International Journal of Radiology Sciences
Online ISSN: 2664-9829, Print ISSN: 2664-9810
Received: 01-11-2018; Accepted: 03-12-2018; Published: 01-01-2019
www.radiologyjournals.com
Volume 1; Issue 1; 2019; Page No. 01-05

Comparison of carotid coils for cardiovascular imaging

Sonum Naidu[1], Michelle Campoli[2], Audrey Kaufman[3], Anoop Sahota[4], Renata Pyzik[5], Zahi Fayad[6], Venkatesh Mani[7]
[1-7] Translational and Molecular Imaging Institute, Icahn School of Medicine at Mount Sinai, Hess Center for Science and Medicine, 1470 Madison Avenue, New York, NY, United States

DOI: https://doi.org/10.33545/26649810.2019.v1.i1a.1

Abstract
Background: Carotid atherosclerosis is known to cause thrombosis, embolization and stroke. Identifying high-risk patients requires imaging that allows for disambiguation of arterial plaque components. Development of coils that produce images with superior signal to noise ratios (SNR) is of use to the field. The purpose of this study is to compare the performance of the Machnet® and Medlion® 4-channel phased array carotid coils qualitatively and quantitatively.
Methods: Ten volunteers underwent neck scans on a 3.0T Siemens Biograph mMR machine at the Icahn School of Medicine at Mount Sinai. Each subject was scanned without using contrast or medication with the Machnet® and Medlion® coils. Images were analyzed by two analysts blinded to coil configuration. Signal intensities in the tissue and background were used to calculate the signal-to-noise and contrast-to-noise ratios of the images. Values were compared using paired t-tests.
Both analysts qualitatively assigned the images a score of 1-5 (1 poor, 5 excellent) based on four criteria: overall image quality, vessel wall delineation, flow suppression, and artifacts. Scores were compared using a Kruskal Wallis test. Pearson correlation coefficients were calculated to determine the correlation between the quantitative and qualitative results.
Results: Comparisons of SNR and CNR values from the two coils were not statistically significant for the vessel wall, lumen and muscle SNRs, and the lumen-wall CNR, (p=0.8961, 0.1674, 0.7018 and 0.4454, respectively). Correlation coefficients were significant ($r > 0.67$, $p < 0.05$) for only the Medlion® coil when correlating the vessel wall SNR to qualitative scores of Overall Quality, Wall Delineation and Flow Suppression (r= 0.764, r=0.714, r=0.909), CNR to Overall Quality and Flow Suppression (r=0.686, r=0.883) and lumen SNR to Overall Quality, Wall Delineation and Flow Suppression (r=0.814, r=0.696, r=0.676). The same trends were not seen as strongly for the Machnet® coil.
Conclusion: The results suggest that imaging with the Medlion® coil provides images of comparable quality in terms of SNR, CNR and subjective analysis when compared with the Machnet® coil.

Keywords: Atherosclerosis, Carotid imaging, Phased-array surface coil, Signal-to-noise ratio, Contrast-to-noise ratio

Introduction

Magnetic resonance imaging is a well-established, safe, and noninvasive method for diagnosing and monitoring carotid atherosclerosis. Plaque buildup in these arteries causes thrombosis, embolization, and ultimately stroke, making it crucial to have an imaging method capable of both accurately depicting plaque stability and identifying high-risk patients [1]. Black blood magnetic resonance (MR) imaging, in particular, produces images with high soft tissue contrast that allow for better evaluation of the vessel wall and the features that define atherosclerotic plaques[2]. Such characteristics, like a lipid-rich necrotic core, calcification, or intraplaque hemorrhage [3], are important to identify as they influence the risk of thrombosis more heavily than the narrowing of the lumen itself [4].

