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Combination of selective water excitation and magnetization transfer on T1-FFE sequence shoulder joint MRI

Comparative study with T1-SPIR Sequence as an Alternative to Increase Anatomical and Pathological information of Muscles

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ABSTRACT

Constraints which arise in the examination of shoulder joint MRI when general practitioner and radiologists need an informative image of muscle without meaningful contributions from fat signal around the tissues. The routine protocol used was not able to accommodate this issue, consequently, the muscle image in the routine sequence clearly also experiences signal suppression. The combination of Selective Water Excitation (SWE) and Magnetization Transfer (MT) techniques in 3D-FFE applied to be able to display muscle images better by applying selective pulses and chemical changes in the shoulder joint tissue.

This study was a comparative analytic study with a quasi-experimental one group post-test only design which aims to determine the effect of SWE and MT as an alternative to improving the image information of T1 FFE sequence shoulder MRI images compared to T1 SPIR sequences. By applying purposive-convenience sampling with time saturation, this study used 20 shoulder MRI patients and 2 radiologists as respondents for image evaluation.

Significant results were shown in the assessment of images information (anatomical and pathological information). All indicators show a P-value of <0,001 ($P < \alpha$). T1 FFE-SWEMT sequence showing superiorities in all aspects assessed compared to the T1-SPIR sequence.

There is a significant effect of combination of SWE and MT techniques to improve images information of shoulder joint MRI when compared with T1-SPIR sequences.

Keywords: Shoulder Joint MRI, SWE, MT, FFE, SPIR.

INTRODUCTION

Pathological imaging of the shoulder is generally done with Ultrasonography and MRI modalities [1]. Along with the development of technology, MRI of the shoulder joint has developed into the imaging technique that is most often used in shoulder imaging for the advanced level because it is considered accurate and very precise in assessing the pathology of soft tissue shoulder joints [2, 3, 4]. This was evidenced in the sensitivity and specificity of detection indicated, for example in the detection of rupture in the rotator cuff, the sensitivity values produced when confirmed by surgical procedures were 91% sensitivity and 97% specificity for full thickness tear (FTT), and 80% sensitivity 95 % specificity for partial thickness tear (PTT) [5].

Fat saturation technique is the most popular technique used to increase tissue contrast on musculoskeletal imaging including the MRI of the shoulder joint. Constraints on the assessment of the resulting image will occur, especially on the MRI examination of the shoulder joint that is performed to assess the anatomy and pathology of muscle images. Moreover, on MRI with administration of both intravenous and intra-articular contrast media, radiologists need an informative image without meaningful contributions from fat around the tissues. Selective Water Excitation (SWE) results in a significant decrease in fat signal. The difference lies in the technique used, where SWE uses a selective pre-pulse specifically on spin water without affecting the spin of other tissues around it. In previous studies, SWE was applied to cartilage imaging, SWE was proven to be able to display contrast, homogeneity of signal suppression, to artifacts generated by surpassing suppression techniques such as STIR, SPIR, and also SPAIR [9].

The technique that can be used to be able to change muscle image signals is the magnetization transfer (MT) technique. When compared with standard MRI, this bound pool proton cannot be assessed. In certain tissues in the human body (liver, thyroid, muscle, and cartilage), however, two pools of protons are in an equilibrium phase, biochemically and magnetically. After saturation of the magnetization of the water molecule bound by a selective pulse, the balance is transferred to the proton bound pool, which results in observable reduction of magnetization, as well as the reduction of MRI signals [6].

3D T1 Fast Field Echo (T1 FFE) Sequence is the right choice in applying a combination of SWE and MT techniques to accommodate problems that arise in previous research. T1 FFE is chosen because it applies gradient pulses with certain angles to determine the desired weighting. The T1 FFE image can display good tissue contrast and a more hyperintense signal compared to the surrounding tissues [7]. FFE is a type of sequence that applies spoiled gradient to do residual refocusing of transverse magnetization [8]. The main advantage in applying the FFE Sequence is pathological detection with T1 weighted images which can be obtained before and after injection of gadolinium-based contrast media. By using combination of SWE and MT techniques in T1 FFE, researchers wanted to assess the improvement in image information (anatomy and pathology) produced compare with T1 SPIR.

METHOD

Type and Design of Research

This research is comparative analytic research with quasi experimental, one group post-test only [9, 10] which aims to determine the effect of applying Selective Water Excitation and Magnetization Transfer as an alternative to increasing images information of T1 FFE sequence of Shoulder MRI compared to T1 SPIR sequences.

