3D Architecture of Rotator Cuff Muscles with Diffusion-Tensor MR Imaging and Tractography: Feasibility and Reproducibility Study in Asymptomatic Volunteers

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Introduction

What are rotator cuff (RC) tears ?

RC tears is a painful and debilitating shoulder condition. It can be acute resulting from **immediate intense stress** or chronic from the degenerative process by **repetitive stress**. The prevalence of RC tendon tears increases with aging with **half of individuals in their 80s.**

Every year in the United States, 250,000 patients have surgical repairs, but 26.6% of reported cases had retears after two years.

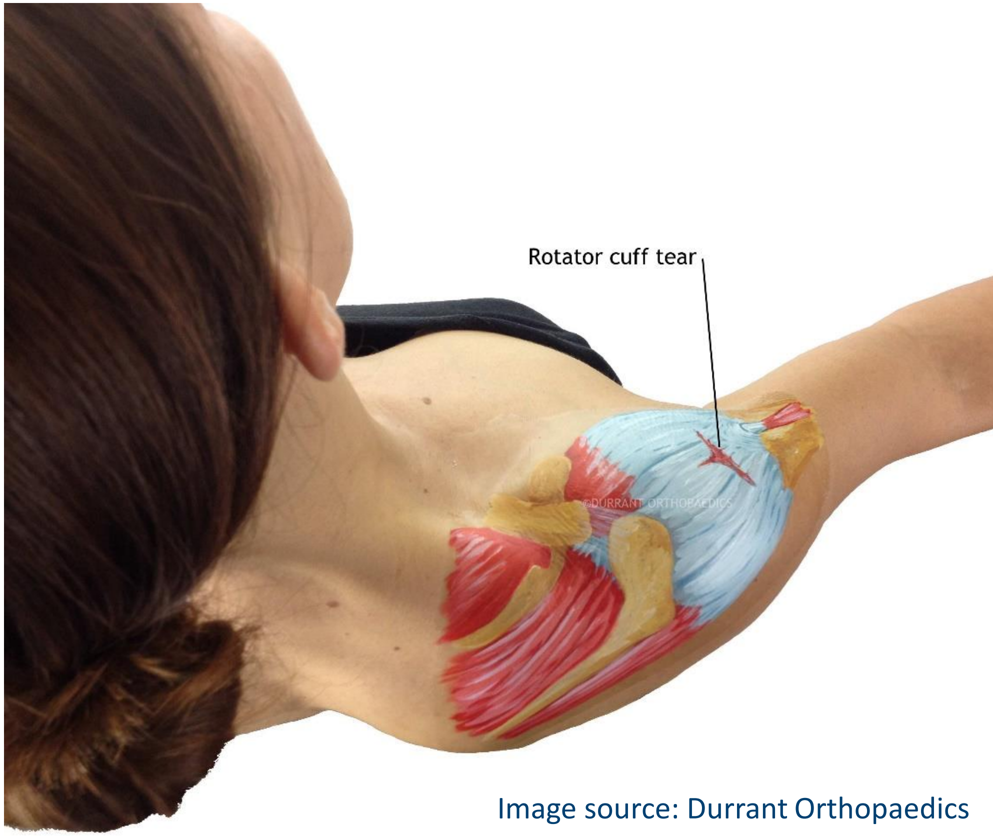


Image source: Durrant Orthopaedics

Why do surgical repairs fail?

RC tears lead to muscle atrophy, fatty infiltration and fibrosis, causing muscle stiffness and decreased elasticity of the myotendinous junction.

There are currently no quantitative measures to inform the surgeon on the quality of the myotendinous junction.

How we can improve patient outcome ?

Assessment of RC muscles' viscoelastic properties using MR-Elastography (MRE) could assist surgical planning. Since stiffness is dependent on anisotropy, Diffusion Tensor Imaging can simplify the inversion algorithm of MRE.

First, we studied if these imaging techniques are reproducible in 6 shoulders of asymptomatic patients

Methods

Six volunteers were reseated 3 times and the right shoulder rescanned.

