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Quantification of the Effect of Shuttling on Computed Tomography (CT) Perfusion Parameters by Investigation of Aortic Inputs on Different Table Positions from Shuttle-Mode Scans of Lung and Liver Tumors

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Abstract

Objectives—To quantify the effect of shuttling on computed tomography perfusion (CTp) parameters derived from shuttle-mode body CT images using aortic inputs from different table positions.

Methods—Axial shuttle-mode CT scans were acquired from six patients (ten phases, two non-overlapping table positions 1.4s apart) after contrast agent administration. Artifacts resulting from the shuttling motion were corrected with non-rigid registration prior to computing CT perfusion maps from four aortic levels chosen from the most superior and inferior slices of each table position scan. The effect of shuttling on CTp parameters was estimated by mean differences in mappings obtained from aortic inputs in different table positions. Shuttling effect was also quantified using 95% limits of agreement of CTp parameter differences *within-table* and *between-table* aortic positions from the inter-aortic mean CTp values.

Results—Blood flow (BF), permeability surface (PS), and hepatic arterial fraction (HAF) differences were insignificant ($p>0.05$) for both *within-table* and *between-table* comparisons. The 95% limits of agreement for *within-table* blood volume (BV) value deviations obtained from Lung tumor regions were $<4.7\%$ ($p=0.18$) compared to $<12.2\%$ ($p=0.003$) for *between-table* BV value deviations. The 95% limits of agreement of *within-table* deviations for Liver tumor regions were $<1.9\%$ ($p=0.55$) for BV and $<3.2\%$ ($p=0.23$) for mean transit time (MTT) respectively, whereas *between-table* BV and MTT deviations were $<11.7\%$ ($p<0.01$) and $<14.6\%$ ($p<0.01$) respectively. Values for normal liver tissue regions were concordant.

Conclusion—CTp parameters acquired from aortic levels *within-table* positions generally yielded higher agreement than mappings obtained from aortic levels *between-table* positions indicating differences due to shuttling effect.

Keywords

Non-rigid Registration; Body Perfusion Imaging; Shuttle-mode CT; CT acquisition parameters

Introduction

Computed tomography perfusion (CTp) has enabled the evaluation of tumors non-invasively and enhanced our ability to understand and monitor the effects of anti-angiogenic therapies [1, 2]. Functional CT measures the enhancement of the tissue upon intravenous injection of contrast bolus generating a time-versus-enhancement or time density curve (TDC) of the tissue. A distributed parameter model and deconvolution [3] analysis is used to acquire tissue perfusion parameters from TDCs derived from tissue and vascular regions of interest (ROIs). Perfusion parameters such as blood flow (BF), blood volume (BV), mean transit time (MTT), permeability surface area product (PS), hepatic arterial fraction (HAF) (for liver perfusion) are obtained from functional CT scans.

The 64-slice commercial CTp technology acquires images at a relatively high temporal sampling frequency, typically 1s or less during contrast enhanced scan acquisitions. A potential limitation of the current 64-slice commercial CTp technology is the small (4cm) z-axis coverage of volume-of-tissue obtained from continuous (Cine) acquisitions. A shuttle-

mode CT scanner counteracts the limitation by acquiring repetitive axial scans by shuttling the CT table back and forth between two consecutive imaging table positions. The shuttling effectively doubles the volume of tissue that can be evaluated per bolus to 8cm. The acquisition of a larger volume is especially useful for Liver anatomy due to the inclusion of the portal vein in shuttle mode imaging for dual input comparisons of TDCs from the arterial and venous inputs. However, there is a 1.4s time difference between the acquisitions of each table position scan (sampling interval of 2.8s) to incorporate the time needed for the CT table to move back and forth from one table position to the next, which necessitates the investigation of its effect on perfusion maps computed from shuttle-mode CT. Ng et al. [4, 5, 6] showed that acquiring the images at a higher temporal sampling interval could reduce radiation exposure. They found that increases in sampling interval (SI) beyond 1s were associated with significant departures from CT perfusion parameters from the reference 0.5s SI acquisitions. Other studies have suggested that increasing the SI to 3s yields satisfactory CTP parameters [7, 8].

