USING CINE PHASE CONTRAST MRI TO INVESTIGATE STRAIN PATTERNS AFTER SUPRASPINATUS TENDON TEARS

John E. Novotny; Hehe Zhou

Dept. of Mechanical Engineering, Center for Biomedical Engineering Research
University of Delaware
Newark, Delaware

INTRODUCTION

Rotator cuff (RTC) tears are a common pathology of the human shoulder. Of the four muscles composing RTC, the supraspinatus is the most commonly involved [1]. Magnetic resonance imaging (MRI) and magnetic resonance arthrography (MRA) are widely used to diagnose both the presence and extent of the RTC tear, although there is discussion as to the sensitivity and specificity of these methods. This may be due to the fact that the tendon tear may be indistinguishable if the muscles are not in retraction or with limited effusion or fatty infiltration. Furthermore, it is impossible with static MRI and MRA to observe dynamic muscle function. This study proposes to apply a dynamic magnetic resonance imaging technique, cine phase contrast MRI (CPC-MRI), to the observation of the RTC.

CPC-MRI was originally developed for myocardial study [2,3]. With this technique, a repeated motion is observed and a composite visualization of one cycle produced. Four images are produced which encode information about the velocity of the tissue at each pixel location and throughout the motion cycle. The first is a gray-scale image representing the overall velocity magnitudes at each point. The other three images represent the components of the velocity magnitude in each of the three x, y and z scanner dependent coordinates. From this velocity distribution, it is possible to get the displacement field within the tissue.

A linear forward-backward integration method (f-b method) for computing trajectories of objects from CPC-MRI velocity information was presented by Pelc et al. [4. In their phantom test using reciprocal rotation, the measured and calculated trajectories agreed to within 3.3%. In order to prevent the attenuation of linear f-b model, Yudong zhu et al. developed a Fourier transformation based method [5]. This technique incorporated compensation for the frequency response of the cine interpolation, which further improved tracking accuracy. Recently these techniques have been used to study displacement patterns in muscles of the leg and arm [6,7]. The previous literature [4,5] has shown that CPC-MRI can offer detailed information about the cyclic motion of musculoskeletal soft tissue and bones with an effective trajectory tracking method.

This study proposes to apply CPC-MRI to observe the RTC. Velocity images from CPC-MRI will be transformed to displacement fields with the Fourier transformation based method and then to strain patterns within the supraspinatus muscle and tendon. This data will be generated in the anatomical coordinates obtained from the motion of glenohumeral joint. The method may offer a better way for radiologist and orthopedics to observe and understand the dynamic RTC function, diagnosis RTC tears and follow post-operative repair status and rehabilitation methods.

EXPERIMENT METHOD

MRI data is collected from a CPC- MRI scanner (GE Medical systems, Milwaulkee, WI, 1.5T). The subject was placed in a supine position on a slightly angled bed within the scanner table in order to increase motion space (Fig.1). The subject was to repeat a cyclic motion, which had been shown to activate the supraspinatus muscle of the RTC without necessitating scapular motion [8,9]. This was humeral elevation ranging from 10^0 to 60^0 in scapular plane with the forearm in a neutral position. A 2.5 kg load provided a simulated gravity load to the humerus by a cable-pulley device. Dual radiofrequency coils were situated over the glenohumeral joint, parallel to each other to improve the scanning quality. The frequency of movement was subject controlled by a metronome and triggered to the scanner with an optical sensor at the end of each cycle.

After positioning the subject, a high-resolution static MRI scan was acquired to define the glenohumeral joint and muscle geometries (0.5 mm thickness). From this scan, the scanning plane for the CPC-MRI images was carefully selected. It passed through the longitudinal plane of supraspinatus starting it at the attachment of supraspinatus on the rim of the humeral head and continuing parallel to the scapular plane. The CPC-MRI scan was then performed over the next five minutes. The subject moved their glenohumeral joint through the prescribed range of motion cyclically. The two-dimensional CPC-MRI image of three-dimensional velocity in the scan plane during one cycle was generated (Figure 2).

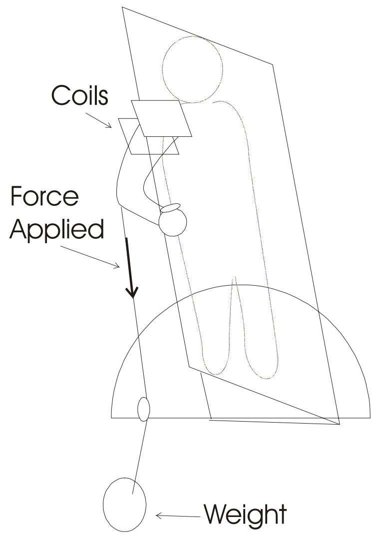

Figure 1: Subject position in the MRI scanner. An inclined plane gains some extra space for shoulder motion. A force is applied to the humerus through a hanging weight. Radiointensity coils aid in image quality.