The vibrating actuator from a Resoundant machine was placed on the supraspinatus.

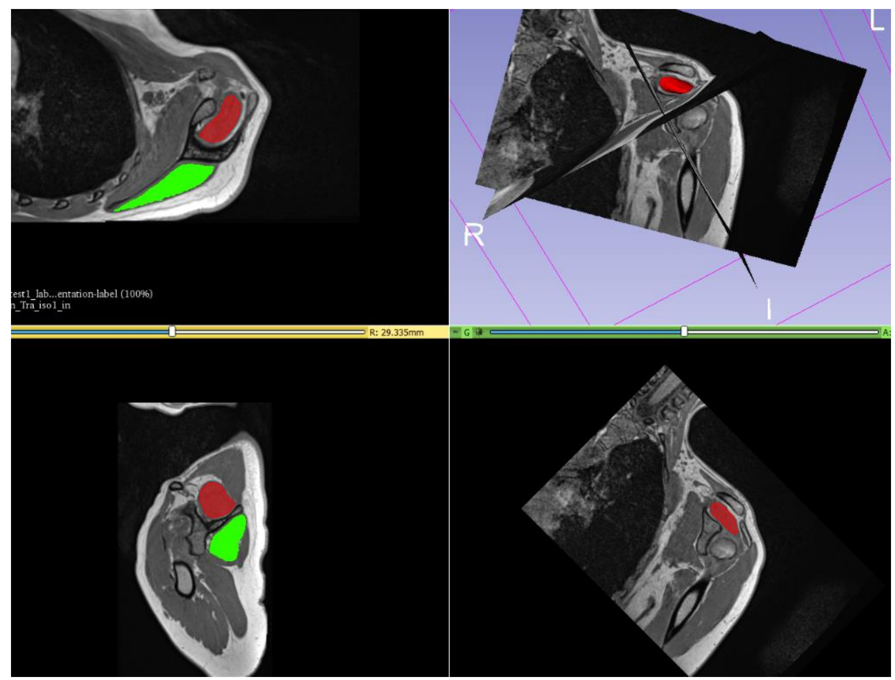
Magnetic Resonance Elastography (MRE) were at: 100Hz, 30 slices, TR/TE = 3300/40 ms, voxel =3x3x3 mm3

Diffusion Tensor Imaging (DTI) was matched MRE slices and resolution, with 12 diffusion-encoding gradients at b=500 s/mm^2 (2 averages); b=800 s/mm^2 (4 averages); TR/TE = 5800/57ms.

Analysis was performed with Mrtrix3 for tractography, mean diffusivity (MD) and fractional anisotropy (FA)

T1 vibe (TR/TE = 5.76/2.46ms, voxel = 1 x 1 x 1mm^3) was used for segmentation

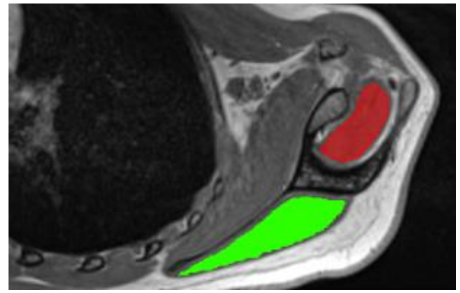
Segmentation of the supraspinatus and the infraspinatus



