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MORPHOMETRIC ASSESSMENT OF SPLENIC DIMENSIONS AND THEIR RELATIONSHIP WITH SPLENIC WEIGHT: A CROSS-SECTIONAL CADAVERIC STUDY

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ABSTRACT

Background: Accurate characterization of splenic size is relevant to anatomical description, radiological interpretation, surgical planning, and assessment of pathological enlargement or atrophy. Cadaveric morphometry provides direct measurements of organ dimensions and permits assessment of relationships among splenic weight, dimensions, and estimated volume. The objective of this study is to describe the morphometric characteristics of formalin-fixed adult cadaveric spleens and to evaluate the relationships of splenic dimensions and gross splenic weight with calculated splenic volume, including the possible association of superior and inferior border indentations with organ volume.

Materials and Methods: Sixty-four formalin-fixed cadaveric spleen specimens were examined. Length, width, thickness, border indentations, and gross splenic weight were recorded. Measurements were obtained using a spreading caliper with rounded measuring points and a graduated scale; weight was measured using a digital balance. The longitudinal length used for volume estimation was defined as L = (ML + CCL)/2, where ML is maximum length and CCL is craniocaudal length. Splenic volume was calculated as $V = 0.524 \times W \times T \times L$. Descriptive statistics, Shapiro–Wilk testing, Pearson and Spearman correlations, Kruskal–Wallis testing, and linear regression with HC3 robust standard errors were performed.

Results: Mean splenic weight was 164.83 ± 79.81 g and mean calculated splenic volume was 119.93 ± 69.97 cm^3. Splenic weight showed a very strong positive correlation with volume (Pearson $r = 0.942$, $p < 0.001$). Length, width, and thickness were also strongly correlated with volume ($r = 0.810$, 0.768, and 0.818, respectively; all $p < 0.001$). Superior and inferior border indentation counts were not significantly associated with volume (Kruskal–Wallis $p = 0.250$ and 0.644, respectively). Splenic volume increased progressively across splenic-weight quartiles (Kruskal–Wallis $H = 47.15$, $p < 0.001$). In simple robust linear regression, splenic weight explained 88.8% of the variance in calculated volume ($R^2 = 0.888$).

Conclusion: Gross splenic weight was strongly associated with calculated splenic volume in this cadaveric series. Length, width, and thickness showed strong bivariate relationships with volume, whereas the number of superior and inferior border indentations did not. These findings support the value of gross splenic weight and basic morphometric dimensions in describing variation in cadaveric splenic size.

Keywords: spleen; cadaveric anatomy; morphometry; splenic volume; splenic weight; anatomical variation.

INTRODUCTION

The spleen is a highly vascular lymphoid organ located in the left upper quadrant of the abdomen, between the diaphragm and the fundus of the stomach and in relation to the left kidney and colic flexure. Its size and shape show substantial anatomical variation, and the organ is clinically important in hematological, immunological, traumatic, and surgical conditions.[1,2] Assessment of splenic size commonly relies on linear dimensions, particularly splenic length, in clinical imaging. Direct volumetric assessment is more comprehensive because organ volume reflects multiple dimensions rather than a single linear measurement. In anatomical research, cadaveric morphometry provides an opportunity to characterize these dimensions directly and to examine how splenic size varies among specimens.[3] Splenic surface morphology is also variable. Notches or clefts are frequently observed along the splenic borders and have traditionally been discussed in relation to developmental morphology. Recent anatomical evidence suggests that splenic surface variation is broad and is not necessarily explained by a simple lobulated developmental origin.[1] Although previous studies have described splenic dimensions and surface variations, the relationship between gross splenic weight and calculated volume in a cadaveric series, together with the contribution of individual dimensions and border indentations, warrants further characterization.[4] Therefore, the present study aimed to describe the morphometric characteristics of 64 formalin-fixed cadaveric spleens and to assess the relationships between splenic weight, linear dimensions, border indentations, and calculated splenic volume.

