent the hilum, visible vessels, and acoustic shadows from ribs, the operator was directed to position the ROI in a uniform area. Every

pixel value inside the specified rectangular ROI was retrieved by the algorithm. The Mean Pixel Intensity (MPI) was the main quantitative measure computed. The algorithm output is the Mean Pixel Intensity (MPI), a unitless value where higher numbers indicate greater echogenicity (brightness). Because of its reliability, repeatability, and previous validation in the characterisation of parenchymal tissue, Mean Pixel Intensity was chosen.[17] All analyses were carried out by two skilled operators. Region of Interest (ROI) selection and placement were standardised across subjects to ensure consistency.

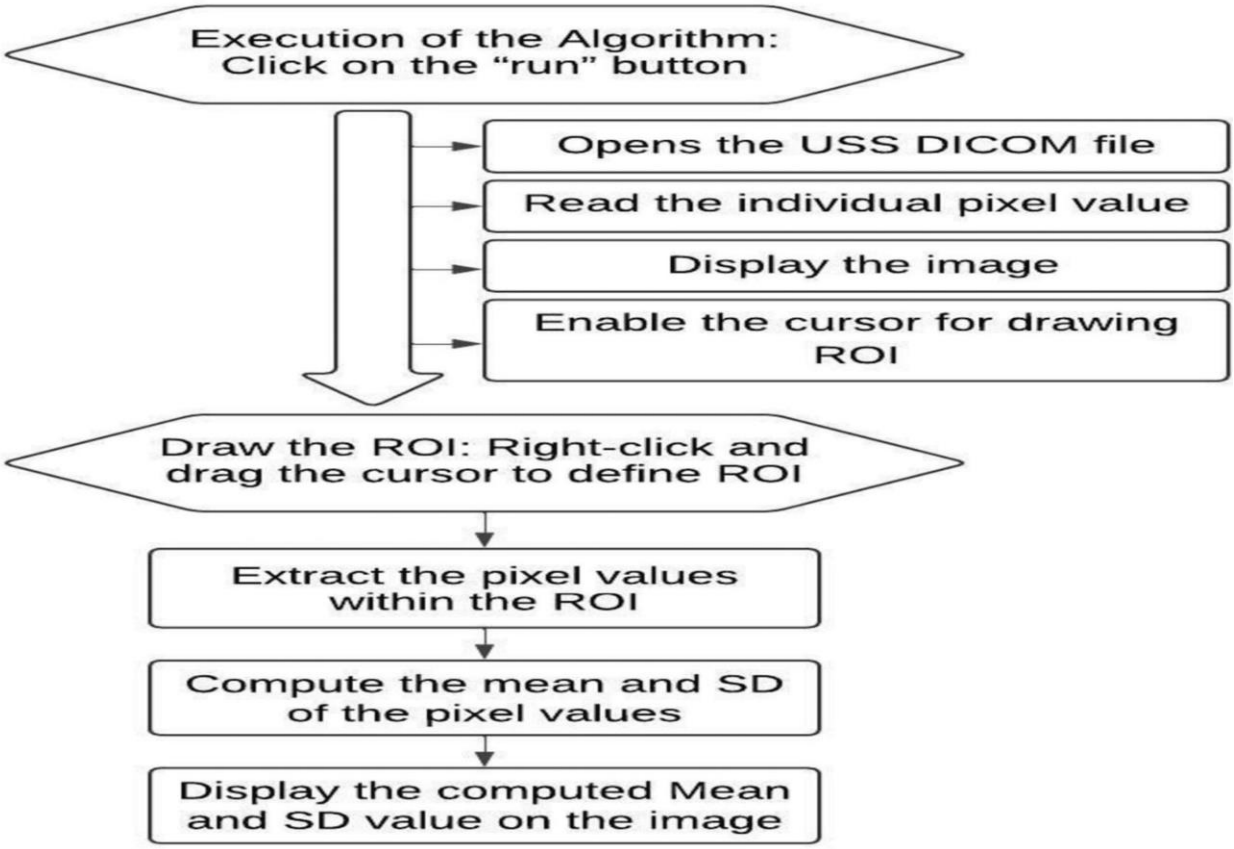

Figure 2: Schematic illustration of the MATLAB algorithm workflow

Statistical Analysis

Version 23.0 of the Statistical Package for Social Sciences (SPSS) program was used for statistical analysis. Before analysis, all data were verified for quality and completeness. The Shapiro-Wilk test was used to determine whether continuous data, such as splenic length, width, height, estimated volume, and Mean Pixel Intensity (MPI), were normal. Normally distributed data were summarised as mean ± standard deviation (SD), whereas non-normally distributed data were expressed as median with range. Frequencies and percentages were used to summarise categorical variables such as gender. Based on data distribution, comparisons were made between children with sickle cell disease (HbSS) and healthy controls (HbAA). Group means were compared using independent samples t-tests for continuous variables with a normal distribution. The Mann-Whitney U test was used for data that were not normally distributed. The Chi-square (χ^2) test was used to compare categorical variables. Each splenic dimension was measured three times to increase measurement reliability, and the value that occurred most frequently was noted for analysis. Standardised region of interest (ROI) placement was used for echotexture analysis to reduce interobserver variability. A p-value of less than 0.05 was deemed statistically significant, and all statistical tests were two-tailed. Where applicable, tables and figures were used to display the results.