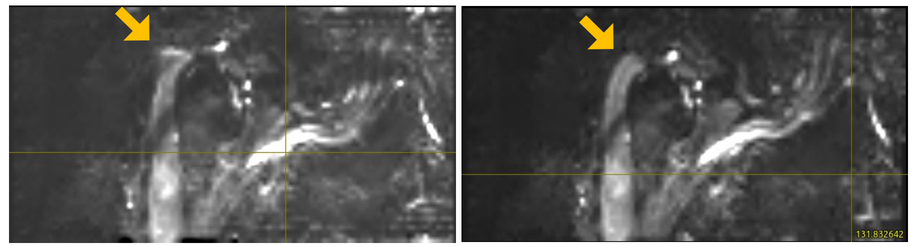
Methods

Post processing steps

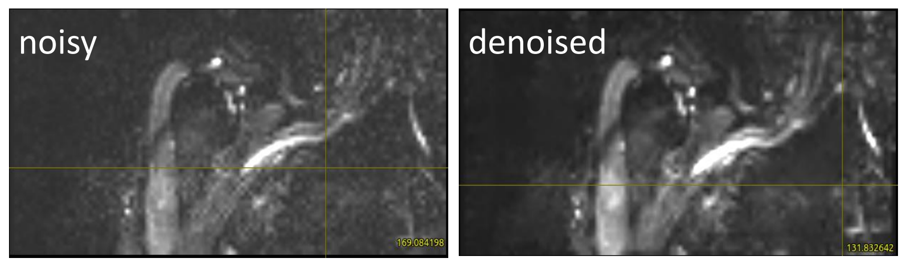
Muscles Segmentation (T1 VIBE)



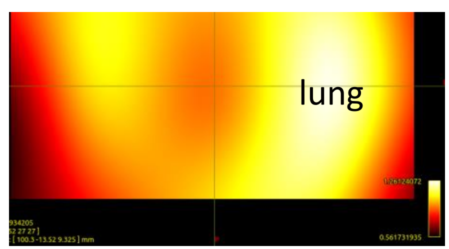
Correct EPI distortion artefact



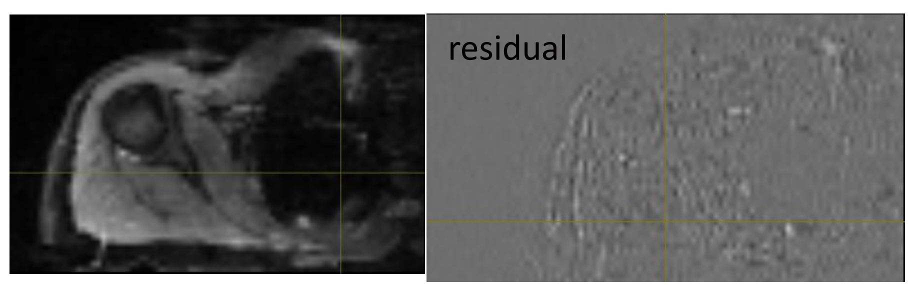
Denoise DWI



Correct B1 inhomogeneity



Correct for Gibbs ringing artefact



Methods

Post processing steps

Average the images over all the acquisitions

↓

Register T1, MRE, DWI

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Calculate the diffusion tensor, FA and MD

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Calculate the orientation distribution function (ODF)

