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Research Paper

Assessing the image quality of brain magnetic resonance images taken with 1.5T and 3T scanners

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1. Introduction

Magnetic resonance imaging (MRI) is the ideal modality for brain imaging, as high quality anatomical detail is provided while having a higher sensitivity and specificity over other imaging modalities such as Computed Tomography (CT) (Isalm & Munir, 2019; Khan et al., 2019). MRI does not make use of ionising radiation, but acquires images in multiple planes without repositioning the patient, through the generation of powerful electromagnetic fields and radiofrequency pulses. Depending on the gradient and the number of radiofrequency pulses set, different MRI sequences are created. An MRI sequence is a series of radio-frequency pulses used to obtain a signal from the patient, to produce an image of the examined area with a particular appearance (weighting) (Liang et al., 2021).

MRI scanners of a high field strength such as 3Tesla (T) scanners, produce scans with an improved signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) and therefore with an improved image quality when compared with scanners of a low field strength such as 1.5Tesla (T) scanners. The improvement in SNR and CNR on images acquired with high field strength scanners varies with the type of sequence used, where signal improvement may be more evident on certain sequences than on others (Wardlaw et al., 2012). Due to the increase in the SNR, scans produced with high field scanners have an improved spatial and temporal resolution in line with the findings of this research in the case of axial T2W and axial fluid attenuated inversion recovery (FLAIR). Yet, this improvement in image quality is counter-acted by the presence of artefacts which may be more intense and evident on scans produced with a stronger magnetic field (Grover et al., 2015; Vargas et al., 2009; Vujmilović et al., 2016).

Research indicated that 1.5T scanners are better than 3T scanners at visualising anatomical structures near the base of the skull (Wardlaw et al., 2012). Brain scans produced with 3T scanners tend to have an increased signal drop out in this area produced from adjacent anatomical structures. This type of artefact is termed as magnetic susceptibility artefact. Such artefacts result from the presence of any ferromagnetic materials, and air-tissue interfaces present at the skull base due to the air-filled paranasal sinuses (Somasundraram & Kalavathi, 2012; Vargas et al., 2009). Flow artefact is also a common type of artefact produced on high field MRI scanners as a result of fluid movement such as blood or cerebrospinal (CSF). This artefact appears on MRI brain scans particularly in the posterior fossa, due to the increased blood flow magnetisation (Scarabino et al., 2017). Spike-noise artefacts, radio-frequency (RF) interference artefacts, central dot artefacts, Gibbs ringing, and chemical shift artefacts, can still be found

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on images acquired from 1.5T units but are among the artefacts produced in MRI which are more aggravated and may be more conspicuous on 3T imaging (Bernstein et al., 2006).

There seems to be conflicting arguments in the literature on the use of high (3T) vs low (1.5T) field MRI for brain imaging. While high field units have a better image quality, they are inferior in demonstrating the base of the skull due to their higher susceptibility to artefacts in this area justifying further research on the topic.

This research aimed to investigate if there was a statistically significant difference in the image quality of MRI brain scans produced with a 1.5T and 3T scanners, found in a state general hospital in Malta, through the use of a novel approach.

2. Methods

An MRI brain examination database was compiled for image quality review. Images were randomly selected from patient MRI examinations of adult patients (males and females) in the age range of 18 to 65 years and with the diagnostic report having no significant abnormalities, in order not to obscure anatomical structures. Twenty (20) MRI brain scans (10 on a 1.5T scanner and 10 on a 3T scanner), were included in this study. The selection of the sample size was based on the number of images in each sequence (n=2), the number of examinations (n=20) and the time (5 minutes) taken for the radiologists to review the examinations (2 sequences x approx. 30 images = 60 images per patient x 20 patients = 1200 images).

The two groups were matched based on the patients' ages as shown in table 1. Research indicates that the contrast between GM and WM changes with age (Tymianski, 2013) therefore, patients were categorised into 5 age groups due to anatomical changes which occur at different ages. Each age group was matched on the two scanners i.e. an equal number of patients were scanned on each scanner for the different age groups. The MRI scans were performed on a General Electric (GE) SIGNA Explorer Lift 1.5T and a Philips 3T Ingenia scanner.

