Optimization of filter size for HARP analysis of lower leg muscle

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Introduction. Cine tagged MRI analyzed by harmonic phase (HARP) analysis [1] can be used to analyze motion in muscle [2,3]. However, a challenge is the existence of signal loss due to physiologic structures (e.g. bone, blood vessels, Figure 1) that roughly coincide with tag direction. The objective of this study was to determine the effects of filter dimensions in HARP processing on inter-tag distances in data sets with this type of physiologic signal loss.

Methods. One subject participated in this optimization study and provided informed consent prior to participation. The subject was positioned supine on the MR table with the right foot strapped in an MR compatible isometric exercise device. The isometric exercise device was equipped with a load cell (Interface Force, model SSM-AJ-500) to measure maximum voluntary contractions (MVC), which were displayed via data acquisition software (LabVIEW, National Instruments) to provide real time, visual feedback to the subject [4]. Several practice contractions were conducted, and cine-tagged MR images [TR=265.05 ms; FOV=179 mm×179 mm; slice thickness=7.1 mm; reconstructed voxel size=1.4×1.4×7.1 mm^3; nominal tag spacing=7.1 mm; EPI factor=43] were acquired dynamically over 20 time points as the subject went from rest to plantarflexion. Horizontal and vertical tag lines were acquired in separate scans. Images were analyzed using HARP analysis [1] in MATLAB (Mathworks, Inc.). Elliptical filters in the HARP analysis were applied with unity gain and Gaussian roll-off. In the images with vertical tags, the long axis of the ellipse was varied by 10-pixel increments (a=15-55 pixels), and the short axis was varied by 1-pixel increments (b=1-5 pixels). In the data with horizontal tags, a=30 and b=5. The inter-tag distance was determined by dividing the position vector by the unwrapped phase difference vector. Inter-tag spacing was compared in the soleus muscle along a line perpendicular to the tags (Figure 1, blue line). Strain was calculated using the mean inter-tag distances before/after contraction.

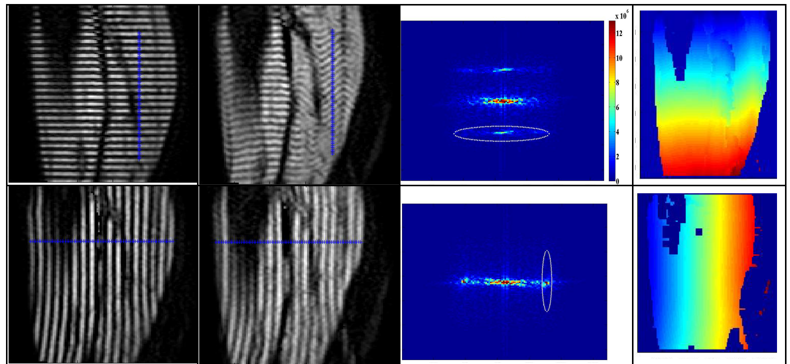

Figure 1. Horizontal (top row) and vertical (bottom row) tagging in calf muscle. Tagged images of relaxed (Column 1) and contracted (Column 2) lower leg muscles. Blue lines show the lines used for analysis of inter-tag spacing. Fourier transforms of the data (Column 3) demonstrate different orientations for the tag directions. Unwrapped phase values after HARP analysis (Column 4).

Results. The Fourier transform of the data (Figure 1, Column 3) demonstrates the challenge of optimizing filter size. For the horizontal tags, the first harmonics are offset vertically; however, for the vertical tags, the first harmonics are offset horizontally, along the broader dimension of the zero frequency peak. For the horizontal tags in relaxed muscle, the mean inter-tag spacing after HARP analysis over the line of interest was 7.03 mm for the relaxed image, which was comparable to the mean value measured by hand in the unprocessed image (7.05 mm). The mean vertical tag spacing measured in the unprocessed image was 6.90 mm, which was as much as 1% lower than the mean values determined via HARP processing (Figure 2). In relaxed muscle, the mean calculated inter-tag distance of the vertical tags increased with increasing filter short axis length; however, the range of values also increased with increased short axis length at a greater rate. The trend was similar in the contracted muscle, with a greater increase in range. Strains were calculated for a range of filter dimensions (Table 1).

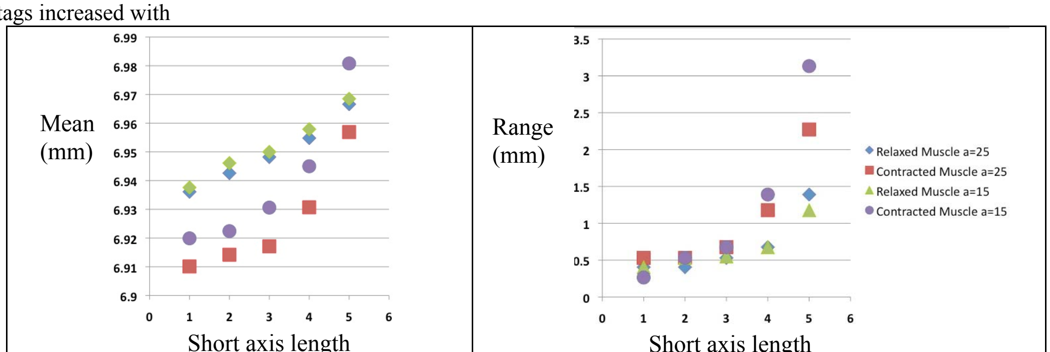

Figure 2. Mean and range of inter-tag spacing for vertical tag lines. For clarity, only the values for long axis length a=25 and a=15 are shown.

Conclusions. Since tags in relaxed muscle are expected to be closest to the pre-processed values, an increase in the range of values for the inter-tag spacing of the relaxed muscle indicates uncertainty in tag measurement, suggesting that smaller short axis lengths are preferred for the filter. Indeed, for b=5 and a=15, the mean tag distance for the contracted muscle is larger than the applied tags (Figure 2), resulting in an apparent reversal of the actual strain pattern. Thus, uncertainty and inaccuracy in inter-tag spacing propagates into erroneous strain calculations. Our results suggest that filters with smaller short axis lengths (b=1-3) are preferred for applying vertical tags to measure muscle motion near structures such as bones or large arteries that are roughly aligned with the tags for use in calculating strain.

	b=1	b=2	b=3	b=4	b=5
a=15	-0.255	-0.341	-0.279	-0.185	0.177
a=25	-0.375	-0.409	-0.448	-0.347	-0.139

Table 1. Strain values (%) between contracted and relaxed muscle.

References **1.** Osman NF, *et al.*, MRM. 42, 999. **2.** Parthasarathy V, *et al.*, J Acoustic Soc Am. 121, 2007. **3.** Piccirelli M, *et al.*, J Vision. 7, 2007. **4.** Maguire MA, Weaver TW, Damon BM, Med & Sci in Sports & Ex. 39, 2007.