ORIGINAL RESEARCH PAPER

Radiology

Three Magnets in a Row: Comparing Image Quality, Signal-to-Noise Ratio, and Contrast-to-Noise Ratio between 3T, 1.5T, and 1T MRI Scanners

KEY WORDS: Magnetic resonance imaging; Signal-to-noise ratio; Contrast-to-noise ratio; image quality.

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ABSTRACT

This study is aimed at comparing the signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and image quality between three MRI scanners of increasing field strength (1T, 1.5T, and 3T) in a typical clinical setting. MRI of the brain was performed on 59 healthy participants (female 34) on the three scanners. Double blind method was used to present the images to three neuroradiologists. Image quality and amount of artifact were scored. SNR and CNR were calculated. 1T and 3T resulted in higher SNR than the 1.5T. There was a significant difference in all values of SNR across scanners ($p < 0.0001$). CNR differed significantly between 1T and the other scanners ($p < 0.001$). There was no significant difference in CNR between the 1.5T and 3T. Although the 3T produced better image quality of the three scanners, the difference in image interpretation of the healthy population by the radiologists' was comparable across scanners.

Introduction

Magnetic resonance imaging (MRI) at higher field strength provides improved signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR), offering better image quality that entails higher diagnostic accuracy. MRI at higher field strength has many advantages, including improved visualization, sensitivity, and spatial definition. In MRI, the intrinsic SNR increases approximately linearly with an increase in the main magnetic field strength. This increase in SNR is applied to improve spatial resolution or reduce scan time (Moseley, Liu, Rodriguez, & Brosnan, 2009). However, in practice, the actual SNR achievable is less than the intrinsic SNR gained due to hardware limitations such as magnetic field inhomogeneities, thermal noise from radio frequency coils, or nonlinearity of signal amplitude. Other issues affecting SNR include factors associated with image processing or patient-related factors resulting from respiration or motion. Operating at higher field strength involves more challenges, including increased specific absorption rates (SAR), increased acoustic noise and greater safety screening, as well as increased cost of the equipment and its maintenance and operation.

Practical differences in diagnostic imaging technologies, such as the category of imaging sequence and implementation of phased array coils or increasing the number of channels in coil design, can increase image accuracy. Therefore, it is difficult to identify the best imaging method and the field strength to use. The procurement planning and equipment utilization must comply with the clinical need and services provided in healthcare facilities (Wardlaw et al., 2012).

The aim of this study is to investigate the effect of magnetic field strength on image quality in healthy volunteers in a typical clinical setting. This study compares the utilization of three MRI scanners (1T open, 1.5T, and 3T). These scanners are of equal technology generation. The study evaluates image SNR, CNR and also assesses the theoretical increase of SNR with increasing field strength.

Materials and Methods

This study was conducted at the Radiology Department, King Abdulaziz University Hospital (KAUH), Jeddah, Saudi Arabia.

Participants

Healthy Adults (aged 18 – 99 years) with no history of neurological or cardiological disorders were asked to participate. Participants included were categorized into four groups: A (18 – 29 years), B (30 – 39 years), C (40 – 49 years), and D (< 50 years). Participants were scanned once on all three MRI systems on separate appointments. The local Bioethics Committee at KAUH granted the approval for this study, and all the participants gave their consent to participate in this study.

MR Data Acquisition

The MRI scanners used were: (i) 1T open magnet system (Panorama 1T open MR system- Philips Medical Systems, the Netherlands). (ii) 1.5T closed magnet system (MAGNETOM Symphony 1.5 T, Siemens, Germany). (iii) 3T closed magnet system (MAGNETOM Verio 3T, Siemens, Germany). Brain MR images were acquired using spin echo T1-weighted and double turbo spin echo T2-weighted sequences with similar parameters (Table 1). An effort was made to maintain identical scanning conditions between all fields of strength; scanners were located in the same building, on the same floor, across from one another, in identical humidity and temperature conditions.

Table 1. MRI Scanner Acquisition Parameters

MRI System	Sequence[1]	TR (msec)	TE (msec)	Band width	Acquisition time (min:sec)	Number of channels
3T	T1	450	15	201	3:56	12
	T2	2070	163	250	2:54	
1.5T	T1	450	15	201	3:56	12
	T2	2070	159	250	2:54	
1T	T1	611	15	153	5:05	2
	T2	2075	172	357	4:42	

[1] For all sequences: 22 axial slices were acquired, with slice thickness = 5 mm, distance factor = 6 mm, FOV = 230 x 230 mm^2, acquisition matrix size = 256 × 256.