Results

Demographic Characteristics

The spleen was visualised in all 45 normal control subjects recruited in the study. Of the 49 SCD subjects selected for the study, the spleen was visualised in 45, which corresponds to the healthy normal controls' data. The spleen was not visualised in 4 of the SCD

subjects and was now excluded from the study. Representative ultrasound images of both control and SCD subjects are depicted in Figures 3 and 4. The median age of the SCD group was slightly lower than that of the control group (7.3 and 9.8 years, p=0.01). Gender distribution was comparable (SCD: 57.8% male; Control: 71.1% male, p=0.27). Anthropometric parameters (weight, height, BMI) were significantly lower in the SCD group (p<0.05), reflecting the known growth implications of the disease (Table 1).

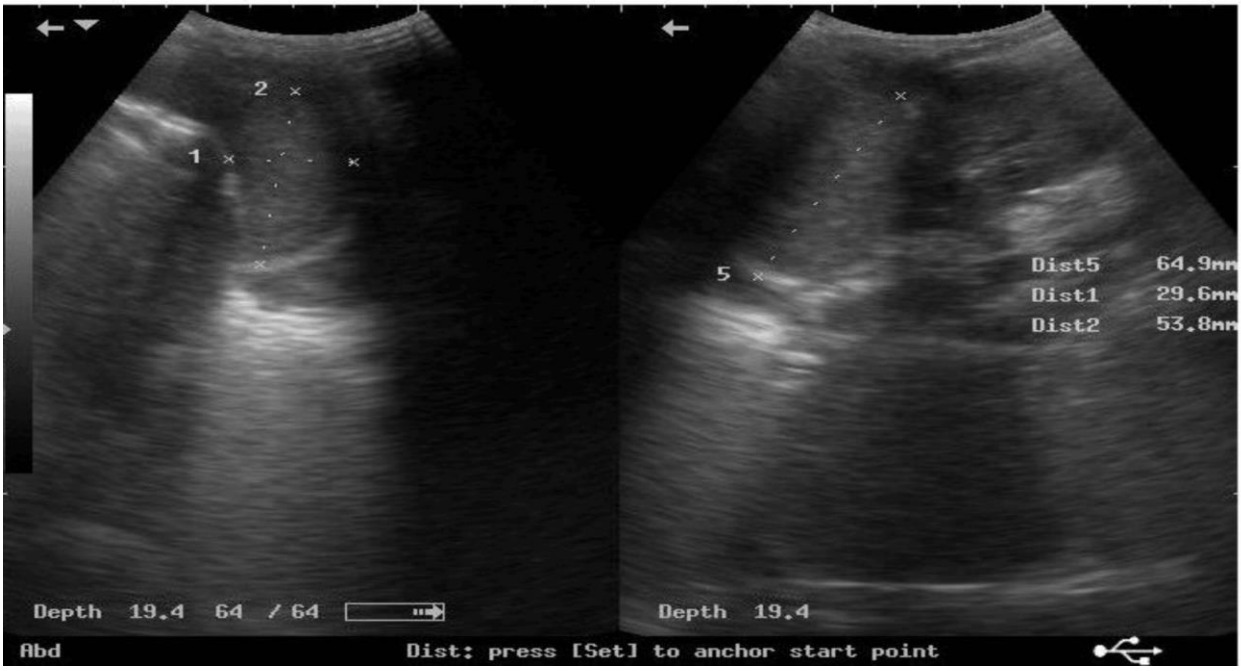

Figure 3: Ultrasound spleen image of the 9-year-old male SCD subject

The image shows spleen orientation with measurement of spleen width[1], splenic height[2] and maximum splenic length[5].

