

ORIGINAL ARTICLE

Efficacy of motion-correction in absolute quantification of colonic PET-CT for drug response therapy

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Abstract

Aims The study aimed at: a) characterizing and correcting bowel-motion induced artefacts whilst imaging the region in pre- and post-drug therapy ^{18}F-FDG scans; b)developing a motion model of the gut using a fully 3D non-rigid registration technique for applying to NACT digitised images.

Methods A motion correction technique for PET-CT scans, particularly those of the abdomen and colon was developed. Attenuation and activity image volumes were generated at different points in the respiratory cycle using the Nonuniform Rational B-spline Cardiac Torso (NCAT) anthropomorphic phantom. The movement of the abdomen was characterised as part of the image registration process and assessment of the motion correction technique was performed quantitatively with Region of Interest (ROI), image fidelity, and image correlation techniques; semi-quantitatively with line profile analysis; and qualitatively by overlaying non-motion-corrected and motion-corrected image frames.

Results Motion correction was successful for frames that were substantially different to the reference (large motion); these frames had considerable differences between the ROI activities in the non-motion corrected and reference frames. Large motion correction resulted in an improvement in image fidelity factor (from 0.848 to 0.976).

Conclusion In principle, PET-CT motion correction of the colon can be performed using image registration between different frames in the respiratory cycle. Clinically, frames at different points in the respiratory cycle can be obtained by respiratory gating during PET image acquisition. Future work can concentrate on developing this technique so that it can be applied to clinical data.

Key words: *Motion-correction, NCAT, Quantitative measurement*

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Introduction

Physiological motion significantly affects the quality of the medical imaging scan: it not only causes artefacts on hybrid functional-structural scans such as the PET-CT, but also

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reduces the accuracy of uptake parameters, which are based on the measurement of radionuclide uptake. Accurate measurement of radionuclide concentration within organs provides an accurate assessment of disease severity and can therefore be used to measure the response of various drug therapies. One application, where this is particularly useful, is the diagnosis and assessment of inflammatory bowel disease (IBD) in paediatric patients. Due to the nature of drug therapies for this disease, an accurate assessment of disease severity is important for correct dosing of current drug therapies - some of which have undesirable side effects and varying toxicities. Drug companies invest heavily in drug development and many experimental drugs never make it to market [4]. An accurate quantitative method of measuring radionuclide uptake in pathological tissues would not only provide an accurate way of assessing the clinical severity of disease, but would also provide a quantitative method for assessing the effectiveness of developmental drugs [8]. Endoscopy is as useful for direct visualisation of the lesion as for biopsy. However, biopsy of the diseased bowel is not always possible in proximal small bowel disease or in the presence of strictures, and it may be uncomfortable or contraindicated in very active disease. Therefore, a less invasive approach is needed, particularly for the assessment of the response to drug therapy in paediatric IBD.

Most current motion-correction techniques focus on the correction of motion within the lungs and the upper abdomen: these are two areas where motion is a particular problem. To the authors' knowledge there has been no work to quantify the motion associated with the movement of the ascending, transverse, or descending colon or on a method to correct for this motion.

We have proposed a motion-correction technique based on the registration of reconstructed images acquired at different time points within the respiratory cycle. The motion-correction technique developed in this work is likely to be applicable to applications other than those concerning measurement of the response to drug

