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Estimation of spleen volume using MR imaging and a random marking technique

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Abstract. The aim of this study was to apply a random marking volumetric technique in MR images for estimation of spleen volume. The MR imaging was performed in phantoms and 16 patients with indications unrelated to splenic disease. Images were transferred to a workstation to perform volumetric measurements using the random marking technique and the conventional technique of manual planimetry. Two observers independently measured splenic volume in order to evaluate reproducibility of both volumetric techniques. Phantom experiments revealed that the accuracy of the random marking technique and manual planimetry was approximately the same. In vivo splenic volume measurements derived from both volumetric techniques were highly correlated ($r = 0.99$, $p < 0.0001$). For both observers intraobserver variation was found to be lower with the random marking technique than with manual planimetry. Interobserver coefficient of variation using the manual planimetry was 4.6 % and was reduced to 2.9 % by adopting the random marking technique. The random marking technique was almost two times faster than the manual planimetry. The combination of the random marking technique with MR imaging might provide accurate, reproducible, quick splenic volume estimations.

Key words: Volume measurement – Spleen – MRI

Introduction

The increase of splenic size, known as splenomegaly, is a manifestation strongly related with a variety of diseases [1, 2, 3]. Evaluation of splenomegaly using palpation is difficult and may lead to inaccurate diagnosis [4]. Accurate measurements of splenic volume is an important parameter in diagnosing splenomegaly and in improving therapeutic management of patients. Splenic volume measurements have already been reported using magnetic resonance (MR) data. Most of the volumetric studies have been performed using the conventional technique of manual planimetry based on the user's ability in precisely tracing the organ boundaries in all MR sections [5, 6, 7]. The volume index of the spleen has also been used to predict organ size [8]; however, splenic volume estimations based on simple linear measurements in MR data may provide a number related to the size of the organ of interest and not an accurate volumetric measurement [8]. To our knowledge, the application of the random marking technique in a series of MR slices for the estimation of spleen volume has not been investigated. This technique is independent on the operator's outlining dexterity. It has been applied in several studies using tomographic sections [9, 10, 11].

The purpose of the present study was to investigate whether the combination of MR imaging and the random marking technique can provide efficient splenic volume estimations.

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Materials and methods

Patient study

Sixteen adult patients (10 men and 6 women) without a known history of splenic disease underwent abdominal MR examinations using a 1.5-T unit (Magnetom Vision Plus, Siemens, Erlangen, Germany). Standard quadrature radio-frequency body coil was used for both excitation and signal detection. Splenic shape and position appeared normal in all patient examinations. The axial T1-weighted gradient-echo images from which splenic volume was calculated were obtained from a breathhold 2D fast low-angle shot (FLASH) technique (TR/TE/flip angle: 168 ms, 4.1 ms, 90 °). High-performance gradients (23 mT/m) and a relatively long receiver bandwidth (260 Hz/pixel) were used to increase the number of slices in the selected TR and minimize chemical shift artifacts. The slice thickness was 8 mm, with an interslice gap of 2 mm. A rectangular field of view covering an area of 25×50 cm^2 was used. The image reconstruction matrix was 128×256 pixels, compromising for a square pixel matrix. The mean whole-body specific absorption rate value for the aforementioned imaging sequence parameters never exceeded the value of 3 W/kg. Splenic volume measurements were performed using the random marking technique and manual planimetry. The aforementioned volumetric techniques are available in the Analyze software (Mayo Foundation, Rochester, Minn.) running on a SUN Sparc 5 computer workstation (Sun Microsystems, Mountain View, Calif.).