Clinical implementation of the shuttle-mode scanning technique to CT perfusion has been limited to the brain [9, 10] and cardiac [11, 12, 13] applications. In our previous paper [14], we discussed the feasibility of the shuttle-mode technology for body perfusion applications by computationally correcting artifacts induced due to shuttling motion using image registration techniques. In this paper, we extend the feasibility study to investigate the effect of shuttling on CT perfusion parameters obtained from registered and motion corrected images by comparing CTP mappings obtained from aortic inputs from both table positions. To the best of our knowledge, this is the first study evaluating the effect of shuttling on perfusion parameters derived from aortic inputs from different table positions.

Materials and Methods

Patient Selection

The prospective study was approved by our institutional review board and was compliant with Health Insurance Portability and Accountability Act (HIPAA). Written and informed consents were obtained from all patients and they were informed of the 27s breath hold requirement before acquiring scans. The study was performed on shuttle-mode CT scans obtained using the GE 750HD CT scanner (GE Healthcare, Waukesha, WI) from six patients (three with Lung parenchymal and three with Liver parenchymal masses) under breath hold conditions. The patients (mean age: 60.5 years; 3 males, 3 females) had primary lesions greater than 3cm in diameter with well-defined tumor margins. Patients who were allergic to the contrast media and weighed more than 227kg were excluded from the study.

CT perfusion scanning technique

The shuttle-mode scans were acquired 5s after a 50mL nonionic contrast agent bolus (ioversol [Optiray], 320mg of iodine per milliliter; Mallinckrodt, Inc., St Louis, Mo) was administered using an automatic injector (MCT/MCT Plus; Medrad, Pittsburgh, Pa) at a rate of 7mL/s. Ten phases of cine scans were acquired where each phase of the CT perfusion scan (120 kVp, 220 mA, 8.42 mGy) was 2.8s long with a 1.4s lag between table position scans as shown in the timeline of the acquisition in Figure 1. The figure also illustrates that

the two table position scans were acquired from non-overlapping volumes, such that there was a 5mm z-axis distance between the most inferior table position 1 slice and the most superior table position 2 slice. The images were reconstructed to eight slices per table position with a 5 mm thickness resulting in a total coverage of 80 mm along the cranio-caudal (z) direction considering both table position scans. A 27s breath hold was imposed to minimize breathing motion during the scan.

CT Perfusion Analysis

CT perfusion parameters were obtained from the shuttle-mode scans using the commercially available CT perfusion software (CT Perfusion 4, GE Healthcare, Waukesha, WI). Before CT perfusion analysis was performed, the scans were non-rigidly registered using the NiftyReg software [15, 16] to the first phase of the acquisitions as described in our previous study [14]. This resulted in eight anatomically matched slices per table position for the ten shuttle mode phases. The CT Perfusion 4 (CTPerf4) software version 4.3.1 (Advantage Workstation 4.4; GE Healthcare) was used to compute the perfusion maps on the data sets. A single vascular input algorithm that uses aortic input was used to compute perfusion values from the Lung scans. A dual vascular input algorithm that uses abdominal aorta and portal vein inputs was used to compute perfusion values from the Liver scans. To evaluate the vascular properties of body tumor masses, regions of interest (ROIs) were defined on tumor (Liver and Lung) and normal (Liver) tissue regions (C.S.N, with more than 10 years' experience in interpreting CT studies) as shown in Figure 2. The ROIs around the primary tumor (>3.0 cm diameter) were manually drawn with a freehand cursor by avoiding vessels and artifacts. Normal tissue was identified using circular or oval ROIs on Liver parenchyma. The time when the arterial signal begins to rise (pre-enhancement set point), and the final time point of the cine acquisitions (post-enhancement set point) were specified within CTPerf4 software to generate the BF, BV, MTT, PS, and HAF maps.

Aortic Levels and CT Perfusion Maps

To determine the effect of aortic input on perfusion parameters, maps generated from aortic levels on different table positions were analyzed. Aorta levels 1 and 2 were identified from the most superior and inferior slices of the table position 1 scans respectively. Aorta levels 3 and 4 were identified from the most superior and inferior slices of the table position 2 scans respectively. The largest portal venous ROI was chosen and consistently used for all aortic levels when computing CT perfusion maps using Liver scans. The *within-table* position variation in perfusion parameters was quantified by comparing maps from aortic levels 1 versus 2 (1 vs 2), and aortic levels 3 versus 4 (3 vs 4). The *between-table* position variation in perfusion parameters was evaluated by comparing maps from aortic levels 1 versus 4 (1 vs 4), and aortic levels 2 versus 3 (2 vs 3). The objective of the analysis was to determine whether perfusion maps generated using the four aortic levels differed in values *within* and *between* table positions, indicating shuttling effects.

