Pulse Sequence 3D WATS for Evaluation Of The Anterior Cruciate Ligament (ACL) nd Posterior Cruciate Ligament (PCL) on MRI Knee

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Abstract: This study was motivated by the increasing MRI examination of the knee injury. Ligament injury of the knee joint is a complex problem in orthopedic surgery. Magnetitic Resonance Imaging (MRI) is the most advanced diagnostic modality for evaluating the abnormalities in the musculoskeletal system, especially abnormalities in the knee joint. 3D WATS is a pulse sequence for 3 Dimensional images with gradient echo technique T1 contrast combined with the Water Selective Excitation. The joint ligaments to be evaluated for this study were Anterior Cruciate Ligament (ACL) and Posterior Cruciate Ligament (PCL). This study used descriptive with retrospective retrieval method. Sample of data were collected from patients who had been examined for MRI knee with clinical indication of trauma at Husada Utama Hospital within one year. There are 44 Patients received 3D WATS sequence images. Then the 3D WATS sequence was reconstructed for interpretation and evaluation of abnormalities reflected in ACL and PCL. Based on the results of the evaluation on ACL there were 25% normal, 25% partial tear, 36% completed tear, and 16% post operation. Whereas in PCL there were 57% normal, 18% partial tear, 16% completed tear, and 11% post operation. From these results, it can be concluded that the 3D WATS sequence could be used for evaluation of abnormalities in the ligaments of the knee joint especially in ACL and PCL.

1 INTRODUCTION

MRI is currently the most advanced diagnostic modality for evaluating abnormalities in the musculoskeletal system. This is because MRI can produce images with high tissue contrast value so as to produce a good anatomy and pathology view (Gold et al. 2009). It includes trauma disorders such as fractures in bone and ligament injury, and non-traumatic disorders such as Osteo Artritis (joint degenerative disorder), mass or tumor, and infection (Polly *et al*. 1998).

Abnormalities in the most common musculoskeletal system are abnormalities caused by trauma or sport injury and degenerative disorder (Hetta and Niazi 2014). Especially in knee joint, traumatic disorders often occur in addition to joint degenerative disorders *(Osteo Artritis)*. Trauma on knee joint may be fracture, dislocation, and injury to the joint ligaments. Fractures and dislocations can be easily detected with plain x-ray radiograph, while ligament injuries cannot be detected with x-ray radiograph. Ligament injury in the knee joint is a complex problem in orthopedic surgery (Gregory et al. 2005). Therefore, a good image is required to detect abnormalities in the knee ligaments (Khandelwal *et al.* 2018).

MR imaging technique is relatively complex because the resulting image depends on many parameters (Attard, Castillo, and Zarb 2018). When the selection of parameters is appropriate, MRI image quality can provide a detailed image of the human body with contrasting differences, so that the anatomy and pathology of body tissues can be carefully evaluated (Notosiswoyo dan Suswati S. 2004). Determination of this technique is tailored to the tissue character of the organs to be evaluated. Knee joint has various tissues such as bones, muscles, tendons, and ligaments (Tokuda et al.

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2012). Therefore, sequencing techniques are required to produce images with good tissue contrast.

In the MRI of the knee, routine sequences used include: T1W, T2W, and Proton Density (PD) Fatsat /non Fatsat. The routine sequence used is only a 2D sequence. So, it needs multi planning slices to be able to produce a good image. 3D WATS sequences are usually only used when there are indications of osteoarthritis abnormalities or for the evaluation of cartilage areas (Peter, 2004). So, this sequence is rarely used on MRI examination of the knee.

3D WATS is a pulse sequence for 3 Dimensional images with gradient echo technique with T1 weighting contrast and combined with Water Selective Excitation (WATS). Water Selective Excitation is a technique used to liquidate fluids and suppress fat. This technology utilizes the effects of a chemical shift between fat and water, with spatial selectivity based on the selective frequency of water excitation. This technique is faster than conventional fat-suppression techniques and produces a better image (Jing Wu et al. 2012). 3D imagery results can be reconstructed so that only one-time scanning can produce images with various slices (Kirchgesner et al. 2018). Thus, this technique is best used on musculoskeletal MRI.

