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# Fusion of Multinuclear Magnetic Resonance Images of Knee for the Assessment of Articular Cartilage*

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***Abstract*— The onset of osteoarthritis (OA), a most common knee joint disease, can be characterized by the degeneration of articular cartilage (AC). Degenerative changes in AC have been assessed by the morphological and physiological measurements using non-invasive modality such as Magnetic Resonance Imaging (MRI) to obtain MRI images of the knee. However, visualization and quantification of AC from MR images is difficult due to the low visibility contrast of AC compared to surrounding tissues, low and varying signal intensities in cartilage region and variable intensities in different slices of single dataset. In this work, we present a method to fuse multinuclear ($^{23}$Na and $^{1}$H) MR images acquired in the same plane without changing the position of the human knee as well as the Radio Frequency (RF) coil. This work is performed towards our hypothesis that fusion of sodium and proton images will provide an enhanced image that can be used for an accurate assessment of cartilage morphology. Our result shows that merging of sodium knee MR image with proton knee MR image resulting in enhanced contrast information in the cartilage region and resolves low visibility and varying intensities issue with 2D/3D proton MR. We conclude that the proposed method can further be utilized for the accurate assessment of cartilage morphology.**

## I. Introduction

Osteoarthritis (OA) is a serious, painful and life altering joint disease that will lead to failure of synovial joint organ and permanent disability in elders [1]. It has been reported that symptomatic OA affects 9.6 % men and 18 % women population around the world [2]. OA affects a number of joints in human body. However, it is most common in knee joint that can be characterized by the gradual loss of articular cartilage (AC). AC is flexible yet soft tissue that exists on the end bones. In normal human knee, thickness of AC is about to 4mm with curved surface [3] that results in difficulties to visualize the minimal changes during onset of OA from the data acquired using most of the imaging modalities. So far, Magnetic Resonance Imaging (MRI) has been evidenced as the most promising imaging modality as it provides morphological and physiological assessment of AC degeneration by means of images and quantitative information [4]. MRI is non-invasive, non-ionizing and in-vivo modality.

Generally, assessment of AC from MR images requires acquisition of MR images in sagittal plane using a standard pulse sequence that is sensitive to cartilage visualization. Sagittal plane acquisition allows the collection of data to assess AC at right angles to the weight-bearing sites in the knee cartilage. In addition, one can acquire additional data in coronal and axial planes for the assessment of patellar cartilage and essential coverage to weight-bearing sites [5]. Research has shown that a typical 2D/3D MR pulse sequence on hydrogen-based MRI can be acquired to evaluate the morphology of cartilage. However, due to local variation in cartilage tissue properties, cartilage images obtained from most pulse sequences suffer from low visibility contrast and low signal intensities on cartilage region as compared to surrounding tissues as shown in Figure 1 (a) and Figure 1 (b) respectively [6], variable intensities in different slices of single dataset as shown in Figure 1(c) and varying intensities in cartilage region of single slice as shown in Figure 1 (d).

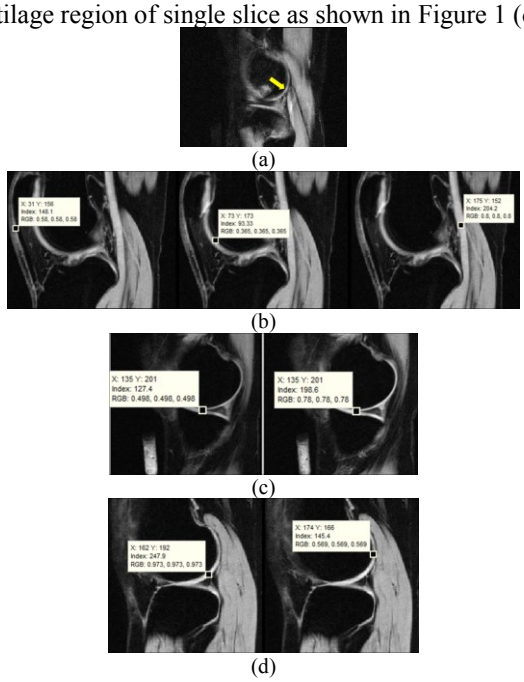

Figure 1. (a) low visibility contrast in cartilage (yellow arrow), (b) low intensities in cartilage region (middle image) compared to other tissues (left and right image), (c) variable intensities in different slices of single dataset and (d) variable intensities in cartilage region of same slice