Statistical Analysis

Statistical analysis was performed using MATLAB™ (MathWorks, Natick, MA) and R 3.3.0 (R Foundation, Vienna, Austria). Summary statistics (median and interquartile range) were computed for the CT perfusion parameters (BF, BV, MTT, PS, and HAF (Liver)) obtained

from the four aortic levels for the primary tumor for Liver and Lung patients and normal tissue regions for Liver patients.

Deviation in inter-aortic CTP values were estimated with 95% limits of agreement to characterize the extent of variability in the CTP parameter mappings that was attributable to aortic level specification from different table positions. To accommodate the potential for tissue and vascular heterogeneity within the targeted volumes, all analyses measured agreement with respect to the mean values of CTP parameters obtained within ROIs on identical slice locations. Linear mixed effects modelling was used to estimate deviations in perfusion value mapping acquired using different aortic levels from the inter-aortic mean value (reference parameter value) using the software package *nlme* in R 3.3.0 (R Foundation, Vienna, Austria). Nested random intercepts were used to account for the correlation induced by the presence of four aortic levels and two table positions, inducing compound symmetric covariance. The resultant 95% prediction intervals of observable deviation computed from the estimated model fits were used to characterize the extent of variability attributable to aortic level specification and reported as 95% limits of agreement. Multiple analyses were implemented to estimate CTP parameter mappings attributable to various arrangements of the aortic levels.

- i. Inter-aortic parameter mappings: The 95% limits of agreement among the CTP parameters obtained from all aortic levels (1-2-3-4 in Table 3) were compared against the inter-aortic mean parameter values. This was used to estimate the extent to which parameter mappings obtained from a randomly chosen aortic level were expected to deviate from the inter-aorta parameter mappings.
- ii. Binary comparisons: *Within-table* position comparisons were performed by comparing the CTP values obtained from aortic levels identified on the most superior and inferior slices of each table position (1 vs 2, 3 vs 4 in Tables 4 and 5). *Between-table* comparisons were performed using the CTP values obtained from closest (2 vs 3) and farthest (1 vs 4) aortic levels on the two table positions, as shown in Figure 3 to obtain the entire range of variation of CTP values obtained from the closest to the farthest aortic level differences between table positions. For binary comparisons the percentage differences were computed from the inter-aortic mean of the two aortic levels being compared. In addition to 95% limits of agreement, mean percentage deviations and the corresponding *p* values were obtained from the linear mixed model analyses using 2-sided tests of the null hypothesis (mean percentage difference, based on Wald's test).

Results

Summary statistics obtained for CT perfusion values from a sample Liver and Lung patient are reported in Tables 1 and 2 respectively for illustrative purposes. Table 3 shows the 95% limits of agreement computed by comparing CTP parameters obtained from all four aortic levels (1-2-3-4) with the inter-aortic mean values (reference) for all Lung and Liver patients. Figure 4 depicts mean percentage deviations of BF maps obtained from all aortic levels (shown using different colors) compared to the reference and the 95% limits of agreement (shown in dotted lines) for Lung tumors obtained from all patients. Figure 5 depicts mean

percentage deviations of BF maps obtained from all aortic levels (shown using different colors) compared to the reference and the 95% limits of agreement (shown in dotted lines) for Liver tumor and normal tissue regions obtained from all patients. Each point on the plot represents a tumor ROI drawn per level of a scan. The '0' represents the inter-aortic mean mapping, with points closer to 0 representing parameter values showing greater concordance with the inter-aortic mean value.

