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Measurement of Liver Volume by Ultrasound and Computed Tomography

P. Fritschy, MD, G. Robotti, MD, G. Schneekloth, MD, and P. Vock, MD

Abstract: A morphometric method to calculate liver volumes from transverse sections is evaluated (point-integrating method). In the first part of the study, 10 liver specimens were investigated by computed tomography (CT) and ultrasound (US); the calculated volumes were compared to the volumes obtained by water displacement of the organs. While CT showed an ideal agreement ($r = 0.994$), volumes calculated from US sections correlated less well (percentage differences from +12.5% to −9%, $r = 0.915$). In the second part of the study, the livers of 10 randomly selected patients were investigated by CT and US. Liver volumes were calculated using the point-integration method. Compared to the CT examination, US results show a good correlation with a correlation coefficient of $r = 0.977$. The point-integration method is very valuable to measure organ volumes from transverse sections. The method can be applied "offline" to photographic films, data do not have to be recorded electronically. The time required to calculate the volume of an organ is comparable to other methods. **Indexing Words:** Ultrasound · Computed tomography · Liver volume · Morphometric methods

Liver volume is an important parameter in various hepatic diseases and is of particular value in follow-up examinations during treatment.[1,2] Judgment of liver size by palpation or percussion is subjective.[3,4] A more precise estimation of liver size is available using one or more diameters, e.g., cranio-caudal, anterior-posterior, and transverse diameters.[5–9] Sonography (US) and computerized tomography (CT) provide transverse sections of parenchymal organs and thus display the anatomical data for morphometric analysis.

Although the basic principles of morphometry were first published in 1847,[10] the method was not used in medicine until Hennig[11] and Weibel[4,12–14] developed appropriate techniques for the analysis of microscopic structures. CT evaluation programs for organ volume measurements are also based on morphometric principles;[15,16] volume measurements of liver and spleen with this technique have been described.[17–19] The application of morphometric volume measurement to sonography has not yet been systematically evaluated. In this study the volume of postmortem livers was estimated by sonographic and by CT morphometry. In order to establish the accuracy of these methods, the results obtained were compared to the liver volumes determined by water displacement.

MATERIAL AND METHODS

In the first part of this study, 10 liver specimens were scanned in transverse sections by US and CT. The livers studied were fixed in formalin; prior to the examination they were put into water for 10 days to wash out the formalin and to establish more physiological conditions. At the time of the scans, the weight of the livers ranged from 750 g to 1340 g. The CT study was done with a fanbeam-scanner (Somatom SF, Siemens, Erlangen, GFR), the sonographic study with an automatically operated 8-head-compound-scanner (Octoson, Ausonics, Australia). The interscan distance was 10 mm for both methods. The CT sections, stored on floppy disks, were first evaluated with the area-measuring program of the scanner,[15,16] then copied on film with unchanged window setting; from these films the areas were measured using the point-integrating method.[13,14] The sonographic tomograms were analyzed using the point-integrating method.[13,14] The reference volumes of the 10 in vitro livers were measured by water displacement of the organ.

From the Department of Diagnostic Radiology, University Hospital, Inselspital, Bern, Switzerland (Director: Prof. Dr. W. A. Fuchs). Manuscript received April 30, 1982; revised manuscript accepted March 21, 1983. For reprints contact P. Fritschy, Department of Diagnostic Radiology, University Hospital, Inselspital, Bern, Switzerland.