Age-groups	Frequency of patient scans		Percentage
	1.5T scanner	3T scanner	
25 – 29	1	1	10%
30 – 39	2	2	20%
40 – 49	4	4	40%
50 – 59	2	2	20%
60 – 65	1	1	10%

Table 1: Frequency of scans of patients on both scanners for each age-group.

These brain scans were all acquired using the local protocol for routine brain imaging, which includes an axial 3DT1W, axial T2W, axial FLAIR, axial diffusion weighted imaging (DWI) and sagittal T2W sequences.

This research consisted of two phases whereby both objective and subjective image quality were evaluated. In phase 1 data related to objective image quality was collected. In phase 2 data related to subjective image quality was collected.

2.1. Phase 1: Objective image quality data collection

Phase one consisted of measuring the SNR and the CNR, of each sequence of every brain scan included in this study. To calculate the SNR and CNR, three regions of interest (ROIs) were placed on each brain scan. All ROIs were of the same size (area=10mm$_2$) and placed in the same position on all scans to reduce variation (Mavroidis et al., 2017). An MRI radiographer acting as an intermediary person performed the objective evaluation in a room and on a monitor used for diagnostic reporting. The ROIs were placed on the same slice for each examination, on a slice which clearly distinguishes between grey matter

(GM) and white matter (WM). This slice was the one at the level of the caudate nucleus for both axial and sagittal sequences, specifically on the anterior left region of the brain. Two ROIs were each placed on the GM and WM to record the mean signal intensity (SI) from the two areas (SI_{GM} and SI_{WM}). Another ROI was placed on the background noise to record the standard deviation from that area (SD_{AIR}), as shown in Figure 1. For consistency, the ROIs, the SNR and CNR were calculated as follows (Magnotta & Friedman, 2006; Rosen et al., 2018):

SNR = mean SIGM/mean SDAIR

CNR = [mean SI_{GM} – mean SI_{WM}]/SD_{AIR}

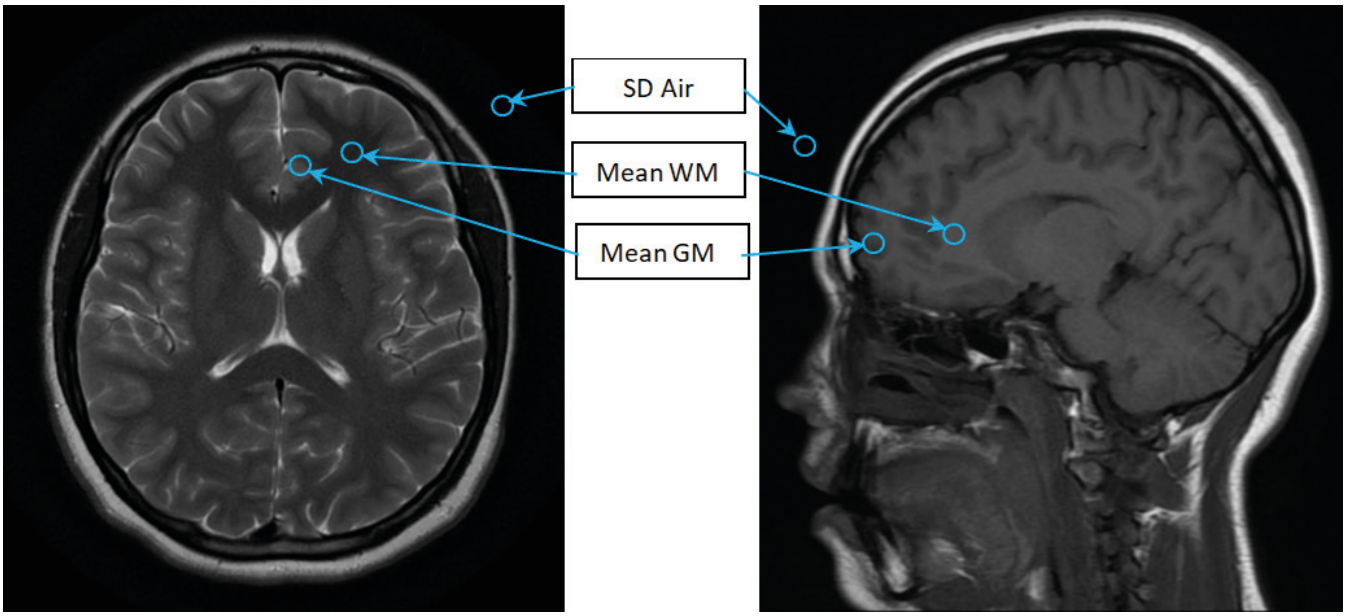

Figure 1: Location of the ROIs from where measurements were taken from GM and WM areas to calculate SNR and CNR. Axial T2W (left) and Sagittal T1W (right) brain MRI scans adapted from Gaillard (2020).