Tables 4 and 5 show the mean percentage differences and 95% limits of agreement computed for comparing *between table* position (1 vs 2; 3 vs 4) and *within table* position (2 vs 3; 1 vs 4) aortic levels for Lung and Liver patients respectively. CTp mappings obtained from within-table aortic inputs generally showed greater agreement than between-table parameter mappings. Significant biases ($p < 0.01$) were observed for *between-table* BV parameter mappings for Lung tumor regions (mean percentage difference: 10.3%, $p < 0.01$), and BV and MTT parameter mappings for Liver tumor and tissue regions. The mean percentage deviations from *between-table* mean BV were 11.6%, ($p < 0.01$) for Liver tumor regions and, 10.52% ($p < 0.01$) for Liver normal tissue regions. The percentage deviations in MTT for Liver tumor and normal tissue regions were 13.88% ($p < 0.01$) and 8.38% ($p = 0.04$) respectively. Figure 6 shows mean percentage deviations in BV values for *between-table* (1 vs 4) comparisons in Lung tumor (95% limits of agreement shown in dotted lines). Figure 7 shows mean percentage deviations in BV and MTT values for *between-table* (1 vs 4) comparisons in Liver tumor and normal tissue regions (95% limits of agreement shown in dotted lines).

Discussion

We performed a feasibility study to quantify the effect of shuttling on CT perfusion parameters by comparing perfusion maps obtained from aortic inputs on different table positions. Our results demonstrate that in general, CTp parameter values obtained from *within table* aortic inputs (1 vs 2, and 3 vs 4) have greater concordance than *between-table* parameter values (2 vs 3, 1 vs 4). Furthermore, if CTp values are chosen irrespective of the aortic input, we observe higher 95% limits of agreement, as shown in Table 3. These values were computed from CTp maps derived from all aortic levels 1, 2, 3 and 4 pooled together. For example, Table 3 shows that a PS parameter map obtained from an aortic level chosen at random is expected to deviate from the inter-aortic mean by $\pm 17.5\%$ for Lung tumor, $\pm 13.7\%$ for Liver tumor, and $\pm 17.4\%$ for Liver normal tissue regions. These 95% limits of agreement become much smaller when we constrain the aortic input to a single table position as evident from the 1 vs 2, and 3 vs 4 comparisons. This indicates greater concordance between *within-table* CTp values; a PS parameter obtained from aortic level 1 input (table position 1) is expected to deviate from values obtained from aortic level 2 input (both inputs from table position 1) by $\pm 6.07\%$ for Lung tumor, $\pm 5.56\%$ for Liver tumor and $\pm 6.75\%$ for Liver normal tissue region as shown in Tables 4 and 5. This indicates that choosing the aortic level consistently from the same table position is important to restrict the degree of deviations in CTp parameters obtained for perfusion analysis using the shuttle-mode CT technology.

We also observed higher mean percentage deviations and 95% limits of agreement for *between-table* aortic level comparisons than within-table comparisons. This was expected due to the 1.4s time difference between the acquisitions of the two table position scans and is consistent with prior sub-sampling studies [4–6], which report significant deviations of CT perfusion parameters acquired from subsampled datasets with $SI > 1s$.

We recognize that there are several limitations to our study. This study was conducted as a pilot study with a very limited number of patients; however the analysis was performed on tumor and normal tissue regions derived from 8–14 levels per phase per subject (out of a total of 16 levels from table positions 1 and 2), which contributed to the characterization of intra-aortic CTP value differences. Also, the comparison of CTP parameter values within a tumor region but across table positions was not performed here because the table position scans were acquired from non-overlapping anatomical regions. In this setup, differences in CTP values across two table positions arising due to shuttling cannot be independently isolated from other factors that can also lead to CTP parameter variation across volumes, such as tumor heterogeneity and image artifacts. For the current analysis, the tumor and normal tissue regions were assumed to be relatively homogeneous and CTP parameter comparisons were performed across the same two-dimensional slice locations. Volumetric comparisons of tumor/tissue regions incorporating tumor heterogeneity to identify shuttling effects across table positions was outside the scope of the current study design and is a subject of future work. We also recognize that the normal tissue regions considered here may not be completely normal due to the exposure of the patient to prior therapies.

In conclusion, our study presents that CT perfusion parameter values can be reliably acquired from shuttle-mode body acquisitions, when the aortic levels are chosen consistently from a single table position. The variation in CTP values observed due to shuttling are within the expected range compared to values reported in prior subsampling studies.