MATERIALS AND METHODS

This was a cross-sectional descriptive cadaveric morphometric study of 64 formalin-fixed human spleen specimens. The specimens were examined during anatomical study. The present analysis was based on gross morphometric measurements recorded for each specimen. This present study was done on 64 formalin fixed human adult cadaveric spleens of both the sexes obtained from cadavers during routine dissection for undergraduate students in Navodaya Medical College, Raichur, Karnataka. Present study omitted cadavers with any pathologic abnormality and also with any signs of decomposition were ruled out of the study. Instructions of Cunningham's manual of practical anatomy was followed, which directed to pull the greater curvature of the stomach to expose the spleen and the ligaments gastrosplenic and lienorenal which are attached to the hilum. The spleen was separated and stored in 10 percent formalin. Then spleens were examined to determine the presence of splenic notches, length, breadth, thickness and weight. The results were tabulated and analyzed with their variations and compared with available literature.[5]

Morphometric measurements were obtained using a spreading caliper with rounded measuring points and a graduated scale [Figure 1]. The following variables were recorded: maximum length (ML), craniocaudal length (CCL), maximum width (W), maximum thickness (T), superior border indentation count, inferior border indentation count, and gross splenic weight. Weight was measured separately using a digital balance [Figure 2 & 3].[6]

Figure 1: Measurement of a formalin-fixed cadaveric spleen using a spreading caliper with rounded measuring points and a graduated scale. Length- 14.7, width- 8.9 & thickness- 5.6.

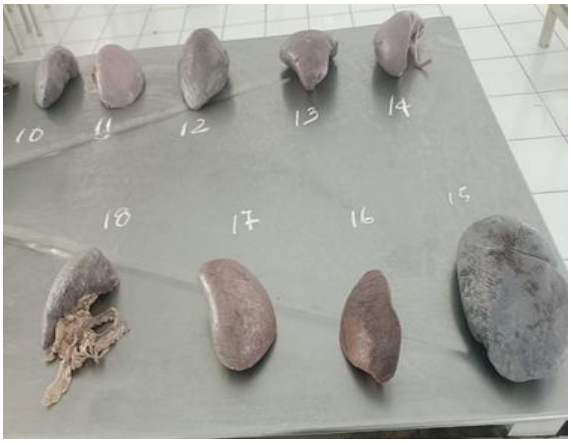

Figure 2: Multiple formalin-fixed cadaveric spleen specimens demonstrating variation in gross morphology and border indentations.

Figure 3. Measurement of gross splenic weight using a digital balance. Weight -409 gm.

For the present dataset, the recorded 'length' variable represents the mean longitudinal dimension derived from ML and CCL:

$L = (ML + CCL) / 2$

This definition is important because the symbol W in the volume equation denotes width, whereas splenic weight is a separate variable.

Calculation of splenic volume

Calculated splenic volume was estimated using an ellipsoid-based formula:

$V = 0.524 \times W \times T \times L$

where V is splenic volume (cm^3), W is maximum width (cm), T is maximum thickness (cm), and L is the mean longitudinal dimension [(ML + CCL)/2]. The constant 0.524 approximates $\pi/6$. Volume values were recalculated from the recorded morphometric measurements for all 64 specimens before statistical analysis.

Statistical analysis: Continuous variables were summarized using mean ± standard deviation (SD), median, interquartile range (IQR), and minimum–maximum values. Distributional characteristics were assessed using the Shapiro–Wilk test. Associations with calculated splenic volume were examined using Pearson correlation and Spearman rank correlation. Because indentation counts are discrete variables and volume distributions were non-normal, differences in volume across indentation-count groups and across splenic-weight quartiles were evaluated using the Kruskal–Wallis test.

A simple linear regression model was used to quantify the association between splenic weight and calculated splenic volume. A multivariable model incorporating splenic weight, length, width, thickness, and superior and inferior indentation counts was also examined. HC3 heteroscedasticity-robust standard errors were used. Multicollinearity was assessed using variance inflation factors (VIFs), and residual diagnostics included the Breusch–Pagan test and Durbin–Watson statistic. Two-sided $p < 0.05$ was considered statistically significant.

RESULTS

Descriptive characteristics: The 64 specimens demonstrated substantial variation in gross splenic size. Mean splenic weight was 164.83 ± 79.81 g, with a median of 141.50 g and a range of 72–409 g. Mean calculated splenic volume was 119.93 ± 69.97 cm^3 (median 99.76 cm^3; IQR 72.28–146.70 cm^3; range 45.55–383.91 cm^3). The distribution of splenic weight and calculated volume was non-normal on Shapiro–Wilk testing, supporting the use of rank-based analyses where appropriate.

[Table 1] summarizes the distribution of the principal morphometric variables. The highest variability was observed for splenic weight and calculated volume. The Shapiro–Wilk results indicate that splenic weight, calculated volume, and indentation counts were clearly non-normal; length also showed a modest departure from normality.

