

Retrospective Examination of Vessel Wall Imaging in Intracranial Arterial Structures in Cases with Acute or Chronic Cerebral Ischemia

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ABSTRACT

Introduction: We aimed to reveal the current status of high-resolution magnetic resonance imaging (HR-MRI) and its potential to identify different intracranial vessel wall pathologies. We also aimed to investigate the diagnostic performance of contrast-enhanced HR-MRI T1-SPACE sequence in determining vessel wall pathologies and to determine its contribution to conventional methods.

Methods: We retrospectively reviewed HR-MRI images of 33 consecutive patients with 30% or above stenosis based on clinical, digital subtraction angiography (DSA), computed tomography angiography (CTA), and magnetic resonance angiography (MRA) evaluations. All patients had a history of stroke, and 33 stenotic vessel segments in anterior-posterior circulation were reviewed. On HR-MR images, plaque eccentricity, presence or absence of intraplaque hemorrhage, contrast enhancement pattern, and plaque length were evaluated. As causes of atherosclerosis, the presence of diabetes mellitus, hemoglobin A1c, total cholesterol, triglycerid, and high-density lipoprotein levels, history of smoking, history of taking statin drugs, and hemoglobin levels were acquired, and the correlation between these variables and plaques labeled as stable or unstable in these patients was investigated.

Results: Atherosclerosis was observed in 29 of the 33 cases included in our study, and stenosis in intracranial vascular structures due to moyamoya disease was observed in 4 cases. In patients with intracranial stenosis secondary to moyamoya disease, diffuse concentric homogeneous enhancement was observed within the vessel wall in the prestenotic artery segment. In patients with stenosis due to atherosclerosis, increased heterogeneous enhancement was observed within the atheroma plaque. A significant correlation was observed between eccentric-concentric plaque and atherosclerotic segment length.

Conclusion: The vessel lumen can be evaluated using CTA, MRA, and DSA, but the vessel wall cannot be evaluated using these traditional techniques. Vessel wall imaging is helpful for identifying atheromas in intracranial and cervical carotid arteries, and for determining the morphologies of vessel walls and the surrounding structures.

Keywords: Atheroma plaque, magnetic resonance imaging, digital subtraction angiography, vW-MRI

Introduction

Stroke is an important cause of disease-related deaths and leads to devastating outcomes. Atherosclerotic plaque formation in intracranial arteries is the most common cause of ischemic stroke (1,2). Vessel wall changes, such as vessel wall thickening or the presence of soft atherosclerotic plaques without luminal stenosis, are often overlooked; however, these morphological changes may be important for understanding the etiology of ischemic stroke (3). Conventional methods for assessing the vessel lumen often do not provide information about the underlying pathological processes involving the vessel wall (4).

Magnetic resonance angiography (MRA) is a good screening tool with minimal invasiveness and no ionizing radiation, and the vessel wall can also be evaluated with additional sequences. High-resolution magnetic resonance imaging (HR-MRI) has been introduced for direct assessment of the vessel wall beyond only luminal information, such as the severity of stenosis in the vessel walls (5). HR-MRI can reveal characteristic radiological features associated with vessel wall pathologies in diseases such as intracranial artery involvement, such as atherosclerosis, dissection, Moyamoya disease, and vasculitis (6,7). Black-blood HR-MRI is recently used in the evaluation of cerebrovascular diseases (2). Contrast-



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enhanced magnetic resonance high-resolution variable flip angle turbo-spin-echo (T1-SPACE) technique using different flip angle evolutions enables high-spatial-resolution images of the intracranial vessel wall and is helpful for more accurately detecting intracranial vascular lesions (2).

In this study, we aimed to reveal the current status of HR-MRI and its potential to identify different intracranial vessel wall pathologies. We also aimed to investigate the diagnostic performance of contrast-enhanced HR-MRI T1-SPACE sequence in determining vessel wall pathologies and to determine its contribution to conventional methods.