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Conflicts of Interest and Source of Funding:

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References

1. Miles KA, Charnsangavej C, Lee FT, Fishman EK, Horton K, Lee TY. Application of CT in the investigation of angiogenesis in oncology. *Acad Radiol*. 2000; 7(10):840–850. [PubMed: 11048881]
2. Miles KA, Lee TY, Goh V, et al. Current status and guidelines for the assessment of tumour vascular support with dynamic contrast-enhanced computed tomography. *Eur Radiol*. 2012; 22(7):1430–1441. [PubMed: 22367468]
3. Lee TY. Functional CT: physiological models. *Trends in Biotechnology*. Aug; 2002 20(8):S3–S10. [PubMed: 12570152]
4. Ng CS, Hobbs BP, Wei W, et al. Effect on perfusion values of sampling interval of CT perfusion acquisitions in neuroendocrine Liver metastases and normal Liver. *Journal of computer assisted tomography*. 2015; 39(3):373–382. DOI: 10.1097/RCT.0000000000000212 [PubMed: 25626401]
5. Ng CS, Chandler AG, Wei W, Anderson EF, Herron DH, Kurzrock R, Charnsangavej C. Effect of Sampling Frequency on Perfusion Values in CT Perfusion of Lung Tumors. *AJR. American Journal of Roentgenology*. 2013; 200(2)doi: 10.2214/AJR.12.8664

6. Ng CS, Chandler AG, Wei W, et al. Effect of sampling frequency on perfusion values in perfusion CT of lung tumors. *Am J Roentgenol.* 2013; 200(2):W155–162.
7. Kamena A, Streitharth F, Grieser C, et al. Dynamic perfusion CT: optimizing the temporal resolution for the calculation of perfusion CT parameters in stroke patients. *Eur. J Radiol.* 2007; 64(1):111–118. [PubMed: 17383135]
8. Abels B, Klotz E, Tomandl BF, Villablanca JP, Kloska SP, Lell MM. CT perfusion in acute ischemic stroke: a comparison of 2-second and 1-second temporal resolution. *Am J Neuroradiol.* 2011; 32(9): 1632–1639. [PubMed: 21816919]
9. Halpin SF. Brain imaging using multislice CT: A personal perspective. *Br J Radiol.* 2004; 77(1):S20–S26. [PubMed: 15546839]
10. Konstas AA, Goldmakher GV, Lee TY, Lev MH. Theoretic Basis and Technical Implementations of CT Perfusion in Acute Ischemic Stroke, Part 2: Technical Implementations. *Am J. Neuroradiol.* May.2009 30:885–892. [PubMed: 19299489]
11. Bamberg F, Hinkel R, Schwarz F, et al. Accuracy of dynamic computed tomography adenosine stress myocardial perfusion imaging in estimating myocardial blood flow at various degrees of coronary artery stenosis using a porcine animal model. *Investigative Radiology.* 2012; 47(1):71–77. [PubMed: 22178894]
12. Wang Y, Qin L, Shi X, Zeng Y, Jing H, Schoepf UJ, et al. Adenosine-stress dynamic myocardial volume perfusion imaging with second generation dual-source computed tomography: Concepts and first experiences. *Journal of Cardiovascular Computed Tomography.* Mar-Apr;2010 4(2):127–135. [PubMed: 20430344]
13. Bastarrika G, Ramos-Duran L, Rosenblum MA, Kang DK, Rowe GW, Schoepf UJ. Adenosine-stress dynamic myocardial CT perfusion imaging: initial clinical experience. *Invest Radiol.* Jun; 2010 45(6):306–13. DOI: 10.1097/RLI.0b013e3181dfa2f2 [PubMed: 20421800]
14. Ghosh P, Chandler AG, Altinmakas E, Rong J, Ng CS. Correction of Motion Artifacts from Shuttle Mode Computed Tomography Acquisitions for Body Perfusion Imaging Applications. *J Computer Assisted Tomography.* May-Jun;2016 40(3):471–77. DOI: 10.1097/RCT.0000000000000387
15. Modat M, Cash DM, Daga P, Winston GP, Duncan JS, Ourselin S. A symmetric block-matching framework for global registration. *Progress in Biomedical Optics and Imaging - Proceedings of SPIE.* 2014; :9034.doi: 10.1117/12.2043652
16. Modat, M., Daga, P., Clarkson, MJ., Ourselin, S. NiftyReg. (Version 1.3) [Software]. 2010. <http://sourceforge.net/projects/niftyreg/>

Figure 1.
Time line of the shuttle-mode acquisitions.