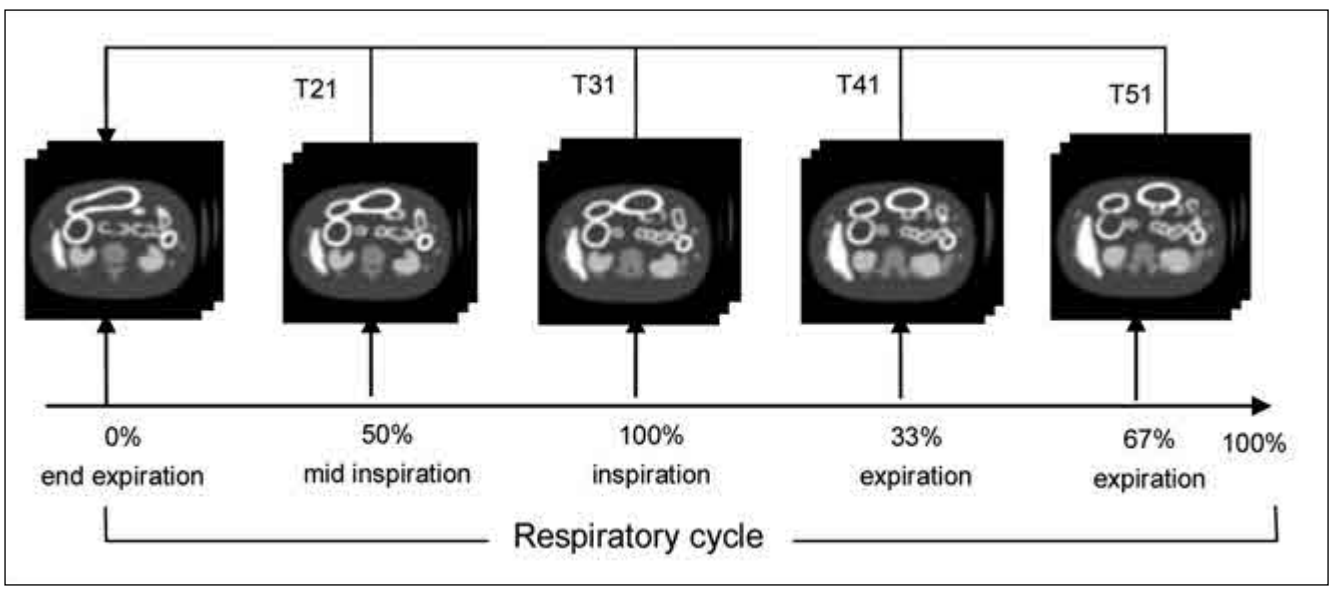

Figure 1 *Sketch of the motion-correction methodology used in this study to estimate the inter-frame 3D motion parameters (T21, T31, T41 and T51); T21 is the transformation which aligns frame 2 (50% inspiration) to the end-expiration frame (reference frame); T31 is the transformation describing the 3D motion between frame 3 (full-inspiration) and the reference frame, and so on.*

therapies or assessing IBD; however, the principles will generally be the same.

Materials and Methods

An image-based motion-correction approach using a voxel-intensity-based and multi-resolution multi-optimisation (MRMO) algorithm, first described by Bouchareb *et al.* [1, 6] was adopted as the motion-correction technique presented in this study. The 3D motion-generated parameters (through a respiratory cycle) were co-registered to a reference frame using a time efficient scheme. The reference frame is considered to be the end-expiration frame because it's the most reproducible phase in breathing cycles (see Figure 1).

This work utilised the NCAT phantom developed by Segars *et al.* [2]. The NCAT phantom is dynamic anthropomorphic digitised phantom capable of generating several sets of image data (called frames) at different points in the respiratory or cardiac cycle. The air inside the small intestine and colon was set to a background of 100 counts/second/pixel and the activity outside the phantom was set to 0 counts/second/ pixel. The organ-to-background activity ratios were set at 2-6:1. In each image volume, a set of five lesions of varying diameters (5, 10, 15 & 20 mm) with activity-to-background ratios of 10:1 were generated.

The properties of the image registration software used in this work are such that if it is applied to image sets generated by the NCAT phantom at different points in the respiratory cycle, the motion between the two image sets can be quantified by the transformation parameters already described. To simulate the effects of the point spread function (PSF) of a real PET scanner, on the activity images, each image volume was convolved with a Gaussian kernel.

Abdomen and colon motion was characterised through translation, rotation, scaling and shearing parameters. Quantitative and qualitative parameters including image comparison, ROI static-frame analysis, long-frame analysis and lesion analysis, were evaluated.

Results & Discussion

Characterisation of abdomen and colon motion

Translation parameters

The largest translations estimated to register the different respiratory frames to the reference, were found to be in the Z-axis or head-to-feet (Figure 2a). There was an extremely small, if not zero, X-axis translation component. Translations below 3 mm are likely to be below the resolution of a typical PET scanner, therefore correction parameters below this are not likely to be clinically beneficial.

Rotation parameters

The largest rotation estimated to register the different respiratory frames to the reference frame was found to be about the X-axis (Figure 2b). As we breathe in, the chest rotates upwards, and this compliments the translation in the Y direction. The remaining rotations about the Z and Y axes are smaller in magnitude.

Scaling parameters

Scaling parameters follow a similar trend to the translation parameters. The predominant scaling is in the Z-axis, followed by the Y-axis, and with no scaling required in the X-axis (Figure 2c).

