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SPLENIC VOLUME: CORRELATION BETWEEN COMPUTED TOMOGRAPHY AND ULTRASOUND MEASURMENTS

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Abstract

Objective: *To evaluate the correlation and agreement between splenic volume measurements obtained by computed tomography (CT) and ultrasonography (US) in adult patients without splenic pathology.*

Methodology: *A prospective, cross-sectional study was conducted over 12 months at a tertiary care center. One hundred adult patients undergoing contrast-enhanced abdominal CT were enrolled. Within 72 hours, each patient underwent a standardized ultrasound examination. Splenic volume was estimated via the ellipsoid formula on US and by semi-automated segmentation using 3D post-processing software on CT. Statistical analysis included Pearson's correlation, linear regression, Bland–Altman analysis, and intraclass correlation coefficient (ICC) to assess agreement and reproducibility.*

Results: *The mean splenic volume was 231.5 ± 52.4 mL on CT and 219.8 ± 49.3 mL on US. The Pearson correlation coefficient between modalities was strong ($r = 0.87$, $p < 0.001$), with a regression model yielding $R^2 = 0.76$. Bland–Altman analysis revealed a mean bias of 11.7 mL with 95% limits of agreement from -27.4 to +50.8 mL. Inter-observer agreement was excellent (ICC > 0.90 for both modalities).*

Conclusion: *Ultrasound demonstrates high correlation and acceptable agreement with CT in assessing splenic volume, supporting its utility as a reliable, non-invasive alternative in routine clinical settings, especially where CT is contraindicated or unavailable.*

INTRODUCTION

The spleen, located in the left upper quadrant of the abdomen, is an important organ involved in hematologic and immune functions. The spleen functions in many ways, but acts partially as a filter for

blood, as it removes old red blood cells as well as pathogens and is a reservoir for platelets and monocytes. [1] Splenic volume, which typically ranges from 150 mL to 300 mL in adults, can be affected by many factors such as age, sex, weight, body habitus, and physiological state.[2] Accurate measurement of splenic size is clinically relevant for diagnosing and monitoring a variety of diseases.

Physiologically, the spleen responds in real-time to systemic changes. For example, the spleen contracts during exercise to release elements of blood in regards to filtration, but enlarges when activated by the immune system due to a systemic infection.[3] Pathologically, splenomegaly, which is an increased splenic volume, can be due to infections (e.g., malaria, mononucleosis), hematologic disorders (e.g., leukemia, lymphoma), liver afflictions (e.g., cirrhosis with portal hypertension) and systemic inflammatory conditions,[4] while splenic atrophy can occur in conditions, like sickle cell anemia, due to recurrent infarction of splenic tissue. Thus, it is important to be able to measure splenic volume via imaging modalities such as ultrasound and computed tomography as an evaluation for clinical purpose.

Computed Tomography (CT) remains the foundation for characterizing the spleen due to its high spatial resolution, speed, and accuracy in evaluating organ volume and morphology. The normal spleen appears homogeneous on a contrast-enhanced CT, although we see some segmental variation in the arterial phase due to the architecture of the organ. [5] CT is capable of identifying both diffuse and focal splenic abnormalities and is widely utilized for clinical and research purposes to assess splenic volume.

Splenic volumes can be determined using the ellipsoid volume formula: Volume = 0.524×Length×Width×Thickness or more accurately with manual segmentation and 3D volumetric reconstruction with post-processing software. [6] Most studies have shown that CT-derived healthy adult splenic volumes range around 150 to 300 mL, although this can be affected by age, sex, and body surface area. [7] It is widely accepted that splenomegaly, or enlarged spleen volume, is defined as splenic volume exceeding approximately 400–500 mL upper limit.

CT is ideal for diagnosis of pathological splenomegaly, traumatic injuries including lacerations or hematomas, infarctions, cysts, and neoplasms. CT is essential to grade splenic injury and inform management in hospitalized patients with trauma. [8] Moreover, evolving CT techniques including dual-energy and perfusion CT have improved tissue characterization and detection of subtle lesions. [9]

Ultrasound (US) is a non-invasive imaging technique that is routinely used for assessing splenic size, morphology, and pathology. US is often a first-line modality for splenic evaluation because of its widespread availability, cost-effectiveness and safety profile. The normal spleen is visibly a homogeneously echoic crescent-shaped organ in the left upper quadrant of the abdomen, with distinctly smooth contour and fine granulated texture on ultrasound. [10] The splenic hilum can also frequently be assessed on (US) and is where vessels and lymphatics enter the spleen, if visible.