2.2. Phase 2: Subjective image quality data collection

Phase two consisted of a rating tool divided into two sections to review scans based on their quality using the software programme ViewDex (Sweden) (Håkansson et al., 2010). The first section consisted of grading anatomical structures using visual grading analysis (VGA) (Ludewig et al., 2010), whilst the second section assessed for the presence of artefacts.

Image review was performed by two radiologists independently selected through purposive sampling, with a minimum experience of 2 years in reporting MRI scans at the hospital where the study was conducted. Image review was performed in the radiologist's office where they usually perform image reporting. Based on the results obtained in phase one of the study, for phase two, only sequences which had significantly different SNR and CNR values between the two scanners were included. The scans were presented to the radiologists in a random and anonymised format. Furthermore, they were unaware of which scanner was used for each case and were blinded from each other's responses.

The first section of the rating tool consisted of a list of six (6) brain anatomical criteria as presented in European guidelines on quality criteria for CT (European Commission, 1999), since equivalent guidelines on image quality criteria for MRI are not yet established. Establishment of MRI anatomical criteria may contain a more exhaustive list of anatomical structures given the better contrast resolution of MRI over CT. The anatomical criteria were graded using a Likert scale from 1-5, where a score of 1 indicates that the radiologist is *'confident that the criterion is not fulfilled'* and a score of 5 indicates that the radiologists is *'confident that the criterion is fulfilled'* (Ludewig et al., 2010). The images were presented on ViewDex alongside the first section of the rating tool (Figure 2).

