Freehand Liver Volumetry by Using an Electromagnetic Pen Tablet: Accuracy, Precision, and Rapidity

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The purpose of this study is to assess the accuracy, precision, and rapidity of liver volumes calculated by using a freehand electromagnetic pen tablet contourtracing method as compared with the volumes calculated by using the standard optical mouse contourtracing method. The imaging data used as input for accuracy and precision testing were computed by software developed in our institution. This computer software can generate models of solid organs and allows both standard mouse-based and electromagnetic pen-driven segmentation (number of data sets, $n = 70$). The images used as input for rapidity testing was partly computed by modeling software ($n = 70$) and partly selected from contrast-enhanced computed tomography (CT) examinations ($n = 12$). Mean volumes and time required to perform the segmentation, along with standard deviation and range values with both techniques, were calculated. Student's t test was used to assess significance regarding mean volumes and time calculated by using both segmentation techniques on phantom and CT data sets. P value was also calculated. The mean volume difference was significantly lower with the use of the freehand electromagnetic pen as compared with the optical mouse (0.2% vs. 1.8%; $P < .001$). The mean segmentation time per patient was significantly shorter with the use of the freehand electromagnetic pen contourtracing method (354.5 vs. 499.1 s on phantoms; 457.4 vs. 610.0 s on CT images; $P < .001$). Freehand electromagnetic pen-based volumetric technique represents a technologic advancement over manual mouse-based contourtracing because of the superior statistical accuracy and sensibly shorter time required. Further studies focused on intra- and interobserver variability of the technique need to be performed before its introduction in clinical application.

KEY WORDS: Liver volumetry, computed tomography (CT), pen tablet, contour tracing

INTRODUCTION

Volumetry of abdominal solid organs has a great potential clinical impact. The most common applications are the preoperative assessment of living liver donors¹⁻⁴ and the evaluation of

the response to therapy or the progression of disease in pathologies that affect the spleen. Solid organ volumetry has been investigated using computed tomography (CT), magnetic resonance (MR) imaging, and ultrasonography using different measurement techniques and yielding variable results.^{5,6} Excellent results have been demonstrated especially on cross-sectional imaging where both MR imaging and CT have been shown to enable accurate volumetric assessment of solid organs in humans and phantoms.⁷⁻⁹

Volumetric assessment performed with cross-sectional imaging requires segmentation of the organ of interest. This is achieved by outlining, manually or by application of mathematical algorithms, the area of the organ in each image. Methods that do not require organ segmentation have been investigated, showing only unsatisfying accuracy.¹⁰

Volumetry of abdominal organs is not routinely assessed for clinical use, and the reason is twofold. On one hand, manual contourtracing is extremely time-consuming and requires fairly skilled hands; on the other hand, reliable and practical segmentation algorithms are neither widely nor readily available, despite continuous investigation.^{11,12}

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Pen tablet drawing is an alternative approach to image manipulation. It has been used proficiently for several years mainly by professional illustrators, architects, and designers. To our knowledge, there are no articles in the literature investigating potential advantages of the application of this technique to abdominal solid organ volumetry, especially with regard to accuracy (the closeness of measurements of a quantity to its actual value), precision (the degree to which repeated measurements under unchanged conditions show the same results), and rapidity.

The accuracy of most cross-sectional imaging-based volumetric techniques largely depends on excellent contourtracing, but this is a time-consuming operation, and it is difficult to master with a standard mouse-based approach. Thus, the purpose of our study was to assess solid organ volumes calculated by using a freehand electromagnetic pen tablet as compared with the volumes calculated by using the standard mouse-based contourtracing technique.

MATERIALS AND METHODS

Image Preparation

The imaging data used as input for accuracy and precision testing were computed by software developed in our institution that can generate liver models (mathematical phantoms) of specified volume and allows both standard mouse-based and electromagnetic pen-driven segmentation (Fig. 1). Phantom volume was set to 1,700 ml, as suggested by reviewing previous report in literature.¹³ Images used as input for rapidity testing were computed by modeling software or selected from normal contrast-enhanced (CE)-CT examinations of the abdomen. Normal CE-CT examinations were defined on the basis of the absence of focal lesions or diffuse disease on CT images.