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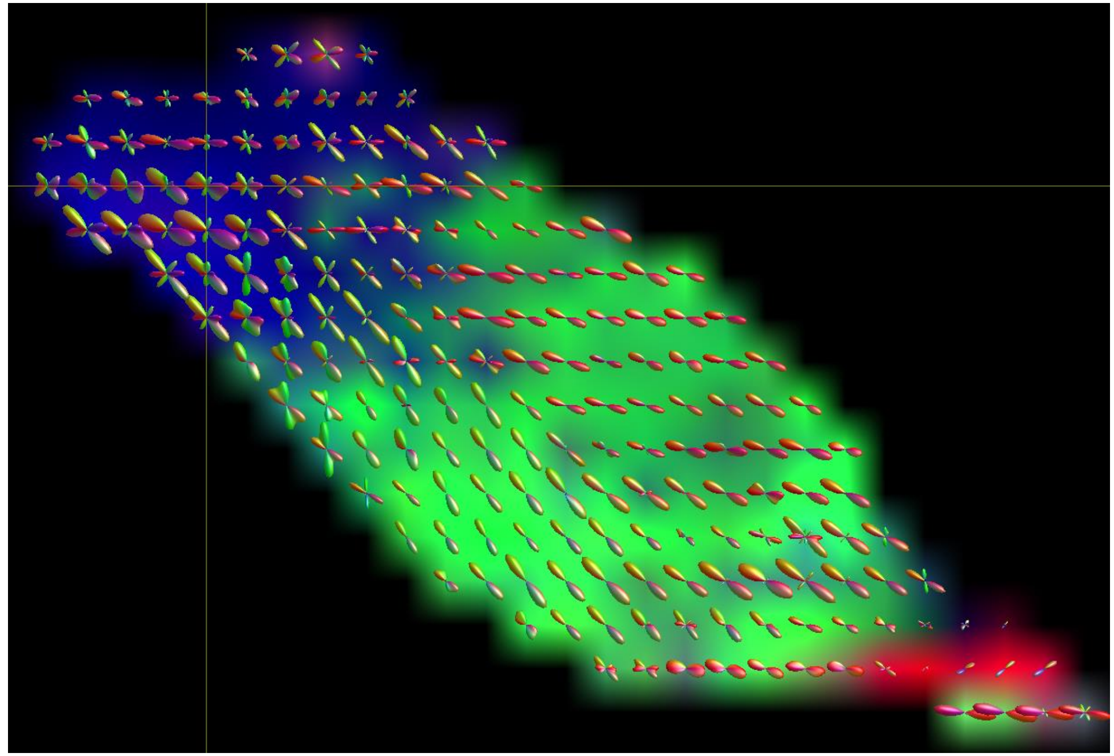