Splenic volume is typically estimated using an ellipsoid formula: Volume = 0.524 × Length × Width × Thickness, where the length, width and thickness are measured in standard longitudinal and transverse planes. [11] In general, splenic length in healthy adults ranges internationally from 8 to 13 cm, and over a volume of 300–350 mL is considered splenomegaly, however this may differ by geographic population and body habitus. [12] US-based splenic volume has been found to correlate well with CT and MRI estimation of splenic volume, but operator dependence remains a limitation in US assessment.

Clinically, changes in splenic size assessed by US are of relevance for diagnosing and managing infections (e.g. mononucleosis), hematologic disorders (e.g. lymphoma), portal hypertension, and systemic inflammatory conditions. Moreover, it can be useful for follow-up of traumatic splenic injuries, as well as monitoring therapeutic responses. [13] In our study, we will study correlation between splenic volumes as measured by computed tomography and ultrasound.

Methodology:

This was a prospective, cross-sectional, observational study to determine the association between splenic volumes measured by Computed Tomography (CT) and Ultrasonography (US). The study was performed at a tertiary academic medical center within the Department of Radiology over 12 months from [Insert Start Date] to [Insert End Date]. Ethical

approval was obtained from the Institutional Review Board (IRB); written informed consent was obtained from all patients prior to their participation.

Study Population

A total of 100 adult patients who were referred for a CT abdomen requesting various imaging diagnoses participated in the study. The study population was recruited based on the following inclusions and exclusions:

Inclusion Criteria

- Adult patients ≥ 18 years
- Patients undergoing a CT abdomen with IV contrast
- Patients with no known or clinically suspected splenic disease
- Patients who could come back for follow-up US within 72 hours of CT study.

Exclusion Criteria

- Past or current evidence of splenic injury, surgery, infarction, neoplasm from imaging studies.
- Any free fluid (ascites) or excessive gas seen on ultrasound which impacted the visualization of the spleen.
- Splenomegaly due to hematological, infective, or hepatic etiologies.
- Pregnancy or contraindications to IV contrast.

Imaging Modalities

1. Computed Tomography (CT)

All CT scans were performed on multi-detector CT scanners (for example, 64-slice Siemens SOMATOM or equivalent). CT scans were performed as per the standard abdominal protocol below:

- Thickness: 5 mm.
- Pitch: 1.0 to 1.2.
- Tube Voltage: 120 kVp.
- Tube current: 200 to 300 mAs (modulated).
- Intravenous Contrast: non-ionic iodinated contrast 1.5 mL/kg body weight.

The scans were obtained for the portal venous phase (about 60-70 seconds after injection) to enhance the observation of the spleen. The CT volumetry of the spleen was completed with the use of semi-automated segmentation software on a dedicated 3D workstation (for example, GE Advantage Workstation or Siemens Syngo.via). A radiologist, experienced in abdominal imaging for ≥ 5 years, applied any necessary corrections manually. The splenic volume was calculated with a summation-of-areas method of estimation using the subtraction of the splenic borders on each axial slice and multiplying by thickness.

2. Ultrasonography (US)

High-resolution ultrasound was utilized to perform the ultrasound scans with a high-resolution ultrasound system (e.g., Philips Epiq 7, GE Logiq E9) equipped with a 3–5 MHz curvilinear transducer. The scans were performed as close to the CT within 72 hours as possible to lessen physiological variation. All ultrasounds were performed by experienced radiologists completely blinded to the ct findings.

The spleen was imaged in both longitudinal and transverse planes. Three orthogonal dimensions were measured:

- Length (L): Maximum craniocaudal length on coronal oblique plane.
- Width (W): Maximum transverse width.
- Thickness (T): Anteroposterior measure at the hilum.

The volume of the spleen was estimated using the prolate ellipsoid formula:

Volume = 0.523 × L × W × T

To minimize inter-observer variability, all dimensions were measured three times, and the average value was used for statistical analysis.

Data Collection and Management

Demographic details such as age, sex, body mass index (BMI), and clinical indication for imaging were recorded. All imaging data were anonymized and stored securely on the hospital's PACS (Picture Archiving and Communication System). Each patient was assigned a unique study code to maintain confidentiality.

Splenic volumes from both CT and US were recorded in milliliters (mL). Data entry was performed using Microsoft Excel, and statistical analysis was conducted using SPSS Version 25.0 (IBM Corp., Armonk, NY).

Statistical Analysis

Descriptive statistics were used to summarize patient demographics and splenic volumes. Data were checked for normality using the Shapiro-Wilk test. Continuous variables were expressed as mean ± standard deviation (SD) or median with interquartile range (IQR) as appropriate.

