Radio-frequency coil selection for MR imaging of the carotid vessel wall

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Abstract. This aim of this study was to identify the radiofrequency coil that will produce optimum image quality for scanning the carotid vessel wall using magnetic resonance imaging. A comparative cross-sectional study was conducted using 10 volunteers. Each volunteer was scanned three times using a 1.5T Signa HDxt machine equipped with one of three different coils: a neurovascular array (NV) coil, an 8-channel CTL spine array coil, and a 3-inch surface coil. A qualitative image quality rating was assigned to each image. The images were also evaluated by measuring the signal to noise ratio (SNR) using Osirix 4.2.3 software. The noise was estimated from the mean intensities of the region of interest in the background of the images and the signal was measured in the muscle adjacent to the vessel wall. The SNRs of the three coils were compared using one-way ANOVA, with 104 images used for the data analysis. The mean image quality scores for the NV head coil, CTL coil, and 3-inch coil were 3.4, 3.33, and 1.67, respectively. In addition, the SNRs differed significantly (p < 0.05). The mean SNR for the 3-inch coil was significantly higher (56.21 ± 25.06) than those for the NV head coil (27.34 ± 15.47) and CTL coil (21.77 ± 13.14). The Bonferroni post-hoc test revealed that there was no significant difference between the NV head coil and the CTL coil (p = 0.21). The optimum SNR value was 20-27. These results indicate that the NV head coil and CTL coil can be used to evaluate the carotid arterial wall with optimum image quality and higher resolution. These coil can deliver fast and robust data to image the carotid vessel wall in vivo.

1. Introduction

High spatial resolution magnetic resonance imaging (MRI) is a promising technique for assessing carotid atherosclerosis because it allows direct visualization of the diseased vessel wall and can be used to characterize the morphology of individual atherosclerotic carotid plaques [1]. MRI has been used to the study the human carotid artery [2], to diagnose atherosclerosis [3, 4], and to measure atherosclerosis [5, 6, 7]. Different types of radiofrequency (RF) coils can be used in MRI machines. In past studies designed to image arteriosclerosis in the carotid artery, researchers have used phased array coils [3, 4], custom-built phased array coils [5, 8], phased array surface coils [6, 7, 9, 10], and a 3-inch surface coil [11].

The MRI machine and the type of coil used can affect image quality. For example, Anumula et al. 2005 [12] compared the signal to noise ratio (SNR) and image quality obtained using dual-element
phased array coils at 1.5 T and 3 T MRI machine. The mean SNRs for in vivo studies obtained at 3 T (17.6 ± 1.8 and 14.8 ± 2.7 for the left and right coils, respectively) differed from those at 1.5 T (8.6 ± 1.1 and 7.0 ± 1.0). The aim of this study was to identify the type of coil that will produce optimum image quality for scanning the carotid vessel wall. High quality images are crucial to diagnose arteriosclerosis and measuring the diameter of the artery.

2. Materials and Methods

2.1. Study population
Ten healthy volunteers (5 males and 5 females) ranging in age from 22 to 55 years old were recruited from the Advanced Medical and Dental Institute (AMDI) staff. The volunteers were asymptomatic with no history of stroke, hyperlipidemia, hypertension, or diabetes. Informed consent was obtained from all volunteers. The consent forms and the imaging protocols were approved by the Research Ethics Committee (Human), Universiti Sains Malaysia.

2.2. MRI examination
The volunteers were scanned using a Signa HDxt 1.5 T (GE Healthcare, Wisconsin, USA), and three different coils were tested: a neurovascular array (NV) coil (Invivo Corporation, Pawaukee, Wisconsin), a 3-inch surface coil (GE Medical Systems, Milwaukee, Wisconsin, USA), and an 8-channel CTL spine array coil (USA Instruments, Aurora, OH, USA). A 3D time-of-flight (TOF) sequence was used to identify the carotid bifurcation, and images were taken 1 cm above it. 2D fast spin echo (FSE) images with two contrast weightings (T1w and T2w) were obtained. The total length of the coverage was 80 mm. Table 1 summarizes the imaging parameters used in this study. Flow compensation was used to suppress flow artifacts. A double inversion recovery (IR) technique with cardiac gating was used to generate double IR proton density (PD) plaque images.