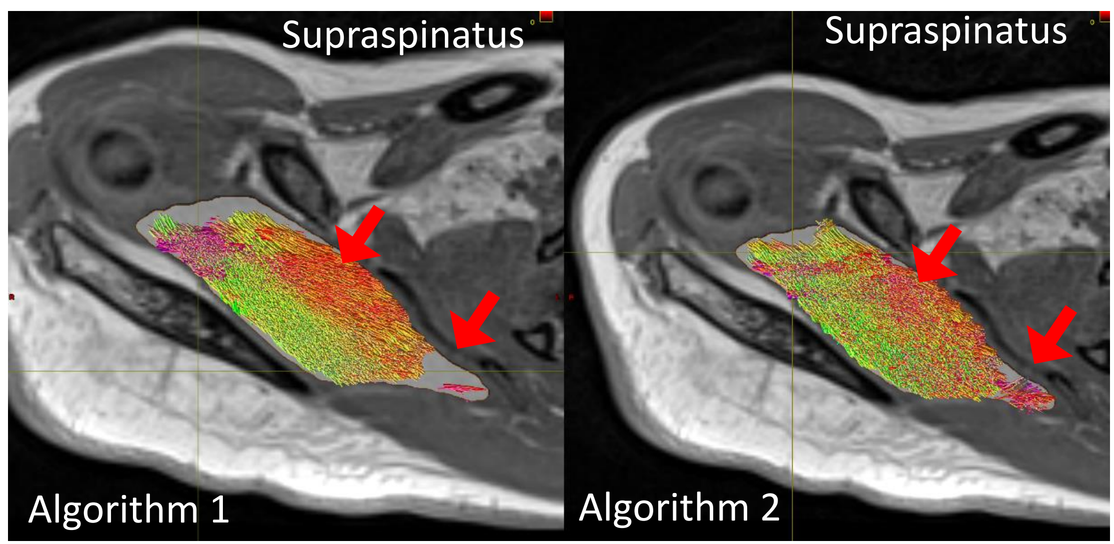
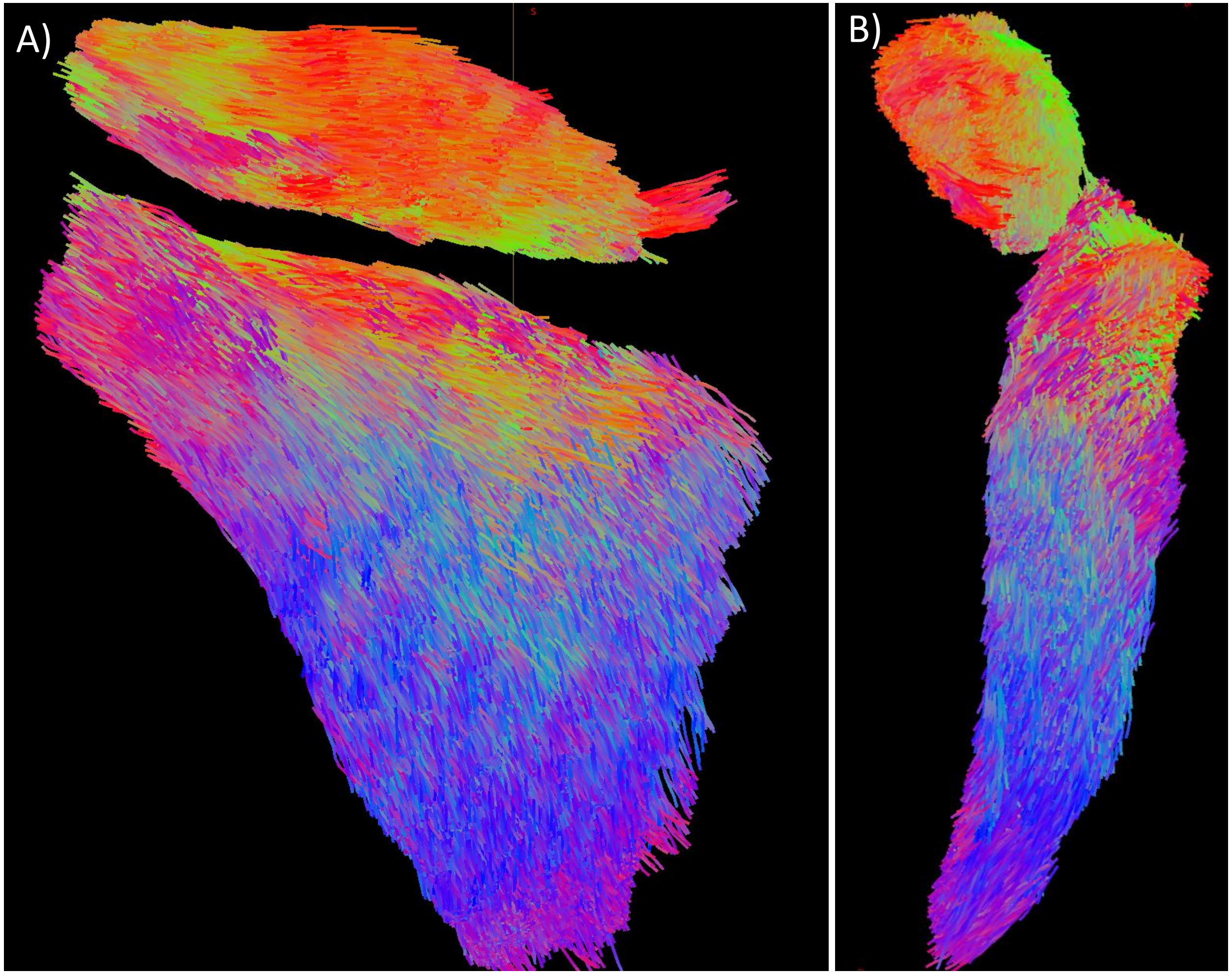
Determine the best tractography algorithm