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Recently, Fadzil and co-workers have proposed a method to acquire two different nuclei ($^{1}$H and $^{23}$Na) MR images in the same plane [7]. The advantage of this method is the acquisition of sodium and proton based images without changing the position of the knee and acquisition of sodium images that has high signal intensities in cartilage region compared to other tissues. With higher signal contrast in cartilage region, the cartilage region can now be extracted from sodium images. We hypothesise that the merging of segmented cartilage regions from sodium image and proton knee MR images that are acquired in same plane will result in an enhanced cartilage region. Thus, this objective of this work is to develop imaging techniques for the fusion of sodium and proton images that will provide the enhanced image for an accurate assessment of cartilage morphology.

## II. Material and Methods

Material used in this work was acquired using a customized dual tuned knee coil ($^{1}$H/$^{23}$Na) on 1.5T MRI scanner with multinuclear spectroscopic capabilities.

### A. Data Acquisition

For this research, four in-vivo human knees are scanned at 1.5T clinical MR (Siemens Medical Solutions, Erlangen, Germany). Initially, the performance evaluation of the dual tuned knee coil was performed by correcting the Radio Frequency inhomogeinity and measuring the signal-noise-ratio (SNR) as reported earlier [8]. In the first experiment, a phantom was scanned followed by the in-vivo human knee MR scan of subject's dominant knee (right knee). For the in-vivo imaging, 3D MEDIC (multi-echo data imaging combination) that reduces the motion artifacts and 3D Gradient Echo (GRE) are used for proton and sodium scanning respectively. Following parameters are used for imaging pulse sequence: 3D MEDIC (TE=20 ms, TR=37ms, voxel size = 0.47x0.51x1.5mm$^3$, flip angle=8°, scan time =5 min) and 3D GRE (TE = 4.0 ms, TR=11.4ms, voxel size = 2.81x2.81x8mm$^3$, flip angle = 62°, Bandwidth = 80Hz/Pixel, averages =300 per scan and scan time =30 min). Sample proton and sodium MR images of knee are shown in Figure 2.

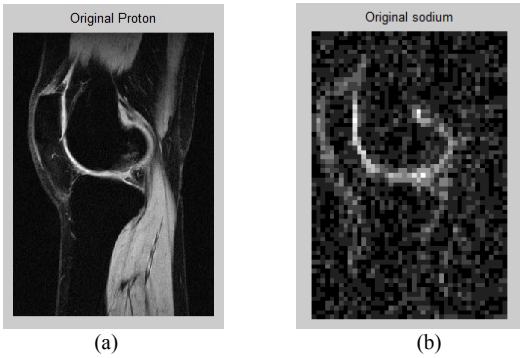


Figure 2. (a) proton MR knee image and (b) sodium MR knee Image

### B. Fusion of Sodium and Proton Slice

Research has shown that images taken from the same scene under different conditions may reveal new information about the scene. The details from the images can then be combined to produce a more detailed image [9]. In particular to cartilage information, MR images acquired using two different pulse sequence are fused to provide the better contrast between cartilage and bone that helps in AC segmentation [10]. It was evidenced that fusion of two orthogonal 3D MR Datasets results in a single isotropic volume dataset consists of high resolution MR image. Segmentation of cartilage from resulting fused data is more accurate then single channel data [11]. Recently, a study has shown that multi-nuclei ($^{3}$He, $^{129}$Xe and $^{1}$H) MR imaging is performed simultaneously to assess the structural and functional changes in lungs. Multinuclear data is capable of registration to obtain mutually complementary information on structure and function of lungs [12].

Proton MRI can provide high-resolution images that contain excellent anatomical details of tissue. For articular cartilage, physical defects and advanced degeneration in cartilage that is associated with OA can be seen in proton MR images [13]. On the other hand, information on sodium signals can be better depicted from the analysis of sodium images [13]. In addition, contrast between cartilage and surrounding tissues is better in sodium images due to the rich sodium content in cartilage [7, 14]. As discussed earlier that we have acquired sodium and proton MR images without changing the position of the subject's knee as well as the knee coil. Acquired MR images provide visual and quantitative information of articular cartilage at different levels. Sodium MR knee images contain high signal intensities in the cartilage region compared to surrounding tissues due to the rich sodium content in cartilage. Thus, sodium rich region (cartilage) is extracted from all the slices of sodium MR using the method proposed by Fadzil *et al.* [7]. The sodium images are used to merge with proton images to enhance the signals in cartilage region.

