Original article

EVALUATION OF IMAGE QUALITY AND ACQUISITION TIME IN ADULT BRAIN MAGNETIC RESONANCE IMAGING USING 1.5 TESLA: A SINGLE CENTRE STUDY

Authors: U. S. Yahaya[1], I. Garba[1], M. Abba[1], M.A Suwaid[2]

[1]Department of Medical Radiography, Faculty of Allied Health Sciences, College of Health Sciences, Bayero University Kano, Nigeria

[2]Department of Radiology, Faculty of Clinical Sciences, College of Health Sciences, Bayero University Kano, Nigeria

Corresponding Author: U.S.Yahaya. Email:usmansaniyahaya@gmail.com. telephone: +2348161337824

ABSTRACT

Context: Brain Magnetic Resonance Imaging (MRI) has relatively more sequences and a longer image acquisition time which are challenging factors that affect image quality, and require evaluation for optimisation.

Aim: The study established baseline scan acquisition time and image quality of the adult brain MRI on a 1.5T scanner to determine whether there is a need for optimisation.

Methods: The study prospectively evaluated male and female adult brain MRI images of consenting patients at a local MRI centre in Nigeria. It focused on axial T1 and T2 weighted, and Fluid Attenuation Inversion Recovery (FLAIR) sequences. Image quality was quantitatively assessed using the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR), and qualitatively using Visual Grading Analysis (VGA) by four observers with over 5 years of experience. The image acquisition time for each patient was recorded and data were analyzed using VGA and SPSS version 25.

Results: Images of 100 adult patients for brain MRI were evaluated. The result showed that quantitatively T1W had the highest SNR for grey matter (51.58) and white matter (40.16) whilst, T2W had the

highest CNR (9.23). Qualitatively, T2W had the highest VGA score of 4.75. The FLAIR sequence had the lowest image quality both qualitatively and quantitatively. The T1W sequence had the longest scan time of 5:38 mins, whilst T2W had the least acquisition time of 2:43 mins.

Conclusion: The result showed that T2W had better CNR and VGA scores than T1W and FLAIR. The T1W sequence had better SNR over T2W and FLAIR, with a relatively longer acquisition time requiring optimisation.

Keywords: Acquisition time, Brain, CNR, Image quality, MRI

INTRODUCTION

Magnetic Resonance Imaging (MRI) is a noninvasive imaging system that provides excellent brain soft tissue contrast images with high-resolution anatomical details for medical diagnosis and clinical research.[1,2]. Advances in MRI technologies have resulted in detecting brain abnormalities, such as tumours, aneurysms, and subclinical vascular pathologic changes. [2] Compared to Computed Tomography (CT) imaging, MRI involves no ionising radiation and better image quality with increased tissue contrast [3], especially for the brain due to the presence of the surrounding cerebrospinal fluid.[4]. The MRI sequences such as T1 and T2 weighted and Fluid Attenuation Inverted Recovery (FLAIR) are commonly performed in routine brain imaging [5], and axial sequences allow for reproducible image acquisition and comparison.[2,6]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 known as weighting that determines image quality.[6]

The image quality of the MRI scanner is described by many key performance parameters such as spatial resolution, contrast resolution, and noise.[6] In addition, image quality is affected by the image acquisition time, storage, transmission, processing, and analysis [6]. These factors adversely affect the image's quality and the perceptibility of its details, which could lead to misdiagnosis.[7] The image acquisition time is the most challenging factor limiting MRI effectiveness in all patients who are likely to move and require sedation.[8] Most often, the routine practice requires a reduction in the scan time, especially for motion-inclined patients or patients with time-critical diseases such as dementia, multiple sclerosis, and Parkinsonism.[9]

Our facility which is equipped with a 1.5T MRI scanner has brain examinations as one of the most commonly performed procedures. However, to our knowledge, no study evaluated image quality and acquisition time for the adult brain MRI examination to determine the scanner performance. Therefore, this study evaluated image quality and acquisition time of adult brain MRI based on the axial T1, T2 and FLAIR sequences to establish the baseline practice for possible optimisation.

Materials and methods

This was a prospective study conducted on consented adult patients who presented for brain MRI at NSIA Kano Diagnostic Centre (NKDC) located at Aminu Kano Teaching Hospital Kano State in Nigeria from April 2020 to July 2023. Ethical approval was sought and obtained from the research and ethics committee with reference number NHREC/28/01/2020/AKTH/EC/3293.