Random marking technique

The current volumetric technique randomly marks voxels in a 3D array of known size. The voxels appear as colored points in all sections imaging the object of interest. The user can select the marked voxels which lie inside the object being measured in each section. The ratio of the marked voxels on the object to the total number of marked voxels within the 3D array provides an estimation of the object's volume; therefore, if a sufficient number of voxels (P_t) are randomly marked within the total volume (V_t) and the number of voxels falling inside the object of interest is P_{obj}, then the object's volume (V_{obj}) is referred to as a fraction (V_v) of V_t:

$$V_v = V_{obj}/V_t \cong P_{obj}/P_t \quad (1).$$

According to the binomial distribution [12], the standard error (SE) of the foregoing volume estimation is given by the following equation:

$$SE = [V_v (1 - V_v)/P_t]^{½} \quad (2).$$

The relative standard error (RSE) is equal to:

$$RSE = (SE/V_v) \times 100\,\% \quad (3).$$

To reduce the SE of the foregoing volume estimations, the object of interest must comprise as large a portion of the total volume as possible. The MR slices not imaging the spleen at the beginning and at the end of the examination were ignored. This means that voxels were not marked in the above slices. For each patient examination, a reference image was interactively selected from any of the several middle images in which the spleen appeared to have the larger size. A subregion fully encompassing the spleen in the reference image was manually traced. The same subregion was automatically transferred in all MR slices imaging spleen (Fig. 1); therefore, a subvolume encompassing the spleen was defined.

Splenic volume was measured by applying the random marking technique in the foregoing slice data sets (Fig. 2). The operator interactively selected the voxels hitting the spleen in each slice. The total number of voxels within the spleen boundaries was automatically calculated by the computer software.

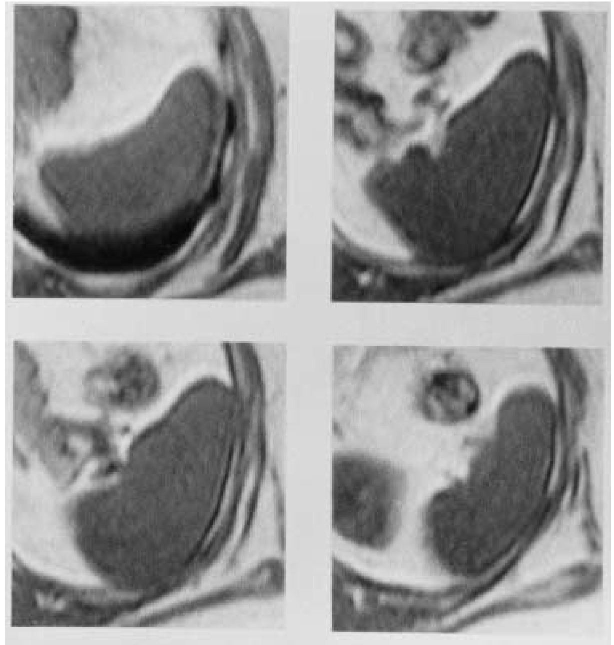

Fig. 1. Four MR slices derived by the procedure of defining a subvolume around the spleen

Fig. 2. Voxels illustrated as *white dots* are randomly marked on an MR slice

The total number of voxels (P_t) that should be marked was correlated with the quantities V_V and SE as shown in Eq. (2). An RSE of 5 % is considered as sufficient for volume estimations using the random marking technique [9]. The fraction (V_v) of spleen volume to the total volume was expected to be more than 25 % of V_t. Considering that V_V was equal to 0.25, the optimal number of marked voxels (P_t) which can yield an RSE of 5 % was 1200 using Eqs. (2) and (3).

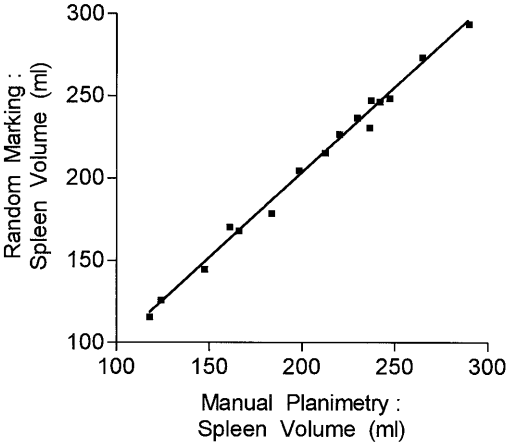

Fig. 3. Correlation of in vivo splenic volume estimations using random marking and manual planimetry

