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Determination of normal splenic volume on computed tomography in relation to age, gender and body habitus

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Abstract. The purpose of our study was to examine variations in normal splenic size in relation to age, gender and body habitus in vivo, and to determine normative data for splenic volume on CT. The width (W), length (L), thickness (Th), cross-sectional areas and volume (Vol) of the spleen were obtained from abdominal CT examinations of 140 patients who underwent CT for indications unrelated to splenic disease. Splenic volume did not vary significantly ($-0.04 < r < 0.05$, $p > 0.10$) with the patient's age, gender, height, weight, body mass index or the diameter of the first lumbar vertebra, the latter considered as representative of body habitus on CT. The mean value of the measured splenic volume (S Vol) was 214.6 cm^3 with a range from 107.2 to 314.5 cm^3. S Vol correlated well with all the linear and the maximal cross-sectional area measurements and could be calculated using the formula: S Vol = 30 + 0.58 (W × L × Th.). Employing the same formula splenic volume was reliably assessed in 47 patients with clinically evident splenomegaly. Quantitative assessment of splenic volume might be of value in assessing mild variations in splenic size, because splenomegaly is the most common manifestation of splenic involvement in many disorders.

Key words: Spleen – CT – Volume determinations

Introduction

The spleen is involved in a wide spectrum of abnormal conditions including acute and chronic infections, immunological and circulatory disorders, and haematopoietic and storage diseases [1]. The most common pathological finding in these conditions is an increase in organ size [2]. In vivo, only significant splenic enlargement can be diagnosed clinically [3, 4]. Splenic size can be reliably evaluated in vivo employing imaging methods [5–8]. There are however, problems in definition of splenomegaly [9]. In regular practice splenic enlargement on CT is diagnosed on the basis of subjective or crude criteria, i.e. when spleen extends below the ribs or accounts for more than two thirds of the distance between the posterior and anterior abdominal wall [3, 10]. The product of the width, the thickness and the length of the spleen (the so-called "splenic index") has also been proposed as an indicator for evaluating splenic size on CT [11]. Nevertheless, size criteria being widely accepted for assessing splenic involvement on CT are still to be established. The purpose of this study was to determine the volume of the normal spleen in vivo by CT and its variations in relation to age, gender and body habitus.

Materials and methods

The study comprised abdominal CT examinations of 140 consecutive patients with diseases which could not influence the spleen; 28 patients (16 men and 12 women) were 20–40 years old, 37 (16 men and 21 women) 40–60 years old, 62 (36 men and 26 women) 60–80 years old and 13 (5 men and 8 women) over 80 years old. Patients with clinical or laboratory evidence of infection, lymphohaematogenous disorders, immunological conditions, portal hypertension, ascites and cardiac or renal failure were not included in this study. Abdominal CT did not reveal any abnormality in the spleen, the pancreas or the liver – except for small simple cysts or haemangiomas – or findings which may influence the shape or the position of the spleen.

The CT examinations were performed during the past 3 years on a Philips LX CT scanner (Philips, Eindhoven, The Netherlands) with axial 10-mm consecutive sections and the patient in deep expiration. Employing the CT software splenic parenchyma area was measured in all CT sections of each examination (Fig. 1). Splenic volume was calculated by summing up the consecutive

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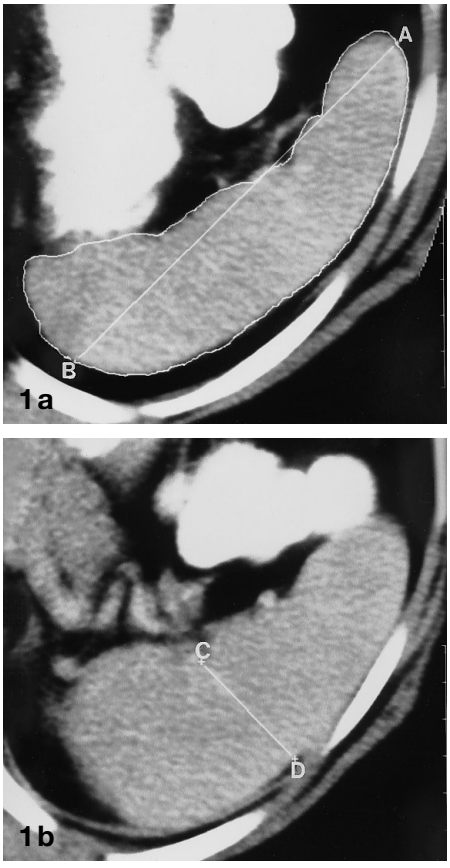

Fig 1. Measurements of **a** the maximal width *(A–B)* and a cross-sectional area of the spleen, and **b** the thickness at hilum *(C–D)* determined on a plane perpendicular to maximal splenic width and through the hilum

splenic areas after taking into account the slice thickness [7]. In each CT examination were also measured: (a) the maximal width (W) of the spleen, determined as the largest diameter on any transverse section (Fig. 1); (b) the maximal thickness (Tm), defined as the largest distance between the inner and outer borders of the spleen perpendicular to the plane of the maximal width; (c) the thickness at hilum (Th), determined as the distance between the inner and outer borders of the spleen on a plane perpendicular to the splenic width and through the hilum; and (d) the transverse diameter of the first lumbar vertebra (dL1), which is considered to represent patient's body habitus on CT [12, 13]. Splenic height or length (L) was assessed from the number of consecutive CT sections through the spleen. The height (He) and weight (We) of each patient were noted and the body mass index (BMI) was calculated according to the formula: $BMI = He/We^2$.

Splenic volume and linear measurements of the spleen were related to each other and to the age, He, We, BMI and dL1 of the patients, employing Pearson's correlation coefficient. Splenic volume of men was compared with those of women in the age groups utilizing the student's *t*-test.