In this work, multi-view fusion by taking average of sodium and proton images is performed as the images are acquired from the same modality. However, MR images acquired consists of two different matrix sizes with same field of view (FOV) and the different number of slices acquired in each dataset

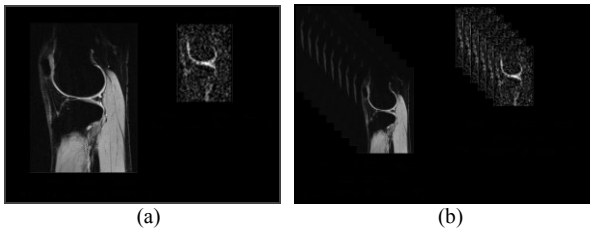


Figure 3. (a) MR datasets with two different matrix size and (b) MR datsets with different number of slices.

### C. Slice Localization and Re-sampling

During the merging of sodium and proton images, a preprocessing step to extract the sodium region from all sodium slices in one dataset is performed. Sodium extracted slice contains high signal intensities in AC region compared to surrounding tissues. However, number of sodium extracted slices of single dataset and the image dimensions both are different as compared to proton MR images. In order to resolve this issue, the sodium slice in FOV is

localized to determine the corresponding slices to be merged with the proton slice as shown in Figure 4. The sodium extracted region is up-sampled to have the same dimensions of the proton image as depicted in Figure 5.

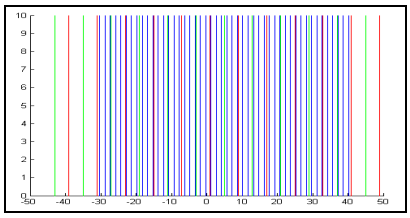

Figure 4. Sodium and proton slice location in same field of view

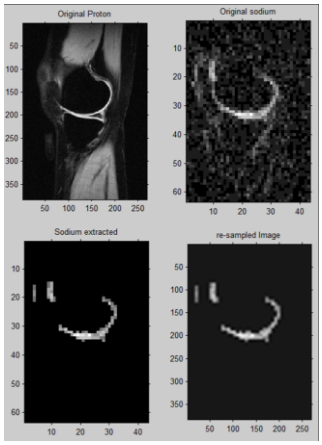


Figure 5. First row: original proton and sodium image, Second row: original sodium extracted slice and re-sampled slice showing same size as proton slice.

In the Figure 4, location of slices are indicated by the color information as Red color represents the sodium slice, Blue color represents the proton slice and Green color represents the midpoint location between two sodium slices. For the merging, sodium slices midpoint location were added with corresponding proton slices with a product and average function, for an example, slice number 2 of sodium sequence were merged with slice number 1, 2 and 3 of proton sequence. For the re-sampling, cubic spline interpolation was applied on the sodium extracted slices of single dataset corresponds to the proton slice size followed by the normalization. This results in size of sodium slice corresponding to the size of proton slices. As depicted in Figure 5, the original proton slice is 384 x 269 pixels while original sodium slice is 64 x 44 pixels. After the extraction of sodium rich region, image size is same as original sodium slice. At the same time, re-sampling of sodium-extracted slices produces the same slice size (384 x 269) as proton slice. Furthermore, the merging is performed by adding re-sampled sodium extracted slice with corresponding proton slice and taking average of them.

### *D. Cartilage Contrast Measurement*

After performing merging, contrast between cartilage and surrounding background region is determined using the method reported earlier for retinal blood vessels [15] as defined in the Equation 1.

$$C_{|AC-BG|} = \left| \frac{1}{n}\sum_{i=1}^{n} I_{AC_i} - \frac{1}{n}\sum_{j=1}^{n} I_{BG_j} \right| \qquad \ldots\ldots (1)$$

where, $I_{AC}$ and $I_{BG}$ represents the intensities of AC and background region in merged image respectively, $n$ is the number of pixels selected in cartilage and background region. In the similar way, contrast between cartilage and surrounding background region is determined from the original proton slices. Furthermore, average contrast between cartilage and background measured from all merged slices is compared to average contrast between cartilage and background measured from original proton slices.