The purpose of this research was to know the role of 3D WATS sequence for the detection of ACL and PCL trauma on MRI knee. In addition, to find out the advantages and disadvantages of the 3D WATS sequence for detection trauma on MRI Knee, this sequence can be used as a protocol standard in MRI knee examination.

1.1 Gradient Echo Pulsequence

A gradient echo pulse sequence uses an RF excitation pulse that is variable, and therefore flips the NMV through any angle (not just 90°). A transverse component of magnetization is created, which magnitude is less than in spin echo, where all the longitudinal magnetization is converted to the transverse plane. When a flip angle other than 90° is used, only part of the longitudinal magnetization is converted to transverse magnetization, which processes in the transverse plane and induces a signal in the receiver coil (Figure 1).

After the RF pulse is withdrawn, the FID signal is immediately produced due to inhomogeneities in the magnetic field and T2* dephasing therefore occurs. The magnetic moments within the transverse component of magnetization dephase, and are then rephased by a gradient., so it is called Gradient Echo. (Westbrook and Kalbot, 2011).

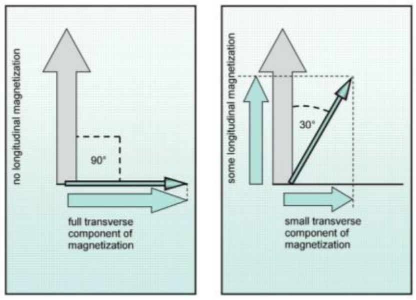

Figure 1: The flip angle control the amplitude of the signal

When the gradient field is switched on, the magnetic field strength along its axis is sloped or graded. The Lanmor equation states that the precision frequency of a hydrogen proton's magnetic moment can change according to the strength of the magnetic field affecting it. It is used as a reference for Rephasing magnetic moments in the Gradient Echo technique.

As displayed in Figure 2, a gradient is applied to incoherent (out of phase) magnetization. The magnetic moments have fanned out due to T2* dephasing and the fan has a trailing edge consisting of slow nuclei (shown in blue), and a leading edge consisting of faster nuclei (shown in red). A gradient is then applied, so that the magnetic field strength is altered in a linear fashion along the axis of the gradient. The direction of this altered field strength is such that the slow nuclei in the trailing edge of the fan experience an increased magnetic field strength and speed up.

In Figure 2 the blue spins are experiencing the red, 'high end' of the gradient. The faster nuclei in the leading edge of the fan experience a decreased magnetic field strength and slow down. In Figure 2 the red spins are experiencing the blue 'low end' of the gradient. After a short period of time, the slow nuclei have sped up sufficiently to meet the faster nuclei that are slowing down. When the two meet, all the magnetic moments are in the same place at the same time and have been rephased by the gradient. A maximum signal is therefore induced in the receiver coil and this signal is called a gradient echo. Gradients that rephase are called rewinders.

The advantages of the gradient echo sequence were the faster data acquisition. This is because the use of RF angles is less than 90o and varies so that TR (Time Repetition) and TE (Time Echo) are used very shortly. However, this sequence is particularly

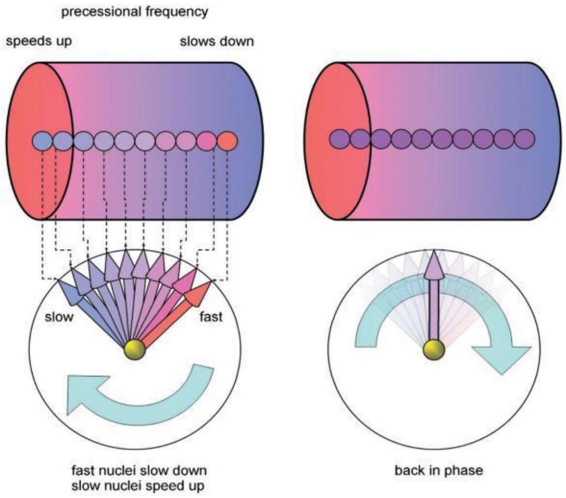

Figure 2 : Rephasing mechanism in gradient echo technique. The blue spin as a slow nuclei and the red spin as a fast nuclei

susceptible to magnetic field inhomogeneity so that artefact occurs (Westbrook and Kalbot, 2011).

To obtain the T1W image, a rather wide flip angle was used for long longitudinal relaxation. And for a well-formed T1 image contrast must minimize the relaxation time of T2 * by using short TR and TE (Luo *et al.* 2012).