Table 1: Descriptive statistics of splenic morphometric parameters (n = 64).

Variable	N	Mean ± SD	Median	IQR (Q1–Q3)	Range	Skewness	Shapiro–Wilk W	p
Splenic weight (g)	64	164.83 ± 79.81	141.50	102.75–198.25	72–409	1.23	0.886	<0.001
Length, L (cm)	64	9.69 ± 1.65	9.60	8.58–10.80	6.40–14.70	0.51	0.959	0.032
Width, W (cm)	64	6.82 ± 1.36	7.05	5.70–7.83	3.90–9.10	−0.26	0.966	0.072
Thickness, T (cm)	64	3.24 ± 0.85	3.30	2.58–3.63	1.50–5.60	0.55	0.964	0.059
Calculated volume (cm^3)	64	119.93 ± 69.97	99.76	72.28–146.70	45.55–383.91	1.85	0.830	<0.001
Superior indentations (n)	64	1.66 ± 1.44	1.00	1.00–2.25	0–5	0.83	0.876	<0.001
Inferior indentations (n)	64	0.69 ± 0.99	0.00	0–1	0–4	1.48	0.706	<0.001

Correlation of morphometric variables with splenic volume: Splenic weight showed the strongest bivariate association with calculated splenic volume (Pearson $r = 0.942$; Spearman $\rho = 0.909$; both $p < 0.001$) [Table 2]. Length, width, and thickness were also strongly positively associated with volume. In contrast, neither superior nor inferior border indentation count showed a meaningful association with volume.

Table 2: Bivariate associations between splenic morphometric variables and calculated splenic volume.

Parameter	Pearson r	Pearson p	Spearman ρ	Spearman p
Splenic weight	0.942	<0.001	0.909	<0.001
Length, L	0.810	<0.001	0.761	<0.001
Width, W	0.768	<0.001	0.864	<0.001
Thickness, T	0.818	<0.001	0.730	<0.001
Superior border indentations	0.128	0.312	0.037	0.771
Inferior border indentations	0.025	0.847	−0.034	0.792

Splenic volume across splenic-weight quartiles: To examine the relationship without assuming linearity, specimens were divided into four equal groups according to splenic weight [Table 3]. Mean volume increased progressively from 62.47 cm^3 in Q1 to 207.97 cm^3 in Q4. The between-quartile difference was statistically significant (Kruskal–Wallis H = 47.15, $p < 0.001$).

Table 3: Calculated splenic volume across quartiles of splenic weight (16 specimens per quartile).

Weight quartile	Splenic-weight range (g)	Mean volume (cm^3)	SD	Median volume (cm^3)	Volume range (cm^3)
Q1	72–99	62.47	20.81	53.60	45.55–113.42
Q2	104–141	89.46	23.58	87.05	61.94–144.80
Q3	142–196	119.81	28.79	123.21	77.47–171.19
Q4	205–409	207.97	77.25	174.93	137.23–383.91

Border indentation analysis: Calculated splenic volume did not differ significantly across categories of superior border indentation count (H = 6.62, p = 0.250) or inferior border indentation count (H = 1.67, p = 0.644). The distribution of volume across individual indentation categories is shown in [Table 4].

Table 4: Calculated splenic volume according to the number of border indentations. Kruskal–Wallis H and p values are shown for each indentation series.

Border	Indentation count	N	Mean volume (cm^3)	SD	Median (cm^3)	H	p
Superior	0	14	123.72	57.27	117.88	6.62	0.250
	1	22	110.50	73.99	93.80		
	2	12	121.02	84.40	103.00		
	3	8	107.55	49.15	107.59		
	4	4	97.04	37.41	100.13		
	5	4	202.86	78.33	218.39		
Inferior	0	38	114.83	53.53	99.34	1.67	0.644
	1	12	127.13	85.84	121.67		
	2	12	136.89	100.34	102.17		
	4	2	71.69	30.95	71.69		

Regression analysis: In the simple regression model, splenic weight was strongly associated with calculated volume [Table 5]. The model explained 88.8% of the observed variance ($R^2 = 0.888$; adjusted $R^2 = 0.886$). The coefficient for splenic weight was 0.826 cm^3/g (95% CI 0.693–0.959; $p < 0.001$).

Table 5: Simple linear regression of calculated splenic volume on splenic weight using HC3 robust standard errors.