Image quality and spatial resolution of MR scans are largely defined by the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) [5]. The SNR compares the level of desired signal to the level of background noise in the image, and is calculated by dividing the signal intensity in the tissue of interest by the standard deviation of the intensity outside of the patient's anatomy [2, 5]. The CNR, while similar, accounts for the difference in signal between two tissues rather than the raw image signal [6]. It can therefore be calculated by taking the quotient of the difference in intensity between two tissues of interest (i.e. the vessel wall and lumen) and the standard deviation of the background noise.

In addition to the SNR and CNR, images can also be evaluated qualitatively by an image analyst. Because atherosclerosis progresses relatively slowly, it is important that measurements of plaque morphology taken over time are not only precise, but also reproducible [2]. Thus, images should ideally have clear delineation of the vessel wall, sufficient flow suppression, and minimal artifacts, all of which are intertwined and would be expected to improve with increasing SNR and CNR. Lack of these criteria causes the vessel wall to be less distinguishable and can produce artifacts that mimic plaque [2] within the lumen, thereby limiting the analyst's ability to draw accurate conclusions.

The SNR can be improved by adjusting variables like the field of view, magnetic field strength (T), scan time, and other parameters that affect the level of background noise [6]. The use of radiofrequency (RF) coils is also key in imaging of the vessel wall because they act as receivers for the MR signal [4]. Because smaller coils tend to have higher sensitivity and lower penetration depth, combining the signal of multiple small surface coils collected into a larger phased array has proven to produce images with significantly higher SNR over a larger field of view [4, 7]. These advantages, combined with the superficial location of the carotid arteries [3, 4], make multi-channel phased array surface coils favorable for imaging and in-depth evaluation of carotid plaque composition despite its sub-millimeter size

[8].

There are still various limitations to achieving the ideal image quality for disambiguation of plaques in the carotids. For example, signal tends to drop with increasing depth below the skin, and artifacts appear around the carotid bifurcation due to complex blood flow patterns [2]. However, disease and plaque deposition frequently occur in this area, though both the location of plaque buildup and the bifurcation vary depending on the patient. This can make occasional repositioning of the coil during image acquisition necessary [9]. Multiple studies over time have thus aimed to design coils that can more fully cover regions of disease, optimize SNR and CNR, and achieve homogeneous signal throughout the target vessel [4]. Tate *et al*. constructed an experimental 16-channel phased array coil that did in fact produce images with superior SNR when compared to a commonly used 4-channel coil. However, the 4-channel coil was still favorable in terms of having the flexibility to be placed over the bifurcation in patients with varying anatomy [9].

The Machnet® 4-channel phased array carotid coil is FDA 510k approved, commercially available, and already widely used for imaging of the carotid arteries. Medlion® Inc. has also recently developed a 4-channel coil that has passed safety testing using procedures similar to those used for FDA 510k clearance. This new coil utilizes low impedance nanomaterial-based antenna technology that makes high speed and resolution imaging possible. Both coils provide similar anatomic coverage of the carotid arteries from the aortic arch through the circle of Willis, however, in phantom studies, the Medlion® experimental coil has been shown to provide images with improved SNR.

The purpose of this study was to compare the in vivo performance of the two coils through both qualitative and quantitative assessment of the obtained images. Both coils were tested at 3.0T with all other imaging parameters held constant.

Methods

Ten healthy volunteers over the age of 18 underwent imaging tests of the neck on a 3.0T Siemens Biograph mMR clinical scanner in the Hess Center at the Icahn School of Medicine at Mount Sinai. Subjects were scanned without using contrast or medication for 15 minutes using the Machnet® coil (Figure 1a) and for 15 minutes using the Medlion® coil (Figure 1b), with a 5-minute break in between. The scans acquired include: (i) Multiplane localizers, (ii) 3D time of flight (TOF) angiogram (iii) Axial T2 weighted spin echo and (iv) Isotropic 3D SPACE.