The procedure was performed using a Siemens 1.5T MAGNETOM-ESSENZA equipped with a 16-channel head coil. The scanner had a Syngo MR E11 software version and was manufactured in Shenyang, China in the year 2016, and installed in December 2019 at the study centre.

Following consent and filling of the MRI questionnaire, patients were asked to lie supine on the scanner table with head first into the scanner. The patient`s head was positioned in a dedicated 16-channel head coil. The head was adjusted using form pads and positioned with the aid of the positioning laser lights within the iso-centre of the scanner. The axial light was centred at the inter-pupillary line, coronal light was centred at the external auditory canal and sagittal light aligned with the mid-sagittal plane. The patient was strapped for safety and immobilization. The localizer images were acquired in three different planes axial, coronal, and sagittal. The local routine MRI protocols for the brain were T1-weighted (T1W) image, T2-weighted (T2W) image, and T2-FLAIR. The brain images were acquired in different planes axial, sagittal and coronal. However, only axial images for T1W, T2W and FLAIR were considered in this study for reproducible image acquisition and comparison. For each patient, the following demographic information such as age, weight and gender was recorded. For each axial sequence, the following information echo time (TE), repetition time (TR), phase matrix, slice thickness, net acquisition time, and number of signal averages (NSA) were recorded.

Qualitative Image Quality Evaluation

The MRI images obtained were independently and blindly graded qualitatively by four observers: two board-certified radiologists and two qualified radiographers with > 5 years post-qualification experience. The

images were evaluated based on the visibility of the established anatomical criteria for brain images by the European guidelines on image quality criteria presented in Table 1 [10]. Each anatomical criterion was evaluated using a 5-point rating scale as presented in Table 1.

Table 1: Established **b**rain Anatomical **c**riteria graded on a 5-point Likert-type scale by allocating a score of 1 to 5.

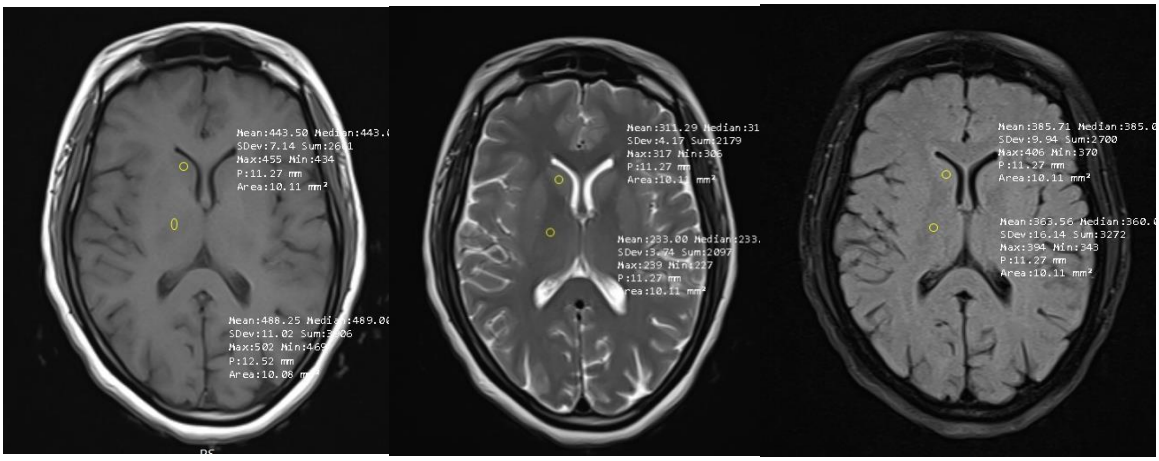
S/N	Anatomical criteria	
1	Visually sharp reproduction of the border between white and grey matter.	
2	Visually sharp reproduction of the basal ganglia.	
3	Visually sharp reproduction of the ventricular system.	
4	Visually sharp reproduction of the cerebrospinal fluid around the mesencephalon.	
5	Visually sharp reproduction of the cerebrospinal fluid over the brain.	
Grading scale score		
1	Poor	Confident that the criterion is not fulfilled.
2	Restricted	Somewhat confident that the criterion is not fulfilled.
3	Sufficient	Indecisive whether the criterion is fulfilled or not
4	Good	Somewhat confident that the criterion is fulfilled
5	Excellent	Confident that the criterion is fulfilled.