Predictor	Coefficient (cm^3)	HC3 robust SE	95% CI	p
Intercept	−16.255	10.059	−35.971 to 3.461	0.106
Splenic weight (g)	0.826	0.068	0.693 to 0.959	<0.001

A multivariable model including splenic weight, length, width, thickness, and indentation count explained 97.4% of the variance (adjusted R^2 = 0.971). However, length, width, and thickness showed marked multicollinearity (VIF 54.78, 57.03, and 22.28, respectively) [Table 6]. Because these dimensions are themselves components of the formula used to calculate splenic volume, the full model should be interpreted as an exploratory analysis rather than evidence that each dimension independently determines volume [Table 7].

Table 6: Exploratory multivariable regression model with HC3 robust standard errors.

Predictor	Coefficient	HC3 robust SE	95% CI	p	VIF
Splenic weight	0.272	0.077	0.122 to 0.423	<0.001	12.53
Length, L	12.197	2.223	7.840 to 16.554	<0.001	54.78
Width, W	6.400	3.123	0.279 to 12.521	0.040	57.03
Thickness, T	35.199	3.092	29.138 to 41.259	<0.001	22.28
Superior indentations	−0.062	1.096	−2.210 to 2.086	0.955	2.42
Inferior indentations	3.410	2.087	−0.681 to 7.501	0.102	1.55

Table 7: Diagnostic characteristics of the exploratory full regression model.

Diagnostic metric	Value	Interpretation
Sample size	64	All specimens had complete values for the analyzed variables.
R^2	0.974	97.4% of variance explained by the full model.
Adjusted R^2	0.971	Adjusted for number of predictors.
Breusch–Pagan LM	24.87	p = 0.00036; evidence of heteroscedasticity.
Durbin–Watson	1.971	No obvious residual autocorrelation.

DISCUSSION

The principal finding of this study was the strong association between gross splenic weight and calculated splenic volume. The Pearson correlation of 0.942 and the simple regression R^2 of 0.888 indicate that heavier spleens in this cadaveric series generally had substantially larger calculated volumes. This relationship is anatomically plausible because organ weight reflects the overall amount of splenic tissue and blood content present at the time of examination. The strong correlations observed for length, width, and thickness should be interpreted in the context of the volume equation used in this study. Calculated volume was directly derived from these dimensions; therefore, strong correlations are expected and should not be interpreted as independent causal relationships. The exploratory multivariable model demonstrated this issue clearly, with VIFs exceeding 20 for length, width, and thickness. For this reason, the simple splenic-weight model provides a more interpretable summary of the principal association.[4]

Splenic surface indentations showed no statistically significant relationship with calculated volume. This finding suggests that the number of visible superior or inferior border indentations is primarily a feature of surface morphology rather than a useful proxy for overall organ size in this series. The finding is consistent with the concept that splenic surface morphology can vary considerably among individuals without necessarily reflecting total organ dimensions.[7,8]

The quartile analysis further supported the weight–volume relationship. Mean calculated volume increased from 62.47 cm^3 in the lowest splenic-weight quartile to 207.97 cm^3 in the highest quartile. The statistically significant Kruskal–Wallis result demonstrates that the association was not confined to a single extreme group.

The findings should nevertheless be interpreted within the limitations of cadaveric morphometry. Formalin fixation may alter tissue dimensions and weight, and the sample may not represent the living population. In addition, donor age, sex, cause of death, fixation duration, and other biological variables were not available in the dataset supplied for this analysis. Calculated rather than directly measured displaced volume was used, and the derived volume is dependent on the accuracy of the recorded dimensions.[9,10]

Strengths and limitations: The principal strengths are the relatively complete morphometric dataset, standardized use of a spreading caliper and digital balance, recalculation of volume from the recorded dimensions, and use of both parametric and non-parametric association measures. The main limitations are the cadaveric design, possible effects of formalin fixation, limited sample size, absence of donor demographic variables in the supplied dataset, and the mathematical dependence of calculated volume on length, width, and thickness. The absence of donor body weight should also be noted; the weight analyzed in this manuscript is gross splenic weight.

CONCLUSION

In this series of 64 formalin-fixed cadaveric spleens, gross splenic weight showed a very strong positive association with calculated splenic volume. Splenic length, width, and thickness were also strongly correlated with volume, while superior and inferior border indentation counts were not. The progressive increase in volume across splenic-weight quartiles reinforces the weight–volume relationship. For interpretation and reporting, splenic weight appears to be a useful summary measure of overall organ size, whereas border indentation count does not appear to provide a meaningful estimate of splenic volume.

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