Consequently, 70 data sets computed from virtual phantoms consisting of 30 axial sections each and 12 data sets computed from CE-CT consisting in 30–36

Fig. 1. Screenshot of the computer application developed to perform the study during phantom segmentation. This software allows both standard mouse-based and electromagnetic pen-driven segmentation on a tablet personal computer. Images were presented in a craniocaudal order and switched automatically upon segmentation completion. Actual volume, segmented volume, and time spent were recorded into a logger from which the data were subsequently retrieved and entered in an electronic worksheet for statistical analysis.

axial section each were evaluated in this study. Both phantom and CT images were 512×512 pixels in size. Virtual phantoms consisted in a binary set of data, in which pixels contained inside the liver volume were rendered in black, while pixels located outside were rendered in white.

Virtual phantoms and CT images were transferred in a Digital Imaging and Communications in Medicine format to our image-processing laboratory for further analysis on a Windows™ Vista sp1 32-bit tablet personal computer, which included an AMD Turion™ 64 X2 Mobile (TL-64) microprocessor operating at 2.2 GHz clock speed, a Nvidia GeForce Go 6150 graphic adapter, 2.0 Gb Random Access Memory, an additional memory cache of 1,820 Mb ReadyBoost on an external high-speed (100×) flash device, and a Wacom® “Penabled” touch screen working on a screen resolution of 1,280×800 pixels. Any patient information was removed from each image.

Data sets were then entered into the above-mentioned computer application for contourtracing. Axial orientation of sections was chosen to perform measurements because of its wide availability and ease of manipulation.

Mouse-Based Technique

Images were viewed on 1-megapixel touch screen display (Hp Pavilion tx2000) in a user-friendly setting, which included proper light condition and hardware position. Measures were performed with a Logitech LX3 optical mouse working at 1,000 dpi. The operator was instructed to perform accurate contourtracing at a comfortable speed. Images were presented in a craniocaudal order. For each section containing liver parenchyma or its phantom equivalent, the liver contours were manually traced in a freehand fashion to outline a region of interest (ROI).

Magnetic Pen-Based Technique

Images were viewed on the same screen, a 1-megapixel touch screen display (Hp Pavilion tx2000) in a user-friendly setting, which included proper light condition and hardware position. Measurements were performed with an EMR Wacom™ electromagnetic pen. This hardware allows pointer viewing before the pen tip reaches the screen and does not draw erroneously when

something other than the pen, such as hands, touches the sensor board surface. More information about the electro-MR technology can be found at the developer website (<http://www.wacom-components.com/index.php/technologies/EMRpen/>). The operator was instructed to perform accurate contourtracing at a comfortable speed. Images were presented in a craniocaudal order. For each section containing liver parenchyma or its phantom equivalent, the liver contours were manually traced in a freehand fashion to outline an ROI.

Liver Volumetry

All tracings, with both techniques, were performed by one radiologist (S.P., with 3 years experience with CT imaging of the liver). The liver volumes were then calculated by multiplying the sum of the organ surfaces that were manually traced on each section by the section thickness (5 mm on CT images, 5 mm on virtual phantoms). The liver volumes of each patient were recorded. Actual phantom volumes were also recorded for measurements on phantom data set. The total time required to segment was recorded for each slice for all patients.

Statistical Analyses

Data related to segmentation for each patient were collected and analyzed in a Microsoft Excel workbook. Liver volume measurements determined by using the mouse-based technique, the electromagnetic pen contourtracing technique, and the actual phantom volume were collected for each data set, along with standard deviation, range, absolute difference, and percentage difference. The time required to segment the liver, with standard deviation and range values, was calculated with both techniques. Student's *t* test was used to assess significance of mean volumes and times calculated by using both segmentation techniques on phantom and CT data sets. *P* value was also calculated.

RESULTS

Liver volumetry was successfully performed in all data sets with both segmentation techniques.

Fig. 2. Graphical representation of accuracy and precision for volumes calculated with mouse-based segmentation on a scatter plot centered on the 1,700-ml axis.

Liver Volumetry

Actual volume of liver phantoms was set to 1,700 ml. The mean volume calculated on phantom data sets ($n=70$) with mouse-based and pen-based contourtracing was, respectively, $1,669.3 \pm 43.5$ ml (standard deviation; range, 1,591.2–1,746.3; Fig. 2) and $1,696.8 \pm 28.5$ ml (standard deviation; range, 1,650.5–1,745.4; Fig. 3). Mean

volume difference between liver volume calculated with the mouse-based technique and the phantom volume was 30.7 ml (1.8%). Mean volume difference between liver volume calculated with the electromagnetic pen-based technique and the phantom volume was 3.2 ml (0.2%). The mean volume difference between the two techniques was 27.5 ml (1.61%). This difference was highly significant at Student's t test ($P < .001$).