Shearing parameters

Shearing is the final and the most complicated-to-interpret motion parameter. It forms the final level of optimisation. The X shearing component is approximately linear. The Y shearing component has a parabolic nature, and the Z shearing component has a less intuitive relationship (Figure 2d).

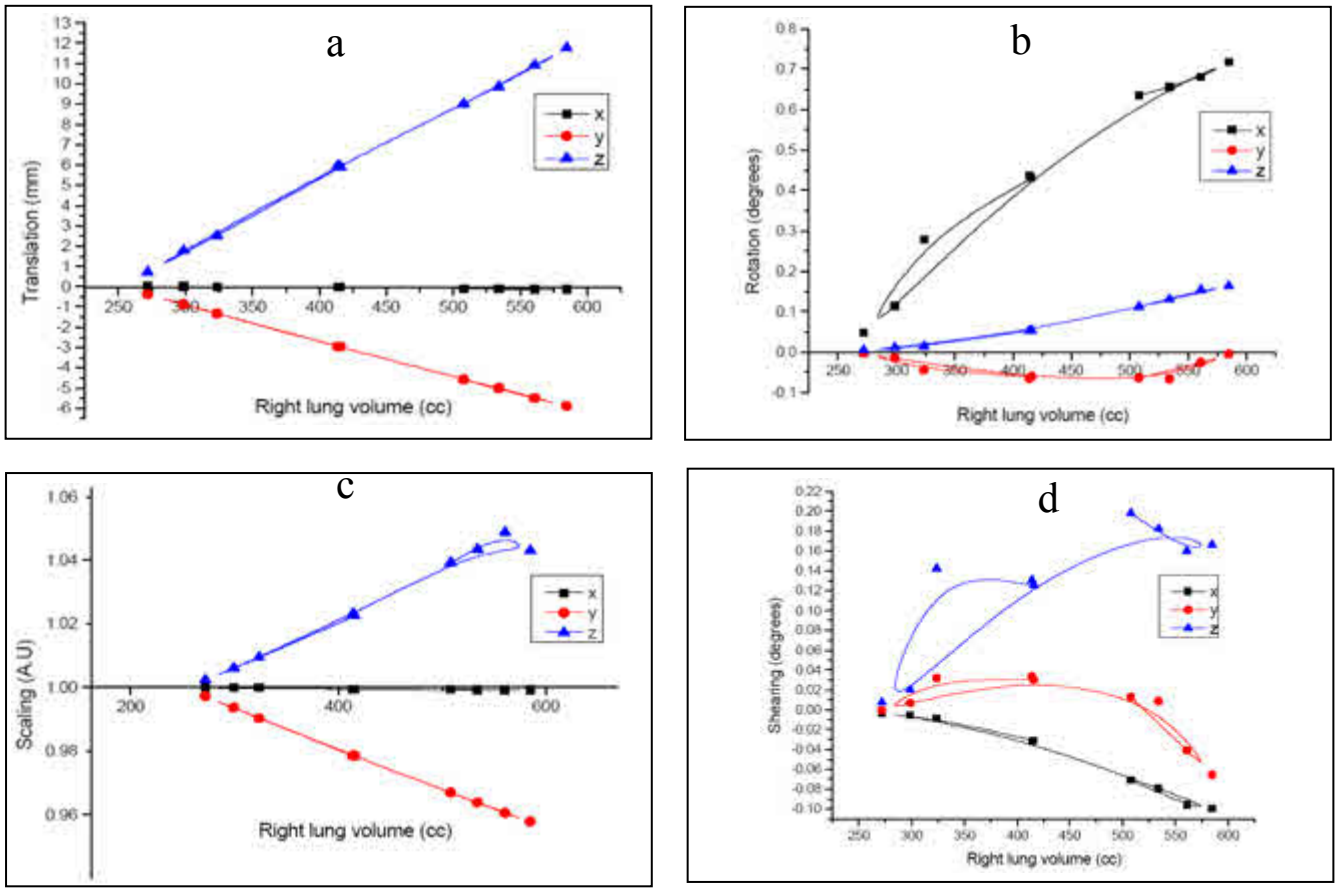

Figure 2 *Translation (a), rotation (b), scaling (c) and shearing (d) registration parameters*

Image Comparison

Image comparison was performed quanti tatively with image fidelity, Qf (Equation 1), and correlation measurements, Qc, (Equation 2), and with ROI analysis [3, 5]

Equation 1

$$Q_f = 1 - \frac{\sum_i \sum_j [P(i,j) - P^*(i,j)]^2}{\sum_i \sum_j [P^*(i,j)]^2}$$

Equation 2

$$Q_c = \frac{\sum_i \sum_j [P(i,j) \times P^*(i,j)]^2}{\sum_i \sum_j [P^*(i,j)]^2}$$

It can be seen from Figure 3 that the fidelity of the images is greatly increased after correction of motion between the image frames and the reference frame, with the lowest value after correction being 0.976.