| Image parameters | TOF | T1w | T2w | Double IR PD Plaque |
|------------------|-----|-----|-----|---------------------|
| TR (ms)          | 16  | 400 | 3000| 1500                |
| TE (ms)          | 4   | 10  | 100 | 55                  |
| TI (ms)          | –   | –   | –   | Gated               |
| Thickness (mm)   | 2   | 4   | 4   | 4                   |
| Matrix           | 256 x 160 | 256 x 256 | 256 x 256 | 256 x 256 |
| NEX              | 1   | 4   | 4   | 4                   |
| FOV (cm)         | 16 x 16 | 16 x 16 | 16 x 16 | 16 x 16             |

Table 1: Imaging parameters.

*TR = Repetition time, TE = Echo time, TI = Inversion time, NEX = number of excitations, FOV = field of view.

2.3. Image evaluation
An image quality rating was assigned to each image following Zhang et al. [8]. Using their scale, the quality of each image from the three contrast weightings for every patient was evaluated by one reviewer. The images were excluded from the analysis due to motion artifacts if one or more of the two images (T1w and T2w) had a rating lower than three. The images also were evaluated quantitatively by measuring the SNR using Osirix 4.2.3 software (Figure 1). SNR is defined as the ratio of signal to image noise. The signal (S) was computed by drawing a region of interest (ROI) in the muscle adjacent to the
vessel wall. This location was chosen because the vessel wall was only 1.5 mm thick, thus the assessment of the vessel wall SNR was prone to errors [12]. The noise standard deviation (SD) measurement was computed from the background region of the image in an area free of any visible artifacts. The SNRs calculated for the three coils were compared using one-way ANOVA.

Figure 1: Axial image of the carotid arteries at approximately 1 cm distal to the carotid bifurcation in one subject. The signal was measured in the ROI, which was located in adjacent muscles. The noise level was measured by calculating the mean of the signal from four ROIs in the image background.

3. Results
Overall, 180 images were available for analysis. However, after qualitative analysis, 76 images with an image quality score less than 3 were excluded from the data review, leaving 104 images for SNR measurement. However, out of 104 images, the 3-inch coil was able to acquire only 16 usable images, whereas NV head coil and CTL coil were able to produce 44 usable images each. Figure 2 shows an example of good (A, B & C) and bad images with motion artifacts (D). Mean image quality scores for the NV head coil, CTL coil, and 3-inch coil were 3.4, 3.33, and 1.67 respectively. The mean SNR for the 3-inch coil (56.21 ± 25.06) was significantly higher (p < 0.05) than those for the NV head coil (27.34 ± 15.47) and CTL coil (21.77 ± 13.14). The Bonferroni post-hoc test revealed that there was no significant difference between the NV head coil and CTL coil (p = 0.21).
4. Discussions
Quality of MRI images of the carotid vessel is crucial for diagnosing arteriosclerosis and taking quantitative measurements of the carotid artery wall. The first step to achieve high quality images is to identify the most suitable coil for use in the MRI machine. Several factors can affect image quality, such as patient motion, including swallowing and respiration; distance of the carotid artery from the coil, especially in obese patients; and incomplete flow suppression [8]. The factors that affect the SNR include magnetic field strength of the system, proton density of the area under examination, voxel volume, repetition time (TR), echo time (TE), flip angle, and number of excitations (NEX) [13]. In this study, most of these factors were standardized so that we could focus on identifying the type of coil that provided the best images.

Figure 3 shows the SNR and image quality score in these three coils. Note that, although the SNR in 3-inch coil is significantly higher ($p < 0.05$) than NV head and CTL coil, image quality score in 3-inch coil is low compared to the other coils. This due to the SNR equation, as it written as $\text{SNR} = \frac{S}{\text{SD noise}}$. Thus, when the SD of the noise is low, the SNR will be high. In this study, the mean SD of noise for the 3-inch coil was $9.79 \pm 16.56$, whereas it was $52.26 \pm 23.44$ for the NV head coil and $46.30 \pm 22.14$ for the CTL coil. At first glance the low noise value for the 3-inch coil seems advantageous, but it was outweighed by poor image quality. The mean image quality score for the 3-inch coil was 1.67 compared...
to 3.4 for the NV head coil and 3.33 for the CTL coil. The poor quality was due to artifacts caused by subjects’ movement (figure 2), as they were not comfortable with the positioning required by 3-inch coil.