Image Assessment

Three double-blinded board-certified neuroradiologist observers (Reader 1, Reader 2, and Reader 3) scored the quality of images and the conspicuity of artifacts. All data relating to participant identity, date of scan, sequence parameters, and magnet identity were removed and the images were presented to each observer in a random order via the PACS viewer (IDS7, Sectra Systems, Sweden). Ten structures in all axial brain images were scored

(Figure 1). The structures evaluated, at the level of the ganglionic structures, include caudate (C) lobe, lentiform (L) nucleus, internal capsule (IC), insula (I), and the six segments of the middle cerebral artery (MCA): sphenoidal segment (M1), insular segment (M2), opercular segment (M3), cortical segment (M4), lateral MCA territory (M5), and posterior MCA territory (M6). Additional evaluation of the gray-white matter interface in the supra-ganglionic level was carried out. A score (between 0 – 3) was assigned to each reading point depending on the visualization quality (no visualization, poor visualization, visualization, to excellent visualization, respectively). The amount of artifacts caused either by motion, magnetic susceptibility or flow was evaluated and assigned a score (between 0 – 2) as (absent, present or severe).

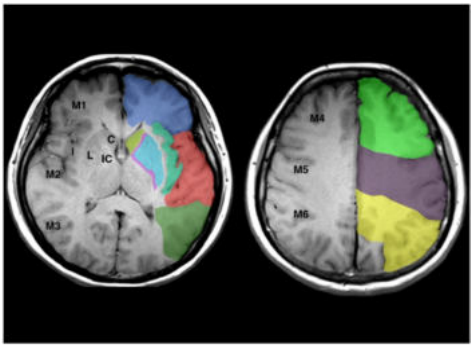

Figure 1. Brain Structures objectively assessed were divided based on vascular distribution.

[Images acquired on 3T system, Siemens, Germany]

Quantitative Evaluation

SNR was measured for gray and white matter separately. Four regions of interest (ROI) were placed on the image using the PACS software: two circular ROI were placed on the gray and white matter around the Sylvian fissure, and two ROIs were placed on the background air pixels. The diameters of the ROI on the brain parenchyma were based on the anatomy. The ROI diameter in air was about 2 cm. SNR was calculated using the formula previously described (Firbank, Coulthard, Harrison, & Williams, 1999).

$SNR_{single} = 0.655 \times (S/SD_{air})$

where S is the mean signal in the large circular region of gray/white matter and SDair is the average of the standard deviation in the two smaller regions placed in air. CNR was determined from the difference in SNR between gray and white matter (Orbach et al., 2006).

Statistical Analysis

Friedman test was used to compare the readings of the three radiologists. One-way repeated measure of ANOVA was used to compare the mean reading scores of the three radiologists and investigate variability. Cronbach's alpha was calculated for internal consistency between radiologists. Analysis was done using SPSS version 20.0.

Results

Participants

Of the 68 participants recruited, only 59 (87%) were included due to the availability of their complete data and MRI scans on all scanners. The study population consisted of 34 (58%) female. The mean age was 36.7 ± 10.8 years, with age ranging 18 – 62 years. Participant numbers in each age group: A (17), B (17), C (16), and D (9).

SNR and CNR

Table 2 lists the range of SNR for gray matter (GM) and white matter (WM) and CNR values across the magnets. Table 3 shows the comparison of SNR and CNR across the magnets. Both the 1T open and the 3T resulted in higher SNR than the 1.5T scanner (Figure 2). There was a significant difference in all values of SNR across scanners. CNR differed significantly between the 1T open and both the 1.5T and 3T scanners. There was no significant difference in CNR between the 1.5T and 3T scanners (Figure 2).