Methods

Study Population and Image Evaluation

Thirty-three patients [20 male, 13 female; mean age: 59.89 (ranged from 28 to 80)] with significant intracranial vascular stenosis in clinical examination, computed tomography angiography (CTA) or MRA evaluation, and no known cardiovascular disease were included in the study between 2018 and 2019. HR-MRI method was applied to all of the patients, and the images were analyzed through the local database system Sectra PACS. Images reported by 2 radiologists with more than 20 years of CTA and MRA reporting experience. HR-MRI was performed in patients who had stenosis >30% on CTA, MRA, or DSA. While 30-50% stenosis was considered as mild stenosis in our study; 50-70% was accepted as moderate; 70% and above were evaluated in the category of high-grade stenosis. The shape of the plaque, the segment involved, the length of the segment involved, the enhancement of the plaque, and the presence of intraplate hemorrhage were evaluated using retrospective HR-MRI images. If these cases have CTA examination, the presence of calcification in the plaque was evaluated. In patients with stenosis secondary to atherosclerosis, atheroma plaques are classified as eccentric or concentric.

When assessing intraplate hemorrhage, abnormal intraplate T1 signal consistent with blood and blood products was defined as 150% of the T1 signal of the adjacent muscle. When evaluating significant plaque enhancement, the postcontrast T1 signal was defined as a 2-fold greater signal increase than the precontrast T1 signal. Cholesterol, triglyceride, high-density lipoprotein, mean platelet volume, hemoglobin A1c values of patients with atherosclerosis-related stenosis were examined. The use of aspirin in these cases was questioned.

Oral and written consent was obtained from all patients who participated in our study. The study was conducted in accordance with ethical standards as outlined in the Declaration of Helsinki of the World Medical Association. Ethical approval was obtained from a regional Ege University Ethics Committee (approval number: 19-12.1T/54, date: 25.12.2019). Cases with a history of cardioembolic cerebrovascular disease, allergy to MRI contrast agents, or acute renal failure were excluded from the study.

Imaging Technique and Protocol

MRI examinations were performed in the supine position using a 1.5 Tesla (Magnetom Amira, SIEMENS) and a 64-channel head coil. Patients admitted to the Tesla MR unit were seated, and a 20-gauge vascular

access was established through the antecubital vein. In all patients, the examination was successfully terminated within 60 minutes. 0.1 mmol/kg Gadovist (gadobutrol, Bayer) or 0.2 mmol/kg Dotarem (gadoteric acid, Guerbet) was used as the IV contrast agent. Contrast material was administered at a rate of 3 mL/sec., and postcontrast imaging was performed 6 min after the contrast material was administered. T2-weighted and diffusion-weighted imaging (DWI) series were obtained after contrast agent administration. DWI series were obtained using non-ecoplanar imaging. After the contrast injection was finished, 30 mL of saline was infused. Localizer, 3D time-of-flight MRA, susceptibility weighted imaging, T1-SPACE three-dimensional (3D), pre-postcontrast 3D T1-SPACE, T2-weighted fat sat, DWI (b0 and b1000), and ADC mappings was performed.

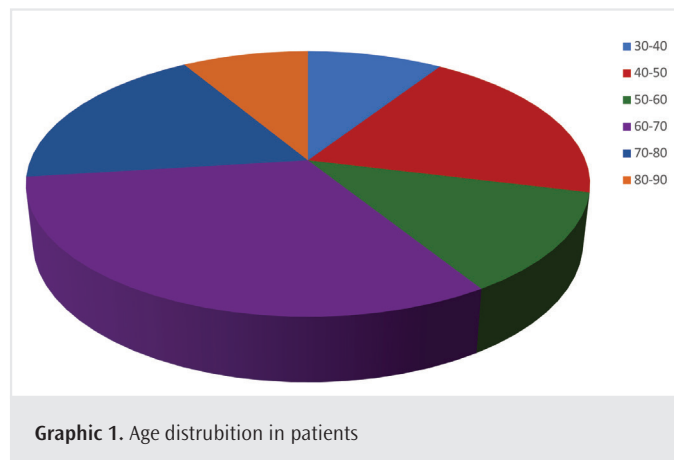
The imaging parameters for 3D T1-SPACE were as follows: TR, 900 ms; TE, 14 ms; matrix, 320 × 320; field of view, 17 × 17 cm²; slice thickness, 0.5 mm; number of sections, 224; and scan time, 8:29 min. 3D thin-layer images were postprocessor, and the original images of 3D T1-SPACE sequence were imported into the Siemens workstation.