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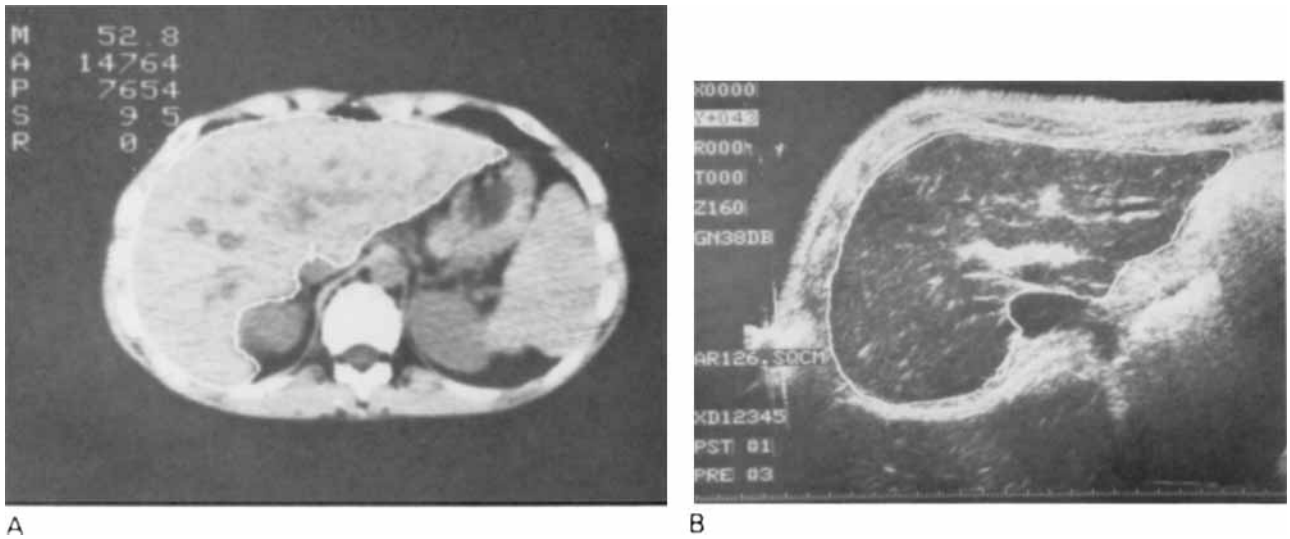

FIGURE 1. Area measuring program in CT (**A**) and US (**B**). Demarcation of the liver contour by a light pen and joy stick, respectively. For evaluation of the liver volume, the obtained areas are summarized and multiplied by the interscan distance.

In the second part of this study, the liver of 10 randomly selected patients was investigated by US and CT; again the interscan distance was 10 mm for both methods. Since the goal of the article was to evaluate a method to measure liver volumes rather than to show a clinical application, no selection of patients or specific pathology was made.

In the area-measuring program, the liver contour was delineated on the CRT screen with the use of a light pen (Fig. 1). The computer calculated the area of the selected region of interest. The volume was obtained according to the following formula:

$$(1) \qquad \mathrm{Vol_L} = h \cdot \sum_{i=1}^{n} A_i \qquad (\mathrm{cm^3})$$

in which h = interscan distance (cm); n = number of scans; A_i = the area of the liver on each single scan ($\mathrm{cm^2}$); and $\Sigma_{i=1}^{n} A_i$ = sum of the areas of all the scans ($\mathrm{cm^2}$).

When applying the point-integrating method, square paper was used as a morphometric screen (Fig. 2). The area of the liver slice is directly proportional to the number of points within the liver contour. The volume may then be calculated using the following formula:

$$(2) \qquad \mathrm{Vol_L} = h \cdot \sum_{i=1}^{n} N_i \cdot d^2 \cdot k \qquad (\mathrm{cm^3})$$

in which h = interscan distance (cm); n = number of scans; N_i = number of morphometric screen points within the limits of the liver in one scan; $\Sigma_{i=1}^{n} N_i$ = sum of the points within the liver contour of all the scans; d = the interpoint spacing of the morphometric screen (cm); and k = enlargement factor of the film. For our application, the real interpoint-distance (enlargement factor taken into consideration) was about 1.5 cm.

To obtain a reference value, the liver specimen volumes were measured by water displacement. The measured volumes of the liver specimens determined by CT and US were correlated with the reference volumes using the linear regression method; percent differences of both methods (US and CT) were analyzed by the paired t test (mean values) and the F test (standard deviations).

To test the accuracy in vivo, the volume measurements obtained by CT and US of the 10 patients were plotted in a XY-diagram and evaluated by linear regression analysis. The same statistical analysis was done for the comparison of point-integration method versus area-measuring program of CT images.

RESULTS

To evaluate the accuracy of the point-integrating method, we compared the liver volumes calculated by the area-evaluation program with those obtained by the point-integrating method using the same data set (liver specimens, CT). The linear regression analysis shows a nearly ideal agreement between the two methods with a correlation coefficient of $r = 0.989$; the equation of the correlation line is $y = 1.03x - 33$ (Fig. 3).