ODF, main orientations of the fibers in the infraspinatus



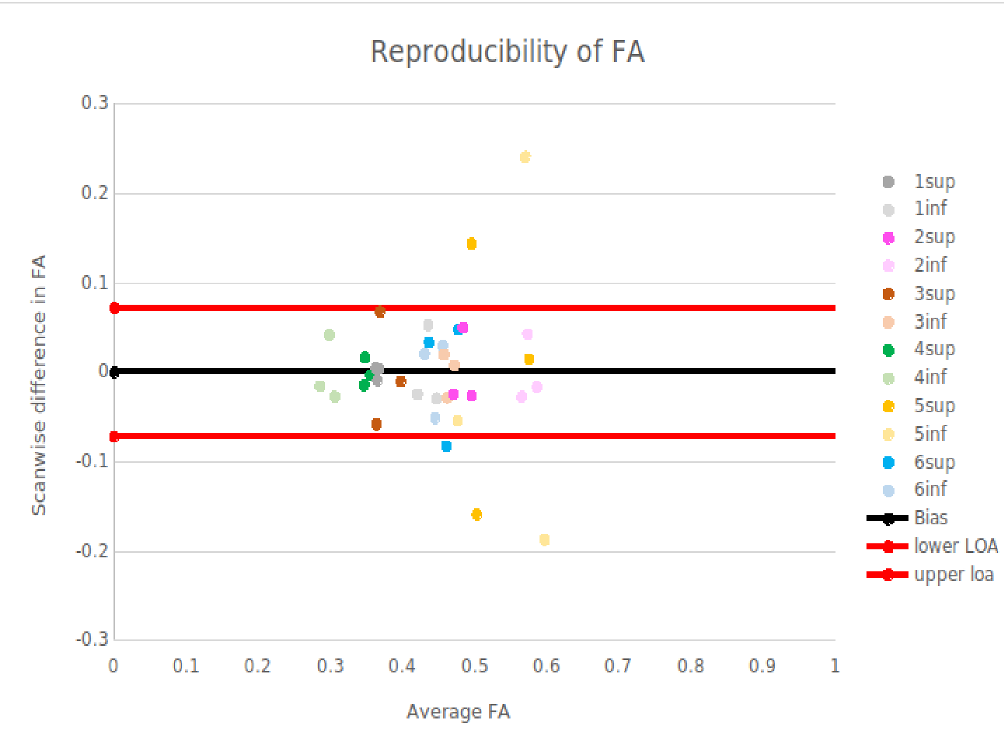


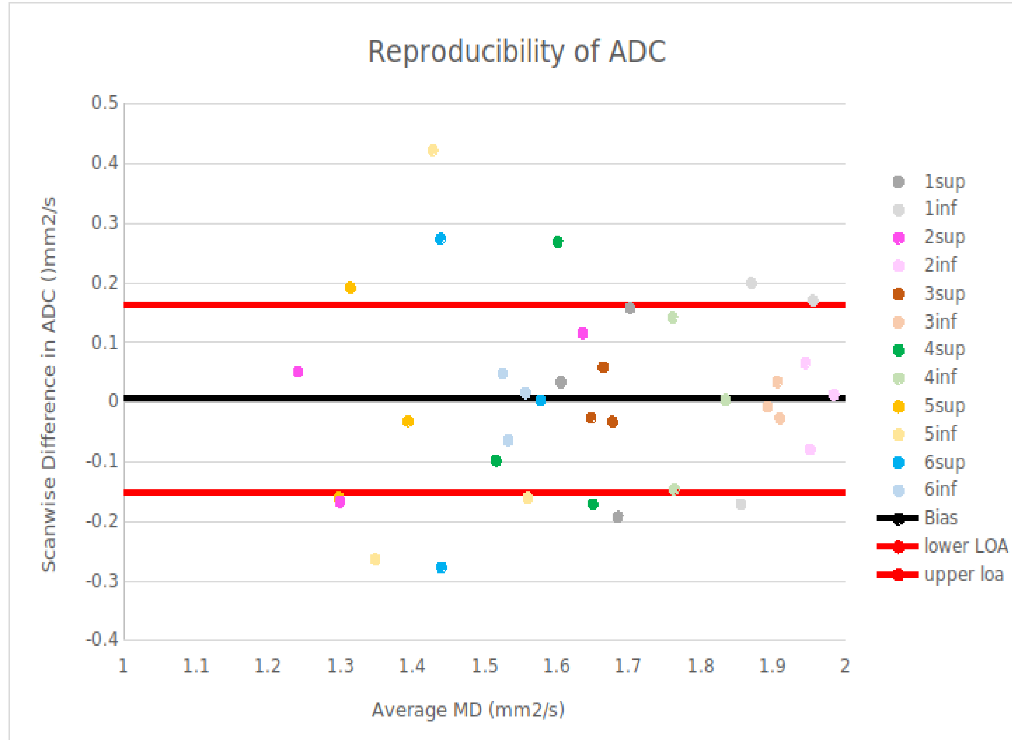
Results



Coronal (A) and sagittal (B) views of the supraspinatus and infraspinatus from 10,000 tracks generated from MrTrix. Criss-cross of fibers tracks are observed longitudinally and transversely corresponding to the low FA measured (0.42+-0.07).

