Optimal choice of deformable image registration reference for abdominal perfusion CT imaging with Volume Helical Shuttle mode

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Introduction

Deformable registration for quantitative imaging requires great care. Radiotherapy planning CTs are commonly used as reference volumes for deformable registration[1], permitting translation of clinical regions of interest (ROIs). However, perfusion imaging[2] involves creation of parameter maps with fidelity near the level of individual voxels, so erroneous deformations will seriously impair quantitative results. Instead perfusion images can be registered to one another and planning ROIs can be transferred with a second deformation pass wherein ROIs are deformed, retaining quantitative utility.

To accurately model contrast enhancement, perfusion imaging necessitates periodically burst sampling (e.g., 1s) over a prolonged period[2] (e.g., 10min). Modern scanners provide special "*fast and long*" modes for this purposes, such as GE® Volume Helical Shuttle mode (VHS; wherein the table *shuttles* back and forth during imaging). While ultimately beneficial for perfusion imaging[3], VHS presents additional respiratory motion correction challenges. VHS reciprocating scan passes also cause patient motion. Dynamic contrast enhancement (DCE) will further impair registration efforts.

The goal of this work was to identify which imaging phase represents the optimal registration target in a two-stage DCE liver perfusion study using VHS. The optimal phase was found by cross-registering image volumes and comp-aring mean-squared error (MSE) for each cross-registration.

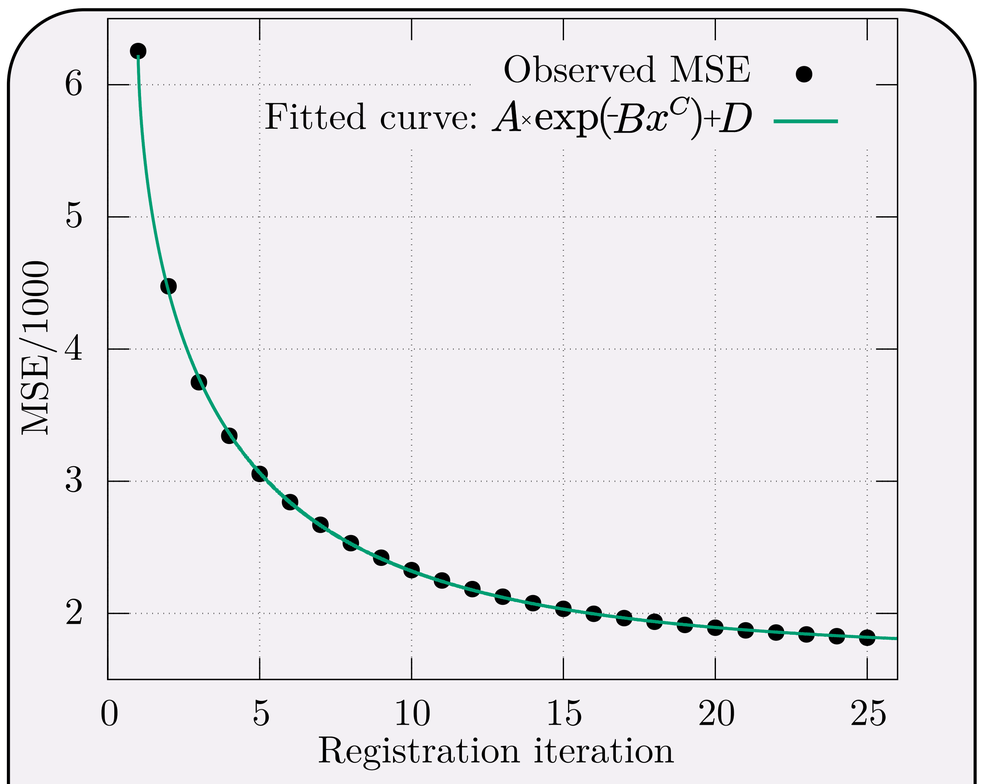

Figure 1: *representative example of a MSE-registration iteration graph demonstrating asymptotic convergence.*