The axial SPACE images were analyzed using VesselMASS software (VesselMASS, Division of Image Processing, Department of Radiology, Leiden University Medical Center, Leiden, Netherlands) by two independent analysts blinded to coil configuration. The inner and outer walls of the left and right common carotid arteries were manually traced (Figure 2) up to the bifurcation, or lower if images were no longer analyzable, to extract the signal intensities of the wall and the lumen.

Contours were also drawn in the image background and the sternocleidomastoid muscle to calculate signal intensity in these regions, and the standard deviation of the background Signal was used as the noise level to calculate the SNR and CNR. Intensities generated by measurements performed only on slices analyzed by both analysts were averaged and used for calculations. The signal-to-noise ratios of the vessel wall to the image background, the lumen to image background and the muscle to background, as well as the lumen-wall contrast-to-noise ratio were calculated.

Images were then subjectively analyzed by both analysts based on four criteria: overall quality, vessel wall delineation, flow suppression, and presence of artifacts. A score of 1-5, 1 being poor and 5 being excellent, was assigned to each slice in both sets of images. Only scores assigned to the slices evaluated by both analysts were included in the analysis.

All data are presented as means and standard deviations. For quantitative analysis, SNR and CNR data were compared between the two coils using paired t-tests. For qualitative analysis, ordinal data were compared using a Kruskal Wallis test. Pearson correlation coefficients were used to determine the linear relationship between the qualitative and quantitative parameters

Fig 1: Coils used for imaging manufactured by a) Machnet® and b) Medlion® Inc.

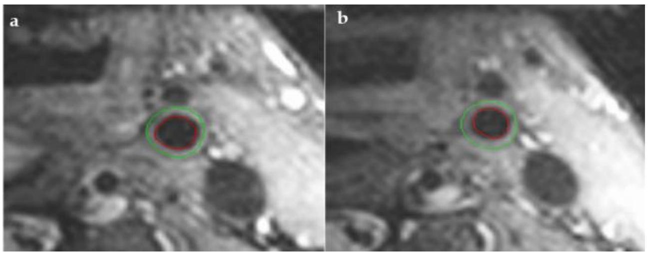

Fig 2: Analyst drawn contours using VesselMASS on images produced by the a) Machnet® coil and b) Medlion® coil

Results

All 10 patients underwent MR imaging, however, for the first patient, the quality of the images was not sufficient to be used for quantitative analysis due to motion artifacts. Therefore, only the images for patients 2 through 10 were analyzed quantitatively.

Quantitative Data

Table 1 and Figure 3 display the SNR and CNR values calculated using the signal in the image background, vessel lumen, vessel wall, and sternocleidomastoid muscle, averaged across the two analysts for all images. Also shown in the table are the results of the paired t-tests. All tests were conducted at a two-sided significance level of 0.05 in IBM SPSS Statistics (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.)

Table 1: Signal-to-Noise ratios and results of paired T-tests

Imaging Parameters	Machnet® Mean ± SD	Medlion® Mean ± SD	p-value
Vessel Wall SNR	17.28 ± 4.96	17.09 ± 4.09	0.8961
Lumen SNR	5.19 ± 1.10	5.82 ± 0.90	0.1674
Muscle SNR	49.77 ± 13.45	52.23 ± 9.89	0.7018
Lumen-Wall CNR	12.09 ± 3.98	11.28 ± 3.48	0.4454

