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Dual-Echo magnetic resonance imaging pulse sequence in diagnosis of temporomandibular disorders: Diagnostic accuracy study

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***Abstract*---**Objective: This study was conducted to assess the diagnostic accuracy of different MRI pulse sequence dual-echo-PD in the diagnosis of temporomandibular disorders. Subjects and methods: Twenty seven patients (54 Temporomandibular joints) with painful joints or limited mouth opening or unexplained longstanding headache were enrolled in the study to examine the diagnostic accuracy of magnetic resonance imaging sequence dual-echo in delineation of the articular disc position, the disc morphology, and the cortical bone in comparison to the gold standard of MRI scanning sequence: proton density weighted images. Results: Dual-echo-PD weighted image showed 94.7% sensitivity and 96.3% diagnostic accuracy in identifying articular disc position. Dual-echo-PD showed no statistically significant difference than proton-density in delineation of disc morphology or cortical bone. Conclusions: The dual-echo imaging sequence can be used instead of using PD to delineate disc position, morphology, and cortical bone.

***Keywords*---**temporomandibular, morphology, Dual-echo-PD.

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Introduction

Temporomndibular joint is a hinge joint located just anterior to the external auditory meatus, consists superiorly of the temporalis bone and inferiorly of the mandible. TMJ contains an articular disc within the joint capsule, and its contractile muscles of mastication [1]. It is considered as a synovial joint which has a common feature exhibited by inclusion of: disc, bone, fibrous capsule, fluid, synovial membrane, and ligaments [2]. Temporomandibular disorder (TMD) is an umbrella term for a group of musculoskeletal disorders that affect the joint and supporting system. It is the second most common cause of pain in the mouth and face after odontogenic pain around the temporomandibular joint (TMJ) [3]. TMD occurs with a peak incidence between 20 and 40 years of age. TMD symptoms include jaw pain or dysfunction, earache, headache, facial pain and TMJ clicking, and limited capability to open the jaw [4] [5]. It is classified into two broad types ; those primarily involving the muscles and those involving the temporomandibular joint articular disc [6]. Muscle disorders are far more common than the intracapsular disorders [7][8].

The predominant TMJ finding among patients with TMD is internal derangement related to articular disc (AD) displacement. Disc displacement is one of the most frequent pathologic findings of the TMJ, associated with and without pain [8] [9]. Sometimes, this displacement can cause deformation of the AD, such as changes in its biconcave morphology. Magnetic resonance imaging has become the examination of choice in evaluating the TMJ. MRI allows excellent depiction of the TMJ anatomy and abnormalities because of its inherent tissue contrast and high resolution [10].

Both articular disc displacement and morphology change can be depicted in proton density (PD) weighted MR images. Due to mechanical overload associated with the mentioned abnormalities release of inflammatory mediators may result, causing pain in the joint. With magnetic resonance imaging, the presence of inflammatory changes in the retrodiscal tissues and synovial membrane of the TMJ is observed by an increased signal in the T2 weighted images, which is known as joint effusion (JE) [11].

In order to detect the position and deformity of the articular disc, proton density-weighted images (PDWI) are necessary, while T2-weighted images (T2WI) are necessary to detect the level of joint effusion, which is usually accompanied with pain. Different protocols have been proposed for evaluating the TMJ and related disorders from various aspects, but certain basic MRI parameters are necessary for TMJ examination with optimal image quality and efficiency [10][12]. A dual-echo technique is generally used for two-dimensional (2D)-PDWI and -T2WI scans. Closed- and opened-mouth positions are acquired with sagittal and coronal sections of the TMJ to determine displacement and reduction of the articular disc [13] [14].

Subjects and Methods

Study Design and Setting

Study design: A diagnostic accuracy study.

Data collection: A prospective study, as the data collection was performed before the performance of index tests and reference standard.

Study setting: The study was conducted in the Radiology Department, Faculty of Medicine Cairo University from January 2020 to June 2021 where a total of twenty seven patients were recruited from the outpatient clinics of Oral and Maxillofacial Surgery clinic, Faculty of Dentistry - Cairo University fulfilling the inclusion criteria.