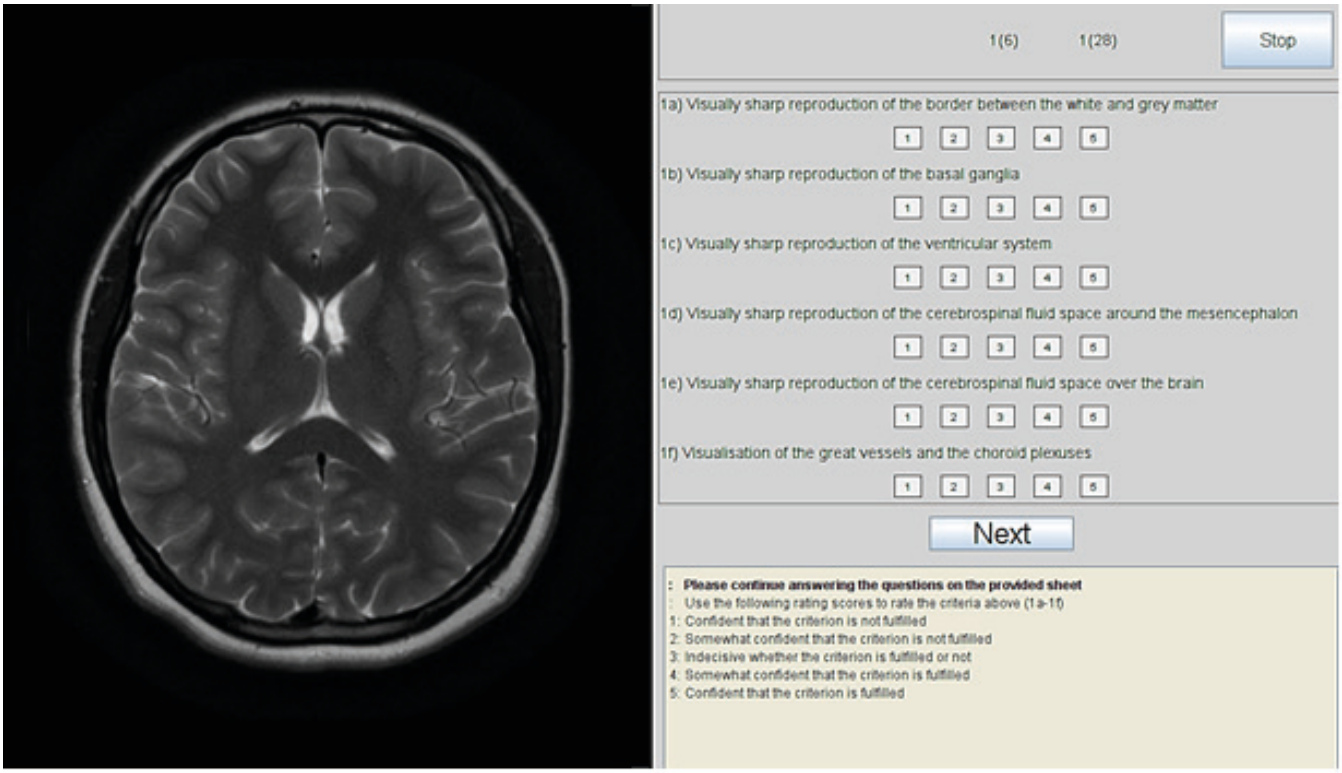

Figure 2: ViewDex software setup. The setup consisted of the MRI scan and the rating tool (Gaillard, 2020).

Furthermore, on a separate sheet, the radiologists were presented with the second section of the rating tool. The radiologists were asked to rate the presence of artefacts in each anatomical criterion, derived from the same CT quality criteria guidelines, with a yes, maybe or no answer.

2.3. Ethical consideration

Prior to commencement of this research, approval from the Faculty Research Ethics Committee (FREC) and the University Research Ethics Committee (UREC) was obtained (Ref 5531_3006202). All the data collected in this research were presented to the researcher in an anonymised format by intermediary persons. Additionally, participants were still asked to give written consent to participate in the study.

2.4. Data analysis

Data analysis was performed using IBM SPSS© version 27 and results with a p-value <0.05 were considered as statistically significant. Reliability for phase one was tested through inter-rater reliability by having two intermediaries collecting the data from the same three cases independently, using the intraclass correlation coefficient (ICC). All ICCs obtained were close to 1, each with a p-value <0.05 indicating satisfactory reliability. Reliability for phase two was tested through intra-rater reliability by duplicating three scans within the set of scans provided to the radiologists, and inter-rater reliability was tested by comparing the radiologists' responses. The Kendall's Tau test was then used to evaluate variables with an ordinal scale while the Kappa test was used to evaluate variables with a nominal scale. The p-values obtained for all tests performed were <0.05, thus indicating satisfactory reliability.

For phase one, normality testing using the Shapiro-Wilk test was performed which showed a normal distribution, therefore the independent sample T-test was used to analyse the data (Kim, 2019).

For phase two, the first section of the rating tool was analysed by plotting visual grading characteristic (VGC) curves based on the frequency of scores obtained from the VGA (Eng & Morgan, 2017). The VGC curves were plotted in the form of graphs, where the X (1.5T) and Y (3T) axis present the image quality of the 2 different groups being compared. The area under the curve (AUC) was obtained to measure the difference in image quality between

the scans acquired by the two different scanners. An AUC<0.5 indicated that images presented on the *x*-axis (1.5T) have a superior image quality compared to those presented on the *y*-axis (3T). An AUC>0.5 indicates that images presented on the *x*-axis (1.5T) have an inferior image quality compared to those presented on the *y*-axis (3T). An AUC of 0.5 indicates that the image quality of both groups of images being compared is equivalent. The second section of the rating tool was analysed using the Chi-square test to determine whether there was a correlation between the amount of artefacts and the two different types of scanners used (McHugh, 2013).

3. Results

3.1. Phase 1: Objective image quality results

Table 2 presents the SNR data analysis for each sequence for both MR units. The Axial T2W, FLAIR and Sagittal T2W sequences had a significantly higher magnitude for the 3T scanner ($p<0.05$). However, the increase in the mean SNR value was not statistically significant for the 3DT1W and DWI sequences ($p>0.05$).