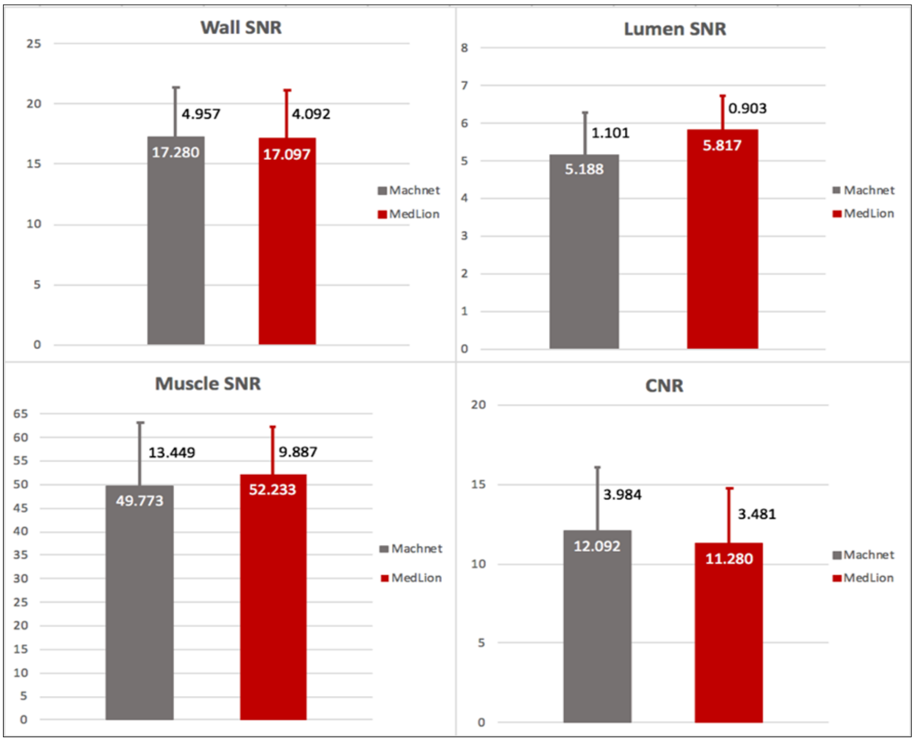

Fig 3: Signal-to-noise and contrast-to-noise ratios of images acquired with each coil

Qualitative Data

Qualitative measurements were based on the overall quality, clarity of the vessel wall, level of flow suppression and presence of artifacts observed during analysis. The scores assigned by both analysts were averaged for each patient's images. Table 2 and Figure 4 display the means and standard deviations of each coil's scores, as well as the results of the Kruskal Wallis test.

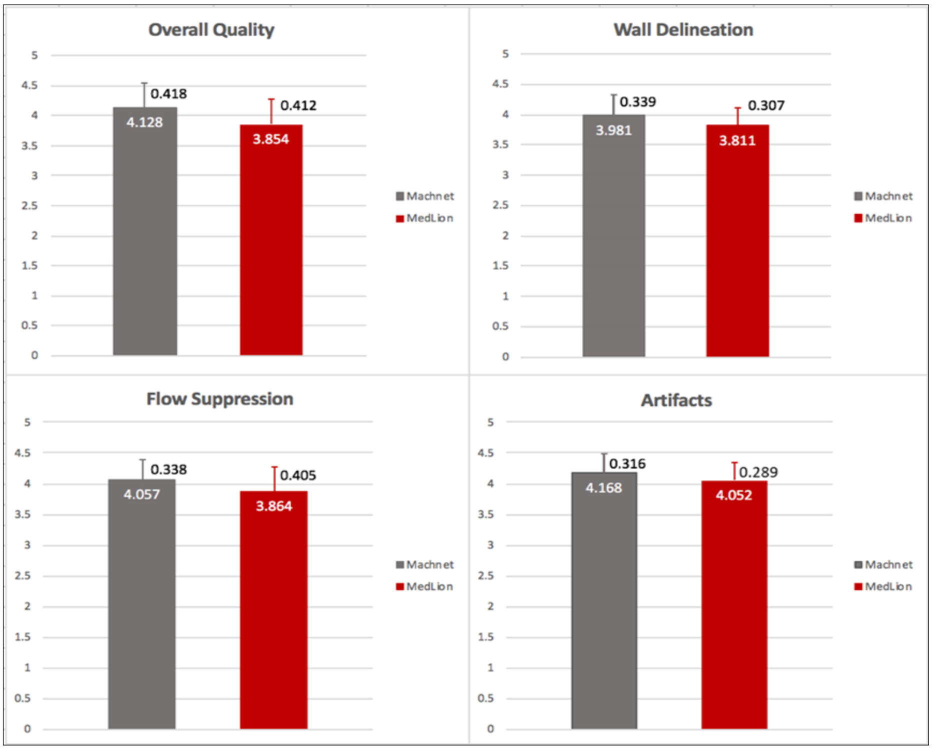

Fig 4: Subjective image quality scores assigned to images acquired with each coil