Table 1. Water volume estimations using the random marking technique and manual planimetry

	Volumetric technique	
True water volume (ml)	Manual planimetry	Random marking
150.0	148.1 (1.3)	152.4 (1.6)
200.0	204.2 (2.1)	204.5 (2.2)
250.0	256.5 (2.6)	256.1 (2.4)

Numbers in parentheses denote the percentage volume difference from the true water volume

Manual planimetry

Manual planimetry is the conventional technique for measuring spleen volume in our department. To simulate routine volume measurements, splenic volume was estimated using the initial MR slices and not those provided by defining a subvolume around the spleen. Spleen boundaries were manually traced on a slice-by-slice basis. The area within the trace was automatically calculated using the Analyze software. The sum of the areas was multiplied by the slice thickness to provide the total spleen volume. For all volume estimations using both techniques, the section thickness was considered to be 10 mm [13]. The spleen volume measurements obtained from the random marking technique were compared with those obtained from the manual planimetry. All the aforementioned measurements were performed by a senior radiologist.

Phantom study

Measurement accuracy of both random marking technique and manual planimetry was evaluated relative to measurements of three balloons containing a known water volume of 150, 200, and 250 ml. We chose to fill the balloons with these volumes of water in order to resemble typical spleen volumes. They were individually scanned with the MR imaging technique used for patient examinations. To estimate water volume using the random marking technique, 1200 voxels were also marked.

Measurement reproducibility

The senior radiologist was asked to measure spleen volume of all the patients three more times with both the random marking technique and the manual planimetry; thus, the radiologist totally estimated spleen volume four times with each volumetric technique. Moreover, a medical physicist familiar with spleen anatomy measured spleen volume of the 16 patients examined using the random marking technique and manual planimetry, four times with each volumetric technique. The medical physicist was blinded to the volumetric results obtained from the radiologist. Intraobserver variation of the random marking technique and manual planimetry was assessed for both observers.

For each patient an average splenic volume was obtained from the four consecutive volume measurements performed by the radiologist using the random marking technique. This was repeated for the medical physicist. The aforementioned average splenic volume measurements derived from the two observers were used to evaluate interobserver variation using the random marking technique. The same procedure was followed in order to find interobserver variation for the conventional technique of manual planimetry. Intra- and interobserver variation were expressed as coefficient of variation (CV) values.

Results

Phantom and patient study

Phantom experiments revealed that the accuracy of the random marking technique and the manual planimetry was almost the same (Table 1). Then accuracy of both volumetric techniques was reduced as water volume increased. The mean value of the estimated splenic volume of all the patients using the random marking was 208.0 ml with a variation from 115.7 to 293.6 ml. The application of the manual planimetry to the complete MR slice data set provided a spleen volume range from 117.9 to 289.8 ml with a mean volume of 204.8 ml. An excellent correlation was found among the two volumetric techniques ($y = 1.033 \times -3.69$, $p < 0.0001$, $r = 0.99$; Fig. 3).

Measurement reproducibility

For both observers intraobserver variation was less with the random marking than with the conventional technique of manual planimetry (Table 2).

Interobserver coefficient of variation value using the manual planimetry was 4.6 %. The corresponding interobserver CV value using the random marking technique was considerably reduced to 2.9 %.

Table 2. Intraobserver coefficient of variation values (%) for splenic volume estimations using the random marking technique and manual planimetry

	Observer	
Volumetric technique	Medical physicist	Radiologist
Manual planimetry	2.7	3.0
Random marking	1.6	2.1

Time expenditure

The mean time needed for splenic volume estimations using the random marking technique was 3.5 min, whereas the corresponding time using manual planimetry was 6.9 min. The foregoing time measurements included the time required to apply corrections or to reiterate splenic volume assessments in any MR section, for both volumetric techniques. For manual planimetry, the corrections refer to the reiteration of tracing of spleen boundaries in any MR section whenever the results were not satisfactory. With regard to the random marking technique, corrections were needed during the procedure of defining a subvolume around the spleen from the original MR slice data set. In 4 patients parts of spleen were not included in the new slice data set and the aforementioned procedure was reiterated.

