Noninvasive identification of peripheral vessels of oral and maxillofacial regions by using electrocardiography-triggered three-dimensional fast asymmetric spin-echo sequences

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Objectives. The aim of this study was to evaluate the 3-dimensional images of thinner main peripheral vessels in oral and maxillofacial regions made without contrast medium by using a new technique, fresh blood imaging (FBI). A second objective was to discern arteries from veins by using the combination of FBI with the subtraction technique.

Study design. Images from FBI were compared with those from 3-dimensional phase-contrast magnetic resonance angiography (MRA) of blood vessels in 20 healthy subjects. All images were scored for visualization and image quality of the main blood vessels. In addition, appropriate flow-spoiled gradient pulses were applied to differentiate arteries from veins in the peripheral vasculature using a combination of FBI sequences and subtraction between systole- and diastole-triggered images.

Results. The scores of MRA using FBI for the visualization of thin blood vessels were significantly better than those using phase contrast, whereas scores for the visualization of main blood vessels were equal. Additionally, we succeeded in our initial attempt to differentiate arteries from veins with a reasonable acquisition time.

Conclusions. Our initial experience shows that FBI could be a useful method to identify 3-dimensional vasculature and to differentiate arteries from veins among thinner peripheral vessels in the oral and maxillofacial regions without using contrast medium. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:493-501)

The risk of a new focal neurologic deficit caused by angiography is about 1%, and this risk rises to 3% in patients investigated for stroke and transient ischemic

Supported in part by a grant-in-aid for scientific research from the Ministry of Education, Science, Sports and Culture of Japan and a grant-in-aid for scientific research from the president of Kyushu Dental College.

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ORAL AND MAXILLOFACIAL RADIOLOGY Editor: William C. Scarfe
Recent advances in magnetic resonance imaging (MRI), 3D data acquisition, and postprocessing technologies are expanding the potential applications of 3D display. In particular, noninvasive techniques, such as magnetic resonance angiography (MRA), have been developed to identify and characterize peripheral blood vessels located in the thoracic, abdominal, and lower extremity regions. MRA could identify some of the main blood vessels in studies of the identification and characterization of hemangiomas, their feeding arteries, and any associated vascular abnormalities in the oral and maxillofacial regions. However, that method is not truly noninvasive and carries the risks of allergy to the contrast medium and the creation of a new focal neurologic deficit. Therefore, it may not be performed repeatedly in a patient. Moreover, contrast agent is not appropriate for some patients, especially those with limited kidney function. The imaging parameters used in both sequences are shown in Table I.

We recruited 20 consecutive healthy subjects (12 men and 8 women, ages 17-64 years, mean age ± SD 34.7 ± 11.1 years). Consecutive healthy subjects were volunteers with no vascular-related lesions, confirmed by history and clinical examination. Informed consent was obtained from each of the subjects before the MR examination. We obtained approval from the Institutional Review Board at Kyushu Dental College. All images were acquired using a 1.5-T full-body MR system (Visart; Toshiba, Tokyo, Japan) with a circular polarized neck coil to visualize the blood vessels in the oral and maxillofacial regions. Conventional single-section sagittal, coronal, and axial scout images of the head and neck were initially obtained. Main blood vessels, such as the lingual, facial, maxillary, and carotid arteries and veins, were identified on an initial set of coronal T2-weighted images with fat suppression by fat saturation. Subsequently, flow-spoiled FBI and 3D phase-contrast MRA (3D-PC-MRA) were applied to the oral and maxillofacial regions, including the lingual, facial, maxillary, and carotid arteries and veins. The imaging parameters used in both sequences are shown in Table I.

For FBI, an inversion recovery pulse attenuates fat signals, followed by an electrocardiogram (ECG)–triggered single-shot half-Fourier FSE to capture the freshly pumped blood. First, an ECG prep scan was acquired during both diastole and systole to determine the appropriate ECG-triggered delay time for the blood vessel of interest with the following parameters: repetition time (TR) of 5 R-R intervals, effective echo time (TE) of 60 ms, inversion time (TI) of 190 ms, echo train spacing (ETS) of 5 ms, a matrix of 128 × 256 pixels, 1 single-acquired section thickness of 60 mm, a field of view (FOV) of 22 × 22 cm, 6 single-shot images with varying flow-spoiled gradient pulses, and a total acquisition time of 10-20 seconds, depending on the cardiac rate of the subject. Thus, an ECG delay time of ~400-800 ms was applied.