Table 2: Image quality scores and results of Kruskal Wallis Test

Criteria	Machnet® Mean ± SD	Medlion® Mean ± SD	p-value
Overall Quality	4.13 ± 0.42	3.85 ± 0.41	0.2002
Vessel Wall Delineation	3.98 ± 0.34	3.81 ± 0.31	0.4265
Level of Flow Suppression	4.06 ± 0.34	3.86 ± 0.41	0.2697
Presence of Artifacts	4.17± 0.32	4.05 ± 0.29	0.5961

Quantitative vs. Qualitative Parameters

Table 3 displays the Pearson correlation coefficients between quantitative measures and qualitative scores. The Medlion® coil in particular showed strong positive correlations between calculated SNR and CNRs and image quality scores ($r > 0.67$, $p < 0.05$).

Table 3: Pearson's Correlation Coefficients

Coil	Quantitative Measure	Qualitative Measure	r value	p value
Machnet®	Wall SNR	Overall Quality	0.3734	0.3222
		Wall Delineation	0.2944	0.4419
		Flow Suppression	0.5445	0.1298
		Artifacts	0.4429	0.2325
	Lumen SNR	Overall Quality	0.2909	0.4476
		Wall Delineation	0.2123	0.5834
		Flow Suppression	0.379	0.3144
		Artifacts	0.3935	0.2947
	Muscle SNR	Overall Quality	0.1584	0.6840
		Wall Delineation	0.167	0.6676
		Flow Suppression	0.0566	0.8850
		Artifacts	0.0141	0.9713
	Lumen-Wall CNR	Overall Quality	0.3842	0.3073
		Wall Delineation	0.3076	0.4207
		Flow Suppression	0.5840	0.0987
		Artifacts	0.4451	0.2299
Medlion®	Wall SNR	Overall Quality	0.764	0.0165
		Wall Delineation	0.7138	0.0308
		Flow Suppression	0.9091	0.0007
		Artifacts	0.4090	0.2744
	Lumen SNR	Overall Quality	0.8144	0.0075
		Wall Delineation	0.6958	0.0374
		Flow Suppression	0.6756	0.0458
		Artifacts	0.3649	0.3343
	Muscle SNR	Overall Quality	0.4478	0.2268
		Wall Delineation	0.3242	0.3947
		Flow Suppression	0.4546	0.2189
		Artifacts	0.1556	0.6893
	Lumen-Wall CNR	Overall Quality	0.6860	0.0413
		Wall Delineation	0.6583	0.0539
		Flow Suppression	0.8931	0.0012
		Artifacts	0.386	0.3049

Discussion

The results of the quantitative analysis indicate that there were no significant differences between the image SNR and CNR given by the Machnet® and Medlion® coils, suggesting that the two coils yield similar quality despite different technology. Qualitative analysis showed that the Machnet® coil was scored slightly higher for each parameter, however, the difference was not statistically significant. While this implies that both coils produce images of comparable quality, the trend in analyst scores could suggest a slight difference in the analyst's perception of image analyzability and could potentially impact reproducibility of the measurements.