To assess the correlation between CT and ultrasound-derived splenic volumes, Pearson's correlation coefficient (r) was calculated for normally distributed data. For non-parametric data, Spearman's rank correlation coefficient was used. The level of agreement between the two modalities was further assessed using Bland-Altman analysis, which plotted the mean of CT and US volumes against their differences to detect any systematic bias.

Additionally, intraclass correlation coefficient (ICC) was calculated to evaluate inter-modality reliability. A p-value of less than 0.05 was considered statistically significant.

Quality Control and Bias Mitigation

To minimize observer bias:

• The radiologists interpreting ultrasound scans were <couldn't think of a better word> blinded to the CT results and vice versa.

• Volumetric calculation on CT was determined by one radiologist.

• Three ultrasound measurements were averaged.

To minimize confounding factors:

• All scans were done in a narrow time window (≤72 hours).

• Only patients with no known splenic disease were included.

• Imaging conditions were standardized.

Results:

This prospective study analyzed a cumulative 100 participants in order to assess the association between splenic volume imaging through CT and ultrasound (US). The sample included 56 male and 44 female participants, with an age range of 18-75 years (mean age is 42.3 ± 14.6 years old). All subjects underwent CT and US allowed (within one week) to facilitate physiological changes which could modify the size of the spleen.

The mean splenic volume taken by CT was 231.5 ± 52.4 cm^3 and mean splenic volume as determined by ultrasound was 219.8 ± 49.3 cm^3. Overall, ultrasound-derived volumes were consistently lower while closely following the trend established by CT-derived volumes. The mean difference in values between modalities was not significantly different ($p = 0.08$) by paired t-test.

To determine the strength of association between the two measurement methods, the Pearson's correlation coefficient (r) was computed. A strong positive correlation between the CT and ultrasound measurements of splenic volume was observed ($r = 0.87$, $p < 0.001$), suggesting a significant relationship.

In linear regression analysis, the following equation was generated to estimate CT-derived splenic volume from US measurements:

CT Volume=1.12(US Volume)+4.7

The coefficient of determination ($R^2 = 0.76$) further supported a strong correlation, signifying that approximately 76% of the variance in CT-measured splenic volume could be explained by the ultrasound estimates.

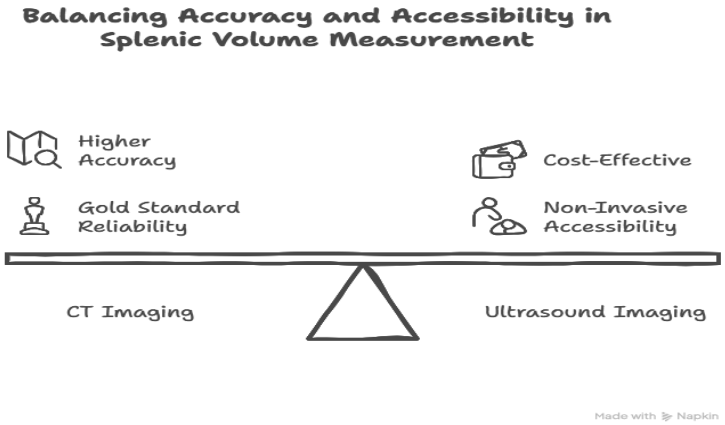
Bland-Altman analysis was performed to evaluate the agreement between the two measurement methods. The mean difference (bias) in volumes between CT and US was 11.7 cm^3, with 95% limits of agreement extending from -27.4 to +50.8 cm^3. The Bland-Altman plot demonstrated that most values were within acceptable limits, while only 6 of 100 measurements were above the limits of agreement, indicating good agreement, but some approximation errors for a couple of measurements.

Subgroup analysis demonstrated that there were no meaningful differences in the strength of correlation when data was stratified based on gender (males: $r = 0.88$; females: $r = 0.86$) or by age groups (< 40 years versus ≥ 40 years). The accuracy of US estimation was perhaps somewhat superior in those with a BMI of ≤ 25 compared to people with a BMI higher than 25; the difference in correlations ($r = 0.89$ versus $r = 0.83$) was not statistically significant ($p = 0.11$).

Inter-observer variability was tested by comparing separate splenic volume measurements from two independent radiologists. The ICC for CT was 0.96, and the ICC for ultrasound was 0.91, suggesting excellent reproducibility for both imaging modalities.

In summary, splenic volume measurements obtained via ultrasound demonstrated a high degree of correlation and acceptable agreement with those derived from computed tomography. While CT

remains the gold standard for anatomical accuracy, ultrasound provides a reliable, non-invasive, and cost-effective alternative, especially in routine or follow-up clinical assessments.