Sequence	Scanner	Sample size	Mean SNR value	Std. Deviation	p-value
3DT1W	1.5T 3T	10 10	584.95 556.34	99.23 143.15	0.610
Axial T2W	1.5T 3T	10 10	167.65 359.81	12.98 65.15	<0.001
FLAIR	1.5T 3T	10 10	95.23 323.46	7.05 75.68	<0.001
DWI	1.5T 3T	10 10	255.00 289.36	90.42 63.45	0.338
Sagittal T2W	1.5T 3T	10 10	177.99 327.66	12.37 81.46	<0.001

Table 2: Data analysis of the SNR for each sequence

Table 3 presents the CNR data analysis for each sequence for both MR units. The mean CNR for the 3DT1W, Axial T2W and FLAIR sequences were significantly different between the two scanners ($p<0.05$). However, the difference was not statistically significant for the DWI and Sagittal T2W sequences ($p>0.05$). Negative CNR values were obtained for the 3DT1W sequence.

Sequence	Scanner	Sample size	Mean CNR value	Std. Deviation	p-value
3DT1W	**1.5T**	**10**	**-246.12**	**33.19**	**<0.001**
	3T	**10**	**-619.21**	**167.78**	
Axial T2W	1.5T	10	60.69	10.21	<0.001
	3T	10	143.47	33.87	
FLAIR	**1.5T**	**10**	**29.66**	**5.35**	**<0.001**
	3T	**10**	**107.61**	**33.46**	
DWI	**1.5T**	**10**	**87.55**	**41.16**	**0.265**
	3T	**10**	**105.69**	**28.13**	
Sagittal T2W	**1.5T**	**10**	**57.34**	**11.22**	**0.464**
	3T	**10**	**65.66**	**33.33**	

Table 3: Data analysis of the CNR for each sequence

The Axial T2W and FLAIR sequences were the only two sequences with a significant difference in both the SNR and CNR values. Therefore, these were then the sequences included in phase two of the study.

3.2. Phase 2: Subjective image quality results

Table 4 presents the subjective image quality results in terms of AUC values obtained in the first section of the image scoring tool. The AUC values for the axial T2W and FLAIR sequences, for both radiologists as well as for those of each radiologist were obtained. Figures 3 and 4 present the VGC curves for the Axial T2W and FLAIR sequences respectively, for all radiologists.

Sequence	Radiologist	AUC value
Axial T2W	1	0.90
	2	0.58
	1 and 2 combined	0.74
FLAIR	1	0.71
	2	0.69
	1 and 2 combined	0.68

Table 4: AUC values of the 1.5T vs the 3T scanner, obtained from VGC curves.