Statistical Analysis

IBM SPSS Statistics 25.0 software was used. The suitability of numerical variables to normal distribution was examined using the Shapiro-Wilk test ($n < 50$). Numerical variables were presented as mean and standard deviation (SD) or median (minimum-maximum). Categorical variables are presented as numbers and percentages.

Results

The mean age of the patients was 59.89 years with a SD of 13.07. The youngest patient was 28 years old, and the oldest patient was 80 years old (Graphic 1). A total of 33 stenotic vessel segments were detected in 33 patients (25 male, 8 female). Atherosclerosis was observed in 29 of the 33 cases included in our study, and stenosis in intracranial vascular structures due to moyamoya disease was observed in 4 cases. Acute ischemia was observed in DWI-MRI in 5 of the cases with stenosis due to atherosclerosis. In our study, in patients with intracranial stenosis secondary to moyamoya disease, diffuse concentric homogeneous enhancement was observed within the vessel wall in the prestenotic artery segment. In patients with stenosis due to atherosclerosis, increased heterogeneous enhancement was observed within the atheroma

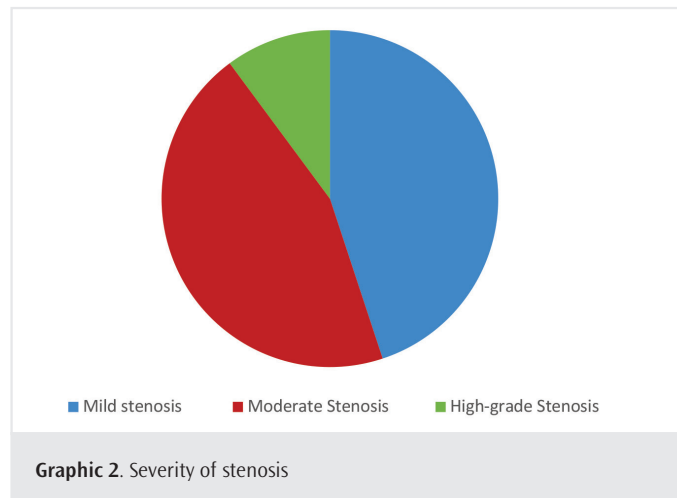


Graphic 1. Age distribution in patients

plaque. In 13 of 29 cases of stenosis due to atherosclerosis; shows multi-segmental involvement. In 18 of 29 patients with atherosclerosis-related stenosis; a significant increase in contrast enhancement was observed in unstable plaques. In vascular structures with multisegmental involvement, the segment with the highest degree of stenosis was evaluated in each case, and the degree of stenosis was measured at the narrowest point. Intraplaque hemorrhage was observed in 9 of the patients with stenosis due to atherosclerosis. CTA examination was available in 13 patients, and 8 of these patients had calcification in the atheroma plaque. High-grade stenosis was observed in 18 cases (70% and above), moderate (50-70%) in 8 cases, and mild (30-50%) in 7 cases (Graphic 2). A significant correlation was found between eccentric-concentric plaque and atherosclerotic segment length (p -value=0.014) (Tables 1, 2). No significant correlation was found between the degree of stenosis and intraplaque hemorrhage ($p>0.005$) (Tables 3, 4; Figures 1, 2).

Discussion

HR-MRI effectively identified distinctive enhancement patterns associated with different pathologies, showing diffuse concentric enhancement in Moyamoya cases and increased heterogeneous enhancement in atherosclerotic plaques. Importantly, this study found a significant correlation between eccentric-concentric plaque morphologies and the length of atherosclerotic segments, highlighting the potential of HR-MRI for diagnosing and categorizing plaque stability.