Participants

Eligibility criteria for patients: patients with pain related to temporomandibular joint for more than one-month duration, or those with limited mouth opening for more than one-month duration or patients with longstanding unexplained headache or tinnitus were included in the study. While patients with history of TMJ surgical intervention, TMJ arthrocentesis for three months, or patients with facial asymmetry or those who cannot undergo MRI scanning safely like those with pace makers, carotid clamp or artery clip were excluded from the study.
PIRT:
P: Patients with symptoms of temporomandibular disorder (TMD)
I1: Dual-echo MRI sequence
R: Proton density- turbo spin echo weighted image and T2- turbo spin echo weighted image
T:

1- Delineation of temporomandibular joint disc position
2- Delineation of temporomandibular joint disc morphology
3- Delineation of cortical bone

Measuring device: Four-point scale
Measuring unit: 0: poor, 1: fair, 2: good and 3: very good

Sample Size Calculation and Medical Biostatistics Unit Approval

A power analysis was designed to have adequate power to apply a two-sided statistical test of the research hypothesis (null hypothesis) that dual-echo is as accurate as T2 and proton density- weighted MR images. According to the results of [15] in which the (mean±SD) value for the control and the intervention were (1.71±0.64) and (1.15±0.86) respectively- and by adopting an alpha (α) level of 0.05 (5%), beta (β) level of 0.20 (20%) i.e. power= 80% and an effect size (d) of (0.724); the predicted sample size (n) was found to be a total of 54 temporomandibular joints. Sample size calculation was performed using G*Power version 3.1.9.4 [16] The sample size calculation was performed and was approved by the Medical Biostatistics Unit, Faculty of Dentistry– Cairo University on 18/10/2019.

Test methods

Detailed history of chief complaint was noted for each patient in his own words following the examination chart of [17]. Bilateral temporomandibular joint palpation examination for each patient was done. MRI scan procedures were explained to all the patients and an informed consent was signed by each patient before their participation in the study.

MR imaging:

The twenty seven patients (54 joints) were scanned using 1.5 T PHILIPS- Achieva® MRI machine[1]. Customized assembled bite blocks were made for each patient using half-cut wooden tongue depressors[2]. Each tongue depressor had the following parameters: L×W×H = 150mm×18mm×1.6mm. The required number of these half cut wedges were assembled together using silkplast® adhesive tape[3]. Each patient was instructed how to put the assembled tongue depressors and bite on during the scan after giving him/her the notice through the microphone.

Survey images were taken on axial, coronal and sagittal cuts with adjusting examining the joint using oblique sagittal cut in relation to the lateral pterygoid muscle. These oblique sagittal cuts are taken for both closed mouth position (Figure) and maximum mouth opening position (Figure).

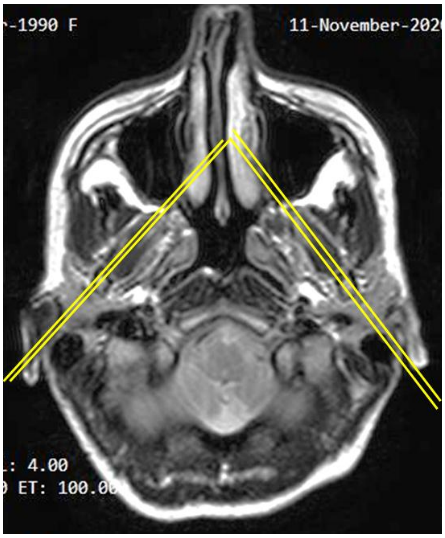

Figure 1: Axial survey MR image showing oblique sagittal lines along with the condylar head and the lateral pterygoid muscle in closed mouth position.

[1] (Philips Medical Systems Netherlands B.V. 2013 – Extended MR WorkSpace 2.6.3.5)
[2] (GTM, Cairo, Egypt)
[3] (Pharmplast, Egypt)

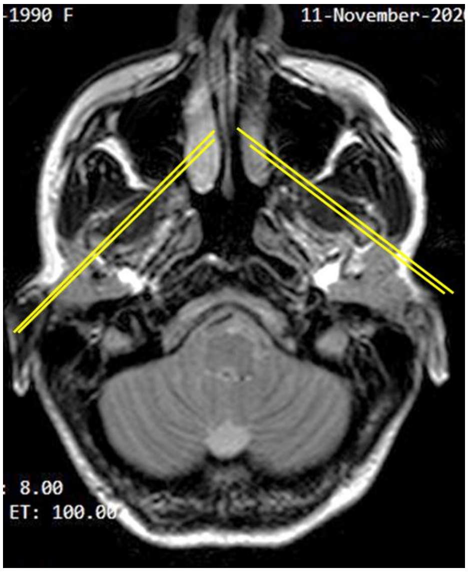

Figure 2: Axial survey MR image showing oblique sagittal lines along with the condylar head and the lateral pterygoid muscle in open mouth position