Quantitative Image Quality Evaluation

The quantitative image quality evaluation was performed by the researcher based on the measurement of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). The SNR was calculated to quantify the signal in an image to the background noise [11]. Furthermore, CNR was calculated to evaluate physical image quality characteristics based on the contrast of relevant structures. From the axial T1W, T2W, and FLAIR, images were selected at the level of the caudate nucleus[11,12] as presented in Figure 1. The caudate nucleus was selected for easy location and consistency of measurement between the different scan protocols. Also, the caudate nucleus is located in the cerebrum which is the largest portion of the brain and contains areas of both grey and white matter [6]. Image quality for the brain parenchyma is based on grey and white matter differentiation [13,14]. Region of interest (ROI) measurement for the

grey matter was performed at the caudate nucleus which is adjacent to the anterior horn of the lateral ventricles. ROI measurement for the white matter was performed at the posterior internal capsule which is located adjacent to the thalamus. At each location, three different measurements were taken to ensure accuracy and consistency. ROI of 10 mm^2 was used for the measurement of both grey and white matter to fit the selected structural area to ensure consistency during analysis [6]. The ROI was carefully positioned on the area of interest to avoid including adjacent tissues that would cause partial volume artifact [6]. The mean and standard deviation (SD) of each ROI were recorded. The noise was considered as the SD of each ROI [15]. SNR was calculated for each ROI as follows: $/\sigma, S$ is the mean ROI and σ is SD. Meanwhile, CNR for each of the sequences T1W, T2W, and FLAIR was calculated as $\frac{WHITE\ MATTER_{SD} - GREY\ MATTER_{SD}}{GREY\ MATTER\ SD}$ [15]

.



T1W **T2W** **FLAIR**

Figure 1: ROI placement at the level of the caudate nucleus and internal capsule

Data analysis

The data were analysed using the Statistical Package for Social Science (SPSS) version 22.0 software manufactured by the international business machine corporation company

(IBM) in 2015 in New York, USA. For the single observer, intra-rater reliability was assessed using the intra-class correlation coefficient (ICC) and was noted to be 0.981 which indicated a perfect consistency. For the multiple observers, inter-rater reliability was calculated using the statistical kappa (κ). A value of 0.66 was obtained which indicated a moderate consistency. The data were checked for normality and were found to be normally distributed. Therefore, mean and standard deviation (S.D) were calculated for the acquisition time, SNR and CNR. In addition, a One-way Analysis of Variance (ANOVA) was performed to compare scan time, SNR and CNR between sequences. Rating scores from the four observers were analysed using the Visual Grading Analysis (VGA) [12] method and were compared between observers and sequences using Kruskal Wallis as the scores were in an ordinal scale and required a non-parametric tool.

Results

A total of 100 patients were included in this study with a mean age and Standard Deviation (SD) of 35.41±14.16 years. Similarly, the patients had a weight range of 44-98 kg with a mean of 67.92 ± 12.36 kg. The gender distribution was 43% and 57% for males and females respectively.

Scanning parameters related to T1W, T2W, and FLAIR are presented in Table 2. All the sequences had the same slice thickness and matrix size. However, the number of signal average (NSA), echo time (TE), and repetition time (TR) differed between sequences.

Table 2: Scan parameters for axial T1W, T2W and FLAIR sequences

Scan parameter	T1W	T2W	FLAIR
Slice thickness (mm)	5.0	5.0	5.0
NSA	1.0	4.0	1.0
TE	8.9	70	78
TR	448	3240	3390
Phase Matrix	81.25	81.25	81.25

Quantitative image quality analysis

The images were evaluated quantitatively based on SNR for both the grey matter (GM) and white matter (WM). The CNR value was also calculated and presented in Table 3. The result showed SNR for GM and WM for axial T1W, T2W, and FLAIR sequences. The T1W had the highest value of SNR for GM, followed by T2W and FLAIR. Significant differences ($p<0.05$) in SNR for GM were noted between the three sequences. Similarly, T1W had the highest SNR for WM followed by T2W and FLAIR. However, the difference was not significant ($p>0.05$) between T2W and FLAIR (Table 3). In terms of CNR, T2W had the highest value followed by T1W and FLAIR. There was no significant difference between T1W and FLAIR. However, there were significant differences ($p<0.05$) between T2W and T1W, and also T2W and FLAIR (Table 3).