## III. Results and Discussion

The main objective of this work is to enhance the cartilage region information available in MR images by performing fusion of sodium and proton MR knee images. The enhanced information on merged/fused images can further be utilized for the accurate assessment of cartilage morphology. In order to enhance the cartilage region, two main challenges were resolved that were found during the merging of sodium and proton MR images of knee.

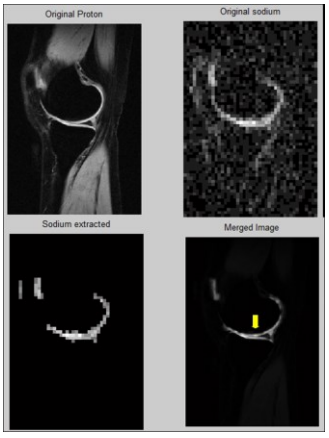


Figure 6. First row: original proton and sodium image, Second row: original sodium extracted slice and merged slice.

Figure 6 shows the results obtained from the merging of sodium and proton slices of single dataset. The first row shows the original proton and original sodium images acquired using dual tuned knee coil. The second row: bottom left image shows the example of sodium extracted cartilage region from sodium MR knee dataset. Finally, the bottom right slice in second row shows the resultant of sodium and proton slice merging. From the image on bottom left, it can be seen that the cartilage region in the resulting slice comprises better contrast (as shown by yellow arrow) compared to surrounding tissues. In addition, average contrast between cartilage and background measured (contrast difference- 142.132) in merged images shows high values compared to average contrast between cartilage and background measured (contrast difference-76.376) in original proton images. Figure 7 shows the contrast between cartilage and background measured from 42 merged and 42 original proton slices. High contrast obtained in the cartilage region of merged image resolves the issues of low visibility contrast in cartilage region of 2D/3D proton MR images.

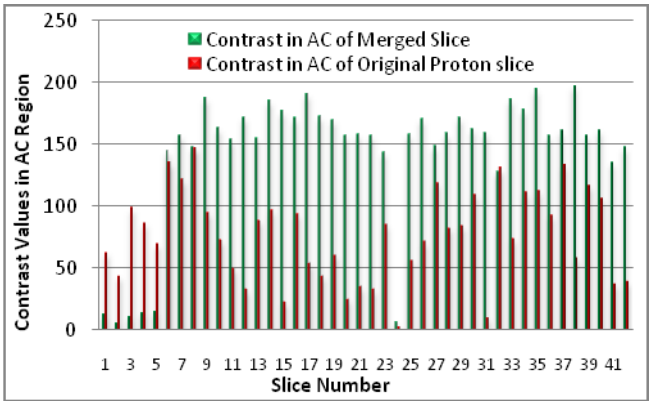


Figure 7. Contrast between cartilage and background region measured from 42 slices of merged (green) and 42 slices original proton (red) MR.

Merging of sodium and proton images not only resolve the issues of cartilage visibility contrast but also solve the purpose of maintaining cartilage varying signal intensities in different slices of single dataset. Two random slices of single merged image datasets were chosen where the pixel value were manually tracked by placing curser on the same pixel location of two different slice. In the merged dataset, slice number 6 and slice number 10 were tracked and it is found that merged slice provide almost similar pixel values at the same pixel location in two different slices as shown an example in Figure 8. In this work, sodium and proton knee MR images are acquired from 4 human subjects. However, we have used only 3 datasets for the experiment. One dataset was eliminated as it contains an artefact due to an improper attachment of coil, which causes RF leak in the coil.

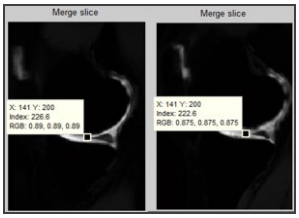


Figure 8. Two merged slices of single dataset showing the similar pixel values at same location.

## IV. Conclusion

Magnetic Resonance Imaging (MRI) has been extensively used for the early detection of osteoarthritis by performing physiological and morphological assessment of articular cartilage on MR data. Morphological assessment of AC is challenging due to the nature and shape of cartilage tissue. In particular to MR images, visualisation and assessment of cartilage is difficult from hydrogen-based MR images due to low visibility contrast and varying signal intensities in cartilage region. Here, a new method to enhance articular cartilage region by the combined assessment as fusion of sodium and proton based MR images is investigated. Results obtained in this work shows the significant improvements as the enhanced contrast in cartilage region of fused images that can further be utilized for an accurate segmentation and the measurement of morphological changes in cartilage in during the early progression of osteoarthritis.

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