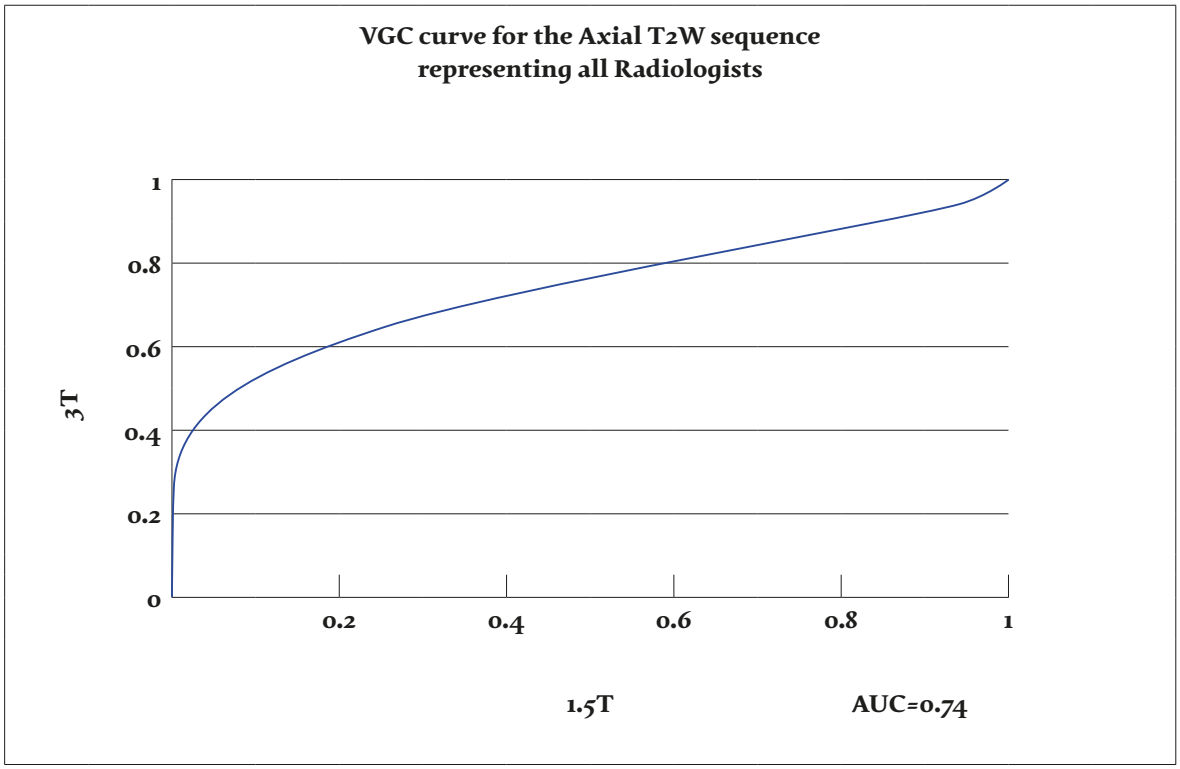

Figure 3: VGC curve for the Axial T2W sequence, representing the VGA for all radiologists.

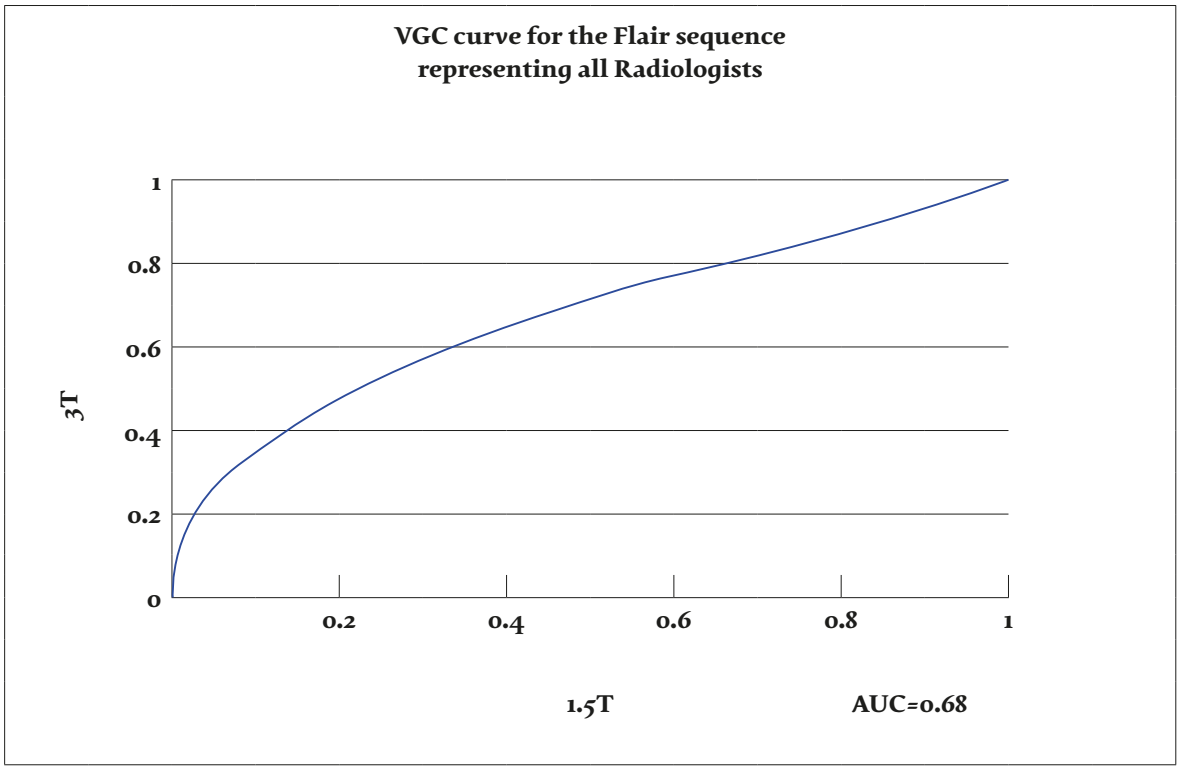

Figure 4: VGC curve for the FLAIR sequence, representing the VGA for all radiologists.

Table 5 presents the results obtained for the second section of the rating tool for the axial T2W sequence, for each radiologist. Radiologist 1 obtained p-values <0.05 when evaluating the 'border between the WM and GM' and the 'basal ganglia', therefore in these cases the potential increase in artefacts on the 1.5T scanner was found to be significant. No correlation was found between the number of artefacts and the scanner used to produce the scans for the remaining structures (p>0.05). Radiologist 2 did not note any artefacts in any of the scans.