Figure 2.
Left panel: Tumor ROI on a Lung scan. Right panel: Normal and Tumor ROIs defined on a Liver scan.

Figure 3. Aortic levels in the two table positions. *Within-table* position comparisons were made between aortic level 1 vs 2, and 3 vs 4. *Between-table* position comparisons were made between aortic level 2 vs 3, and 1 vs 4.

Figure 4.

Observed deviations of inter-aortic parameter mappings obtained from 4 aortic levels (shown using different colors) compared to the inter-aortic mean and 95% limits of agreement (shown in dotted lines) for Lung tumors from all patients (shown using different markers). Each dot represents a tumor ROI drawn per level of a scan. The 0 represents the inter-aortic mean mapping with points closer to 0 representing parameter values showing greater concordance with the inter-aortic mean value.

Figure 5.

Observed deviations of BF and BV maps obtained from 4 aortic levels (shown using different colors) compared to the inter-aortic mean (reference) and 95% limits of agreement (shown in dotted lines) for Liver tumors from all patients (shown using different markers). Each dot represents a tumor ROI drawn per level of a scan. The 0 represents the inter-aortic mean mapping with points closer to 0 representing parameter values showing greater concordance to the inter-aortic mean value.

Figure 6.
Observed deviations in BV values for *between-table* (1 vs 4) comparisons in Lung tumor (95% limits of agreement shown in dotted lines).

Figure 7.
Observed deviations in BV values for *between-table* (1 vs 4) comparisons in Liver tumor and normal tissue regions (95% limits of agreement shown in dotted lines).

TABLE I

Summary of CT perfusion parameters by aortic level for a sample Lung patient. BF, in mL/min/100g; BV, in mL/100g; MTT, in seconds; PS, in mL/min/100g.

Parameter	Aortic level		Median	Inter-quartile range
BF	Table 1	1	100.6	94.1 – 115.9
		2	107.5	100.0 – 115.5
	Table 2	3	104.4	94.2 – 121.9
		4	104.5	93.1 – 119.9
BV	Table 1	1	4.1	3.5 – 4.6
		2	4.1	3.7 – 4.6
	Table 2	3	4.3	4.4 – 4.9
		4	4.4	4.4 – 4.8
MTT	Table 1	1	2.36	2.33 – 2.42
		2	2.33	2.27 – 2.36
	Table 2	3	2.47	2.43 – 2.48
		4	2.42	2.42 – 2.44
PS	Table 1	1	60.7	47.1 – 64.0
		2	63.8	45.6 – 68.4
	Table 2	3	53.1	46.0 – 59.0
		4	52.7	46.0 – 59.0

TABLE II

Summary of CT perfusion parameter by aortic for a sample Liver patient. BF, in mL/min/100g; BV, in mL/min/100g; MTT, in seconds; PS, in mL/min/100g; HAF, ratio without units.

Parameter	Aortic Level	Tumor		Normal	
		Median	Inter-quartile range	Median	Inter-quartile range
BF	Table 1	1	197.3	146.4 – 289.3	256.4
		2	199.5	149.2 – 290.6	254.3
	Table 2	3	197.6	146.4 – 275.2	240.3
		4	194.1	143.4 – 272.0	237.1
BV	Table 1	1	14.3	11.4 – 19.7	17.5
		2	14.3	11.4 – 19.5	18.4
	Table 2	3	16.8	13.3 – 22.5	21.6
		4	26.5	12.9 – 22.1	19.9
MTT	Table 1	1	5.93	5.29 – 6.12	5.58
		2	6.00	5.44 – 6.17	5.72
	Table 2	3	6.72	6.44 – 6.99	6.69
		4	6.76	6.46 – 7.00	6.64
PS	Table 1	1	33.8	25.1 – 53.0	57.3
		2	32.0	23.7 – 52.1	54.1
	Table 2	3	34.8	26.3 – 51.0	63.8
		4	34.0	26.5 – 51.8	63.8
HAF	Table 1	1	0.32	0.19 – 0.38	0.15
		2	0.33	0.20 – 0.38	0.16
	Table 2	3	0.31	0.19 – 0.37	0.15
		4	0.30	0.18 – 0.36	0.15

TABLE III

95% limits of agreement in CTP values obtained for all aorta levels compared to the inter-aortic mean mapping. BF, in mL/min/100g; BV, in mL/100g; MTT, in seconds; PS, in mL/min/100g; HAF, ratio without units.