Population and Samples

The population of this study was patients who performed MRI examinations of the shoulder joint at Premier Bintaro Hospital. By applying the time and sample saturation method, the sample used was all shoulder joint MRI patients in the specified period (total sampling) [11]. The technique used was purposive convenience sampling with time saturation [11], where each patient in the study period was sampled in the study as long as it fulfilled the inclusion and exclusion criteria of the study, the sample used was 20 patients.

DATA ANALYSIS

To find out the further influence of the application of the combination techniques, several statistical tests were conducted. Kappa test was conducted to assess the level of understanding among respondents. With the kappa value at "good agreement" level, then proceed with conducting a Mann Whitney test [12]. This test is used to test ordinal data in this study (anatomical and pathological information). The conclusion of the hypothesis is that the effect of applying a combination of techniques can be done if the value of p <0.05, Ho is rejected, which means that there is a significant effect of the application of SWE and MT on image information on Shoulder Joint MRI T1 FFE sequence.

RESULTS

Differences in the results of the muscle signals intensity can be observed and assessed quantitatively on the signal intensity and qualitative values visually by the radiologist to assess the contrast, sharpness, and detail of the image produced.

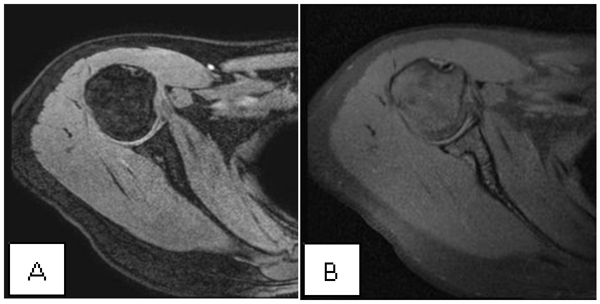

Figure 1. MRI Shoulder Joints on 2 Different Sequences, (a) Axial T1 FFE (b) Axial T1 SPIR.

For the assessment of anatomical and pathological information, relative Visual Grading Analysis (rVGA) was carried out by the radiologist as the respondent. Assessments made by comparing the images of the two sequences can be seen in the table below.

Table 1. Distribution of Anatomical Information Assessment of Respondent 1 in Shoulder MRI.

SEQUENCE	Anatomies	Minimum Value (Number of Assessments)	Maximum Value (Number of Assessments)
T1 SPIR	*m. Supraspinatus*	2 (19)	3 (1)
	m. Infraspinatus	2 (19)	3 (1)
	m. Subscapularis	2 (18)	3 (2)
	Bone Marrow	2 (18)	3 (2)
T1 FFE	*m. Supraspinatus*	2 (4)	3 (16)
	m. Infraspinatus	2 (3)	3 (17)
	m. Subscapularis	2 (1)	3 (19)
	Bone Marrow	2 (2)	3 (18)

The table above shows the tendency of respondents to give the value of 2 is greater, namely as many as 74 assessments of a total of 80 assessments (92.5%) on T1 SPIR sequence images and only 6 assessments of 80 total assessments (7.5%) for the value of 3, while the sequence T1 FFE-SWEMT mostly obtained the value of 3 of 70 assessments out of a total of 80 assessments (87.5%) and the rest (12.5%) for value 2. This can also be seen in the assessments by respondent 2 in table 2.

Table 2. Distribution of Anatomical Information Assessment of Respondent 2 in Shoulder MRI.

SEQUENCE	Anatomies	Minimum Value (Number of Assessments)	Maximum Value (Number of Assessments)
T1 SPIR	*m. Supraspinatus*	2 (17)	3 (3)
	m. Infraspinatus	2 (19)	3 (1)

	m. Subscapularis	2 (18)	3 (2)
	Bone Marrow	2 (18)	3 (2)
T1 FFE	*m. Supraspinatus*	2 (1)	3 (19)
	m. Infraspinatus	2 (3)	3 (17)
	m. Subscapularis	2 (3)	3 (17)
	Bone Marrow	2 (1)	3 (19)

On the assessment given by respondent 2, T1-SPIR scored 2 as many as 72 assessments from a total of 80 studies or by 90% and the remaining 10% for scored 3. Turning around with the T1 FFE-SWEMT sequence, the value of 2 gets a percentage of 10% (8 assessments of a total of 80 assessment) and a score of 3 as many as 72 assessments out of a total of 80 assessments or 90%.

In the pathology assessment shown in each of the images produced, a summary of the assessment can be seen in table 3. On the pathology indicator, there were 6 patients who were dropped off because the results of radiological expertise showed no pathology.

Table 3. Distribution of Pathological Assessment of Shoulder MRI.