Radiologist	Structure	Chi-Square Value	p-value	Maybe (%)		No (%)	
				1.5T	3T	1.5T	3T
Radiologist 1	Border between the white and grey matter	12.8	0.00	90	10	10	90
	Basal ganglia	7.5	0.006	70	10	30	90
	Ventricular system	<0.001	1.000	0	0	100	100
	CSF space around the mesencephalon	<0.001	1.000	20	20	80	80
	CSF space over the brain	<0.001	1.000	0	0	100	100
	Great vessels and the choroid plexuses	<0.001	1.000	0	0	100	100
Radiologist 2	Border between the white and grey matter	<0.001	1.000	0	100	0	100
	Basal ganglia	<0.001	1.000	0	100	0	100
	Ventricular system	<0.001	1.000	0	100	0	100
	CSF space around the mesencephalon	<0.001	1.000	0	100	0	100
	CSF space over the brain	<0.001	1.000	0	100	0	100
	Great vessels and the choroid plexuses	<0.001	1.000	0	100	0	100

Table 5: Summary of the results of the Chi-Square test obtained for the Axial T2W sequence.

Table 6 presents the results obtained for the second section of the rating tool for the FLAIR sequence for each radiologist. No correlation was found between the presence of artefacts and the scanner used to acquire the scan in all structures assessed (p>0.05), for the FLAIR sequence.

Radiologist	Structure	Chi-Square Value	p-value	Maybe (%)		No (%)	
				1.5T	3T	1.5T	3T
Radiologist 1	Border between the white and grey matter	3.333	0.068	60	20	40	80
	Basal ganglia	0.952	0.329	40	20	60	80
	Ventricular system	<0.001	1.000	0	0	100	100
	CSF space around the mesencephalon	<0.001	1.000	10	10	90	90
	CSF space over the brain	0.305	1.053	0	10	100	90
	Great vessels and the choroid plexuses	<0.001	1.000	0	0	100	100
Radiologist 2	Border between the white and grey matter	<0.001	1.000	0	100	0	100
	Basal ganglia	<0.001	1.000	0	100	0	100
	Ventricular system	<0.001	1.000	0	100	0	100
	CSF space around the mesencephalon	<0.001	1.000	0	100	0	100
	CSF space over the brain	<0.001	1.000	0	100	0	100
	Great vessels and the choroid plexuses	<0.001	1.000	0	100	0	100

Table 6: Summary of the results of the Chi-Square test obtained for the FLAIR sequence.

Discussion

Phase one results indicate that the calculated SNR and CNR values were higher on scans obtained with the 3T scanner when compared to those obtained with the 1.5T scanner for all sequences, with the exception of CNR on the 3DT1W sequence (Table 3). These results complement the majority of the reviewed literature, which indicated that with higher field strengths both the SNR and CNR increase (Grover et al., 2015; Lu et al., 2005; Wardlaw et al., 2012). Furthermore, this increase was not the same for all sequences. In fact, this variance was not always statistically significant. Research also indicated that for different areas, the increase in SNR and CNR is not always the same (Scarabino et al., 2017).

CNR values obtained for the 3DT1W sequence were negative. Results indicated that on T1W sequences contrary to T2W scans, SI from GM was lower than that of WM possibly due to GM appearing hypointense when compared to WM (Khan et al., 2019). As the CNR formula requires the mean SI from WM to be subtracted from that of GM, negative values were obtained for the 3DT1W sequence. No literature was found discussing such negative CNR values.

Results from phase 2 indicate that for the first section of the rating tool (VGA), the image quality of scans produced on the 3T scanner were of superior quality when compared to those produced by the 1.5T scanner. This result was in line with phase 1 results and with the majority of the findings found in the literature, however other studies reviewed included more sequences and abnormal brain scans (Springer et al., 2016; Wardlaw et al., 2012). Results also indicated that for the Axial T2W and Axial FLAIR, objective and subjective data were in agreement (Tables 4-8).