Additionally, we performed calculations of the splenic volume using linear measurements, in order to determine a convenient method for assessing splenic volume in regular practice. The reliability of this latter method was tested in 47 abdominal CT examinations of patients with clinically evident splenomegaly, diagnosed by palpation.

Statistical analysis was performed on a computer employing the SPSS statistical package [14].

Results

The volume of the normal spleen did not correlate with individual's age ($r = -0.04$, $p > 0.10$), height ($r = 0.05$, $p > 0.10$), weight ($r = 0.01$, $p > 0.10$), body mass index ($r = 0.03$, $p > 0.10$) or with the transverse diameter of the first lumbar vertebra ($r = 0.05$, $p > 0.10$). The mean value of calculated splenic volume was 214.6 cm^3 with a range of 107.2 to 341.5 cm^3. Splenic volume was not shown to differ between men and women ($p > 0.10$) in the 20–40, 40–60, 60–80 year age groups, whereas the corresponding overall mean values were very close to each other: 215.1 cm^3 for men and 214.0 cm^3 for women.

Positive correlations at statistically significant level ($p < 0.001$) were found between the splenic volume and the width ($r = 0.64$), maximal thickness ($r = 0.68$), thickness at hilum ($r = 0.70$), length ($r = 0.81$) or maximal cross-sectional area ($r = 0.83$), defined as the larger area among all the cross-sectional areas of each patient. The product of L × W × Th presented the highest correlation with splenic volume ($r = 0.94$) among all the combinations of linear measurements. The width to maximal thickness ratio was 1.85 (range 1.12–3.15), the length to maximal thickness ratio was 1.52 (range 0.54–2.44) and the width to length radio 1.27 (0.44–2.37). The wide ranges of these ratios are indicative of the significant variations in the shape of the spleen.

The volume of the spleen (S Vol) was computed employing the formula:

$S\ Vol = 30 + 0.58\ (W \times L \times Th)$ (in cm^3)

The splenic volume calculated by this formula and the actual volume of the spleen assessed by the summation-of-areas technique exhibited strong correlation to each other in both, the group of the 140 patients with normal spleens ($r = 0.97$, $p < 0.001$), and in the group of the 47 patients with splenomegaly ($r = 0.94$, $p < 0.001$). The mean differences between the calculated S Vol, employing the proposed formula and the S Vol measured by the summation-of-areas technique, was approximately 6 and 5 % of the mean volume in the groups of normal and enlarged spleens, respectively.

Discussion

The average weight of the spleen in the adult, determined on operative specimens or autopsy material, has been approximated 150 g (range 100–250 g) [2, 11]. The weight or volume of an excised spleen differs from that in vivo, influenced by the quantity of entrapped blood within it, circulatory conditions during surgery, timing and duration of vessel clamping or uncontrolled loss of

blood from the specimen before it is weighted [3]. It has been anticipated that the spleen weighs 25% more in vivo because of the dynamical nature of its blood supply [1]. According to the results of the present study the mean weight of the normal spleen in vivo is 225 g (range 112–359 g), considering a specific gravity for the spleen of approximately 1.05 g/ml [11]. Consequently, the weight of the spleen in vivo may be as more as 50% than that found on autopsy material. Thus, it appears that the splenic volume in vivo cannot be satisfactorily compared with the weight or volume of an excised spleen.

Variations in splenic volume in vivo were not observed in the present study. The CT studies on other intra-abdominal organs, such as the kidney and the pancreas, have shown morphological alterations and reduction in the amount of parenchyma with advancing age [12, 13]. Although it is well known that age is an important factor in the involution of many organs, the spleen may be an exception to this rule: Histopathological studies have not shown significant changes in the functional components of the spleen in the elderly [1]. According to the results of the present study splenic volume is not dependent on physical data because it was not related to patient's height, weight, body mass index or L1 diameter. The latter has shown to correlate well with the size of other parenchymal organs, namely the kidneys and the pancreas, and it is currently considered as an "internal standard" on CT, representative of body habitus [12, 13]. Additionally, splenic volume did not differ between men and women. This is in agreement with previous studies based on linear measurements of the spleen in ultrasonograms [6, 15].

Computed tomography is considered a reliable method for assessing the volume of the spleen [3] and/or other intra-abdominal organs[7, 16] in vivo. In studies comparing CT volumetrical measurements of intra-abdominal organs in animals, cadavers or patients prior to splenectomy, with the corresponding actual volumes determined by water displacement, a 4% mean error was verified when using the summation of areas technique [7, 16]. Spiral CT avoiding errors due to respiratory movements is expected to be even more accurate in assessing splenic volume. Although the summation-of-areas technique has been applied for measuring the splenic volume [7, 8, 11] the corresponding normative data has not been previously established. However, measuring the splenic volume by that technique is cumbersome for use in regular practice. A reliable assessment of splenic volume can be achieved conveniently by employing the proposed formula, which provides splenic volume measurements in cubic centimetres very close to the actual splenic volume. The accuracy of this formula was tested on CT examinations of patients with normal spleen and in patients with palpable spleen, namely mild to severe splenomegaly. It has been anticipated that evaluation of splenic volume can also be performed employing the splenic index – the product of the three diameters of the spleen – with accepted normal range from 120 to 480 [3, 11]. However, estimation of splenic volume in cubic centimetres by the proposed formula might be preferable to a representative index and also might provide a less wide range of normal values.

Although the spleen is affected by many disorders, some of them being common, the relative published radiological experience is limited. This might be partially explained by the non-utilization of simple, reliable and reproducible methods of evaluating the amount of splenic parenchyma, because the latter is the most commonly influenced morphologic parameter. Quantitative assessment of splenic volume in vivo might be of value in such clinical or research applications.

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