SEQUENCE	Respondent 1		Respondent 2	
	Minimum Value (Number of Assessments)	Maximum Value (Number of Assessments)	Minimum Value (Number of Assessments)	Maximum Value (Number of Assessments)
T1 SPIR	2 (12)	3 (2)	2 (11)	3 (3)
T1 FFE	2 (2)	3 (12)	2 (1)	3 (13)

From the table above, it is stated that the pathology displayed by both images can be assessed properly, but for better detail and sharpness of pathology in T1 FFE sequences when viewed from the value of 3 obtained from both respondents 1 and respondents 2 (85.7% and 92.9%).

As a further justification for assessing the superiority of the combination techniques used, an influence test on anatomical and pathological information was displayed in both of the image sequences (T1 SPIR and T1 FFE-SWEMT). Data obtained from Visual Grading Analysis of two radiologists were tested using the Mann-Whitney test. Before the influence test is carried out, a test is conducted to assess agreement or understanding among respondents using the interrater test in the form of Kappa test. Both the anatomical and pathological information indicators are at the good agreement level (kappa value 0.61-0.8). The results of the Mann-Whitney difference test for anatomy and pathology can be seen in tables 4-5.

Table 4. Mann-Whitney Test Results for anatomical information data on T1 SPIR and T1 FFE images.

Anatomical Information	*Mean Rank*		*P-Value*
	T1 SPIR	T1 FFE-SWEMT	
m. Supraspinatus	24,50	56,50	< 0,001
m. Infraspinatus	23,50	57,50	< 0,001
m. Subscapularis	25,00	56,00	< 0,001
Bone Marrow	23,00	58,00	< 0,001

The table above shows the significance of the difference between the two compared sequences. Of the four anatomically assessed visually, all anatomy has a p value < α (0.05), which means that there are significant differences in the information on the anatomy of the shoulder joint MRI displayed by T1 SPIR and T1 FFE-SWEMT sequence. To determine a sequence that better displays anatomical information can be seen from the mean rank value. It can be seen that T1 FFE-SWEMT is better at displaying anatomical information with a mean Rank value in all anatomies that is judged to be greater than in T1 SPIR sequence.

Table 5. Mann-Whitney Test Results for pathology information in T1 SPIR and T1 FFE

Test indicator	***Mean Rank***		***P-Value***
	T1 SPIR	**T1 FFE-SWEMT**	
Pathological Information	9,5	19,5	< 0,001

The T1 FFE-SWEMT sequence is better at displaying the pathology of shoulder joint MRI when viewed from the mean rank value shown in table 5, where T1 FFE-SWEMT has a value of 19.5 while T1 SPIR is only 9.5.

DISCUSSION

Fat suppression is a basic technique on musculoskeletal MRI which is used for three main purposes, namely (a) to suppress water sensitivity when used in spin-echo (SE) and T2 Weighted sequences, (b) to suppress signals from normal adipose tissue to reduce chemical artefacts shift or to better visualize the uptake of contrast media (for example, gadolinium-based materials), and (c) to increase the dynamic range in water-containing structures such as cartilage when used in conjunction with T1-weighted sequences. Selective Water Excitation (SWE) is one technique that is superior in doing fat suppression.

The application of SWE in accordance with previous studies (Hauger, 2002) was able to produce high suppression homogeneity when compared to the routine sequences used. In contrast to previous studies that were more concerned with cartilage imaging, this study proved the application of SWE could be used as a component in helping muscle imaging in addition to the application of MT applied as a combination. In this study, SWE was used to optimally suppress fat tissues. With this technique, only water is excited by using a composite-selective pulse, while spin fat is left in the equilibrium phase, so that it does not produce a meaningful signal. To get signal changes and tissue contrast, SWE is combined with the application of Magnetization Transfer Contrast (MT).

The SWE technique with the use of binomial pulses (1 3 3 1) and water fat shift is given a value of 1.5 used for fat suppression and optimal tissue contrast [13]. Composite pulse 1331 is considered to be better at suppressing because less tissue has a similar frequency with spin water when applied to the composite pulse [14]. In addition to the application of SWE, additional techniques are applied in the form of Magnetization Transfers with on-resonance pulses. The MT technique can be applied in two ways, off-resonance and on-resonance. The On-resonance method is chosen based on the consideration of the time of T1 FFE-SWEMT sequence considering that if an off-resonance method is used, then time is needed to apply the initial pulse, this will increase the TR value and acquisition time. On-resonance is an option because its application is carried out using composite pulses when the FFE sequence is executed, this will impact on shorter acquisition time and B1 (RF pulse) value to be greater, resulting in greater transparent bandwidth. This bandwidth is useful for keeping the free spin from resonating after applying pulses.

Fat suppression is carried out selectively by only excitation on spin water so that fat signals and tissues with low protons become hypointense and higher protons produce intermediate signals to hyperintense. Things that other suppression techniques cannot do such as SPIR, SPAIR, and STIR to selectively excite water protons. It was further refined by the MT technique which led to optimal excitation of protons in muscle tissue which was indeed expressed as the second tissue after the skin was sensitive to the application of MT. So that in the displayed image, the muscle image will have a higher signal because it is not suppressed by SWE and the signal is increased along with the application of MT.

