Accuracy and precision analysis of a semi-automated spatial tag position detection method

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Introduction

Strain measurements of muscle and tendinous tissue can be calculated from the tissue displacement by using phase-contrast (1) or spatial tagging methods. Application of spatial tags saturates tissue magnetization in a spatially dependent manner, and the motion of these tags during muscle displacement allows reconstruction of the underlying tissue motion. Spatial tags allow for dynamic multi slice data to be acquired, can encode motion in a single image acquisition, and can accurately portray tissue displacement during movement (2), but manual determination of spatial tag location is time consuming, subjective, and may lead to error when no distinct minima are present between two pixels with similar signal. Strain during muscle contraction is less than 7-8% (3) so a high level of precision is required in quantifying tissue displacement. Therefore, the purpose of this project was to develop a semi-automated method for precisely determining spatial tag position in multiple displacement-encoding directions.

Methods

Subjects: Anatomical and spatially tagged datasets were obtained from the tibialis anterior (TA) muscle in 4 young healthy subjects (3 male).

MRI: Data were obtained with a Philips 3T Intera Achieva MR imager/spectrometer. The subject was positioned supine with the foot fixed in an isometric exercise device and the maximum girth of the tibialis anterior muscle centered in a 8 channel SENSE knee coil. T_1-weighted anatomical images of the leg were obtained in 3 planes with TR/TE=500/16 ms, slice thickness (ST)=5 mm, FOV 180×180 mm (axial) or 256×256 mm (coronal, sagittal), and acquired matrix 256×256 (reconstructed at 512×512). Spatially tagged data were acquired using a binomial spatial tagging sequence employing a single shot, gradient-echo EPI readout (TR/TE=10 s/22 ms), 8 slices with ST=10 mm, the same center positions as the anatomical images, FOV 256×256 mm, an acquired matrix 128×116 (reconstructed at 128×128). In separate sagittal image acquisitions, line tags were applied at 0°, 45° and 90° for displacement encoding in the foot-head (Z), anterior-posterior (Y), and YZ directions. For coronal image acquisitions, line tags were applied at 45° and 90° (left-right (X) and XZ directions, respectively). In axial images, line tags were applied at 45° (XY direction). For all tagging directions, the tags were placed 10 mm apart.

Image processing: The following procedures were performed in Matlab v. 7.6.0:

1. Regions of interest were drawn around the tibialis anterior (TA) in sagittal, coronal and axial tagged images.
2. For each encoding direction, the signal intensity data along lines perpendicular to the applied tags were used to create fit signal intensity data and determine tag location.
3. Raw signal intensity data were passively demeaned and scaled to ±1 (blue line in Figure 1).
4. The first minimum was manually defined and this point served as a reference point. Nine or 10 data points in the vicinity of the reference point were fitted to a 6^{th} order (X and Y directions) or a 7^{th} order (all others) polynomial (red line in Figure 1). Polynomial fitting was used because the signal profile may be non-sinusoidal following tissue displacement.
5. The fit signal derivative was calculated (green line in Figure 1) and the next tag position was determined as the next point at which the fit signal derivative changed from negative to positive.
6. This pixel index was defined as the next reference point and the procedure was repeated to find the location of the subsequent tag.
7. This procedure was repeated for each line of interest in the image (Figure 2).
8. Erroneously placed tags were determined by visual inspection and corrected.

For 45° tags, a line was fitted to the detected tag positions. The distance between corresponding points in successive tags was calculated using the Pythagorean theorem. The accuracy and precision of this calculation were determined as the mean and standard deviation (SD), respectively, of the difference between the observed and known tag distances.

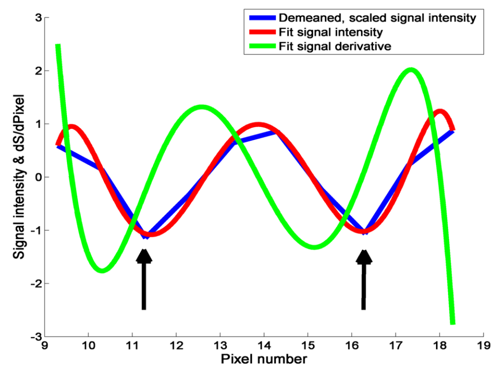

Figure 1. Example demeaned, scaled signal intensity profile and fitting procedure used to determine tag position. Left and right arrows indicate the reference point and detected tag positions, respectively.

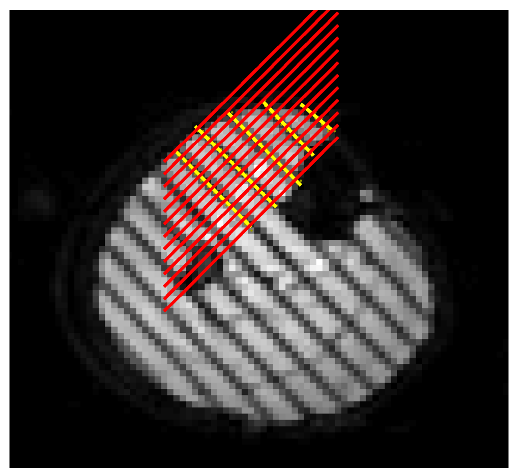

Figure 2. Axial image showing the detected tag positions (yellow lines) and the direction of distance measurement (red lines).

Results

The mean tag distance in all directions and planes for all four subjects was 9.998 (SD 0.26) mm, corresponding to a coefficient of variation (CV) of 2.58% and a relative error of 0.03%. These values did not differ between diagonally, vertically or horizontally applied tags.

Conclusion

There was excellent agreement between the calculated and known tag distances, indicating that this procedure accurately determines tag position in all directions of tag application. Since this method yields accurate results in static images, it can be further applied to dynamic images to determine strain in skeletal muscles and will decrease the data analysis time and increase the objectivity of tag detection.

References

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