Discussion

A wide variety of imaging modalities, including conventional radiography [14], nuclear scintigraphy [15], sonography [16, 17], and computed tomography [18, 19], have already been used to measure splenic volume. Most of them have certain disadvantages in providing accurate volume estimations of the spleen. Radiography and scintigraphy assume a regular geometric shape of the spleen and only linear measurements are performed; however, spleen is characterized by its irregular shape which varies widely among individuals. Moreover, measurements of spleen volume using sonography are often limited by the incomplete scanning of the spleen or by the incomplete visualization of the organ due to the presence of overlying structures and by the observer skill in recognizing organ boundaries [4, 18].

Computed tomography has been considered as a reliable modality for imaging spleen and provides reliable splenic volume estimations [20]; however, MR imaging seems to offer potential advantages over CT, namely the use of non-ionizing radiation and its superior ability in demonstrating and characterizing soft tissues [21, 22].

The random marking technique was compared with the conventional technique of manual planimetry for measuring spleen volume from MR images. Phantom experiments showed no difference in the accuracy of both volumetric techniques. Splenic volume estimations generated by the random marking technique in vivo were highly correlated with those measured by the manual planimetry. The proposed technique was almost twice as fast as the manual planimetry. Moreover, the random marking was found to be more reproducible than the manual planimetry in terms of intra- and interobserver variation.

The reliability of the random marking technique depends on the observer skill to define the real splenic boundaries. Magnetic resonance imaging provides an excellent contrast between the spleen and the adjacent soft tissues; however, motion artifacts caused by patient respiration during scanning time might blur the spleen images. Fast scanning techniques can be used to minimize these artifacts. The MR imaging technique used in the present study allowed generation of 20 images during a single breathhold with a total acquisition time of 20 s. This technique proved to be valuable for reducing the contribution of respiration in MR abdominal images. Splenic volume estimations might also be dependent on slice thickness, slice orientation, and imaging sequence type. No attempts were made to evaluate the influence of the aforementioned factors on the accuracy of splenic volume estimations, since the purpose of the present study was to adapt an efficient volumetric technique to the specific abdominal MR imaging technique routinely applied in our department; however, the excellent agreement of the volume estimations obtained from the random marking technique with the true water volume observed in phantom experiments suggests that the current method is sufficiently accurate for clinical purposes.

Reported experience has suggested that the standard error of volume estimations using the random marking technique can be reduced by increasing the total number of marked voxels within the 3D array [9]. This can be the current practice for measuring volumes of large organs. For small organs having a low V_v value, a large number of voxels should be marked in order to obtain volume estimations with acceptable errors. This would result in a time-consuming volumetric technique requiring the maximum user interaction. We consider that the random marking technique should be applied in predefined volumes where the V_v of the organ of interest would be as large as possible. To increase the V_v of a specific organ, the tomographic slices which do not depict the organ of interest must be removed. Among the other slices, a subvolume containing the organ of interest should be determined. This process allows application of the random marking technique in a new set of slices where the V_v would be approximately maximum and subsequently the standard error of the volume estimations would be minimized; therefore, counting numerous points would not be necessary to add a significant precision to volume assessments.

The present study was limited by the relatively small number of patients included. Another limitation concerned patient selection criteria. This study was limited to patients with normal spleens undergoing abdominal MR examination. A prospective study in a large population, including patients presenting with splenomegaly or other abnormalities of the spleen, is required to evaluate the efficiency of the suggested volumetric technique.

The preliminary results reported in this study are very encouraging. The combination of the random marking technique and MR imaging might provide quick, accurate, and reproducible volume estimations of the normal spleen. The suggested volumetric technique is simple and it might be considered as unbiased taking into account the random marking of voxels in all MR slices imaging spleen. The random marking appears to be an improvement over the conventional technique of manual planimetry for the measurement of spleen volume.

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