Table 3: Quantitative image quality comparison for SNR and CNR in T1W, T2W and FLAIR using ANOVA

Image quality parameter	Sequences (mean of image quality assessment)		P-Value
SNR_g	T1W (51.58)	T2W (28.37)	0.001
		FLAIR (19.99)	0.001
	T2W (28.37)	T1W (51.58)	0.001
		FLAIR (19.99)	0.001
	FLAIR (19.99)	T1W (51.58)	0.001
		T2W (28.37)	0.001
SNR_w	T1W (40.16)	T2W (28.36)	0.001
		FLAIR (27.31)	0.001
	T2W (28.36)	T1W (40.16)	0.001
		FLAIR (27.31)	0.670
	FLAIR (27.31)	T1W (40.16)	0.001
		T2W (28.36)	0.670
CNR	T1W (3.83)	T2W (9.23)	0.001
		FLAIR (4.63)	0.590
	T2W (9.23)	T1W (3.83)	0.001
		FLAIR (4.63)	0.001
	FLAIR (4.63)	T1W (3.83)	0.590
		T2W (9.23)	0.001

Qualitative image quality analysis using VGA

Four observers independently evaluated the images as presented in Table 4. Observer 1 had the highest score for T1W and T2W, whilst observer-2 had the lowest score for all the sequences. All sequences had a score > 4 except T1W and FLAIR for observer 2. Observer 1 recorded the highest score of 5 in T2W.

Table 4: Average VGA scores for each observer for T1W, T2W and FLAIR

Observers	**VGA score of sequences**		
	T1W	T2W	FLAIR
Observer 1	4.952	5	4.9
Observer 2	3.824	4.49	3.928
Observer 3	4.894	4.946	4.936
Observer 4	4.294	4.546	3.98
Total Observer	4.491	4.746	4.436

Table 5 shows the VGA scores of the different criteria. All criteria had a rating score of > 4 except criterion 2 in FLAIR with a score of < 4.

Table 5: Average VGA scores for each criterion for T1W, T2W and FLAIR

Criteria	**VGA scores of sequences**		
	T1W	**T2W**	**FLAIR**
Criterion1	4.50	4.63	4.06
Criterion 2	4.05	4.58	3.84
Criterion 3	4.61	4.84	4.72
Criterion 4	4.60	4.78	4.77
Criterion 5	4.69	4.91	4.81
Overall Criterion	4.49	4.75	4.44

Table 6 shows the VGA scores comparison between T1W, T2W, and FLAIR based on Kruskal Wallis. The T2W sequence had the highest image quality score and, it was significantly different from the score of other sequences. However, there was no significant difference in VGA scores between T1W and FLAIR.

Table 6: Comparison of mean VGA scores between T1W, T2W and FLAIR using Kruskal Wallis

VGA comparison between sequences		P-Value
T1W (4.49)	T2W (4.75)	0.001
	FLAIR (4.44)	0.211
T2W (4.75)	T1W (4.49)	0.001
	FLAIR (4.44)	0.001
FLAIR (4.44)	T1W (4.49)	0.211
	T2W (4.75)	0.001

Table 7 shows the acquisition time for TW1, TW2 & FLAIR. The acquisition time is presented in minutes and seconds. The T1W image had a relatively longer scan time compared to T2W and FLAIR.

Table 7: Acquisition time for T1W, T2W and FLAIR.

SEQUENCE	Acquisition time in minutes and seconds
T1W	5:38
T2W	2:44
FLAIR	2:43

Table 8 shows comparisons of acquisition time using ANOVA between T1W, T2W, and FLAIR. A significant difference in scan time between T2W and FLAIR was noted. However, T1W had the longest acquisition time and significantly differed from other sequences.