Furthermore, although intraplaque hemorrhage was noted in 9 cases with atherosclerosis, the degree of stenosis did not significantly correlate with the presence of hemorrhage. This underscores the importance of

Table 1. Involved arteries and segments

| |
|--|
| Basilar artery |
| Vertebral |
| Vertebral and basilar |
| Left vertebral artery |
| Right internal carotid artery |
| Right vertebral artery |
| Right middle cerebral artery |
| Left internal carotid artery |
| Basilar artery |
| Basilar artery |
| Left vertebral artery |
| Left vertebral artery |
| Right middle cerebral artery |
| Right middle cerebral artery |
| Basilar artery |
| Bilateral internal carotid artery |
| Basilar artery |
| Middle cerebral artery |
| Right middle cerebral artery |
| Left vertebral artery |
| Basilar artery |
| Left vertebral artery |
| Left middle cerebral artery |
| Left middle cerebral artery |
| Left internal cerebral artery |
| Right vertebral artery |
| Left internal carotid artery |
| Basilar artery |
| Left internal carotid artery |
| Left internal carotid artery (Moyamoya) |
| Right internal carotid artery (Moyamoya) |
| Bilateral internal carotid artery (Moyamoya) |
| Bilateral internal carotid artery (Moyamoya) |

Table 2. Involved segment lengths of eccentric plaques

| Eccentric plaque, SD | Mean value (mm) | | 17.8667 | 2.56509 |
|----------------------|-----------------|-------------|---------|---------|
| Segment length | 95% CI for | Lower bound | 12.3651 | |
| | Mean | Upper bound | 23.3682 | |

CI: Confidence interval

Table 3. The comparison of eccentric and concentric plaques length

| | Sig. (2-tailed) | | Mean difference | S.E. difference |
|----------------|---------------------------------|--------|-----------------|-----------------|
| Segment length | Equal variances are assumed | 0.014* | 8.61667 | 3.24406 |
| | Equal variances are not assumed | 0.010 | 8.61667 | 3.06590 |

*T-test was used for equality of means. A significant correlation was found between eccentric and concentric plaque and atherosclerotic segment length. The p -value was calculated as 0.014

Table 4. The comparison of intraplaque hemorrhage and degree of stenosis

| Crosstab | | Intraplaque hemorrhage | | | |
|--|---|------------------------|-------|-------|-------|
| | | | 0 | 1 | Total |
| Grade of stenosis | 1 | Count | 4 | 1 | 5 |
| | | Degree of stenosis | 80% | 20% | 100% |
| | | Intraplaque hemorrhage | 22.2% | 11.1% | 18.5% |
| | 2 | Count | 5 | 1 | 6 |
| | | Degree of stenosis | 83.3% | 16.7% | 100% |
| | | Intraplaque hemorrhage | 27.8% | 11.1% | 22.2% |
| | 3 | Count | 9 | 7 | 16 |
| | | Degree of stenosis | 56.3% | 43.8% | 100% |
| | | Intraplaque hemorrhage | 50% | 77.8% | 59.3% |
| Total | | Count | 18 | 9 | 27 |
| Degree of stenosis | | 66.7% | 33.3% | 100% | |
| Intraplaque hemorrhage | | 100% | 100% | 100% | |
| *There was no significant relationship between the degree of stenosis and intraplaque hemorrhage | | | | | |