1.2 Water Selective Excitation

Water Selective Excitation was a one part of the fat suppression technique with the PROSET (Principle of Selective Excitation Technique) method. This method yields more effective fat suppression and higher SNR than the conventional fat suppression (Kirchgesner et al. 2018). This technology utilizes the effects of a chemical shift between fat and water, with spatial selectivity based on the selective frequency of water excitation (Richard et al. 2006). This technique is faster than conventional fat-suppression techniques and produces better image (Ribot et al. 2015).

In this technique, there were two or more types of pulse combinations that can be used. The first type there are four elements of the combined pulse that is 1: 3: 3: 1 with the amplitude ratio (11.25°: 33.75°: 33.75°: 11.25°). The second type uses three pulse combined elements that are 1: 2: 1 with the amplitude ratio (22.45 °: 45.00 °: 22.45 °). With the technique, only selective frequency of the water to be excited uses a selective pulse component (Figure 3).

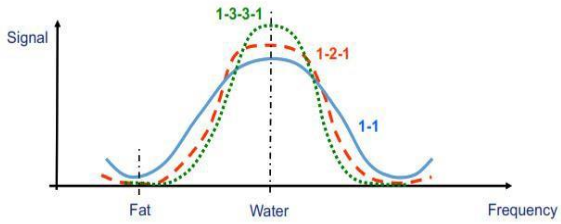

Figure 3. Cobination excitation RF pulse make the signal intensity of the water is very high.

While the fat does not experience excitation, the fat signal is not formed. Thus, the image of the selective water will appear white and the fat will appear black. (Jing Wu *et al.* 2012).

2 MATERIALS AND METHOD

This study used descriptive analysis. The population in this study were all patients who performed MRI Knee examination. The data were collected using retrospective method, *i.e.* by collecting the data of the patient who had performed the genetic MRI examination within 1 year *i.e.* August 2015- August 2016. The sample size of this study were all patients with indication of ACL and/or PCL trauma, in the period time.

From the method,44 patient data that has been done MRI examination of knee with indication of trauma were obtained. Imagery of the 3D WATS sequence was reconstructed for interpretation and evaluation of abnormalities reflected in ACL and PCL. The results of the interpretation are grouped according to the tear grade on ACL and PCL namely: Normal, Partial tear, Completed tear, and Post Operation.

The evaluation data was then compiled based on the specified grade of tear. Data was presented in the frequency distribution table. After that, the data werecompared with the final diagnostic results that have been released by the radiology unit to know the difference between the evaluation results of the 3D WATS sequences and the final outcome of the diagnosis.

MRI equipment used in this research was MRI Philips Achieva 1,5 Tesla superconducting magnetic field. The coil used is the knee volume coil. for image reconstruction using radiant dicom viewer software version 4.2.

3 RESULT

The sample tabulation can be seen in Figure 4. Characteristics of the sample by sex, obtained data of 64% male and 36% female. While based on the age range of patients, most are found in the age range 16-30 years with a sample of 17 patients and followed by the age range 31-45 years with a sample of 15 patients.

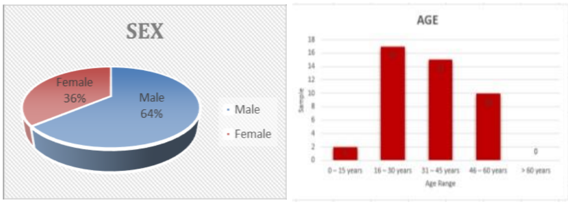

Figure 4 : Characteristics of the data by sex and age

The 3D WATS sequence image results were reconstructed with various slices of axial, coronal, and sagittal slices. Of the three slices, the sagittal/sagittal oblique slices are the most optimal for visualizing the anatomy and morphology of ACL and PCL. This is because the sagittal/sagittal oblique slices, ACL and PCL can be visualized in one field.

Table 1. Result evaluation of the abnormality on 3D WATS image.