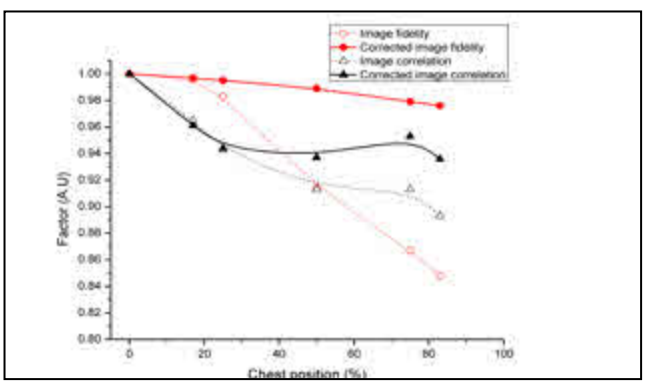

Figure 3 *Fidelity and correlation factors for non-motion and motion corrected frames as a function of chest position*

ROI static-frame analysis

Assessment of the motion correction technique was also performed with ROI

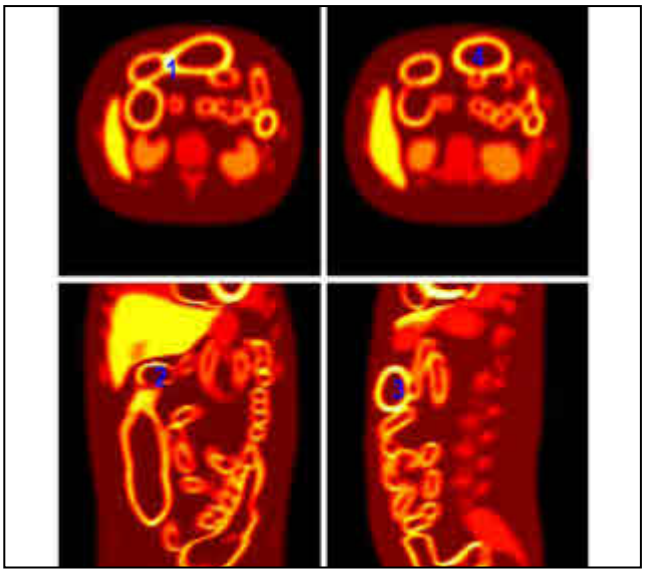

Figure 4 *Elliptical ROIs as per description*

analysis of the activities within regions of the emission images (Figure 4). Four elliptical ROIs were drawn: 1) in the tissue at the top of the transverse colon; 2) the loop between the ascending and the transverse colon; 3) transverse colon in various orientations (transverse, coronal, sagittal) and 4) in the lumen of the transverse colon. It was noticed that for small lung volumes, the motion-correction actually reduces the activity in ROI 1 to below both the reference and non-motion corrected frames (Figure 5a). At chest position (intermediate lung volume), the discrepancy between non-motion corrected frames and the reference, starts to become apparent (Figure 5b). However, it can be seen from the motion-corrected frames that this discrepancy is lower. At large displacements exhibited by respiratory frames further away from the reference (large lung volumes), the difference between reference and non-motion corrected ROIs is large (Figure 5c), whereas the difference between the reference and motion-corrected ROIs is significantly reduced.

