Liver volumetry accuracy of a post-processing solution for whole-organ segmentation based on MDCT imaging

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Accurate liver volumetry is of utmost importance in preoperative assessment preceding liver donation and treatment planning of surgical and intraarterial interventions.[1,2,3,4] At many institutions, contrast-enhanced Multidetector CT (MDCT) is the most widely used radiographic imaging technique for assessment of longitudinal disease evolution and to perform preoperative imaging.

Determination of hepatic volumes using manual tracing is both cumbersome and time-consuming, requiring, historically, on average of greater than 30 minutes in post-processing duration.[5,6] Additionally, this technique suffers from substantial inter- and intraobserver variability. These limitations of manual segmentation techniques have created the impetus to develop semi-automated interactive segmentation techniques. Three main reasons have been identified that complicate accurate of liver volumetry: similar attenuation characteristics of adjacent organs resulting in inseparable Hounsfield Unit (HU) differences between hepatic and extrahepatic anatomy, non-uniform contrast-enhancement of the hepatic parenchyma based on varying delays for arterial and portal-venous imaging depending on institution-based hepatic imaging protocols, and finally the high degree in variability of complex hepatic anatomical structure and shape in native and particularly post-surgery scenarios.[1,7]

A prerequisite for any quantitative measurement technique is to optimize and balance accuracy and precision, thereby establishing outputs as reproducible and standardizable biomarkers, such as liver volumes, which then can be reliably incorporated into both clinical trials and longitudinal comparisons assessing disease evolution. Recent initiatives such as the Quantitative Imaging Biomarkers Alliance (QIBA) and the American College of Radiology Imaging Network (ACRIN) sought to identify sources of variation that may contribute to overall measurement error. These standardization initiatives are crucial to permit comparisons independent of imaging and post-processing platforms, clinical sites, and time of imaging. The goal is to standardize all factors contributing to overall measurement error and to limit the within-subject coefficient of variation to a value of smaller than 20%. Thereby, any change in within-patient measurement greater than 40% can confidently be attributed to disease evolution and / or therapy effect.[8]

The aim of this White Paper is to evaluate the accuracy of a post-processing solution for whole-liver segmentation based on MDCT image datasets assessing whether volumetric whole-liver segmentation can be achieved with high accuracy in an in-vitro phantom.

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Materials and methods

In-vitro liver phantom

A commercially available polymer liver phantom (JS5, Kilgore International, Coldwater, MI), replicating hepatic size and shape of a 75-kg male, was used to assess the accuracy of the post-processing application. The liver phantom was volumetrically evaluated by being lowered into a water bath and the displaced water being weighted according to Archimedes' principle, as described previously.[9] Liver phantom volumetry was repeated five times and the displaced water volume subsequently averaged.

MDCT acquisition

All MDCT in-vitro and in-vivo examinations were performed on a commercially available 128-MDCT scanner; an x-ray tube voltage of 120 kVp and dose-modulated effective reference x-ray tube current of 200 mAs with a gantry rotation time of 0.5 secs and a target pitch of 0.8 were applied, acquiring image series with a collimation of 128 x 0.6 mm, using a matrix size of 512 x 512 pixels, resulting in an in-plane pixel size of 0.76 mm, reconstructing 0.6 mm thin images.

Manual liver volumetry performing whole-organ segmentation

Liver volumetry of in-vitro phantom image series was performed using the Extended Brilliance Workspace environment (EBW version 5, Philips Healthcare, Cleveland, OH) employing a commercially available CT Volume Viewer software package (version 5.0.10778.0). All quantitative volumetric evaluations were performed in consensus decision by two radiologists, (G.F.) and (D.T.B.), with one and seven years' experience in image data post-processing, respectively. All manual volumetry was repeated 3 times with more than one-month interval between individual repetitions.

In-vitro phantom (650 axial slices) volumetric datasets were loaded by the CT Volume Viewer application and made available in axial, sagittal, and coronal reformations. A seed pointer was centrally placed over internal portions of the liver, with an interactively controlled growing color-overlay region-of-interest (ROI) visible to the radiologists; region growing speed (100 mL/sec), seed size (20 mm^2) and sensitivity to attenuation differences (sensitivity 5, range 1 – 10) were standardized for the in-vitro phantom and in-vivo patient datasets. If color-overlay ROIs were noticed outside of the liver on axial, sagittal, and coronal reformations, an eraser tool with identical settings was utilized. This was performed until the radiologists deemed the volumetric assessment appropriate. The CT Volume Viewer application was then prompted to provide volumetric calculation of the hepatic ROI, resulting in the whole-organ volume of the in-vitro livers.