Table 2. SNR and CNR Ranges

	SNR-GM		**SNR-WM**		**CNR**	
	Range	**SD**	**Range**	**SD**	**Range**	**SD**
1T	12.09 – 83.02	14.67	16.97 – 98.38	16.21	0.68 – 22.72	4.17
1.5T	8.52 – 36.83	5.32	2.96 – 44.06	6.89	0 – 15.62	2.26
3T	9.39 – 50.07	8.42	11.71 – 57.69	10.11	0.43 – 13.39	2.42

Table 3.Comparison of SNR and CNR

	SNR-GM		SNR-WM		CNR	
	Mean	SD	Mean	SD	Mean	SD
1 T	44.54	14.67	52.89	16.21	9.87	3.50
1.5 T	17.42	5.32	23.01	6.89	6.25	3.89
P-value	*< 0.0001*		*< 0.0001*		*< 0.006*	
1 T	44.54	14.67	52.89	16.21	9.87	3.50
3 T	26.03	8.42	31.28	10.11	5.01	1.10
P-value	*< 0.0001*		*< 0.000*		*< 0.0001*	
1.5 T	17.42	5.32	23.01	6.89	6.25	3.89
3 T	26.03	8.42	31.28	10.11	5.01	1.10
P-value	*< 0.0001*		*< 0.0001*		*< 0.020*	

Unpaired t-test

**Statistically significant values are italicized.*

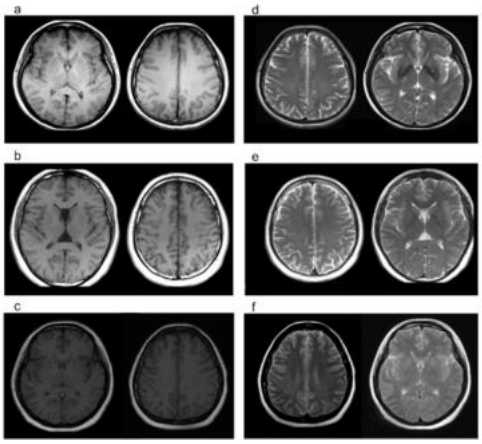

Figure 2. Representative T_1- and T_2-weighted images from 3T, 1.5T and 1T MRI systems. (a) T_1-weighted at 3T. (b) T_1-weighted at 1.5T. (c) T_1-weighted at 1T. (d) T_2-weighted at 3T. (e) T_2-weighted at 1.5T. (f) T_2-weighted at 1T.

Overall Image Quality

177 images were randomly assessed by the radiologists using the ten reading points (Table 4). There was a significant difference in mean score ranks in almost all of the reading points (p < 0.01). There was an inter-radiologists agreement, and the reliability was high (alpha = 0.97). Each reading point was scored from 0 to 3, and the total value represents the MRI score by each radiologist. All scores by the radiologists were normally distributed, and the mean scores for Reader 1, Reader 2 and Reader 3 were 19.4 ± 3.6, 19.8 ± 6.9, and 19.8 ± 6.9, respectively. The 3T scanner resulted in better image quality but with no significant difference in the reading scores by the radiologists.

Table 4. Comparing the ten reading points between the three radiologists average over

	Caudate lobe	Lentiform nucleus	Internal Capsule	Insula	M1	M2	M3	M4	M5	M6
Radiologist1	1.93	1.86	1.72	1.79	2.26	2.33	2.21	2.13	2.14	2.10
Radiologist2	2.10	2.14	2.19	2.41	1.87	1.80	2.11	2.19	2.17	2.17
Radiologist3	1.97	2.01	2.09	1.80	1.87	1.86	1.68	1.68	1.69	1.73
P-value[a]	0.053	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[a]Friedman test

The differences in MRI scores were studied in relationship to: age and gender of the participants, SNR, CNR, and magnetic field strength (Table 5). There was no significant correlation ($p > 0.05$) between the MRI score differences and any of these variables.

Table 5. Differences in MRI score and variable effects

Source		Type III Sum of Squares	Degree of freedom	Mean Square	P-value
MRI score		**28.262**	**2**	**14.131**	**0.302**
MRI score	* Age	8.021	2	4.010	0.711
	* Gender	66.925	2	33.462	0.060
	* SNR GM	0.396	2	0.198	0.983
	* SNR WM	3.339	2	1.669	0.868
	* CNR	39.285	2	19.642	0.190
	* Scanner	1.666	4	0.416	0.998

One-Way Repeated Measure ANOVA (Split-Plot Model)

Artifact related incidences due to motion, magnetic susceptibility, and flow, differed between radiologists ($p < 0.001$) (Table 6). No severe artifacts were present in any of the MR images. The response of the radiologists significantly ($p < 0.001$) differed relative to the presence of these artifacts.

Table 6. Artifact related incidences of the three radiologists ($p < 0.001$).