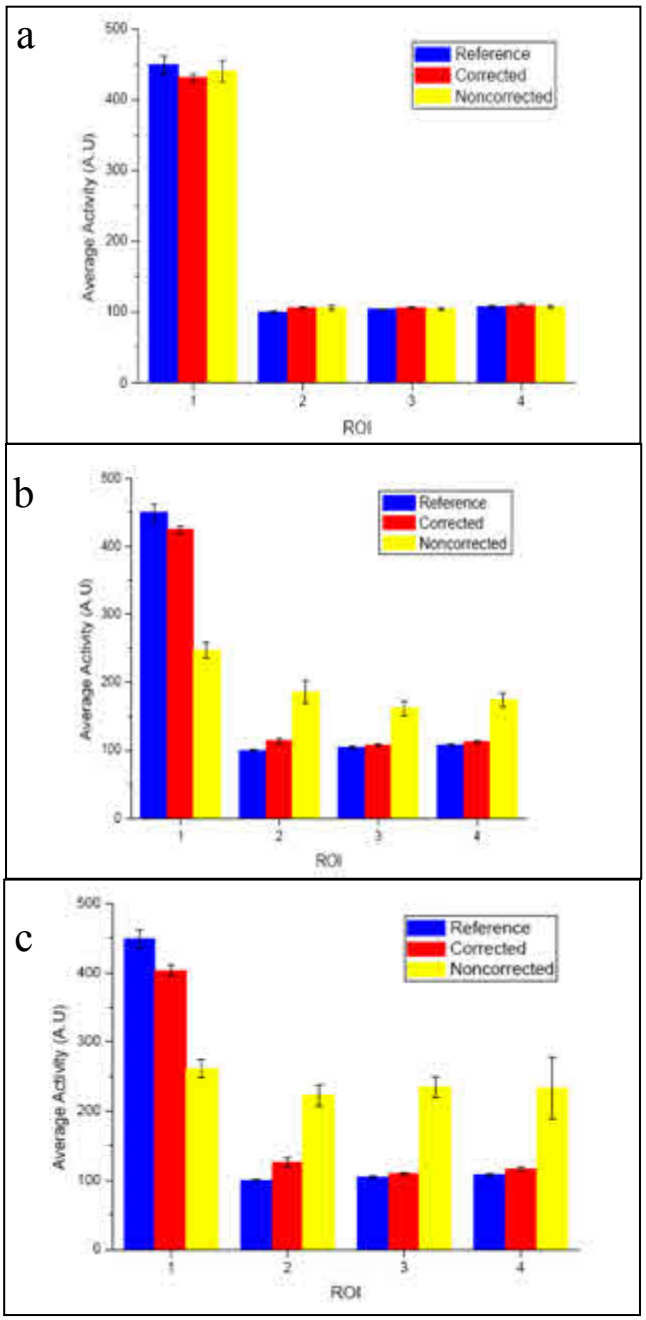

Figure 5 *Motion correction for small (a), intermediate (b) and large (c) lung volumes*

Long-frame analysis

Figure 6 shows the ROI activities for images, which are the sum of all the individual motion-corrected frames, non-motion corrected frames, and a larger time period reference frame (long frames). There appears to be a large difference between the reference and the non-motion corrected frames, and a small difference between the reference and motion-corrected frames. This situation more accurately represents how an ungated clinical