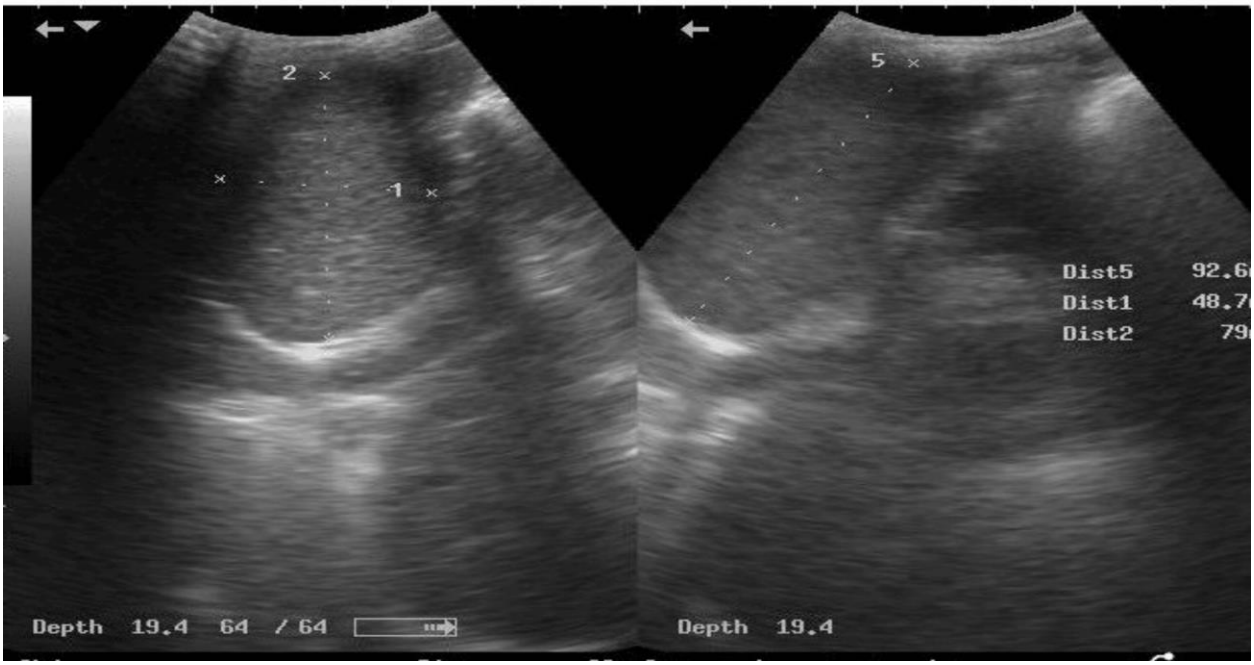

Figure 4: Ultrasound image of the 12-year-old control subject

The image shows spleen orientation with measurement of spleen width[1], splenic height[2] and maximum splenic length[5]

Table 1: Demographic Characteristics of the participants

Parameter	Control subjects	Sickle cell subjects	P value	test value
No of subjects	45	45		
Age (Median, range)	9.76 (2-14)	7.31 (1-14)	0.01*	603.00
Gender n (%)				
Male	32 (71.1)	26 (57.8)	0.27^	1.75
Female	13 (28.9)	19 (42.2)		
Weight (kg), (Median, range)	24 (8-39)	20 (7-31)	0.00*	499.00
Height (cm), (Median, range)	125 (72-140)	115 (66-140)	0.00*	497.500
BMI (kg/m2), (Median, range)	17 (12.6-208)	15.6 (13.4-17.5)	0.02*	715.500

test value (^ Chi-square, * Mann Whitney U-test)

Comparison of Splenic Dimensions and Volume among the study subjects

Children with SCD had significantly smaller spleens in terms of length and width. Calculated splenic volume was also significantly reduced in the SCD group. There was no significant difference in splenic height between the two groups (Table 2).

Table 2: Comparison of Splenic Biometric Parameters Between SCD Patients and Healthy Controls

Parameter	SCD Group (n=45) Mean ± SD	Control Group (n=45) Mean ± SD	p-value	test value
Length (cm)	6.6 ± 1.4	7.2 ± 1.4	0.02	724.500
Width (cm)	3.3 ± 0.7	4.5 ± 0.9	0.00	307.00
Height (cm)	5.4 ± 1.3	5.4 ± 1.1	0.75	972.500
Volume (cm^3)	70.9 ± 47.1	100.1 ± 55.7	0.02	631.500

test value = Mann-Whitney U-test

Comparison of Quantitative Parenchymal Echotexture among the study subjects

The quantitative echotexture analysis revealed a marked difference among the study groups. The Mean Pixel Intensity (MPI) was more than twice as high in the SCD group compared to the healthy controls, indicating markedly diffused and more echogenic parenchyma (Table 3).

Table 3: Comparison of mean pixel intensity among the study subjects

Group	n	MPI (Mean ± SD)	Range	p-value	test value
SCD Group	45	63.47 ± 14.67	30.7 – 95.1	0.00	-11.873
Control Group	45	30.9 ± 12.9	7.4 – 59.6		

test value=Independent sample t-test

Discussion

This study demonstrated significant differences in spleen morphology and parenchymal characteristics between children with sickle cell disease and healthy controls. Children with SCD exhibited significantly reduced spleen length, width, and volume, alongside markedly increased mean pixel intensity, reflecting increased parenchymal echotexture. These findings highlight the combined value of conventional sonographic biometry and quantitative echotexture analysis in the objective evaluation of spleen involvement in SCD.