Results





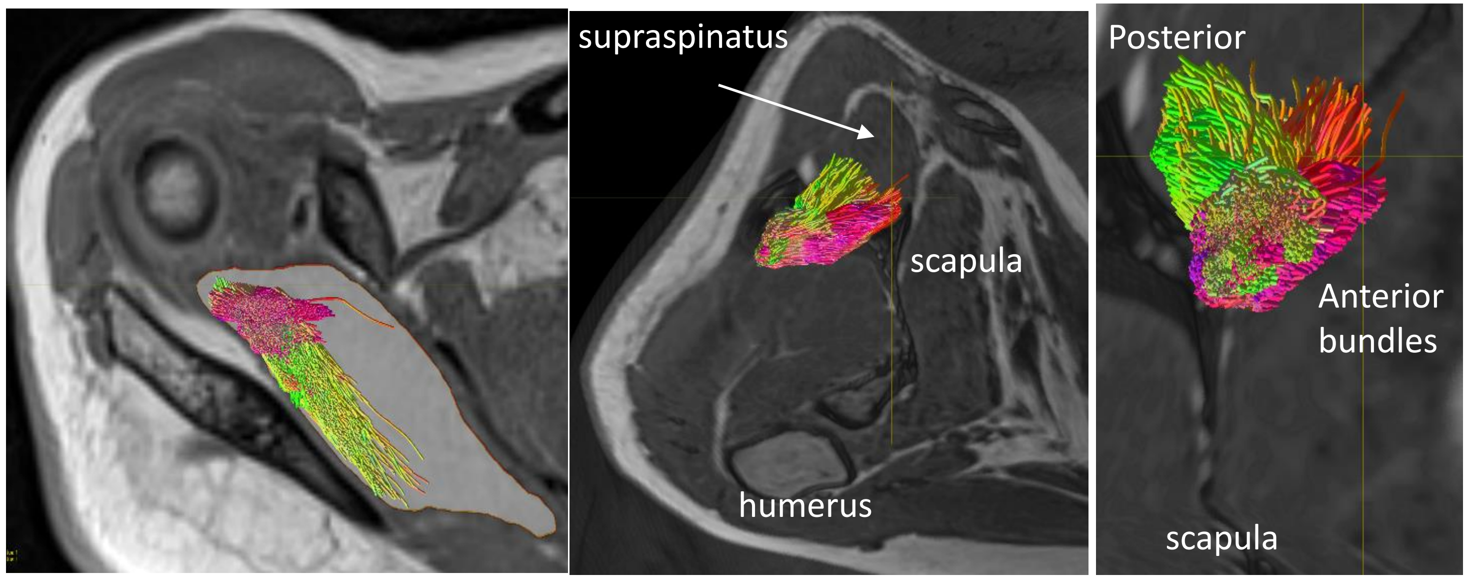
Bland-Altman plots of FA and ADC across three scans (pairwise comparison of scans 1-2, 1-3, 2-3) for each volunteer (1 to 6) in the supraspinatus (sup) or infraspinatus (inf).

For FA, limit of agreement (loa) is 0.071 with a bias at 0.0.

For ADC limit of agreement is 0.157 x 10^-3 mm2/s with a bias at 0.005 x 10^-3 mm2/s.