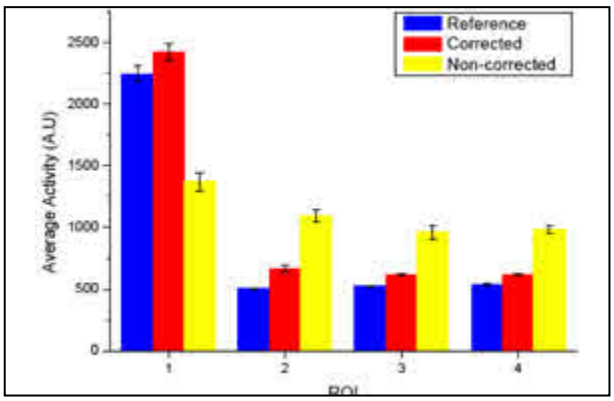

Figure 6 *Motion-correction for long frame*

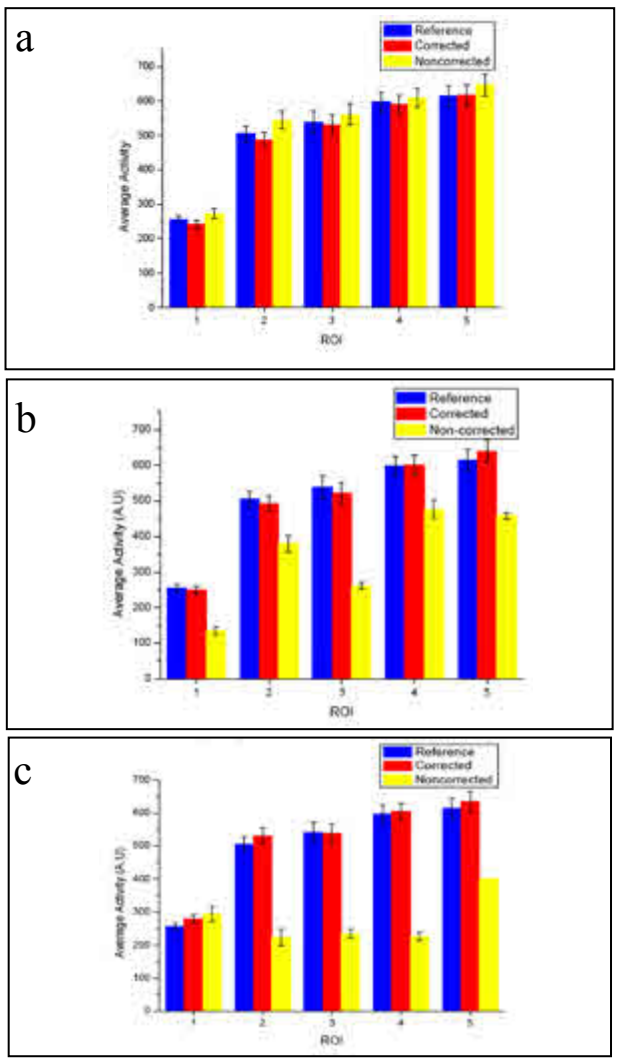

Figure 7 *Lesion activities for small (a), intermediate (b), and large (c) lung volumes*

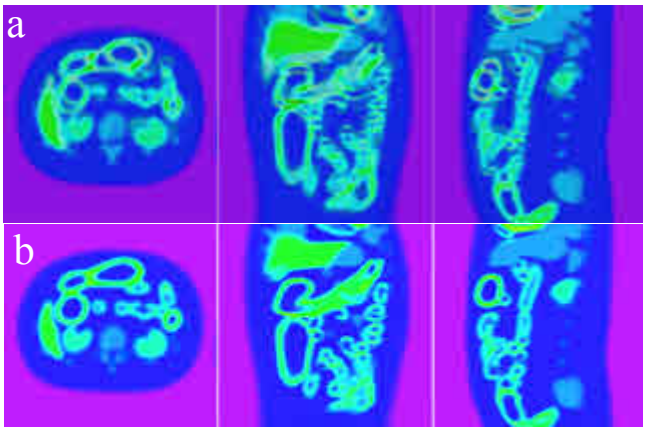

Figure 8 *(a) Frame 5 overlaid onto reference frame. Areas displaying mismatch in alignment due to respiratory motion are the kidneys, liver, transverse colon, and areas of the small intestine; (b) Motion-corrected frame 5 overlaid onto reference frame. Areas where motion-correction has been particularly successful and mismatch largely reduced are the kidneys, liver, transverse colon, and the small intestine*

image would look. For ROI 2, even though this ROI is supposed to be in an area of background activity, it can be seen that the activity is significantly more than background in the non-corrected mage.

Lesion activities

ROIs were created around each of the lesions in the same way as before. Figures 7 shows the motion-corrected and non-motion corrected lesion activities for small, intermediate and large lung volumes. For the small-volume (Figure 7a), it can be seen that the measurements in each lesion are virtually the same, which suggests that there is little difference between the reference and the motion-corrected and the non-motion corrected images. As for Figure 7b, it displays the same behaviour as in Figure 7a, although the difference is much more pronounced. With reference to Figure 7c, the measurements in each lesion are virtually the same for the reference and motion-corrected frames, with

the exception of lesion 1. The anomaly for ROI 1 could be caused by the movement of tissue with a similar activity in the lesion moving into the ROI. This suggests that for large amounts of motion, motion-correction is particularly effective in yielding a correct lesion activity for lesions of sizes ≥10 mm.

Conclusions

The motion-correction technique adopted is especially effective at correcting for motion between 25-100% from the full expiration reference (i.e. chest positions corresponding from ¼ inhale to full inhale). For lesions sizes ≥10 mm, motion-correction appeared to be successful for lesions in various positions in the ascending and transverse colon. It could not be established whether motion correction of lesions <10 mm was successful or not, and this is something that requires further investigation. For normal inspiration (used in this work), the maximum diaphragm movement is set to 2 cm and the maximum anterior-posterior expansion is set to 1.2 cm. Motion-correction will reduce artefacts, improve accuracy of assessing severity and efficacy of a given treatment quantitatively (Figure 8). Another extension of this work would be to include local motion due to the transit of a bolus through the colon or from other stimuli [7].

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