Scans were taken in the following sequence: Proton density (PD)- turbo spin echo weighted image, T2- turbo spin echo weighted image, Dual-echo, all with closed mouth with maximum intercuspation. Afterwards, the patient was instructed to open his/her mouth with maximum opening using the customized bite block to scan the PD- and Dual-echo sequences for open-mouth condition. Each MRI sequence had its own imaging parameters described in details in (
Table 1)

Table 1
Imaging parameters of MRI sequences

Sequence	Coil selection	TSE factor	Echoes	TR (ms)	TE (ms)	FOV (mm)	NSA	Scan duration	Slice thickness (mm)	Slice gap (mm)
PD-WI	SENSE-FLEX-S	5	1	1500	30	150	3	02:31.5	3	0.3
T2-WI	SENSE-FLEX-S	17	1	4353	120	150	4	03:07.2	3	0.3
Dual-echo	SENSE-FLEX-S	14	2	2200	120	150	2	02:25.2	3	0.3
PD (open)	SENSE-FLEX-S	5	1	1500	30	150	3	02:31.5	3	0.3
Dual-echo (open)	SENSE-FLEX-S	18	2	2200	120	150	2	03:18.0	3	0.3

The raw and the enhanced images were exported to a compact disc (CD) with a code number for the patient that was written in an excel sheet with the patient's name, history and clinical examination findings. The scans were examined randomly and blindly later on by the investigator using MicroDicom viewer free software. Laptop had the following specifications; Intel (R) Core (TM) i5 CRU and screen size 15”.

Random allocation sequence generation:

All patients recruited and enrolled in the study were given a code number from #1 to #27 which was also written on the CD of the patient’s MRI scanning data set. Random examination of the CDs was done. The single reading session was maximum 20 minutes to avoid eye fatigue.

Blinding:

The current study was assessed by calibrated investigator, Oral and Maxillofacial Radiology specialist with nine-year experience. The study was single blinded as the investigator did not know any of the patient’s history or chief complaint while examining the MR sequences and giving scores. During the reading sessions there was a basic rule that the dual-echo sequence not to be examined with PD imaging sequence of the same patient during the same session to avoid bias.

Scoring system:

The four-point scale scoring system was used for assessing disc position, morphology and cortical bone delineation, zero=poor, score 1=fair, score 2=good, score 3=very good. Disc position and cortical changes were assessed from PD-WI (Figure) and dual-echo (Figure) images. Then, all the investigator’s data were compared with the condition that was seen and stated in the standard TMJ MR imaging sequences: PD weighted images.

For case diagnosis the articular disc position was assessed in closed mouth PD-WI in relation to the condylar head whether in normal position or anteriorly displaced position and if displaced whether with reduction or without reduction which was detected from open mouth PD (Figure) and dual-echo (Figure) images.

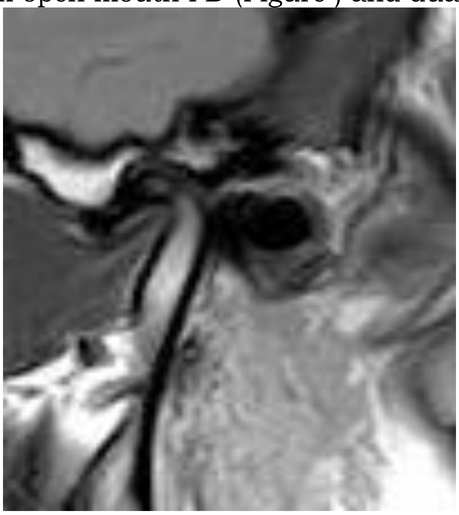

Figure 3: Sagittal PD-WI of left TMJ showing anterior disc displacement with score "3" for disc position and cortical erosion and osteophyte formation with score 3" for cortical changes