The comparison of the volumes measured by water displacement with the results of the point-integrating method shows a very good agreement for the CT examination ($r = 0.994$, $y = 0.97x$

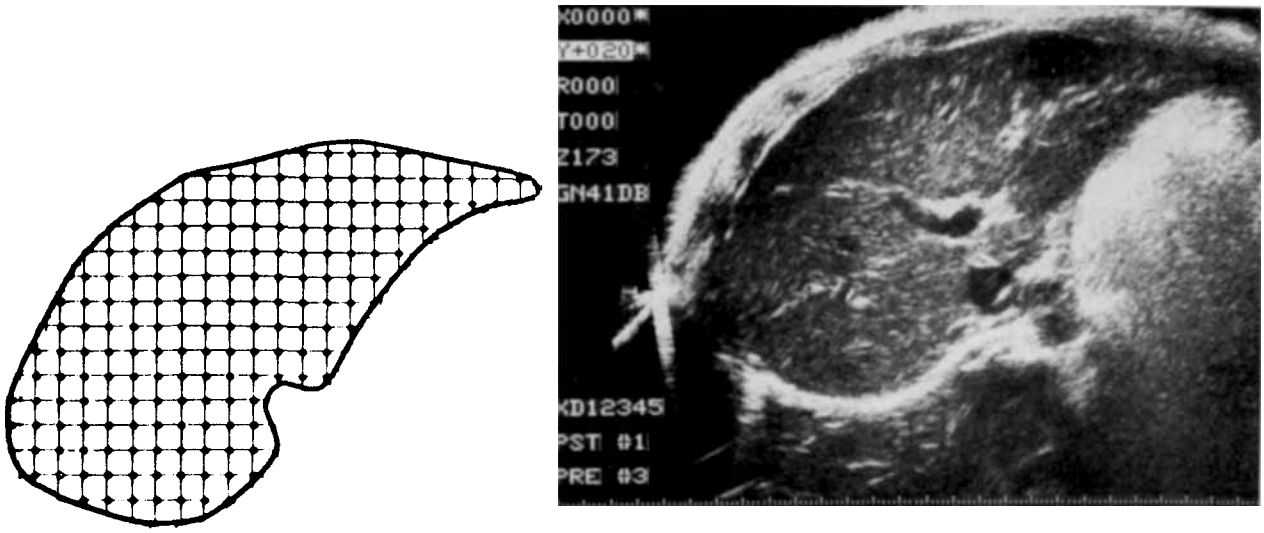

FIGURE 2. (A)(B) Point integrating method in US. All points of the square paper within the liver contour are taken into account. For evaluation of the liver volume the points of each scan are summarized and multiplied by the interscan distance, the square of the interpoint distance, and a correction factor.

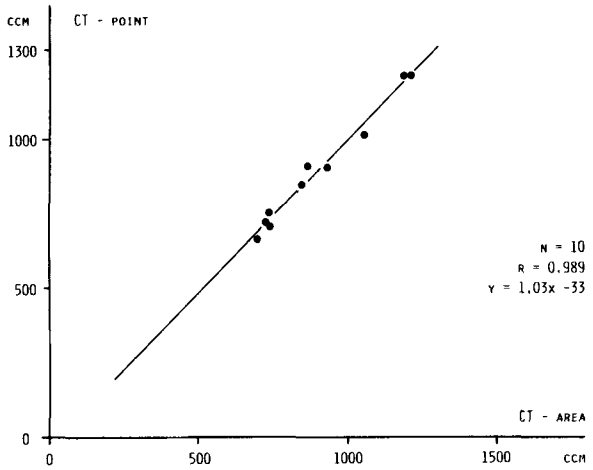

FIGURE 3. Comparison of liver volumes calculated with the point-integrating method (CT point) and the area-evaluation program (CT area) [CT transverse sections of liver specimen; same data set for both volume measuring methods].

−8), while for the US the correlation is not as good ($r = 0.915$, $y = 0.92x + 90$) but still acceptable. The mean percent differences (reference method versus point-integrating method of CT and US, respectively) were not statistically different ($P < 0.05$), but for the US examination the standard deviation of the percent differences was significantly greater ($P < 0.001$) than that seen with CT (Table 1).

The results of the correlation of CT with US (both volumes evaluated by the point-integrating method) were as follows: $r = 0.905$, $y = 0.93x + 110$. They were very similar to those obtained when comparing US to reference values ($r = 0.915$, $y = 0.92x + 90$); not only the correlation coefficients were in the same range, but also the position of the correlation lines was about the same. These results suggest that US systematically over estimates small volumes while it under estimates larger values.