Statistical analysis

Accuracy of the manual segmentation tool was assessed by evaluating the volumetric results of the in-vitro phantom image datasets and the volume displaced by the in-vitro phantom according to the Archimedes' principle employing ANalysis Of VAriance (ANOVA) comparisons.

Results

Accuracy of the manual segmentation application

The in-vitro polymer liver phantom liver phantom volume according to Archimedes' principle was 1581.0 ± 44.7 ml, Figure 1. Manual volumetry utilizing the CT dataset yielded liver phantom volumes of 1628.0 ± 47.8 ml. This represents a mean overestimation of + 3.0% by the manual segmentation tool, Table 1.

Discussion

The practice of using MDCT datasets for liver volumetry has been supported by evidence of substantial congruity between manual assessments of liver volumetry comparing MDCT and ex-vivo liver volume determination results; however, the use of conversion factors to improve measurement correlation was still advocated by various studies.[9,10,11,12] More recently, newer techniques have emerged that automatically assess whole-liver volumes and have shown promising accuracy with substantial decrease in post-processing times.[5]

The initial in-vitro phantom liver assessment validated the approach of using volumetric MDCT datasets in combination with volume-rendering based post-processing to extract whole-organ liver volumes with significant accuracy.[10] The size and shape of the polymer liver phantom with smooth surface dome and uneven concave visceral surface sought to replicate the structural challenges encountered during acquisition and post-processing; a mean overestimation of ~3% can be interpreted as the to-be-expected measurement noise.

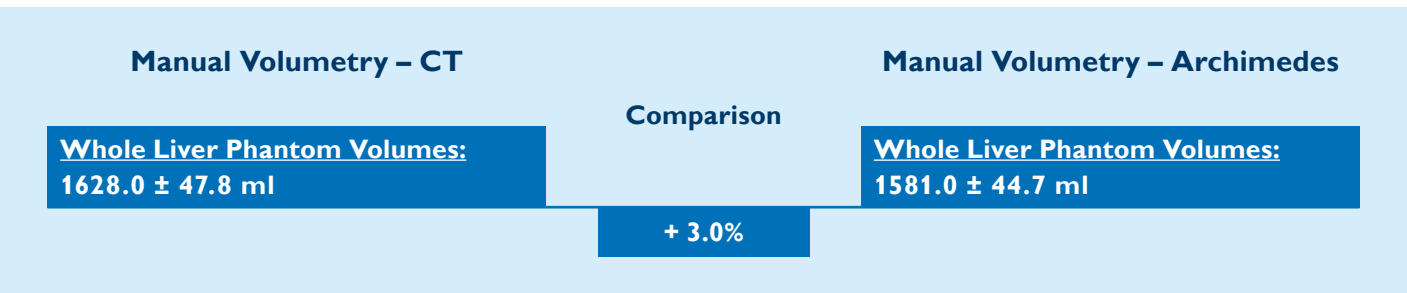

Table 1: Accuracy of the manual segmentation application.