Artifacts	**Motion**		**Magnetic Susceptibility**		**Flow**	
	0	1	0	1	0	1
Radiologist1	131	43	162	12	67	105
Radiologist2	127	47	117	57	24	148
Radiologist3	149	25	173	1	171	1
P-value[a]	0.002		<0.001		<0.001	

a Cochran's Q

Discussion

Most studies comparing 3T with 1.5T in human neuroimaging (Bachmann et al., 2006; Chow et al., 2015; Chu et al., 2016; Foerster et al., 2012; Garcia et al., 2012; Guo et al., 2014; Ho et al., 2010; Kataoka et al., 2014; Krautmacher et al., 2005; Ladino et al., 2016; Perri et al., 2013; Phal et al., 2008; Sohn et al., 2010; Stobo, Lindsay, Connell, Dunn, & Forbes, 2011; Wardlaw et al., 2012) compared the older generation 1.5T with newer generation 3T systems. In order to eliminate these confounds, in our study, comparisons were made between 1T open, 1.5T and 3T scanners of equal technology generation. The overall image quality produced by the 3T scanner was the better of the three scanners. This is inline with many previous studies (Bachmann et al., 2006; Garcia et al., 2012; Krautmacher et al., 2005; Ladino et al., 2016; Phal et al., 2008; Stobo et al., 2011).

Any improvement in image quality has been attributed to the variances in the generation of MR magnet technology, sequences, coils or use of newer contrast agents (Wardlaw et al., 2012). In our study, the same sequences were implemented on all scanners. Due to hardware differences and different spin relaxation properties at the field strengths, the sequences were not perfectly identical on the three scanners. Nevertheless, sequences were optimized as much as possible to obtain similar T1 and T2 contrast on all scanners. Wardlaw et al. found that SNR and CNR improved at 3T, but it depended on the category of imaging sequence. When implementing the same sequences we found an increase in SNR at higher field strength. However, the 1T scanner provided the highest SNR. Wardlaw et al. revealed that the implementation of an eight-channel coil instead of a quadrature coil provided higher SNR compared to the higher field strength. Here we found that using 12 channel coils on both 1.5T and 3T scanners lead to higher SNR values at 3T. Wardlaw et al. stated that artifacts related to susceptibility and chemical shift were worse but did not affect diagnostic accuracy at 3T. In our study, artifacts related to motion, magnetic susceptibility and flow did not seem to affect diagnostic accuracy at the three magnetic field strengths.

In our study, the greatest value of SNR was produced by the lowest magnetic field (the Panorama 1T open magnet system), Table 3. This finding might seem contrary to what was previously stated. However, SNR is not only increased through an increase in the magnetic field alone. SNR can be increased through other measures such as the RF system, gradient system, and computer system, as well as the use of surface coils. Here we attribute the increase in SNR to the use of vertical field receive coils in the 1T open scanner. The coil elements of a vertical-field MR system enclose the subject, thus providing a higher filling factor producing a higher SNR.

Although we found 3T images to be comparatively sharper than the 1T open and 1.5T images, there is little evidence of improved diagnosis in these images. This is in accordance with many studies that have compared the diagnostic accuracy of 3T versus 1.5T MRI scanners in different neurological diseases (Chow et al., 2015; Chu et al., 2016; Foerster et al., 2012; Guo et al., 2014; Kataoka et al., 2014; Perri et al., 2013; Sohn et al., 2010; Stobo et al., 2011).

Improved SNR and CNR achievable at higher field strengths might not always be clinically relevant (Perri et al., 2013). We found that although the overall quality of images produced by the 3T scanner was the better of the three, this does not significantly change the image interpretation. From this we deduce that for an accomplished radiologist all three scanners may produce comparable results. We emphasize the vital role of radiologist experience in the interpretation of MR images. Yet as experience is a variable factor, the implementation of universal guidelines is an important issue to be taken into consideration by healthcare providers.

Some of the robust aspects of this study are the large population size, careful screening of participants, short inter-scan periods, identical scanning conditions, randomized scanner order per subject and the blinded analysis of the MRIs.

Our study was limited to imaging of the brain. All the results were based on 3 MRI scanners only (Philips Panorama 1T, Siemens Symphony 1.5T, and Siemens Verio 3T). Further research is needed on other scanners. The MR sequences were not perfectly identical.

In conclusion, this comparison between 1T open, 1.5T and 3T scanners in healthy individuals provides important information regarding diagnostic imaging. High field MRI scanners (3T) facilitate the production of improved quality images. However, this does not seem to significantly change the image interpretation. The inference that we draw from this is that, in the hands of an accomplished radiologist all three scanners possibly produce comparable results.

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