The subjects had to tilt their head when this coil was put in place, and they had to remain still until the imaging scan was completed, compared to normal supine position when the NV head coil and CTL coil were used, which made them comfortable during the scanning process. In fact, only 16 out of 60 images acquired using 3-inch coil is usable compared to 44 out of 60 images acquired using NV head and CTL coil are usable. A high SNR is commonly considered to be one of the major advantages of MRI. However, in this study, the optimum SNR was founded to be 20-27. This agreeable with Donald et al. (2007) that a SNR higher than 20 offers little in terms of improved image quality[14]. Thus, we can conclude that NV head with SNR of 27.34 ± 15.47 and CTL coils with SNR of 21.77 ± 13.14 can deliver optimum image quality to evaluate the carotid arterial wall for diagnosis of arteriosclerosis.

![Figure 3: SNR and image quality score.](image)

Furthermore, there are limitations of the 3-inch coil as it is not reproducible as only 1 out of 4 images will be usable, which is not practical in clinical setting. The acquisition of the coil is unilateral compared that bilateral in NV head and CTL coil. As a surface coil, this coil also only covers small area compared to NV head and CTL coil which are phase array coils. Due to carotid artery superficial location and length, it is also well suited for imaging using a phased array coil [15]. In addition, 3-inch coil also give less comfort to the patients. However, these results are preliminary and cannot be applied in a general case. A multi-centre study of adequate sample size would be required to implement these parameters in clinical settings.

5. Conclusion
In summary, the NV head coil and CTL coils can provide optimum image quality to evaluate the carotid arterial wall for diagnosis of arteriosclerosis. This coil can deliver fast, reproducible, and robust data and available in the most clinical setting.

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References
[1] Yuan C, Mitsumori LM, Beach KW, Maravilla KR 2001 Radiology 221 285–99.
[2] Hadley JR, Roberts JA, Goodrich KC, Buswell HR, Parker DL 2005 *Magn Reson Imaging* **23** 629–39.

[3] Corti R, Fayad ZA, Fuster V, Worthley SG, Helft G, Chesebro J, et al. 2001 *Circulation* **104** 249.

[4] Corti R, Fuster V, Fayad ZA, Worthley SG, Helft G, Smith D, et al. 2002. *Circulation* **106** 2884.

[5] Yuan C, Beach KW, Smith LH, Hatsukami TS 1998 *Circulation* **98** 2666–71.

[6] Kerwin W, Hooker A, Spilker M, Vicini P, Ferguson M, Hatsukami T, et al. 2003 *Circulation* **107** 851.

[7] Cai J, Hatsukami TS, Ferguson MS, Kerwin WS, Saam T, Chu B, et al. 2005 *Circulation* **112** 3437–44.

[8] Zhang S, Hatsukami TS, Polissar NL, Han C, Yuan C. 2001 *Magn Reson Imaging* **19** 795–802.

[9] Greenman RL, Wang X, Ngo L, Marquis RP, Farrar N. 2008 *Magn Reson Imaging* **26**:246–53.

[10] Saam T, Yuan C, Chu B, Takaya N, Underhill H, Cai J, et al. 2007 *Atherosclerosis* **194**.

[11] Wasserman BA, Smith WI, Trout HH, Cannon RO, Balaban RS, Arai AE. 2002 *Radiology* **223** 566–73.

[12] Anumula S, Song HK, Wright AC, Wehrli FW. 2005 *Acad Radiol* **12** 1521–6.

[13] Westbrook C. RCK & TJ 2005 *MRI in Practice 3rd Edition*. (United Kingdom: Blackwell Publishing)

[14] Donald W. M., Elizabeth A. M., Martin J. G. MRP 2007 *MRI from Picture to Proton* (New York, NY: Cambridge University Press)

[15] Quick HH, Debatin JF, Ladd ME. 2002 *Eur Radiol* **12** 889–900.