Category	ACL		PCL	
	tota	%	tot	%
Normal	11	25	25	57
Partial tear	11	25	8	18
Completed	16	36	6	14
Post Operation	6	14	5	11
Total	44	100	44	10

From the results of the reconstructed 3D WATS sequence evaluation, 27 patients had Tear/Tear Disorder (11 Tear Partial Patients, 16 Complete Tear Patients) on ACL ligaments, 6 patients were evaluated post-operative patients, and 11 patients were normal. While on PCL, 13 patients had Tear/ Tear Disorder (8 partial, 6 Complete), 5 post-reconstruction patients, and 25 normal.

The evaluations result of the 3D WATS image will be compared with the final diagnostic result that have been released by the radiology unit. From result of comparation test with the Wilcoxon Paired Sign Test has been obtained significance value P = 0,157 on ACL tissue and P = 0,083 on PCL tissue (table 2).

Table 2 : Comparation test for 3D WATS and final diagnostic result.

Test Statistics[a]		
	DIAGNOSTIC RESULT ACL - 3D WATS ACL	DIAGNOSTIC RESULT PCL - 3D WATS PCL
Z	-1,414[b]	-1,732[c]
Asymp. Sig. (2-tailed)	,157	,083
a. Wilcoxon Signed Ranks Test		
b. Based on positive ranks.		
c. Based on negative ranks.		

Thus, it can be interpreted that there is no significant difference (P >0.05) between the independently image evaluations in 3D WATS sequences with final diagnostic results by the radiology unit at Husada Utama Hospital.

4 DISCUSSION

The image contrast generated by the 3D WATS sequence was more likely to T1 contrast. T1 weighted contrast on the 3D WATS sequence produces a hyper intensive image of the ligament (ACL and PCL). In 3D WATS, the fat tissue would look hypointense than the conventional T1W spin echo technique and the more visualized ligament hyperintense (fig. 5). This was due to T1 weighting by gradient echo technique using short TR and TE and variable flip angle (Westbrook and Kalbot, 2011).

With short TR and TE (TR 20ms, TE 8.3ms) the ligament tissue image will be hyperintense because this sequence was combined with water selective excitation techniques so that only the frequency of selective water is excited while the fat tissue is not excited. Thus, even with T1 weighting, the fat signal will produce a low amplitude that appears hypointense on the image formed (Westbrook and Kalbot, 2011).

The hypointense fat feature results in an even more contrasting anatomical and morphological features of the soft tissue making it easier to evaluate the abnormalities in the ligament tissue of the knee joint, particularly in the ACL and PCL tissues. It also distinguishes between normal ligaments and abnormal ligaments.

Compared to the Proton Density (PD) SPAIR and T1W spin echo sequence, the image intensity at 3D WATS was higher than the PD SPAIR and T1W spin echo (Figure 5). But, the images contrast and image quality PD SPAIR look better than 3D WATS. This was because the Proton Density contrast uses a fairly long TR (TR> 2000ms). A long TR causes excited protons to have sufficient recovery time. Protons that have a long recovery time will produce a high signal amplitude on the PD weighted contrast.

features of the knee MRI. Proven in cases trauma of ACL and PCL, 3D WATS sequences are capable of displaying normal and abnormal ACL and PCL images quite clearly and firmly as shown in figure 6 and figure 7.

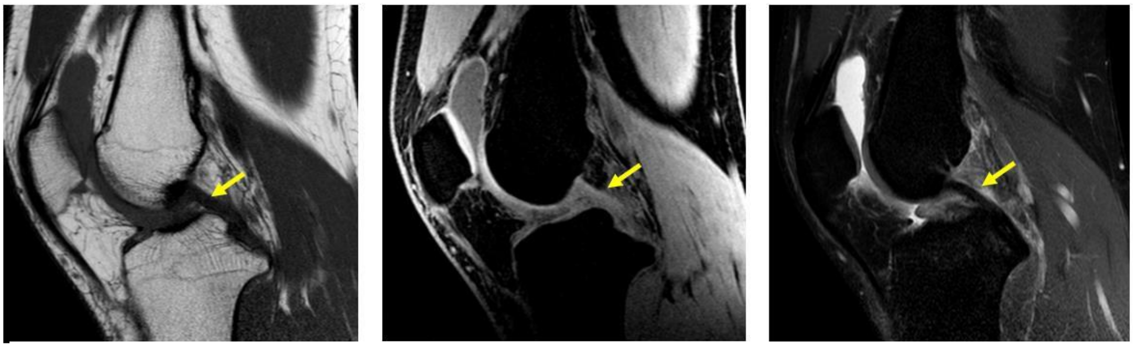

Figure 5 **A** : T1 weighted image contrast looks hypointense in PCL, **B**: 3D WATS images contrast looks hyperintense in PCL, **C**: PD SPAIR image contrast looks hypointense in PCL.