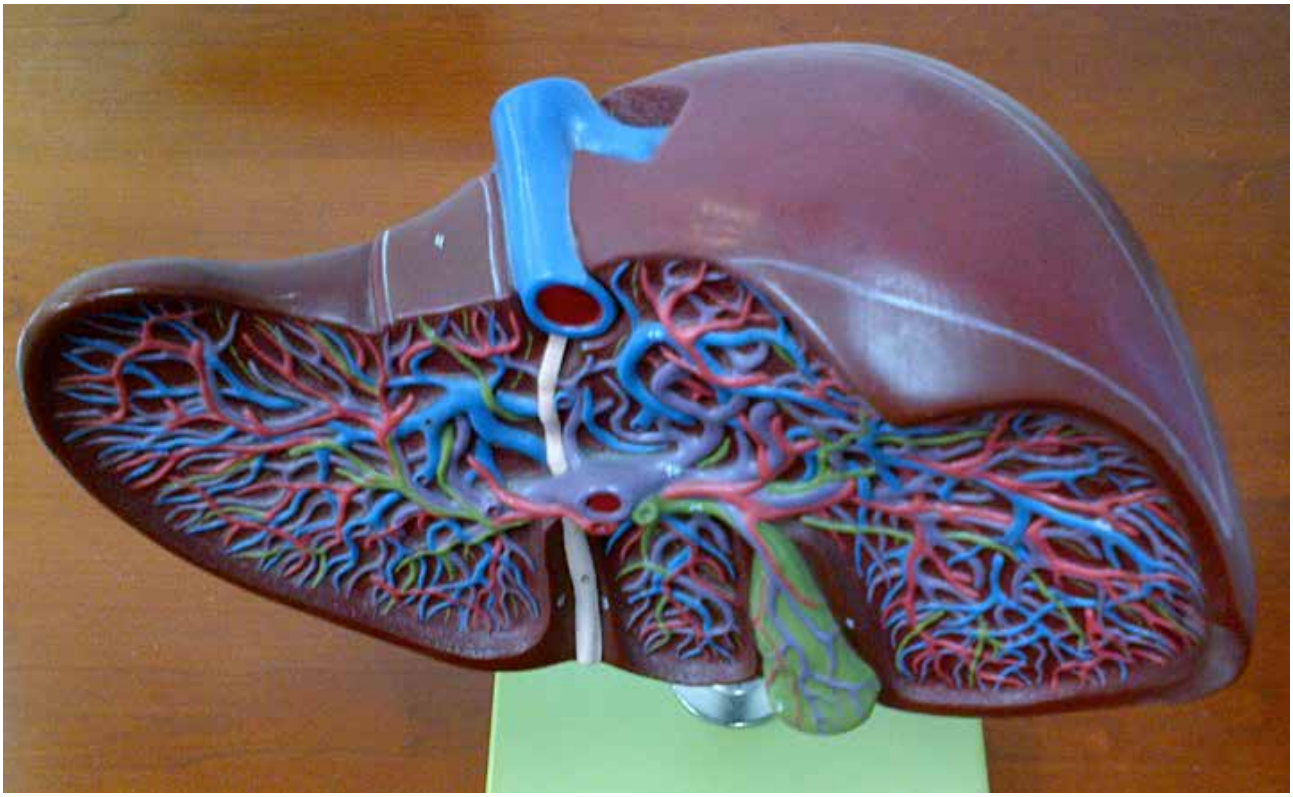

Figure 1: Polymer liver phantom replicating hepatic size and shape of a 75-kg male. Note the smooth dome and uneven concave visceral surfaces.

Generation of whole-liver and lobar volumes can often be cumbersome. Automated tools can prove to be of use in rapidly extracting clinically reliable whole-liver volumes, as evidenced by significantly shortened processing time of automated compared to manual approaches.

This White Paper showed that whole-liver segmentation can be achieved with high accuracy in an in-vitro phantom.

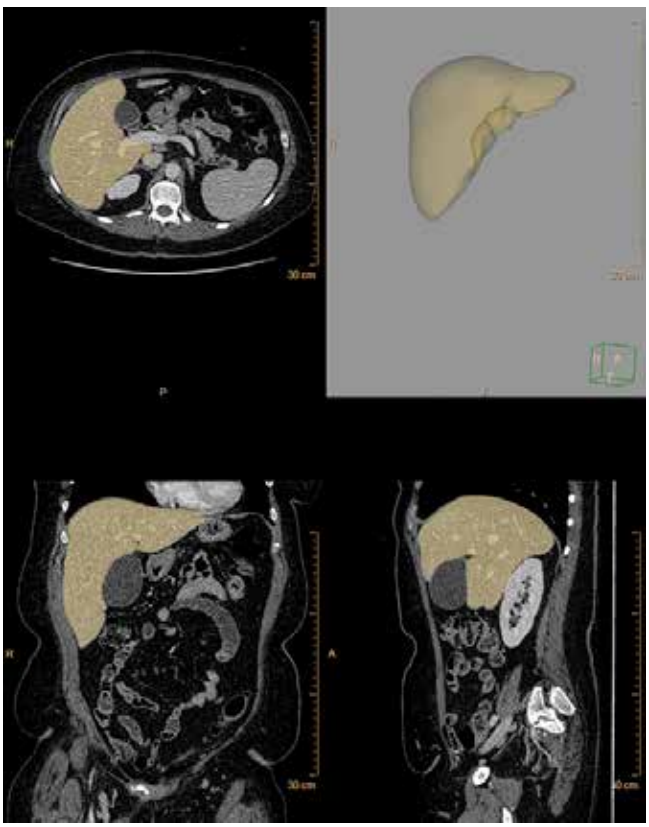

Figure 2: PortalLiver volumetry application showing whole-liver volumetry as color-overlay on axial, coronal and sagittal reformations.

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