Parameter	Aortic Level Comparisons	Lung	Liver	
		($\pm$) 95% Limits of Agreement (%)	($\pm$) 95% Limits of Agreement (%)	
		Tumor	Tumor	Normal
BF	1-2-3-4	8.55	7.25	9.07
BV	1-2-3-4	11.85	10.58	11.63
MTT	1-2-3-4	10.12	13.09	12.78
PS	1-2-3-4	17.47	13.70	17.35
HAF	1-2-3-4	--	6.13	15.05

TABLE IV

Mean percentage difference in CTp values obtained from two aortic levels for Lung tumor regions. BF, in mL/min/100g; BV, in mL/100g; MTT, in seconds; PS, in mL/min/100g.

Parameter	Aortic Level Comparisons	Mean % Difference	(±) 95% Limits of Agreement (%)	p values
BF	Within-table	1 vs 2	5.97	<0.01
		3 vs 4	3.42	0.51
	Between-table	2 vs 3	8.19	0.77
		1 vs 4	8.34	0.01
BV	Within-table	1 vs 2	4.65	0.18
		3 vs 4	4.07	0.96
	Between-table	2 vs 3	7.95	11.07
		1 vs 4	10.33	<0.01
MTT	Within-table	1 vs 2	-1.73	0.06
		3 vs 4	-1.18	0.29
	Between-table	2 vs 3	7.65	11.11
		1 vs 4	4.42	0.30
PS	Within-table	1 vs 2	-1.28	0.67
		3 vs 4	-0.14	0.88
	Between-table	2 vs 3	10.24	0.39
		1 vs 4	7.35	0.39

TABLE V

Mean CTp value percentage difference between aorta levels for Liver tumor and normal tissue regions. BF, in mL/min/100g; BV, in mL/min/100g; MTT, in seconds; PS, in mL/min/100g; HAF, ratio without units

Parameter	Aortic Level Comparisons	Tumor			Normal		
		Mean % Difference	(±) 95% Limits of Agreement	p values	Mean % Difference	(±) 95% Limits of Agreement	p values
BF	Within-table	1 vs 2	1.68	2.90	0.30	4.38	0.93
		3 vs 4	1.04	3.21	0.39	3.86	0.24
	Between-table	2 vs 3	-3.88	8.41	0.33	9.84	0.76
		1 vs 4	-1.47	5.49	0.55	7.95	0.86
BV	Within-table	1 vs 2	-0.28	1.87	0.5507	4.49	0.84
		3 vs 4	-1.71	2.21	<0.01	4.76	0.09
	Between-table	2 vs 3	11.60	11.69	<0.01	12.24	<0.01
		1 vs 4	9.39	9.58	<0.01	10.61	<0.01
MTT	Within-table	1 vs 2	-1.43	2.91	0.33	3.49	0.84
		3 vs 4	-1.38	3.22	0.23	3.31	0.80
	Between-table	2 vs 3	13.88	14.56	<0.01	12.60	0.04
		1 vs 4	10.88	11.66	<0.01	12.74	0.12
PS	Within-table	1 vs 2	-0.96	5.56	0.62	6.75	0.56
		3 vs 4	-2.52	4.46	0.04	8.60	0.07
	Between-table	2 vs 3	13.69	15.35	0.07	18.19	0.08
		1 vs 4	9.04	11.04	0.07	14.37	0.06
HAF	Within-table	1 vs 2	2.69	3.77	0.20	6.72	0.34
		3 vs 4	-2.54	3.79	0.02	5.41	0.02
	Between-table	2 vs 3	-0.09	4.65	0.97	15.50	0.31
		1 vs 4	0.03	6.36	0.99	13.58	0.52