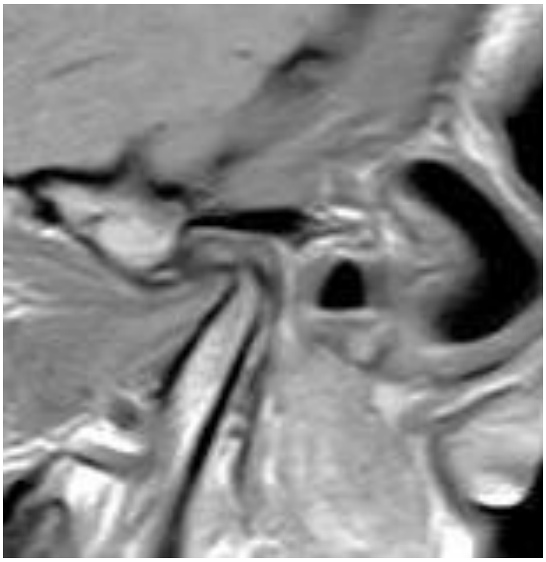

Figure 4: Sagittal dual-echo-PD image of left TMJ showing anterior disc displacement with score "3" for disc position and cortical erosion and osteophyte formation with score 3" for cortical bone delineation

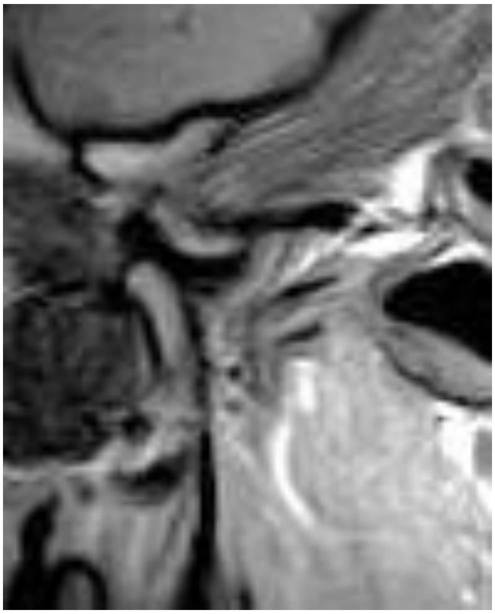

Figure 5: Sagittal PD-WI of left TMG with open mouth position showing an anterior disc displacement with reduction.

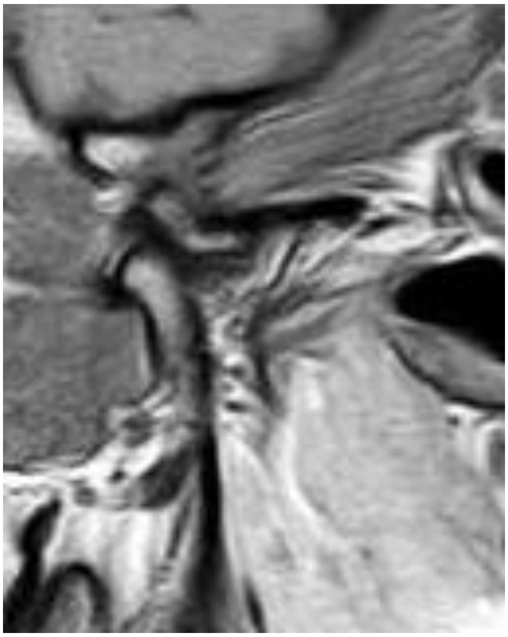

Figure 6: Sagittal dual-echo-PD of left TMG with open mouth position showing an anterior disc displacement with reduction

Statistical methods

Categorical and ordinal data were presented as frequency and percentage values. Categorical data were analyzed using Cochran's Q test followed by multiple. McNemar's tests with Bonferroni's correction. Ordinal data were analyzed using Friedman's test followed by multiple Wilcoxon signed rank tests with Bonferroni's correction. Intra-observer reliability was analyzed using weighted Kappa coefficient. Area under the curve was compared using z-test. The significance level was set at $p \leq 0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.1.1 for Windows[4].

Results
Articular disc position

Frequency and percentage values for disc position status were presented in (

Table 2) using Wilcoxon signed rank test.