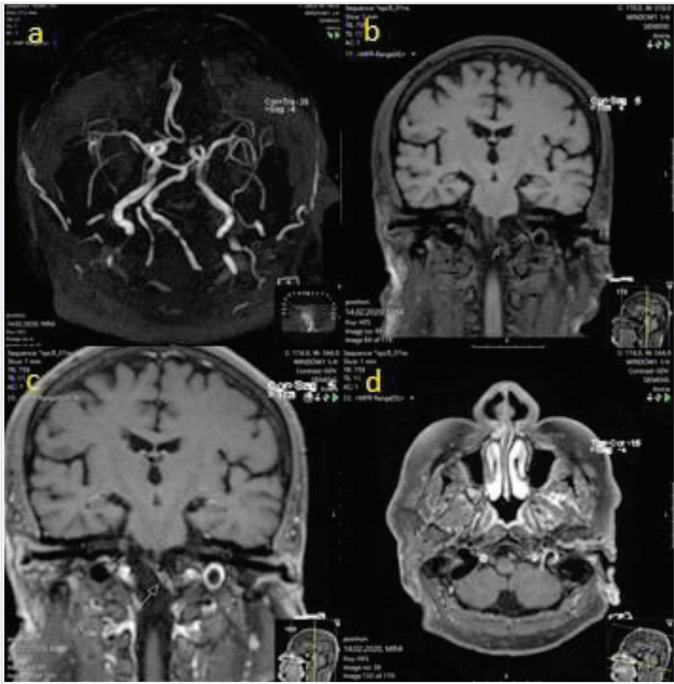


Figure 1. (a) 3D TOF MRA of the patient; high-grade stenosis was observed in the V4 segment of the left vertebral artery. (b) Atheroma plaque observed on precontrast T1W series (black arrow). (c) Contrast enhancement of the postcontrast T1W coronal atheroma plaque was observed. (d) Eccentric atheroma plaques are present in the axial T1W postcontrast series
TOF: Time-of-Flight, MRA: Magnetic resonance angiography

HR-MRI for providing detailed insights that are crucial for understanding the complexities of intracranial vascular diseases beyond what traditional methods offer. These techniques cannot provide detailed information about vascular diseases because luminal pathologies, such as stenosis, are caused by changes in the vessel walls (7). Angiography is a useful, important, and common imaging modality, with digital subtraction angiography (DSA) remaining the gold standard for luminal imaging. However, DSA is invasive and can contain ionizing radiation (8). The CTA, MRA, and DSA modalities focused on luminal imaging. Angiography

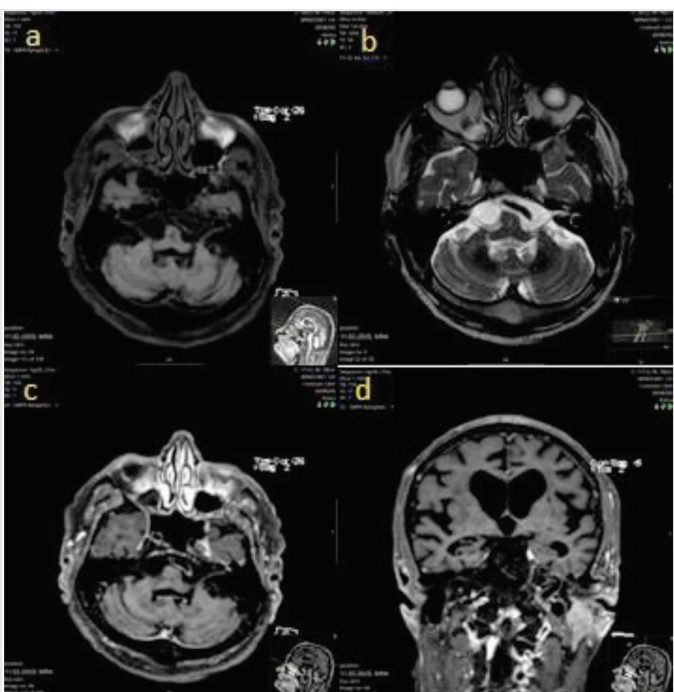


Figure 2. (a) Atheroma plaques observed in precontrast T1-weighted images. (b) Appearance of atheroma plaque in the V4 segment of the vertebral artery in the T2W series. (c, d) Axial and coronal images are enhanced in the postcontrast series

often depicts intracranial artery disease as luminal stenosis, which is often insufficient for evaluating intracranial vascular pathology (8-10). In CTA examination, the vessel wall can be evaluated; however, the low contrast resolution and soft tissue resolution of CT do not provide sufficient information and can not clearly show changes in the vessel wall (11). HR-MRI can directly visualize the intracranial vessel wall, demonstrating its potential to characterize plaque properties (11,12). Atherosclerosis was observed in 29 of the 33 cases included in our study, and stenosis in intracranial vascular structures due to Moyamoya disease was observed in 4 cases. Acute ischemia was observed in 5 of