1.5-pixel WFS is used to maintain defensiveness around musculoskeletal imaging. Small WFS can reduce chemical shift artifacts due to the application of SWE as a fat suppression technique [15]. The fat proton resonates at a frequency slightly lower than water. The difference in frequency is called chemical shift. It depends on the strength of the magnetic field. Because MRI also uses resonance frequencies for spatial encoding, this frequency difference causes a small shift between the position of fat and water in the direction of frequency in MRI images. WFS is defined as the difference of water signals in relation to the fat signal in the image. WFS is expressed in the number of pixels. For muscle imaging requirements, the WFS is recommended not to be too high on the musculoskeletal MRI protocol 1.5 pixel to be able to distinguish signals but not at too high differentiation levels, in contrast to the application of cartilage and imaging of edema (fluid) [16, 15].

Subjective assessment carried out by two radiologists as respondents used the relative Visual Grading Analysis (rVGA) method where the images were assessed compared without using the Reference Image. From the results obtained, it shows the significance of the difference between the two compared sequences. Of the four visually assessed anatomies, all anatomy has a p value <α (0.05), which means that there is a significant difference in the information on the anatomy of the MRI of the shoulder joint displayed by T1 SPIR and T1 FFE-SWEMT sequences. From the two sequences compared, the T1 FFE-SWEMT sequence was superior compared to T1 SPIR when viewed from the mean rank displayed, where the anatomical information of the image in the T1 SPIR sequence only obtained values ranging from 23-25, while T1 FFE-SWEMT was able to obtain values at range 56-58.

This is inseparable from the combination techniques applied. SWE and MT are able to provide differences in intensity between tissues properly, so that one tissue with another tissue has more stringent limits and better details. The homogeneity of the resulting signal becomes very high due to the application of selective pulses on SWE and increased tissue contrast due to the "chemical exchange" process on the MT method [17].

The pathology assessment showed significant differences in the value of two sequences in assessing pathology, which showed p value <0.001 (<α) which means that there were significant differences in pathology information of shoulder joint MRI displayed between T1 SPIR and T1 FFE-SWEMT sequences. The T1 FFE-SWEMT sequence is better at displaying pathological information than T1 SPIR with mean rank acquisition of 19.5 when compared to T1 SPIR which is only 9.5. Pathological assessment carried out is also influenced by the contrast of the tissue and the image signal produced. The ability to display a strict boundary of pathology, detail, and diffusion into the advantages of T1 FFE-SWEMT sequences, with composite pulses that are selective and Magnetization Transfer will affect the acquisition process especially if there is pathology in it, chemical exchange on normal tissue will produce different images with pathological tissues. Another obstacle in the differentiation of types of pathology is the involvement of fat and edema that produces an indefinite boundary, SWE in this case is perfect. This sequence by optimally suppressing spin fat and stimulating edema (spin water) so that it appears in a high degree of contrast (firm boundary).

The results shown are in line with the research that has been done by Rottman and Hajnal, where muscle images can be stimulated by applying magnetization transfer to the related tissue. Changes made when analyzing edema in the muscles in line with the results obtained in this study, the resulting pathology became more assertive than the routine sequences used. On MRI Shoulder (non-contrast MRI, contrast MRI, and direct-arthritic MRI), radiologists assess the T1 FFE-SWEMT sequence efficiency as superior to T1 SPIR, especially in the application of sequences needed in two phases (pre and post contrast) besides saving time in a 3D scanning, the information obtained is better than the T1 SPIR sequence. This is very necessary in observing the comparison of anatomical-pathological information before and after injection of contrast media. T1 FFE-SWEMT sequence is proven to be able to perform sequential functions according to the main purpose of the application of Fat Suppression, which is to optimize enhancement of gadolinium contrast media while being able to distinguish tissue spin that has almost the same proton density.

CONCLUSION

Based on the results and discussion in this study, it can be stated that there is a significant effect of the application of a combination of Selective Water Excitation (SWE) and Magnetization Transfer techniques to improving image information of shoulder joint MRI. The application of a combination of SWE and MT techniques on T1-FFE SWEMT sequence is capable of displaying anatomical and pathological information better than the T1 SPIR sequence.

RECOMMENDATION

Combination of Water Excitation and Magnetization Transfer techniques can be applied in the MRI 1.5 Tesla protocol for examination of shoulder joints in establishing diagnoses in the assessment of muscle anatomy and pathology. Further research is expected to be carried out this combination techniques on other musculoskeletal MRIs.

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