For the in vivo study, 10 patients were examined, both with CT and US. All the data were evaluated by the point-integrating method. US correlated closely with CT ($r = 0.977$); as observed in vitro, small values were over estimated and larger values under estimated by US ($y = 0.86x + 187$; Fig. 4).

DISCUSSION

The results in this article show that the point-integrating method is very valuable in measuring areas and volumes of contiguous slices of organs examined either by US or CT. The great advantage of the method is that it can be applied "offline" to photographic films and thus it is not necessary to have the data recorded electronically; the time required to count the points within the area of interest and to calculate the volume of an organ is comparable to the area-program of a CT scanner. Although the method is simple, the accuracy is very good, as could be proven by comparing the point-integrating method and the area-measuring program of our CT scanner; when applied to a well-defined contour, the area-measuring program is one of the most accurate methods to determine areas, and it may be used as reference in evaluating other area-measuring techniques. The point-integrating method can be applied to any images where an

TABLE 1
Liver Volumes Measured In Vitro

Method	Reference Method (Water Displacement)	Computed Tomography (Point-Integrating Method)		Sonography (Point-Integrating-method)	
	In milliliters	In milliliters	Percent differences*	In milliliters	Percent differences*
Volumes	750	707	− 5.7	829	10.5
	1060	1017	− 4.1	1194	12.5
	760	752	− 1.1	817	7.5
	1260	1214	− 3.7	1154	− 8.4
	720	664	− 7.8	768	6.7
	910	916	0.7	848	− 6.8
	750	720	− 4.0	810	8.0
	1270	1217	− 4.2	1360	7.1
	890	851	− 4.4	810	− 9.0
	970	901	− 7.1	900	− 7.2
Statistics					
Mean	934	896	− 4.1	949	2.1
Standard deviation	206	201	2.5	207	8.7

Percent differences are the relative difference compared to reference volume (water displacement).

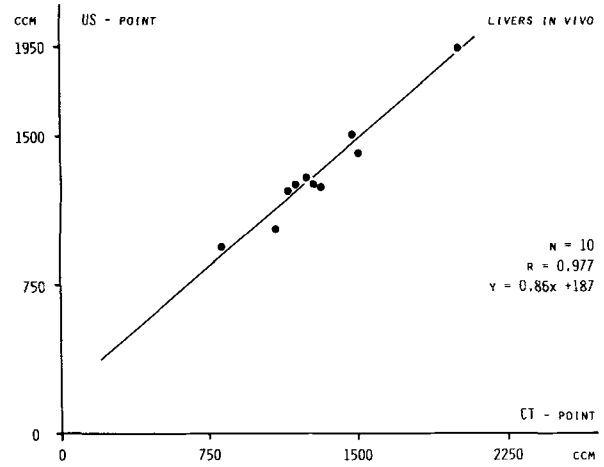

FIGURE 4. Comparison of liver volumes measured from CT and US examinations (randomly selected patients; point-integrating method).

area has to be calculated (e.g., CT, US, NMR, plain films).

CT is a very accurate method to measure areas and volumes from transverse sections. Because of its good density-resolution, most of the organ can be delineated without any difficulty; the fact that there is very little geometric distortion allows measurement of lengths and areas with great precision. This is illustrated by the good correlation (r = 0.994) between the volume of liver specimens measured by water displacement (reference value) and those determined from CT scans. From the technical point of view, CT is accurate enough to be used as reference method. Although our model does not consider artifacts due to unequal inspiration from scan to scan, we conclude that the results of an examination like US can be compared to the data measured (noninvasively) by CT.

US, as seen in the in vitro study, gives a poorer correlation than CT when compared to the reference volume (water displacement). One cause of inaccuracy may be the sound velocity, which changes with tissue quality; pathologic tissue and formalin fixation may produce geometric distortion and result in inaccurate organ size. A further explanation is that US demonstrates the contour of an organ less clearly than CT, although US examinations of the liver are much easier to perform with our 8-head-compound-scanner than with a conventional compound scanner (the dorsal aspect of the organ is better visualized; contiguous slices can be obtained at any desired interscan-distance like in CT).

A systematic error was found with the sonographic method both in vitro and in vivo: whether compared to CT or to water displacement US over estimated small volumes and under estimated large values. The only explanation we can propose for this effect is that the observer tends to complete an ill-defined liver contour according to normal configuration even when the liver is not normal; this hypothesis could explain an under estimation of pathologic conditions with the above described errors.

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