Table 2
Frequency and percentage values for disc position status

Parameter			Sequence		p-value
			PD	Dual-echo-PD	
Disc position	0	n	0	0	0.285ns

[4]R Core Te cam (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Parameter			Sequence		p-value
			PD	Dual-echo-PD	
		%	0%	0%	
	1	n	3	1	
		%	5.6%	1.9%	
	2	n	16	17	
		%	29.6%	31.5%	
	3	n	35	36	
		%	64.8%	66.7%	

*; significant (p ≤ 0.05) ns; non-significant (p>0.05)

There was no significant difference between both sequences (p=0.285) either proton-density-weighted image or dual-echo-PD images with the majority having score (3). Dual-echo-PD sequence showed very comparable results to that of proton density sequence in identifying the articular disc position in relation to the condylar head.

Accuracy of sequence diagnosis:
Accuracy of sequence diagnosis was presented in (
Table).

Table 3
Accuracy of sequence diagnosis

Diagnosis			Sequence
			PD versus Dual-echo-PD
Normal	Dissimilar	n	0
		%	0%
	Similar	n	16
		%	100%
Disc displacement with reduction	Dissimilar	n	2
		%	5.7%
	Similar	n	33
		%	94.3%
Disc displacement without reduction	Dissimilar	n	0
		%	0%
	Similar	n	3
		%	100%

Accuracy of dual-echo-PD sequence in diagnosing articular disc position:
Accuracy of dual-echo-PD was calculated and compared to the proton-density imaging sequence and plotted in (

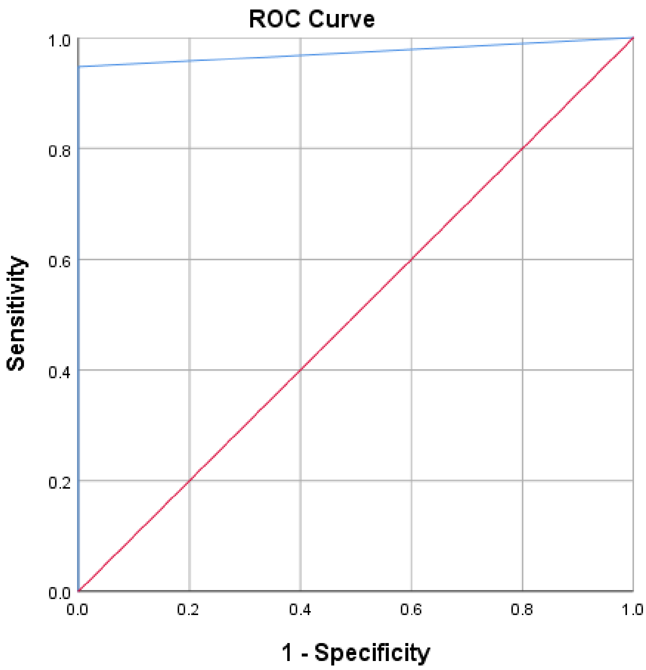

Table) and (
Figure).

Table 4
Accuracy of dual-echo-PD in diagnosing articular disc position

Parameter		Value
True positive	n	36
	%	66.7%
True negative	n	16
	%	29.6%
False positive	n	0
	%	0%
False negative	n	2
	%	3.7%
Sensitivity		94.7%
Specificity		100%
Positive predictive value		100%
Negative predictive value		88.9%

Parameter	Value
Diagnostic accuracy	96.3%
AUC (95%CI)	0.974 (0.931-1)