Table 8: Acquisition time comparison between TIW, T2W, and FLAIR using ANOVA

Sequences (acquisition time)		P-Value
T1W (5.38)	T2W (2.44)	0.004
	FLAIR (2.43)	0.004
T2W (2.44)	T1W (5.38)	0.004
	FLAIR (2.43)	0.988

FLAIR (2.43)	T1W (5.38)	0.004
	T2W (2.44)	0.988

Discussion

The study evaluated image quality and acquisition time in adult brain MRI using a 1.5T scanner. Quantitative image quality evaluation based on SNR and CNR showed that T1W images had higher SNR for both grey and white matter compared to T2W and FLAIR images (Table 3). The finding was consistent with the results obtained from a study on image quality assessment in brain MRI taken with 1.5T and 3T scanners conducted by Borg et al.[6]. The authors reported that SNR for both grey and white matters was significantly higher in the T1W technique. However, the difference in SNR between grey and white matters in the remaining sequences T2W and FLAIR was not significant in the present study. Similarly, in a study on MRI and techniques by Westbrook et al. [16] it was reported that SNR for both the grey and white matter was significantly better in T1W compared to FLAIR and T2W. The reason for higher SNR in T1W may likely be due to a longer acquisition time compared to other sequences in the current study (Table 6). The longer the scan time the better the image quality, however, with a longer scan time, there could be a possibility of motion that affects image quality [17]. It is therefore important to trade off between scan time and image quality to produce images of diagnostic quality.

Although SNR for the grey and white matter was higher in T1W in the present study, TW2 had the highest CNR and showed superior image quality (Table 3). The result aligns with that of Springer et al. [18] who conducted a study that compared brain images using 3T and 7T. The authors also reported higher CNR in TW2. Similar to this study, Borg et al. [6] also reported lower CNR in TW1 compared to TW2 and FLAIR. As reported by Borg et al. [6], the likely reason for lower CNR in TW1 could be due to GM appearing hypointense and therefore given a negative CNR value for TW1. A possible reason for correcting this limitation could be by increasing NEX, however, this may come at the expense of an increase in scan time. [16]

Visual grading analysis is a scientific method of analysing observers' scores based on the visibility of the anatomical criteria graded using a Likert scale [19]. Overall results from the four observers showed superior image quality for T2W

as the anatomical structures were more appreciated compared to TW1 and FLAIR (Table 6). The most visible criterion was criterion 5 which is the visualization of the sharp reproduction of CSF over the brain, whereas, criterion 2 which is the reproduction of the basal ganglia was the least visible (Table 6). The results of the present study differed somewhat from those described by Borg et al. [6] who reported criterion 1 as the most visible. The possible reason for these differences is likely due to the differences in scanner type.

In the present study, all the anatomical criteria were more visible in T2W sequences. The FLAIR sequence had lower VGA scores compared to T1W and T2W (Tables 5 and 6). Similarly, a study by Burmeister et al. [13] also stated that T2W tends to have high tissue contrast compared to other sequences T1W and FLAIR. This is due to the surrounding cerebrospinal fluid around the brain tissue which produces a high signal.

Similar studies have reported the use of one or two observers in image quality assessment [21-24]. Borg et al. [6] reported that part of their study limitations was the use of two raters due to limited resources. Further, a study by Wardlaw et al. [24], had reported that the more the raters the stronger the assessment as bias could be reduced. The present study had four observers who independently assessed image quality. This could be a plus as an increase in the number of raters could improve the credibility of the image quality assessment and should be encouraged.

In the present study, T1W sequences recorded longer acquisition time, followed by T2W and FLAIR respectively (Table 7). This finding is in agreement with the study conducted by Mellerior et al. [25] who studied image quality in patients using both 1.5T and 3T MRI scanners. The authors reported that 3DT1W had the highest scan time. However, in a study by Prakkamakul et al. [26] it was reported that the FLAIR sequence had a longer scan time followed by T1W and the least was T2W. This finding was contrary to the findings of the current study that reported T1W as having a longer scan time. Prakkamakul et al. [26] reported that the increase in scan time in FLAIR is related to the use of higher reputation time and a wider field of view (FOV) compared to other

sequences. The likely reason for the difference in findings of this study and that of Prakkamakul et al. [26] could be attributed to the scanner model and type, type of coil used, and MR scanning parameters selection.

In the current study, both the quantitative and qualitative image quality assessment methods showed T2W having superior image quality. This fact is supported by Burmeister et al. [13] who reported that the T2W technique is preferred due to its ability to generate high contrast as a result of the presence of fluid around the brain and capability to produce an improved appearance of the enhancing structures.