Correlations between qualitative and quantitative measurements were statistically significant only for the Medlion® coil, for a) the vessel wall SNR and qualitative scores of Overall Quality, Wall Delineation and Flow Suppression, b) the CNR and Overall Quality and Flow Suppression, and c) the lumen SNR and Overall Quality, Wall Delineation and Flow Suppression. These positive correlations, with the exception of the relationship between the lumen SNR and flow suppression, are expected since increasing the SNR and lumen-wall CNR should make the vessel wall more distinguishable. We did not expect level of flow suppression to increase with the lumen SNR, therefore this correlation needs to be explored further. The same trends were not seen as strongly for the Machnet® coil.

The results of this study demonstrate that imaging with the Medlion® coil gives similar SNR, CNR and qualitative results when compared to the Machnet® coil. The Medlion® coil is priced lower than the Machnet® coil. Thus, these results indicate that we obtain a similar level of performance with the Medlion® coil at a reduced price. Further investigation with a larger sample size or different imaging parameters is warranted to confirm the difference in signal. Future studies should also include non-healthy individuals to better evaluate which coil produces higher quality images when there is substantial evidence of disease. This will in turn help to evaluate which kind of coil yields superior images, to determine which should be more standardly used for carotid plaque imaging, and to gather data that will help better design MRI coils in the future.

References

1. Kerwin WS, Miller Z, Yuan C. Imaging of high-risk carotid plaque: magnetic resonance imaging. *Semin Vasc Surg*. 2017; 30:54-61. [PMID: 28818259 DOI: 10.1053/j.semvascsurg.2017.04.009]
2. Dong L, Wang J, Yarnykh VL, Underhill HR, Neradilek MB, Polissar N. *et al*. Efficient flow suppressed MRI improves interscan reproducibility of carotid atherosclerosis plaque burden measurements. J Magn Reson Imaging. 2010; 32:452-8. [PMID: 20677277 doi: 10.1002/jmri.22274]
3. Qiao H, Li F, Xu D, Liu G, Yuan C, Zhao X. *et al*. Identification of carotid lipid-rich necrotic core and calcification by 3D magnetization-prepared rapid acquisition gradient-echo imaging. *Magn Reson Imaging*. 2018; 53:71-76. [PMID: 30021124 DOI: 10.1016/j.mri.2018.07.004]
4. Quick HH, Debatin JF, Ladd ME. MR imaging of the vessel wall. *Eur Radiol*. 2002; 12:889-900 [PMID 11960244 DOI: 10.1007/s003300101115]
5. Dietrich O, Raya JG, Reeder SB, Reiser MF, Schoenberg SO. Measurement of signal-to-noise ratios in MR images: influence of multichannel coils, parallel imaging, and reconstruction filters. J Magn Reson Imaging. 2007; 26:375-385. [PMID: 17622966 DOI:

10.1002/jmri.20969]
6. Welvaert M, Rosseel Y. On the definition of signal-to-noise ratio and contrast-to-noise ratio for fMRI data. *PLoS One*. 2013; 8:e77089. [PMID: 24223118 doi: 10.1371/journal.pone.0077089]
7. Ouhlous M, Lethimonnier F, Dippel DW, van Sambeek MR, van Heerebeek LC, Pattynama PM. *et al*. Evaluation of a dedicated dual phased-array surface coil using a black-blood FSE sequence for high resolution MRI of the carotid vessel wall *J Magn Reson Imaging.* 2002; 15:344-51. [PMID: 11891981 DOI: 10.1002/jmri.10067]
8. Anumula S, Song HK, Wright AC, Wehrli FW. High-resolution black-blood MRI of the carotid vessel wall using phased-array coils at 1.5 and 3 tesla. *Acad Radiol*. 2005; 12:1521-1526. [PMID: 16321740 doi: 10.1016/j.acra.2005.08.009]
9. Tate Q, Kim SE, Treiman G, Parker DL, Hadley JR. Increased vessel depiction of the carotid bifurcation with a specialized 16-channel phased array coil at 3T. *Magn Reson Med*. 2013; 69:1486-1493 [PMID: 22777692 doi: 10.1002/mrm.24380]