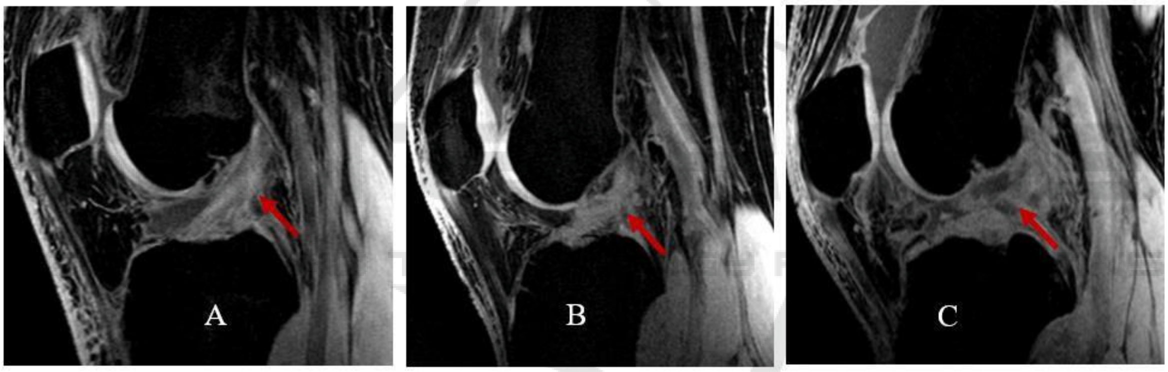

Figure 6. The evaluation 3D WATS image in sagittal plane **A**: normal ACL, **B**: partial tear ACL, **C**: completed tear ACL.

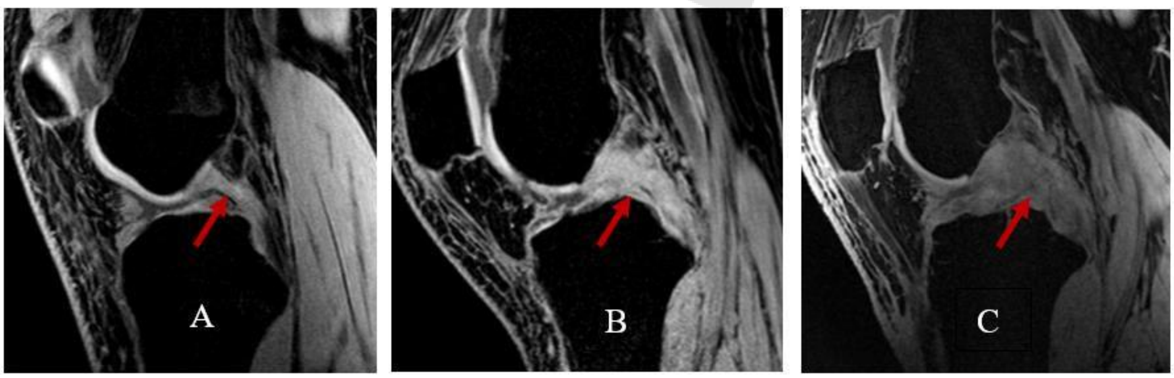

Figure 7. The evaluation 3D WATS image in sagittal plane **A**: normal PCL, **B**: partial tear PCL, **C**: completed

The 3D WATS sequence image was good enough to display anatomical and pathological

5 CONCLUSSION

Based on the results of research that has been conducted, it can be concluded that 3D WATS pulse sequence plays an important role to be able to evaluate abnormalities in MRI knee. This was evidenced by the comparative test of 3D WATS image sequence evaluation results with the overall diagnosis of MRI image has been obtained significance value P = 0,157 on ACL tissue and P = 0,083 on PCL tissue. It can be interpreted that there is no significant difference (P >0.05). Thus, 3D WATS sequences should be used as a routine sequence on MRI knee in trauma cases. However, this sequence must be combined with other routine sequences to produce accurate diagnostic results.

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