Limitations of the study

The study used anatomical criteria developed for CT images. The ideal study design would have been anatomical criteria for MRI, however, these criteria do not exist. The MRI criteria could possess greater image quality involving soft tissue details, therefore providing more anatomical criteria that could be visualised and contribute to image quality. The study is specific to the brain. Findings can only be applied to the brain MRI using 1.5T. There is a need to establish image quality and acquisition time for other procedures such as paediatric brain, and spine. The image quality evaluation was based on normal anatomical structures. The observers were not asked to evaluate or comment on any form of artefact or pathology present. There is a need to include pathological images, as the procedure performed includes patients having both normal and pathologic conditions. Only three (3) sequences TW1, T2W and FLAIR were evaluated. The brain protocol has more than three sequences, all sequences need to be evaluated for complete and robust image quality evaluation. The study involved a single centre with 1.5T, There is a need for more centres including those equipped with low-field strength MRI scanners such as 0.3T. The study involved subjective image quality evaluations based on VGA. The VGA analysis made several assumptions such as considering the ordered qualitative variable (ordinal scale) as an interval scale [14]. For this reason, the mathematical and statistical validity of the VGA score may not be appropriate as reported by Burmeister et al. [13]. It is recommended, that VGC and VGR[12,20]

should be further employed to complement the VGA analysis in subsequent research. The result of this study can only be generalised and limited to brain MRI protocols using a Siemens 1.5T MRI scanner because different manufacturers have different inherent image quality factors.

Conclusion

It is concluded that the T2W sequence had superior CNR and the highest VGA score over T1W and FLAIR. The T1W sequence had superior SNR over T2W and FLAIR, also with relatively longer acquisition time which requires optimisation, especially for unstable patients.

References

1. Y. Luo, J. Ling, Y. Gong, and J. Long, "A cosparse analysis model with combined redundant systems for MRI reconstruction," *Med. Phys.*, vol. 47, no. 2, pp. 457–466, 2020, doi: 10.1002/mp.13931.
2. R. B. Kamble, "Magnetic resonance imaging brain sequences in pediatrics," *Karnataka Pediatr. J.*, vol. 36, no. 1, pp. 27–34, 2021, doi: 10.25259/kpj_32_2020.
3. K. H. Ryu *et al.*, "Initial clinical experience of synthetic MRI as a routine neuroimaging protocol in daily practice: A single-center study," *J. Neuroradiol.*, vol. 47, no. 2, pp. 151–160, 2020, doi: 10.1016/j.neurad.2019.03.002.
4. M. W. Vernooij *et al.*, "Incidental Findings on Brain MRI in the General Population," *N. Engl. J. Med.*, vol. 357, no. 18, pp. 1821–1828, 2007, doi: 10.1056/nejmoa070972.
5. E. Lavdas *et al.*, "Common and Uncommon Artifacts in T1 FLAIR SAG Sequences of MRI Brain," *Curr. Probl. Diagn. Radiol.*, vol. 50, no. 1, pp. 59–65, 2021, doi: 10.1067/j.cpradiol.2019.08.001.
6. M. Osadebey, M. Pedersen, D. Arnold, and K. Wendel-mitoraj, "Image Quality Evaluation in Clinical Research : A Case Study on Brain and Cardiac MRI Images in Multi-Center Clinical Trials," *IEEE J. Transl. Eng. Heal. Med.*, vol. 6, no. February, pp. 1–15, 2018, doi: 10.1109/JTEHM.2018.2855213.
7. K. Lei, J. M. Pauly, and S. S. Vasanawala, "Artifact- and content-specific quality assessment for MRI with image rulers," 2021, [Online]. Available: http://arxiv.org/abs/2111.03780
8. S. Mohammed and M. Abubakar, "Evaluation of MRI artifact in some selected centers in Kano metropolis, Nigeria," *Afr. Health Sci.*, vol. 20, no. 4, pp. 1831–1839, 2020, doi: 10.4314/ahs.v20i4.38.
9. J. Y. Ha, H. J. Baek, and K. H. Ryu, "With Full Basic Sequences : Can It Be a Promising Way Forward for," *Am. J. Roentgenol.*, vol. 215, no. July, pp. 1–8, 2020.
10. F. Machado-Rivas, C. Jaimes, J. E. Kirsch, and M. S. Gee, "Image-quality optimization and artifact reduction in fetal magnetic resonance imaging," *Pediatr. Radiol.*, vol. 50, no. 13, pp. 1830–1838, 2020, doi: 10.1007/s00247-020-04672-7.
11. L. Borg, F. Zarb, and K. B. Grima, "Assessing the image quality of brain magnetic resonance images taken with 1 . 5T and 3T scanners," pp. 32–43, 2022, doi: 10.14614/BRAINMRI/10/22.
12. H. P. Burmeister *et al.*, "Visual Grading Characteristics (VGC) Analysis of Diagnostic Image Quality for High Resolution 3 Tesla MRI Volumetry of the Olfactory Bulb," *Acad. Radiol.*, vol. 18, no. 5, pp. 634–639, 2011,