Since both objective and subjective image quality evaluation findings indicate a higher/better quality images obtained on the higher tesla unit, brain MRI examinations should ideally be performed on the 3T

unit. However, if patients had already been examined on the 1.5T unit, future follow up scans ideally should be performed on the same scanner for comparison purposes. This would facilitate image evaluation and comparison of results over time, by potentially providing less variations related to scanning. Variations over time would then be attributed to anatomical or pathological changes aiding patient diagnosis. Variations are unlikely to be attributed to the characteristics of the different patients within the groups as the size of the adult skull does not vary significantly between individuals.

For the second section of the rating tool, radiologist 1, indicated that artefacts were more common on scans produced by the 1.5T scanner, but this correlation was not statistically significant. Moreover, this radiologist never confirmed any of the artefacts noted as being certain. Phal et al., (2008), and Mellerio et al., (2014), also indicated that artefacts were more common on scans produced with 1.5T scanners, yet the brain scans reviewed in these studies included pathologies (Mellerio et al., 2014; Phal et al., 2008) which could have also mimicked artifacts. These findings are not in alignment with several other studies found in the literature which state that the increase of the magnetic field strength generates more artefacts. These inconsistencies may be caused by several factors such as the experience of the reporting radiologist, and the higher field strength being more sensitive to artefact formation(Grover et al., 2015; Springer et al., 2016; Vujmilović et al., 2016; Wardlaw et al., 2012).

This research provided a novel approach to assess the image quality of MRI brain scans subjectively. The majority of the reviewed literature took into consideration the amount of blurring present on the brain scans in general (Mavroidis et al., 2017; Springer et al., 2016; Wrede et al., 2014). Yet, in this research, image quality of MRI brain scans was performed through VGA which was based on anatomical criteria derived from established guidelines; 'European guidelines on quality criteria for CT' (Rosen et al., 2018). Currently, international guidelines which discuss the quality criteria for brain MR scans do not exist, thus CT based guidelines were used and were validated by two experts accordingly.

Limitations

The limitations encountered in this study were:

Radiologists were asked to rate the presence of artefacts on only 2 of the sequences acquired and the artefacts were only assessed in the areas described by the VGA template. Artefacts in other VGA areas were not assessed and therefore were not recorded as present. In addition to this, the exclusion of the 3DT1W and DWI from VGA assessment due to comparable SNR and CNR means that artefacts on these sequences were also not assessed. It is recognised that echo-planar imaging (EPI) sequences used for DWI imaging, which are sensitive to infarcts, produce more susceptibility artefacts in the region of the skull base on 3T. However, these artefacts were not assessed and may therefore have an impact in the interpretation and diagnosis of certain pathologies such as infarcts in the cerebellum found in the base of the skull.

The need to use CT guidelines. MRI demonstrates greater soft tissue detail so if MRI specific guidelines existed, more anatomical criteria would have been potentially included (Khan et al., 2019).

The sample size of the brain scans included was not representative of the accessible population, however the sample of patients included was homogenous.

Each patient was not scanned twice on each scanner, as this was not possible due to ethical reasons. Instead, scans of patients with similar age ranges and without any significant abnormalities on their scan were included.

The 2 scanners included in this study were of different manufacturers having different inherent factors. However, this study aimed to replicate the local scenario.

Only two radiologists were included to review the images due to the limited amount of resources. However, the radiologists with the most experience in brain MRI reporting were involved in this research.

Only 2 sequences were evaluated by the radiologists. The brain protocol is made up of more than these 2 sequences. Ideally all sequences should have been evaluated by the radiologist as this would provide a more complete evaluation and comparison of the quality of the brain examinations performed on the different field strengths. However, due to time constraints this was limited to only those 2 sequences which provided a significant variation in image quality based on the objective image quality evaluation in phase 1.

Conclusions

From this study, it can be concluded that there are differences in the image quality of MRI brain scans acquired by these 2 types of scanners. Since the patient groups were age matched, variations in patient characteristics were controlled and therefore variations in image quality are attributed to the scanner type. Thus, it is recommended that all patients requiring an MRI for the first time, should be scanned on the 3T unit since this produces better image quality. However, patients requiring a follow-up should be scanned on the same scanner that was used for their initial brain scan. Additionally, the methodology used in this study to evaluate the MRI brain images subjectively involved an innovative approach, not found within reviewed literature. Future research should be undertaken focusing further on this aspect of MRI scanning, in order to try and establish MRI anatomical criteria for assessing brain images.

Conflict of interest statement

None.

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