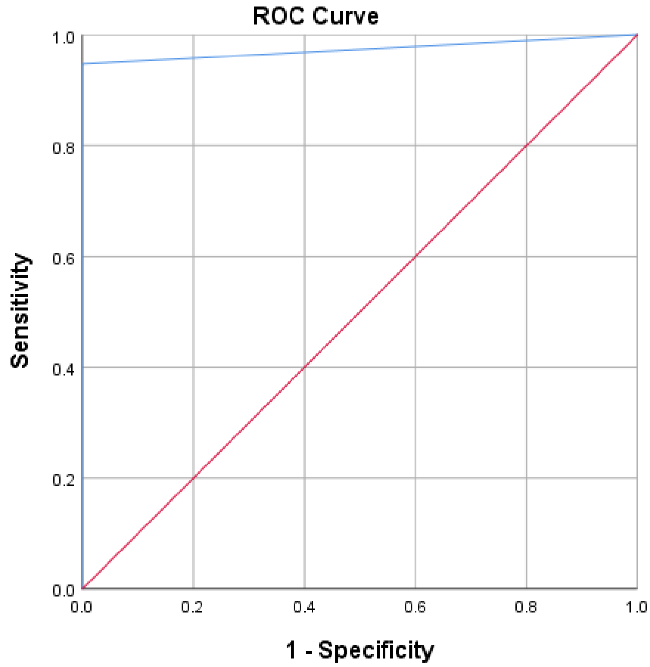

Figure 7: ROC curve for accuracy of dual-echo-PD sequence

Out of 54 scans, 36(66.7%) were true positives, 16(29.6%) were true negatives, 2(3.7%) were false negatives and there was no false positives. The sensitivity was 94.7%, the specificity was 100%, positive predictive value was 100%, negative predictive value was 88.9%, diagnostic accuracy was 96.3% and area under the curve was 0.974 (95%CI; 0.931-1).

Disc morphology

Frequency and percentage values for identification of disc morphology data were presented in (Table) using Wilcoxon signed rank test.

Table 5
Frequency and percentage values for disc morphology

Parameter			Sequence		p-value
			PD	Dual-echo-PD	
Disc morphology	0	n	0	0	0.532ns
		%	0%	0%	
	1	n	2	1	
		%	3.7%	1.9%	
	2	n	17	23	

Parameter			Sequence		p-value
			PD	Dual-echo-PD	
		%	31.5%	42.6%	
	3	n	35	30	
		%	64.8%	55.6%	

*; significant (p ≤ 0.05) ns; non-significant (p>0.05)

There was no significant difference between both sequences proton-density and dual-echo-PD in identifying the morphology of articular disc (p=0.532) with the majority having score (3). However, the dual-echo-PD sequence showed less score (3) than the proton density sequence in identifying the articular disc morphology, thus less confidence.

Cortical bone delineation

Frequency and percentage values for cortical bone delineation were presented in (Table) using Wilcoxon signed rank test.

Table 6
Frequency and percentage values for cortical bone delineation

Parameter			Sequence		p-value
			PD	Dual-echo-PD	
Cortical bone delineation	0	n	0	0	0.637ns
		%	0.0%	0.0%	
	1	n	0	2	
		%	0.0%	3.7%	
	2	n	19	13	
		%	35.2%	24.1%	
	3	n	35	39	
		%	64.8%	72.2%	

*; significant (p ≤ 0.05) ns; non-significant (p>0.05)

There was no significant difference between both sequences proton-density and dual-echo-PD (p=0.637) with the majority having score (3). The dual-echo-PD sequence showed higher confidence in cortical bone delineation results than the proton density sequence.

Intra-observer reliability

Intra-observer reliability for different sequences was presented in (Table) using Weighted Kappa coefficient. There was a strong overall intra-observer agreement (kappa=0.840)

Table 7
Intra-observer reliability for different sequences

Parameter	Sequence	Diagnosis	Kappa

Parameter	Sequence	Diagnosis	Kappa
Sequence diagnosis	PD		0.720
	Dual-echo-T2		0.570
Overall			0.84

Discussion

The current diagnostic accuracy study aimed to assess the diagnostic accuracy of dual-echo MRI sequence in diagnosis of temporomandibular disorders. The sample comprised 27 patients complaining from joint pain and/or limited mouth opening for more than one month duration or longstanding unexplained headache. The MR images for both the right and left joints were assessed to find if there was a significant difference between the proton-density weighted images and the dual-echo images in delineation of articular disc position, morphology and cortical bone.

Magnetic resonance imaging modality was chosen for this study as it is considered the golden standard for TMJ imaging since the early 1990s by [18] then the early 2000s [19] and till 2021 it remains as the best imaging modality and the gold standard as documented by [20]. The standard MR imaging for TMJ as documented by [21] and [22] includes PD and T2-WI. The disc position and cortical changes are best viewed by PD weighted images.

This was explained earlier by [13] that the long TR not only increases the signal to noise ratio (SNR), but it also can clearly depict disc derangement. Also SNR can be increased by decreasing the TE. Therefore, a combination of long TR and short TE results in proton density weighted image with increased contrast between the articular disc and the surrounding tissues without reducing the SNR.