Fig. 3. Graphical representation of accuracy and precision for volumes calculated with electromagnetic pen-based segmentation on a scatter plot centered on the 1,700-ml axis. Liver volume assessments demonstrate better accuracy (mean distance of the dots from the 1,700-ml white axis) and better precision (width of the dots distribution along the y-axis) than the mouse-based technique counterparts.

Fig. 4. Graphical representation of whole liver segmentation times calculated with both mouse and pen-based technique on liver phantoms ($n = 70$). Liver volume assessments demonstrate almost constant superiority of the pen-based segmentation method.

Segmentation Times on Virtual Phantoms

The mean segmentation time per liver on phantom data sets ($n=70$) with mouse-based and pen-based contourtracing was 499.1 ± 135.5 s (standard deviation; range, 255.0–750.2) and 354.5 ± 45.5 s (standard deviation; range, 273.4–426.7; Fig. 4). The mean time difference between the two techniques was 144.6 s (28.9%). This difference was highly significant at Student's t test ($P < .001$).

Segmentation Times on CT Data Sets

The mean segmentation time per liver on CT data sets ($n=12$) with mouse-based and pen-based contourtracing were 610.0 ± 76.7 s (range, 533.3–764.4) and 457.4 ± 88.8 s (range, 289.0–593.4; Fig. 5). The mean time difference between the two techniques was 153.4 s (25.1%). This difference was highly significant at Student's t test ($P < .001$).

DISCUSSION

Solid organ volumetry has sensible clinical applications, especially in the preoperative assessment of liver living donors.^{1–3} Organ volumetry, however, is not routinely performed mainly because of the long time required with segmentation using current mouse-based manual techniques.

Use of an alternative, more user-friendly, pointing device could possibly shorten the time required for volumetric analysis, thus enabling solid organ segmentation to become a routine process.

Our investigation was a proof-of-concept study on freehand electromagnetic pen-based segmentation and volumetry. In this regard, we designed and developed computer software that allowed us to assess accuracy, precision, and rapidity of measurements. The results of our study show that liver volumes calculated by using electromagnetic pen-based hardware are significantly more accurate and precise than those measured with the commonly used mouse-based manual contourtracing method.

The described freehand electromagnetic pen-based technique is also more time efficient than the mouse-based contourtracing method, saving an average time of more than 2 min per volumetry both on phantoms (28.9% average time reduction) and on CT images (25.1% average time reduction). Processing times are not affected from the contourtracing method used, as they intentionally were both obtained by using the same algorithm.

We also observed that liver segmentation on virtual phantoms was faster than on CT data sets. Our interpretation of this result, with the limitation of the small number of CT data sets ($n=12$), is that it may be easier to decide the track to follow on high contrast images like the phantoms used than on CT images, thus leading to less hesitation while drawing.

Fig. 5. Graphical representation of whole liver segmentation times calculated with both mouse and pen-based technique on CT images ($n = 12$). Liver volume assessments demonstrate constant superiority of the pen-based segmentation method.

The mean time to segment a whole liver differs from others reported in the literature.¹³ Specifically, we were able to segment in a much shorter time. It is our understanding that this is due to two main reasons. In the first place, we chose to segment on 5-mm-thick axial images as suggested in the literature,¹⁴ while other studies evaluated minor image thicknesses, thus leading to more section to be processed for a single liver. In the second place, we designed the software application to minimize dead times between contourtracing on contiguous images. As a matter of fact, images were switched automatically as soon as a closed ROI was determined, almost eliminating inactive time. As a result, only net time to segment the liver was recorded.

The limitations of this study included the absence of method validation, such as assessment of inter- and intraobserver variability, which will be addressed in future work. A second limitation was the wide experience in pointing devices of the investigator. We admit that this could have led to lesser differences in measurements between the two techniques. A further limitation was the assessment of accuracy and precision on liver phantoms instead of on actual liver. This possibility is far more complex as it requires accurate volumetry of the explanted organ and it is prone to biases such as liver volume change since it introduces a significant time-lapse between image-based and actual volumetry. A final limitation consisted in the small number of data sets from CT examinations used for rapidity assessment on actual patients. A more consistent number of CT data set need to be evaluated in future work.

Nonetheless, it is our opinion that the freehand electromagnetic pen-based contourtracing technique described in this study represents a technologic advancement over manual mouse-based contourtracing because of the superior accuracy and shorter time required. Future studies focused on intra- and interobserver variability of the technique, especially on CT data sets, need to be performed before its introduction in clinical application.

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