the cases with stenosis due to atherosclerosis on DWI-MRI. In the study of Turan et al. (12), in patients with extracranial carotid disease; it has shown that HR-MRI can reliably identify intraplaque bleeding, which can be a better predictor of clinical events compared to CTA and conventional radiographic methods. Inversion recovery was performed using T1-weighted scans to zero the signal from the blood with a high-resolution 3 Tesla MR (13,14). Abnormal intraplaque T1 signal consistent with bleeding or blood products was defined as 150% of the T1 signal of the adjacent muscle. The intraplaque signal was >150% of the muscle signal in the two central slices, consistent with the imaging features of intraplaque hemorrhage demonstrated in symptomatic middle cerebral arteries (15). There are similar findings in our study. Zhang et al. (16) reported that brain 3D HR-vW MRI is a reliable method for measuring intracranial vessel size and potentially useful for monitoring plaque progression and regression. Zhu et al. (17) reported that 3D T1-weighted SPACE can be used for intracranial vessel wall assessment on both 3T and 7T MRI.

Intracranial intraplaque hemorrhage is an important component of plaque weakness (18). Although our study was performed with 1.5 Tesla, the black blood technique yielded good image quality with 0.7 mm isotropic and whole brain coverage in the basilar artery, vertebral artery, internal carotid artery intracranial segments, and MCA proximal and distal segments (19,20). The imaging features consistent with intraplaque hemorrhage on T1-weighted imaging and the characterization of contrast-enhanced T1-intracranial atherosclerosis were demonstrated in our study. Zhu et al. (17) recently successfully imaged intracranial vessel walls using 3D SPACE or equivalent arrays such as VISTA and CUBE with high scanning efficiency, high resolution, and black blood imaging. Swartz et al. (18) showed that T2 and pre- and postcontrast T1 inversion recovery images can distinguish vessel wall thickening (eccentric), inflammation (concentric), and other wall pathologies. In our study, an increase in eccentric wall thickness was observed in patients with concentric and atherosclerosis-related stenosis, similarly in patients with intracranial vascular stenosis due to Moyamoya disease.

Study Limitations

Our study had some limitations; most of the subjects included in the study had CVD, and a control group was not included. Interobserver variability was not evaluated. In our study, patients who were examined with MRA, CTA, or DSA and had significant stenosis were included in the study. Plaques considered unstable and shown to cause CVD in 60% of patients did not cause significant stenosis. The study was conducted using 1.5-T Tesla MRI. In the literature, most studies were conducted with 3 or 7 Tesla MRI.

Conclusion

Although HR-MRI is not frequently used in our country, it is routinely used worldwide, especially in the USA. Physically and mentally stable patients are preferred because the examination takes approximately 45-60 minutes. In our country, there are no provisions for health practice communication in social security institutions. The examination was coded as MRA and cranial MR with contrast. In cases with stenosis

in intracranial vascular structures with DSA, MRA or CTA; HR-MRI is a problem-solving method in determining the etiology and distinguishing whether the plaque is stable or unstable. HR-MRI cannot be applied to every patient due to the long duration of the examination and the inability of the patient to remain still during the examination. HR-MRI is a suitable method in terms of direct imaging of the vessel wall, increased contrast in the wall, which is significant in terms of unstable plaque, and intra-plaque bleeding.

Ethics Committee Approval: This study was approved by the Ege University Ethical Committee (approval number: 19-12.1T/54, date: 25.12.2019).

Informed Consent: Oral and written consent was obtained from all patients who participated in our study.

Authorship Contributions: Concept - Ö.Ö.; Design - F.Z.A.; Data Collection or Processing - Ö.M.; Analysis or Interpretation - İ.T.R.; Literature Search - C.Ç.; Writing - F.Z.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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