Patients were prepared for MRI scan similar to [23]. Removable metallic objects were removed. Patients were also informed with the procedures of MRI scanning; the time, the supine setting position, the coil, the sounds that he/she would hear during the scanning. This information helped to avoid patient's panic or fear during scanning that might lead to minute motion which would disrupt the scan.

The dual-echo MRI sequence has been chosen in the current study to investigate its reliability in TMJ examination and whether it can replace both sequences (PD and T2-WIs) or not owing to the shorter scanning time that was observed by the dual-echo sequence. The dual-echo MR imaging sequence was examined by [24] for TMJ examination and they concluded that it is an imaging sequence that is free of any major artifacts in comparison to the proton-density weighted images. The dual-echo imaging sequence has been also examined later on by [14] in TMJ examination and they stated that the dual-echo imaging sequence allow for less scanning time and thus less liability for patient motion.

Oblique sagittal planes were chosen for orientation in the current study following [25] whose study was based on the results of [26] that disc displacement could generate changes of the condyle orientation in the coronal plane. This oblique sagittal images have been proposed recently and examined in order to diagnose the disc position in relation to the condyle antero-posterior and also medio-lateral [10].

Four-point scale was used to evaluate the disc position, morphology, cortical bone delineation, similar to [23] starting from poor image (0) reaching very good image (3). Consequently the higher the score for disc position, morphology, cortical bone evaluation the more reliable the image is to diagnose the case.

The present study compared the dual-echo-PD weighted images with the PD-weighted image in identifying the articular disc position in relation to the condylar head position. The dual-echo-PD showed no statistical significant difference in identifying the disc position than the gold standard proton density images. Also the dual-echo-PD had the highest score (3) in 35 cases out of 54 joints in comparison to 36 cases in PD scored with (3), therefore it can be deduced and calibrated the same as the gold standard PD-weighted images confidence in identifying the articular disc position.

The dual-echo-PD weighted images showed almost the same diagnostic results as those of the proton-density-weighted images in identifying articular disc position in relation to condylar head in open and closed mouth positions. The dual-echo-PD weighted images results were similar to proton-density-weighted images in diagnosing the case in 52 joints out of 54; being normal, anteriorly displaced articular discs with or without reduction. Only two cases were counted dissimilar to the proton-density weighted images as they were diagnosed with anteriorly displaced articular discs with reduction, while they were diagnosed as normal in dual-echo-PD images.

The dual-echo-PD weighted images was examined for accuracy tests in diagnosing the disc position of the TMJ; it showed 94.7% sensitivity, 100% specificity, 100% positive predictive value, 88.9% negative predictive value and 96.3% diagnostic accuracy. These results indicated that the dual-echo-PD can be used in diagnosing the articular disc relation to condyle comparable to the gold standard proton-density weighted image.

The delineation of articular disc morphology is one of the diagnostic criteria of the TMJ condition; therefor it was one of the examined criteria of the dual-echo-PD sequence. The dual-echo-PD sequence showed no statistical significant difference in delineation of articular disc morphology than that of the PD sequence, however it showed less score (3) than the PD. This could be attributed to being used to PD images more than the dual-echo-PD images, so the disc morphology was easier and more delineated confidently in PD images.

The results of dual-echo-PD in disc position detection and delineation of its morphology are almost similar to that of the gold standard the PD-WI. However, the total scanning time of dual-echo (PD and T2) is much less than that of the PD and T2-WI together. Consequently the dual-echo can substitute using both sequences to avoid longer scanning time with higher possibility of patient’s motion during scanning. .

The present study examined the cortical bone delineation of the condylar head using the dual-echo-PD versus the proton-density weighted images. Although there was no statistical significant difference in cortical bone delineation between both imaging sequences, yet the dual-echo-PD showed higher confidence with higher number recorded with score (3) which was 39 joints out of 54 than that of the PD images (33).

Consequently, dual-echo-PD showed higher mean and standard deviation (2.69 ± 0.54) than those of PD images (2.65 ± 0.48).

The intra-observer reliability was examined to investigate the reliability of using dual-echo-PD in diagnosing the articular disc position in relation to condylar head and delineating the disc morphology and the cortical bone itself. The current study showed strong agreement in overall intra-observer reliability (0.84) as categorized by [27].

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- Conflict of Interest: There was no conflict of interest.
- Author Contributions:

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Explanations: the article has not been presented either as a poster or oral presentation before.

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