The observed reduction in spleen dimensions among children with SCD is consistent with the established pathophysiology of repeated Vaso-occlusive events leading to ischemia, infarction, and progressive splenic atrophy.[18] Previous studies have similarly reported reduced spleen size in children with SCD,

reflecting advancing disease severity and progression toward autosplenectomy.[19] Alaneme et al, in their study titled "Comparative sonographic assessment of the spleen in individuals with and without sickle cell anaemia, in Nigeria," revealed that individuals with HbSS had significantly smaller mean longitudinal and anteroposterior dimensions, median transverse dimensions, splenic volume, and splenic index than those with HbAA ($p<0.05$).[20] Their results corroborated our claim that repeated Vaso-occlusion and infarction cause the spleen to gradually shrink in HbSS patients. Spleen height did not differ across groups in the current study ($p=0.75$), indicating that overall volume reduction may be a more sensitive predictor of early splenic involvement than some linear dimensions. This result is consistent with a prior study conducted in Nigeria by Akinlosotu et al., who discovered no discernible difference between the median spleen size of individuals with HbSS and those with HbAA.[21] This might be because both studies used the same study population. In keeping with our study subjects, Akinlosotu et al. also only dealt with children. The fact that splenic anomalies in SCA tend to increase with age may be the reason for our study's findings. Ezeike, however, found no statistically significant difference between individuals with HbSS and those with HbAA in terms of splenic length and splenic transverse diameter.[22] Additionally, he discovered that patients with HbSS had larger mean splenic volumes and anterior-posterior splenic dimensions than those with HbAA. This is at odds with the current study conclusions, which may be due to their study inclusion of an adult population. Even though the bulk of the participants in their study group were under 20 years old, Olatunji et al. reported a different finding: that the mean longitudinal and coronal dimensions of the spleen were greater in the HbSS patients compared with the control.[23] This could be because of the different environment and the way the illness is managed in our area.

A key finding of this study is the significantly higher mean pixel intensity observed in the spleens of children with SCD compared with controls. High Mean Pixel Intensity (MPI) demonstrated increased echogenicity that reflects underlying histopathological changes, including fibrosis, hemosiderin deposition, and architectural distortion resulting from chronic infarction. Of the 45 HbSS who participated in this study, has shown overall diffused homogeneously hyperechoic splenic echopattern as recorded by an increase in MPI across the group ($p=0.00$). Luntsi et al. showed enhanced splenic echopattern in 83.3% of patients with HbSS.[24] which corroborated the rate of diffuse homogeneously hyperechoic echopattern obtained in this investigation. This could be explained by the splenic alterations brought on by vaso-occlusion and the severity of the disease in SCD patients. Furthermore, 80% of patients with HbSS had echogenic spleens, according to Gale et al.[25] These same results demonstrated that patients with HbSS frequently had diffusely homogeneous hyperechoic splenic echopattern. However, unlike subjective echogenicity grading, quantitative pixel intensity-based analysis provides an objective and reproducible measure of parenchymal alteration, reducing operator dependence and enhancing diagnostic consistency.[26,27]

The integration of quantitative echotexture analysis with routine splenic biometry offers important clinical implications. Early identification of parenchymal compromise using objective ultrasound markers will allow clinicians to recognise splenic dysfunction before complete loss of splenic tissue occurs. This is particularly relevant in resource-limited settings, where laboratory markers and radionuclide imaging used to assess splenic function are often unavailable or impractical. Quantitative ultrasound thus represents a noninvasive, cost-effective adjunct for monitoring disease progression in children with SCD. The strength of this study lies in the use of an in-house validated algorithm to objectively quantify spleen echotexture, providing a standardised approach adaptable to routine clinical practice. However, the cross-sectional design adopted, which prevents longitudinal evaluation of splenic evolution, and the lack of direct correlation with functional splenic markers like Howell-Jolly bodies or radionuclide studies are among the limitations of this current study. Longitudinal studies are therefore recommended to determine the prognostic value of quantitative echotexture parameters in predicting functional asplenia and guiding clinical decision-making.

Conclusions

This study demonstrates that children with sickle cell disease exhibit significant reductions in spleen dimensions alongside markedly increased parenchymal echotexture compared with age/sex matched healthy controls. Quantitative pixel intensity-based echotexture analysis complements conventional splenic biometry by providing an objective measure of parenchymal alteration associated with chronic splenic injury. The integration

of these ultrasound-based parameters could enhance the assessment of splenic involvement and may facilitate earlier identification of splenic compromise before irreversible autosplenectomy occurs. Further longitudinal studies are required to determine the prognostic utility of quantitative echotexture measures in monitoring disease progression and informing clinical care in children with SCD.

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Conflict of interest: None to declare

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