doi: 10.1016/j.acra.2010.12.011.

13. V. A. Magnotta and L. Friedman, "Measurement of signal-to-noise and contrast-to-noise in the fBIRN multicenter imaging study," *J. Digit. Imaging*, vol. 19, no. 2, pp. 140–147, 2006, doi: 10.1007/s10278-006-0264-x.

14. R. E. Hendrick, "Signal, Noise, Signal-to-Noise, and Contrast-to-Noise Ratios," *Breast MRI*, pp. 93–111, 2008, doi: 10.1007/978-0-387-73507-8_7.

15. C. Pallier, "Signal-to-noise ratios in MRI Why you might care ?," 2015.

16. V. P. B. Grover, J. M. Tognarelli, M. M. E. Crossey, I. J. Cox, S. D. Taylor-Robinson, and M. J. W. Mcphail, "Magnetic Resonance Imaging: Principles and Techniques: Lessons for Clinicians," *J. Clin. Exp. Hepatol.*, vol. 5, no. 3, pp. 246–255, 2015, doi: 10.1016/j.jceh.2015.08.001.

17. J. M. Wardlaw *et al.*, "A systematic review of the utility of 1 . 5 versus 3 Tesla magnetic resonance brain imaging in clinical practice and research," pp. 2295–2303, 2012, doi: 10.1007/s00330-012-2500-8.

18. E. Springer, B. Dymerska, and P. L. Cardoso, *Europe PMC Funders Group Comparison of Routine Brain Imaging at 3 T and 7 T*, vol. 51, no. 8. 2017. doi: 10.1097/RLI.0000000000000256. Comparison.

19. C. Westbrook, C. K. Roth, and J. Talbot, *MRI in Practice Fourth Edition*, Fourth. Blackwell publishing Ltd, 2011.

20. E. Ludewig, A. Richter, and M. Frame, "Diagnostic imaging – evaluating image quality using visual grading characteristic (VGC) analysis," pp. 473–479, 2010, doi: 10.1007/s11259-010-9413-2.

21. A. D. Gilmore, N. J. Buser, and J. L. Hanson, "Variations in structural MRI quality significantly impact commonly used measures of brain anatomy," *Brain Informatics*, vol. 8, no. 1, 2021, doi: 10.1186/s40708-021-00128-2.

22. H. Lu, L. M. Nagae-poetscher, X. Golay, D. Lin, M. Pomper, and P. C. M. Van Zijl, "Routine Clinical Brain MRI Sequences for Use at 3 . 0 Tesla," vol. 22, pp. 13–22, 2005, doi: 10.1002/jmri.20356.

23. L. Lunden *et al.*, "MRI in patients with implanted active devices: how to combine safety and image quality using a limited transmission field?," *Eur. Radiol.*, vol. 30, no. 5, pp. 2571–2582, 2020, doi: 10.1007/s00330-019-06599-6.

24. S. Vujmilović, S. Vujnović, V. K. Dragosavljević, and Z. Vujković, "Patient ' s Comfort and Technical Quality Exams at," pp. 264–274, 2016, doi: 10.4236/ojrad.2016.64035.

25. C. Mellerio *et al.*, "3T MRI improves the detection of transmantle sign in type 2 focal cortical dysplasia," pp. 117–122, 2014, doi: 10.1111/epi.12464.

26. S. Prakkamakul *et al.*, "Ultrafast Brain MRI: Clinical Deployment and Comparison to Conventional Brain MRI at 3T," *J. Neuroimaging*, vol. 26, no. 5, pp. 503–510, 2016, doi: 10.1111/jon.12365.