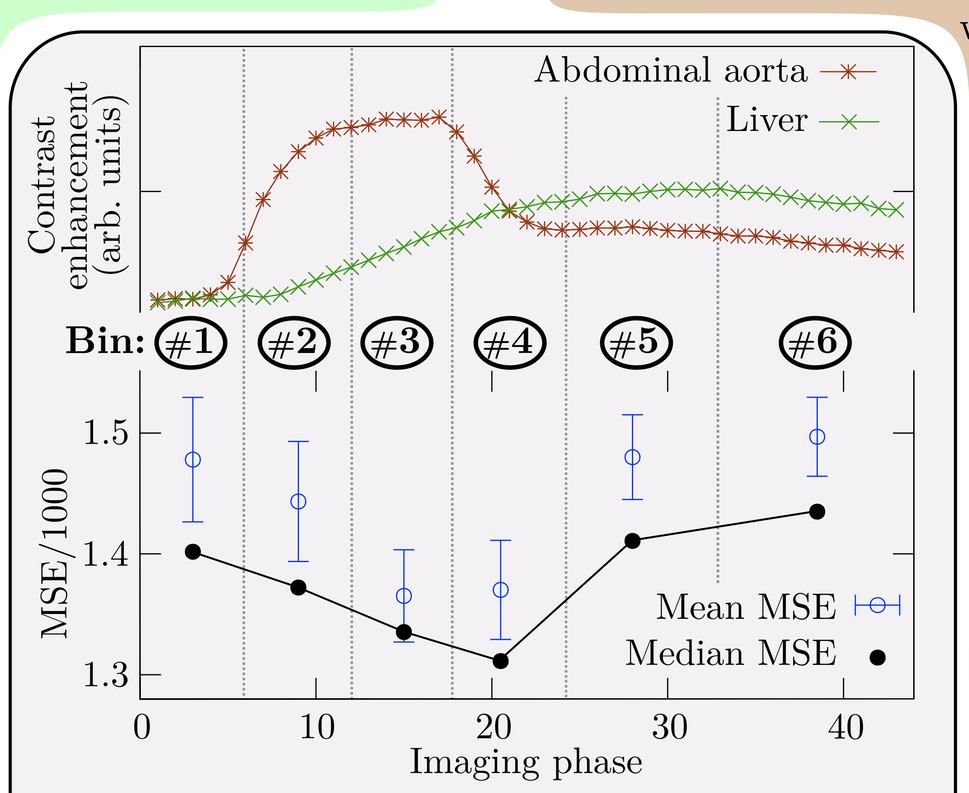

Figure 2: *typical contrast enhancement curves as well as mean and median MSE for each period bin (#1-6).*

Results

Rigid and affine registration were ineffectual, so only the symmetric log-domain demons algorithm[4] was used. Registration attempts were truncated after the 25th iteration; figure 1 demonstrates the fast approach of mean-square error (MSE) to asymptotic values. MSE-vs-iteration curves were fit to a pseudo-exponential, which tended to behave like ~exp(-Bx^{½}) where x refers to registration iteration. Asymptotic MSE were extracted. The mean percent-difference between minimum and asymptotic MSEs was -1.4±4.4% ($mean \pm \sigma_{mean}$).

For MSE comparison purposes, scan duration was divided into 6 bins denoting distinct periods: pre-injection (#**1**; phases 1-5), rapid contrast uptake (#**2**; 6-12), semi-stationary (#**3**; 13-17), rapid washout (#**4**; 18-23), midwash-out (#**5**; 24-32), and prolonged washout (#**6**; 33-43). Each bin contained a heterogeneous mix of respiratory phases. Bin MSE distributions were skewed toward $+\infty$; normality was not assumed. Figure 2 shows organ DCE curves (top; aorta and liver), median and mean MSE (bottom), and the 6 period bins.

A 6-way comparison of the distribution of minimum MSE in each bin was performed via Mann-Whitney-Wilcoxon test. Application of a Bonferroni correction (15 unique comparisons) led to a reduced, conservative confidence threshold of 0.003 (=0.05÷15). Six statistically significant observations were noted (p<0.002). The rapid and prolonged wash-out periods (lowest and highest median MSE, respectively) were each involved in 3 significant observations.

Methods & Materials

43 CT liver perfusion image volumes from a single patient were cross-registered, requiring 1806 (=43×42) registrations over 36 CPU-days. Image volumes were acquired with VHS on a GE® Discovery 690 PET/CT scanner in two logical phases. Phase 1 (contrast injection) required high temporal resolution to capture rapid changes in CT contrast. Total exposure lasted 56s, and was composed of 33 volumetric scans of 1.7s exposure each. An iodinated contrast agent, Omnipaque™ 300, was injected and followed with a saline flush. Phase 2 (washout) comprised 10 volumetric scans 6.5s apart; gradual contrast changes permitted slower sampling and reduced patient dose.

Whole liver was imaged. Reconstructions had 512×512 voxels with dimensions 0.977\0.977\2.5mm and no inter-slice gaps. 57 images comprised each image volume. Liver near the diaphragm traversed 6-7 slices (~17 mm) due to respiration. Registration was performed using the insight toolkit (ITK)[4] via Plastimatch[5].

Discussion & Conclusions

The aim of this work was to **identify an *optimal* registration target in a two-stage liver perfusion study using VHS.** An imaging phase was optimal if the total MSE of other phases registered to it was minimal. Minimum and asymptotic MSE differed by -1.4% on average, so 25 iterations were assumed to sufficiently approximate an infinitely long-running registration scheme.

Comparison of minimum MSE identifed **the optimal registration target within bin #4 (rapid washout; *when aortic contrast agent clearance was most rapid and liver contrast was nearing peak enhancement*)**. Furthermore, bin #**6** (prolonged wash-out; closest to steady-state) presented the ***worst*** registration target.

We are currently exploring whether differences in MSE stem from contrast enhancement, respiratory motion, or some other factor.

Poster presented @ ICCR 2016.

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The authors acknowledge financial support from the UBC, the BCCA OaSIS project, and the Walter C. Sumner Memorial Foundation.

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