Table I. Imaging parameters

<table>
<thead>
<tr>
<th>Sequence</th>
<th>FBI</th>
<th>PC-MRA</th>
<th>T2WI</th>
<th>T1WI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR (ms)</td>
<td>5</td>
<td>30</td>
<td>4,000</td>
<td>500</td>
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<tr>
<td>TE (ms)</td>
<td>80</td>
<td>16</td>
<td>100</td>
<td>15</td>
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<td>Flip angle (°)</td>
<td>90</td>
<td>20</td>
<td>90</td>
<td>90</td>
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<tr>
<td>FOV (mm)</td>
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<td>220 × 220</td>
<td>220 × 220</td>
<td>220 × 220</td>
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<tr>
<td>Section thickness (mm)</td>
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<td>3.0</td>
<td>6.0</td>
<td>6.0</td>
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<tr>
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<td>Slab thickness (mm)</td>
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<td>90</td>
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<td>105</td>
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<tr>
<td>Matrix (pixels)</td>
<td>256 × 256</td>
<td>160 × 256</td>
<td>256 × 256</td>
<td>224 × 320</td>
</tr>
</tbody>
</table>

FBI, fresh blood imaging; PC-MRA, phase-contrast magnetic resonance angiography; T2WI, T2-weighted imaging; T1WI, T1-weighted imaging.
in FBI scanning, depending on the heart rate of the subject. In addition, the coronal slice direction was selected by using an appropriate ECG delay determined from the ECG prep scan based on an operator-dependent technique to minimize the FBI acquisition time. In the venous phase, 500-600 ms was selected as the ECG delay time, depending on the subject, but 100 ms was selected in the arterial phase.

Next, the appropriate strength for the flow-spoiled gradient pulses was determined from the subtraction images obtained between diastole and systole. Divergence of the external carotid arteries to the respective arteries was obtained with flow-spoiled gradient pulses from −10% to 100% in increments of 10%. The strength of a flow-spoiled pulse is a percentage of the area of the readout gradient, which is equivalent to the area from the ramp to the echo center of the readout gradient. This pulse strength was applied in 3D acquisition to trigger every section of encoding. Typical parameters for 3D acquisition were the following: TR 5 R-R intervals, TE 80 ms, TI 190 ms, ETS 5 ms, matrix 256 × 256 pixels, 1 signal-acquired section thickness of 3 mm, FOV 22 × 22 cm, 2 shots, 30 section encodings, and total acquisition time 2.0-4.0 minutes.

Fig. 1. Magnetic resonance angiography using fresh blood imaging (A) and illustration (B) and phase-contrast magnetic resonance angiography (C), and illustration (D) of the indicated vessels in the oral and maxillofacial regions of a 27-year-old healthy male volunteer without contrast medium. Three-dimensional images of the carotid arteries and their branches were visualized. The carotid artery (black star), internal jugular vein (white star), lingual artery (black arrows), lingual vein (white arrow), facial artery (black arrowheads), facial vein (white arrowheads), maxillary artery (black circles), and maxillary vein (white circles) and their branches are more clearly detected by using fresh blood imaging than by using phase-contrast magnetic resonance angiography.
using a nonbreath-holding technique. Both diastolic and systolic ECG-triggered 3D data were acquired under the same conditions. Interpolation in the section direction was performed to improve the spatial resolution. The MRA images using FBI were compared with those using PC-MRA to evaluate whether FBI is a useful method for the detection of thinner main blood vessels in the oral and maxillofacial regions.

Finally, to evaluate the discernment between arteries and veins in the oral and maxillofacial regions, the acquisition of FBI images the systolic source images were subtracted from the diastolic source images and the subtracted images then underwent maximum intensity processing (MIP). The total acquisition time was ~10 minutes, including acquisition of the scout, ECG preparation, flow preparation, and 3D images.

A magnetization-prepared rapid-acquisition gradient-echo sequence was used for the 3D-PC-MRA. The imaging parameters used in the PC-MRA sequences included: 30 ms TR, 16 ms TE, 30 ms TI, flip angle 20°, field of view 22 × 22 cm, matrix 160 × 256 pixels, slab thickness 90 mm, section thickness 3 mm, and acquisitions 1 minute and 10 minutes per sequence. A velocity-encoding gradient of 30 cm/s was chosen for the PC-MRA (Table I).

