Liver volumetry fidelity of a fully-automated, 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.[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 accuracy 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] The purpose of this White Paper was to evaluate the fidelity of a fully automated, post-processing solution for whole-liver segmentation based on MDCT image datasets assessing whether fully automated whole-liver and dual-seed lobar segmentation can be achieved with high accuracy and precision in in-vivo patient populations.

Materials and methods

In-vivo patient population

The institutional database was accessed to identify patients who had received both, a multiphasic contrast-enhanced CT and also had an MRI of the liver within three months, for the indication of evaluation of chronic liver disease during the time period from 01/2011 – 12/2011.

Exclusion criteria included (i) morphologic features of cirrhosis, (ii) history of prior liver / biliary surgery or liver tumor ablation procedures, and (iii) one or more liver lesions greater than 3 cm in size identified by CT or MRI, and (iv) portal or hepatic vein thrombosis. A total of 25 patients were enrolled. Of the 25 patients, 12 were male, with an average age of 68.2 years ± 11.5 (range 44 - 83 years); and 13 were female, with an average age of 55.4 ± 16.4 years (range 27 - 86 years).

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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. Individual contrast bolus-tracking was performed during repetitive low-dose acquisitions at 120 kVp / 40 mAs and placement of a threshold region-of-interest (ROI) within the abdominal aorta at the level of the diaphragm, plotting HU contrast wash-in to a level of 150 HU following contrast administration of 100 ml 320 mg I / ml contrast agent administered at 4 ml / sec injected into a right antecubital vein using a CTA injector. The diagnostic arterial and portal-venous cranio-caudal helical hepatic MDCT acquisition commenced 12 secs and 60 secs post 150 HU wash-in, respectively.

Automated liver volumetry performing whole-organ segmentation

Liver volumetry of in-vivo patient image series were performed using the Extended Brilliance Workspace environment (EBW version 5, Philips Healthcare, Cleveland, OH) employing a PortalLiver volumetry (version 5.0.0.0022) application. Patient volumetric datasets were loaded into the PortalLiver volumetry application; whole-organ segmentation started without any further user input. The liver volumetry process employed by the PortalLiver application using contrast-enhanced MDCT image series belongs to the family of variational approaches algorithms. These algorithms rely on deformation processes of population-based meshes guided by Hounsfield attenuation differences as well as surrounding anatomical structures. Here, variational approaches algorithms are composed of four sequential steps:

1. Anatomical structures in the imaged field-of-view are coarsely segmented to provide spatial context information using high-pass filtration
2. Region of interest with high likelihood to be located inside the liver are defined
3. Liver tissue likelihood within the region of interest is estimated and refined as the mesh evolves
4. Mesh evolution is based on likelihood of and proximity to surrounding structures.

Qualitative evaluations assessing the fidelity of liver segmentation were performed in consensus decision by two radiologists, (G.F.) and (D.T.B.). A 5-point scale was used analyzing the segmentation margins for each Couinaud segment assigning a value of 0 for precise segmentation along the liver edge, +1 / -1 for overestimation / underestimation by ≤ 5 mm in maximum extent, respectively, and +2 / -2 for overestimation / underestimation by > 5 mm in maximum extent, respectively. Hepatic interfaces with gallbladder and IVC were qualitatively evaluated and a value of 0 was assigned if these structures were excluded by liver volumetry, a value of 1 reflected inclusion in the whole-organ segmentation.

Statistical analysis

Fidelity of the automated segmentation tool was evaluated by comparing the qualitative segmentation results with Multivariate General Linear Model (GLM) analyses. The quality score was defined as dependent variable, anatomic location as given by Couinaud segment was defined as fixed factor; a balanced, full factorial model was chosen; Bonferroni Post Hoc analysis was performed for the fixed factor.

Fidelity of liver volumetry

	Hepatic Segments									Extrahepatic Structures	
	I	II	III	IVA	IVB	V	VI	VII	VIII	GB	IVC
Mean	**0.30**	**-0.91**	**-0.87**	-0.30	-0.39	0.00	**-0.48**	0.00	-0.04	0	0.78
Std. Dev.	**0.70**	**1.24**	**1.01**	0.56	0.66	0.00	**0.59**	0.00	0.37	0	0.42
$Range_{Min}$	**0**	**-2**	**-2**	-2	-2	0	**-2**	0	-1		
$Range_{Max}$	**2**	**2**	**2**	0	0	0	**0**	0	1		

Table 1: Fidelity of the automated liver segmentation. 5-point scale for each Couinaud segment assigning a value of 0 for precise segmentation, +1 / -1 for overestimation or underestimation by ≤ 5 mm, and +2 / -2 for overestimation or underestimation by > 5 mm. 2-point scale for hepatic interfaces with gallbladder and IVC assigning a value of 0 if these structures were excluded by automated liver volumetry, a value of 1 reflected inclusion in the whole-organ segmentation.

Results

GLM analyses evaluating the fidelity of segmental edge definition on the automated segmentation approach found that the left hepatic lobe / caudate lobe (segments I, II and III) and segment VI differed significantly from the remaining portion of the right hepatic lobe, Table 1.

The gallbladder was consistently excluded from the volumetric evaluation; the intrahepatic portion of the IVC was included in the majority of cases.

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.[8,9,10,11] 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 qualitative analysis revealed that only segment VI suffered from substantial misregistration in the right lobe while all segments located in the left lobe and the caudate lobe showed significant variations in segmentation fidelity. This may be due to adjacent organs, such as the heart, gastrointestinal tract, kidneys, and spleen, which can have similar attenuation values, and, if not separated from the liver by peritoneal or retroperitoneal fat, lead to variations in edge detection. Few studies have evaluated lobar volumetry; a recent study confirmed our findings that the right hepatic lobe shows less variation in volumetric results than the left for automated systems.[12]

Generation of whole-liver and lobar volumes can often be cumbersome, either when using the manual or interactive approaches. Automated tools can prove to be of use in rapidly extracting clinically reliable whole-liver volumes. Knowledge that greater variations occur mostly in the left hepatic lobe can help in focusing the radiologist to this portion of the liver when validating the automatically generated volume. This evaluation showed that fully automated whole-liver segmentation can be achieved with high fidelity in in-vivo patient populations; segmental analyses identified slight tendencies for underestimating the right hepatic lobe and greater variability in edge detection for the left hepatic lobe.

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