Three-dimensional (3D) static geometries of supraspinatus, humeral head and scapula were reconstructed with imaging software (IMOD 2.7.6, Boulder Laboratory) from the high-resolution static MRI scan. A second program (VTK, Kitware Corp.) was employed to match the contour of the cross section of humeral head in the CPC-MRI image plane with the reconstructed 3D humeral model. Then the transformation matrix between anatomical coordinate and global coordinate in each CPC-MRI frame is obtained of the relative position of current humeral contour to the static 3D model. This allowed for the motion of the humerus and supraspinatus insertion to be followed in three dimensions from the velocities of the single CPC-MRI cut.

Computation of strains in the supraspinatus musculo-tendonous structure was performed. The motion supraspinatus was assumed to be two dimensional in the CPC-MRI scan plane. Also the initial zero strain position of supraspinatus tendon was defined as the humerus in 10^0 elevation. The strain pattern was computed from the velocity distribution with the f-b method and an iterative discrete Fourier transforming optimization [4,5]. First, contours of the tendon and muscle were sketched in the magnitude images of the CPC-MRI by an edge-detecting algorithm. Then, a rough displacement determination was achieved with f-b method assuming that the velocity of same point in tendon edge between frames changed linearly [4]. With the displacement from f-b method as the initial input, the iterative scheme of discrete Fourier transform was applied repeatedly to get the best approximation of real displacement [5, equ. (1)].

$$r_{new} = Iteration(v(r_{old}(n), n) \qquad (1)$$

where r_{new} and r_{old} were the displacements after and before one time iteration, and n is the time frame index. The convergence condition was satisfied when the value of objective function of iteration/optimization was less than some preset value [equ. 2].

$$\sqrt{\sum_{i=1}^{N}(r_{k+1}(i) - r_k(i))^2 \Big/ N} \qquad (2)$$

where N was the number of frames, r_{k+1} and r_k was the $(k+1)^{th}$ and k^{th} displacement sequence respectively. Finally a strain pattern within the supraspinatus was calculated by comparing the change of length of two points at various locations at the midline of the tendon-muscle relative to the initial zero strain position.

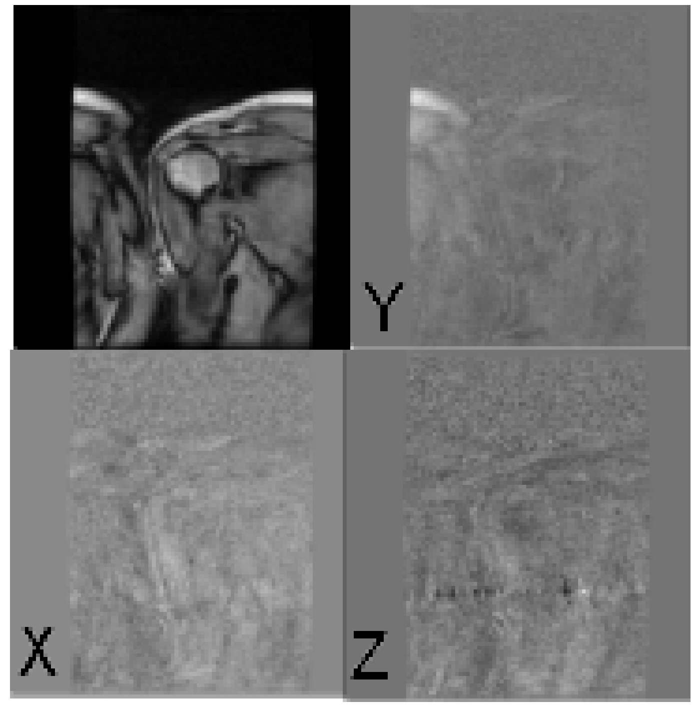

Figure 2: Four sample images of CPC-MRI. Upper left is the magnitude image where the geometry of the supraspinatus can be seen over the humeral head. The three other images show a gray-scale representation of the velocity data for the X (horizontal) and Y (vertical) and Z (in and out of plane) velocities.

RESULTS AND DISCUSSION

We introduced a new method to measure the strain pattern of supraspinatus tendon tear based on velocity data from CPC-MRI. It is non-invasive and has been shown in previous work to be accurate for determining muscle motion [6]. Furthermore, this method can give observers a dynamic way to investigate RTC function. We hope it can offer a better way for professionals to diagnose RTC disease and following post-operation rehabilitation. Normal muscle kinematics have been monitored and now need to be compared to those with rotator cuff tears of different sizes and levels of retraction to determine sensitivity, specificity and predictive values for diagnosis.

REFERENCE

1. Gschwend N, et al.: Arch Orthop Trauma Surg 107:7-15, 1988
2. Nayler GL, et al.: J Comput Assist Tomogr 10: 715-722, 1986
3. Pelc NJ, et al.: Magn Reson Quarterly 7: 229-254, 1991
4. Pelc NJ, et al.: J Magn Reson Img 5:339-345, 1995
5. Zhu YD, et al.: MRM 35:471-480, 1996
6. Asakawa DS, et al.: J Biomech 35: 1029-1037;
7. Pappas GP, et al.: J Appl Physiol 92: 2381-2389, 2002
8. Pearl M, et al.: Clin Orthop 284:116-127, 1992
9. Jenp YN, et al.: Am J Sports Med 24:477-485, 1996