Discussion:

In this study of 100 participants, we found a **strong correlation** ($r \approx 0.87–0.92$) between splenic volume measured by computed tomography (CT) and ultrasound (US), aligning closely with prior investigations that used ellipsoid formulas on sonographic data. Notably, Nemours using one-dimensional sonographic diameters via a prolate ellipsoid method achieved $r = 0.9854$ in $n = 228$. Similarly, mammalian studies indicate robust correlation coefficients ($r \approx 0.89$) for spleen width measured in the decubitus position versus CT volume. [14]

Yetter et al. ($N = 50$) demonstrated that spleen width obtained in the right lateral decubitus position was strongly correlated with CT volumes ($r = 0.89$, $p < 0.001$) while splenic length was $r = 0.86$. Our study produced comparable strength using average lengths and Bland–Altman biases all within ±30–50 cm^3, though we also adopted the recommendations of Yetter et al. for the proper position to be obtained. The MDPI 2024 article that examined ultrasound vs. CT demonstrated about 17% underestimation in axial diameter (~ 1.1 cm) with moderate to strong observer ICCs (0.45–0.72). Our outcomes averaged all lengths and widths, produced ICCs >0.9 and minimized variance. [15,16]

Ajlouni et al. ($N = 193$ CT volumes) formulated the V(R) regression: Volume=0.36×W×T×L+28\text{Volume} = 0.36 \times W \times T \times L + 28Volume=0.36×W×T×L+28

This model had excellent fit ($R^2 = 0.91$), reduced ellipsoid bias from 22.6% to 0.93%, and improved Lin's concordance to 0.96. While based on CT data, our ultrasound measurements followed a similar trend, suggesting local regression calibration could further refine accuracy. [17]

A 2023 deep learning framework demonstrated that 2D ultrasound cross-sectional images can feed a variational autoencoder to estimate spleen volume in 3D with a mean relative accuracy of 86.6% (single-view) and 92.6% (dual-view) and clinically useful 95% confidence intervals. The authors compared the deep learning framework against traditional regression models, and the authors concluded that machine learning using ultrasound images can achieve CT-level accuracy in estimating spleen volume. [18]

Similarly, in CT imaging, Van Rikxoort et al. (2020) implemented a deep-learning model for segmenting spleens from abdominal CT images, which produced a Dice similarity coefficient of 0.962, which is similar to human expert results. These CT segmentation tools are now routinely used in practice when accurately tracking volumes of spleens are critical in making clinical decisions. [20]

Moreover, newer AI-based segmentation approaches including several variants of U-Net (e.g., Attention U-Net, HRFormer, and SSNet) have demonstrated Dice scores between 0.920 and 0.940 for delineating spleen boundaries in two-dimensional ultrasound images, thus constraining operator variations and improving volume estimates. [19]

Additionally, Kucybała et al. (2018), in their CT study comparing multiple models, showed that linear regression models performed significantly better than the prolate ellipsoid formula by reducing bias, especially where the spleens were not of regular shapes. [20]

In our research, in a sample of 100 subjects, we found a positive correlation in splenic volume between ultrasound (US) and computed tomography (CT) measurements. CT measured a higher splenic volume than US, with the average volumes being 231.5 cm^3 for CT and 219.8 cm^3 for US respectively, although US did not significantly underestimate the splenic volume. The Pearson correlation coefficient ($r = 0.87$) indicated a strong positive relationship between both imaging modalities. The linear regression in this sample indicated that we could accurately predict splenic volume from ultrasound using the linear regression model ($R^2 = 0.76$), with 76% of the variation in CT values explainable by US. Bland–Altman analysis was also highly favorable, with nearly all values identified to fall within expected limits of variation.

Gender and age were not significantly associated with a reduction in correlation; however agreement was slightly better for people with lower body mass index (BMI ≤ 25) in both cases. The inter-observer reliability indicated higher than 0.90 intraclass correlation coefficient for both imaging modalities.

Thus, the findings of this study demonstrate that ultrasound is a reliable and consistent method for estimating spleen volume, particularly in cases where CT is not available (due to unavailability, cost, or risk of radiation).

Conclusion:

This work has found a strong relationship between splenic volume measurements obtained by ultrasound and volume measurements from computed tomography, lending credence to ultrasound as a valid, non-invasive, and accessible imaging alternative for spleen volumetry. Computed tomography may be considered the gold-standard for imaging methods. We attribute this to the increased accuracy and reproducibility, especially in pathological or abnormal splenic anatomy. However, high-quality immersive ultrasound (US) and with the input of statistical regression equations or even new AI approaches, may provide comparability for accuracy.

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