On Accelerated Dynamic Contrast-Enhanced Lung Perfusion Using k-t BLAST

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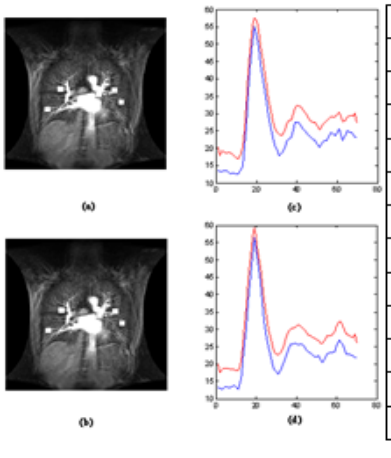
INTRODUCTION: k-t BLAST [1] may accelerate dynamic contrast-enhanced (DCE) lung imaging with only limited penalty in RMS error [2]. Yet the algorithm's known restrictions including initial-overshooting and temporal-smoothing cast uncertainties on perfusion quantifications for disease studies. In this work, we show that while these restrictions are present along accelerated DCE lung images, the tissue perfusion parameters remain highly consistent with those derived from fully-sampled images on both normal subjects and patients, suggesting feasibility of accelerated lung images in clinical examinations.

THEORY AND METHODS: k-t BLAST is a dynamic imaging acceleration technique in which the k-t undersampling is maneuvered to minimize the corresponding aliasing in the spatiotemporal domain [3]:

$$\rho_{x,f} = M^2 S^H (S M^2 S^H + \lambda I)^+ \rho_{alias} \qquad (1)$$

in which a finite and compact $\rho_{x,f}$ enhances reconstruction performance by further reducing the degree of aliasing. DCE lung imaging, shown to be compatible with k-t BLAST [1] for its resemblance to cardiac cine imaging in terms of compact temporal variation [2], could be prone to k-t BLAST's restrictions such as initial-overshooting and temporal-smoothing resulting in deviated estimations of mean-transit time and blood flow. Hence the presence of these restrictions and their impact to quantification require validation as done in this study. DCE lung images were obtained using IR-prepared, segmented EPI technique with TI/TR/TE/ETL =180/6.5/1.2/4, 256x256, 40-60 frames, slice thickness =10~12 mm, with seven coronal slices reconstructed using 5-fold acceleration including 18 fully-sampled low frequency ky-lines for conservation of fast varying contrast. 6 normal subjects and 3 patients were examined. ROIs were manually selected and divided into 6 regions (left upper, left middle, left lower, right upper, right middle, and right lower lungs). Signal-time curves were calculated and fitted to a gamma variate function. Relative perfusion parameters including pulmonary blood volume (PBV) and flow (PBF) were calculated [4].



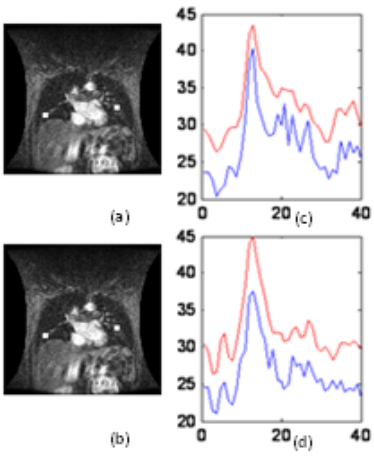
ParamROI	Raw	Recon	Err (%)
PBV_LU	134	137	2.60%
PBV_LM	165	170	3.40%
PBV_LL	199	203	2.20%
PBV_RU	125	125	-0.08%
PBV_RM	155	157	0.26%
PBV_RL	183	182	0.27%
PBF_LU	47600	48000	0.84%
PBF_LM	82300	83400	1.36%
PBF_LL	65600	65900	0.53%
PBF_RU	52300	52300	0.12%
PBF_RM	99900	10100	0.58%
PBF_RL	82400	82300	-0.09%

(e)

Figure 1: (a) Raw and (b) reconstructed images of a normal subject. (c)(d) Time-intensity curves from raw (blue) and recon (red) dynamic sets from right/left lung. (e) Perfusion parameters (LU: left-upper, LM: left-middle, LL: left-lower, RU: right-upper, RM: right-middle, RL: right-lower) from raw and recon images and their disagreements.

RESULTS AND DISCUSSION: Fig 1. depicts the time-intensity curve and corresponding perfusion quantification of the normal subjects. It can be seen that both the curve and the tissue quantifications of accelerated dataset (table in Fig.1, parameters in relative units) remain highly consistent with those from fully-sampled images. Such performance in normal studies can be attributed to the finiteness and compactness of dynamic lung spatiotemporal spectrum as predicted in theory section. The acceleration also benefits from the relative long duration of lung imaging (~70sec) compared with blood circulation (~22sec for one cycle of transit). This alleviates the demand toward temporal resolution hence finiteness of the spatiotemporal spectrum.

For patient studies, the turbulent time-intensity variation due to inability of long breath-holding as often encountered in patients results in smoothened time-intensity estimation after the first pass of contrast agent (Fig 2), likely due to widened spatiotemporal spectrum (hence increased aliasing) caused by turbulence and branching morphology in parenchyma. The tissue parameters however remain closed to true values, for the standard pre-processing of lung quantification involves fitting hence temporal smoothing of intensity curve does not exhibit prominent influences. Therefore temporal smoothing and initial overshooting, while being a restriction of k-t BLAST, inflicts little impact on tissue perfusion quantifications. All nine subjects included in this study showed similar error levels less than 4% (mostly around 2% or less) for relative PBV and PBF.



ParamROI	Raw	Recon	Err (%)
PBV_LU	263	254	-3.46%
PBV_LM	249	252	0.99%
PBV_LL	249	242	-2.80%
PBV_RU	235	244	3.57%
PBV_RM	210	211	0.62%
PBV_RL	230	229	0.48%
PBF_LU	23700	23700	0.20%
PBF_LM	27700	28400	2.73%
PBF_LL	15500	15300	0.91%
PBF_RU	28100	28900	3.03%
PBF_RM	39800	40200	0.87%
PBF_RL	29100	29000	0.29%

(e)

Figure 2: (a) Raw and (b) reconstructed images of a patient. (c)(d) Time-intensity curves from raw (blue) and recon (red) dynamic sets from right/left lung. (e) Perfusion parameters (LU: left-upper, LM: left-middle, LL: left-lower, RU: right-upper, RM: right-middle, RL: right-lower) from raw and recon images and their disagreements.

CONCLUSION: This abstract demonstrates consistency of tissue parameters between fully-sampled and k-t BLAST accelerated DCE lung imaging in both normal subjects and patients. While restrictions of k-t BLAST are present and influence intensity estimation on patient images as predicted, little impact is inflicted on the corresponding perfusion quantification.

REFERENCES: [1] Tsao et al. MRM, 50:1031-1042, 2003 [2] Hsu et al. ISMRM 2007 [3] Tsao et al. MRM, 53:1372-1382, 2005 [4] Levin et al. MRM 2001; 46:166-171