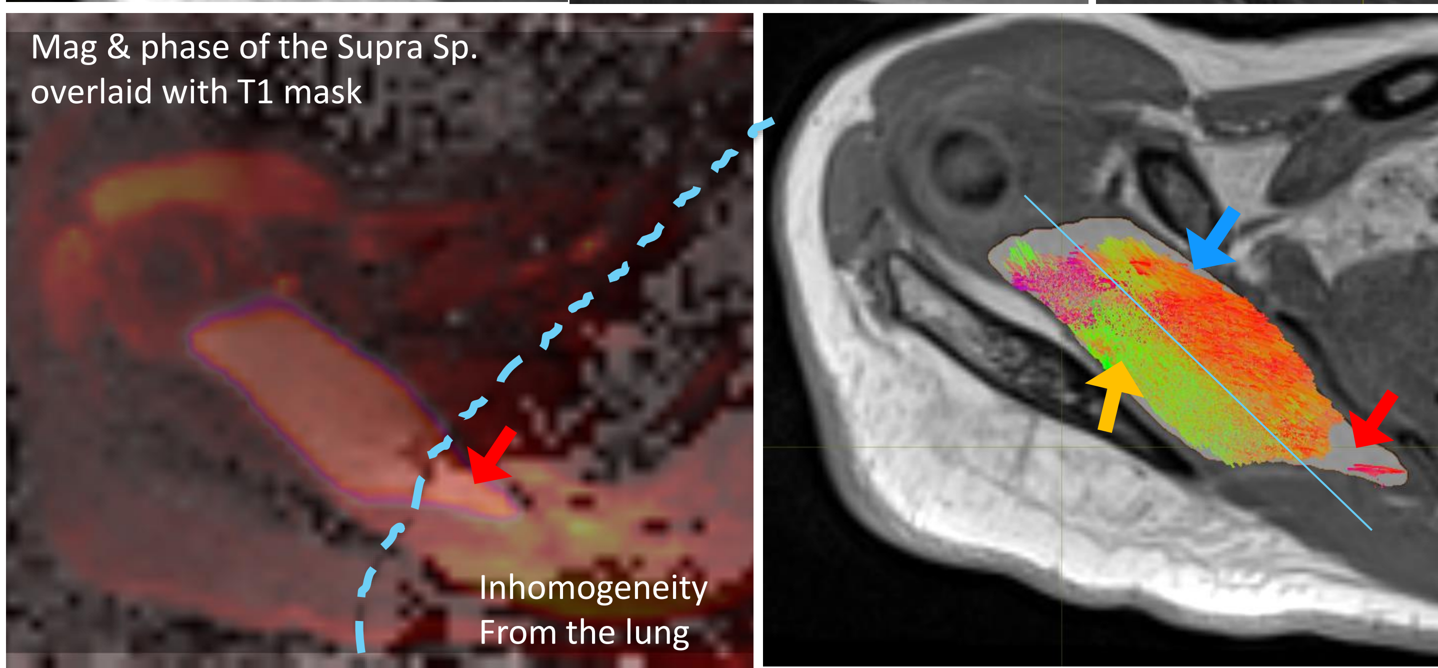
Results

Antero-posterior bundles of the supraspinatus in crossing region of interest can be studied to understand fibers remodeling following rotator cuff tears.



Clear separation between the anterior and posterior bundles is obtained (yellow and blue arrows).

However, one limitation is the inhomogeneity from the lung (dashed lines separation) that impairs part of the tractography (red arrow).



Conclusion

Clear convergence of fibers tracks to the tendons was observed with tractography in the supraspinatus as known in dissection.

Repeatability of DTI metrics from three scans in six shoulders of six asymptomatic volunteers was achieved (coefficient of variance <10%) for the fractional anisotropy, mean diffusivity and eigenvalues.

Our results are consistent with other inter and intra scanner studies performing DTI in muscle. A single scanner study on myocardial DTI reported CV_{ADC} of 19% and 7.2% for CV_{FA} , while in the upper leg had CV_{ADC} reported at 4.5% and CV_{FA} at 15.2%.

Such results are promising for establishing DTI biomarkers across volunteers and scanners that will allow the identification of structural muscle characteristics in RC tears.

Therefore, the diffusion tensor can be used to minimize bias in the calculation of the elasticity metrics with magnetic resonance elastography. DTI is reproducible and repeatable.

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