After acquisition in all patients, postprocessing of the FBI and 3D-PC-MRA images was performed to yield MIP reconstructions. The 3D acquisition could be reformatted into any required orientation.

For subjective analysis, MRA images obtained by the 2 methods were independently assessed by 2 experienced radiologists for visualization of the main blood vessels in the oral and maxillofacial regions, using a 4-grade scoring system. If a discrepancy occurred between the radiologists’ scores, consensus was reached by discussion. Use of the kappa statistical test indicated good diagnostic agreement between the radiologists (κ = 0.71). The source and MIP images from each sequence were analyzed. We selected the carotid arteries, internal jugular veins, maxillary arteries, maxillary veins, lingual arteries, lingual veins, facial arteries, and facial veins as the main blood vessels, including the carotid arteries and their branches, were visualized on FBI (n = 14; Fig. 1, A) and PC-MRA (n = 19; Fig. 1, B) without contrast medium. The lingual, facial, and maxillary blood vessels and their branches were more clearly detected by using FBI than by PC-MRA (Fig. 1). MRA images using FBI could not be visualized in 6 of the 20 subjects, because normal ECGs could not be acquired for unknown reasons, possibly related to the MRI system, despite the subjects’ good health. In 1 case of PC-MRA imaging, there was no effect of fat suppression owing to a prominent dental metal artifact. The visual scores of the main blood vessels are shown in Table II. Significant differences were found in visual

| Table II. Visual scores (mean ± SD) for main vessels in the oral and maxillofacial region on images of subjects using fresh blood imaging (FBI) and phase-contrast magnetic resonance angiography (PC-MRA) |
|----------------------------------|-----------------|-----------------|
|                                | FBI (n = 14)    | PC-MRA (n = 19) |
| Arteries                        | 2.3 ± 0.8       | 1.7 ± 0.9       |
| Carotid arteries                | 2.5 ± 0.8       | 2.6 ± 0.7       |
| Maxillary arteries              | 2.4 ± 0.7       | 1.4 ± 1.0       |
| Facial arteries                 | 2.2 ± 1.0       | 1.6 ± 1.0       |
| Lingual arteries                | 2.1 ± 0.9       | 1.2 ± 0.8       |
| Veins                           | 2.0 ± 1.0       | 1.2 ± 0.9       |
| Internal jugular veins          | 2.1 ± 0.8       | 1.5 ± 1.1       |
| Maxillary veins                 | 2.0 ± 1.2       | 1.2 ± 0.8       |
| Facial veins                    | 2.0 ± 1.0       | 1.3 ± 1.0       |
| Lingual veins                   | 1.9 ± 0.8       | 0.9 ± 0.8       |

RESULTS

Utility of fresh blood imaging on 3D identifications of thinner peripheral blood vessels in the oral and maxillofacial regions

Three-dimensional vasculature images of the main blood vessels, including the carotid arteries and their branches, were visualized on FBI (n = 14; Fig. 1, A) and PC-MRA (n = 19; Fig. 1, B) without contrast medium. The lingual, facial, and maxillary blood vessels and their branches were more clearly detected by using FBI than by PC-MRA (Fig. 1). MRA images using FBI could not be visualized in 6 of the 20 subjects, because normal ECGs could not be acquired for unknown reasons, possibly related to the MRI system, despite the subjects’ good health. In 1 case of PC-MRA imaging, there was no effect of fat suppression owing to a prominent dental metal artifact. The visual scores of the main blood vessels are shown in Table II. Significant differences were found in visual.
scores in each artery [maxillary \( P = .002 \), facial \( P = .046 \), lingual \( P = .004 \)] between the 14 subjects in which FBI could be visualized and the 19 subjects in which PC could be visualized, except for the carotid arteries \( P = .381 \). Regarding the veins, significant differences in visual scores were also found [internal jugular \( P = .046 \), maxillary \( P = .021 \), facial \( P = .049 \), lingual \( P = .004 \)] between FBI and PC.

**Discernment of arteries from veins in the oral and maxillofacial regions by using FBI**

Flow preparation images obtained from 1 subject after diastolic and systolic subtraction are shown in Fig. 2. The diastolic and systolic subtraction images are shown with a flow-spoiled gradient of 0%, but the divergence is most clearly depicted at 10%. Images with stronger flow-spoiled pulses, such as 50% and 60%, show reduced signal intensity. A 10% flow-spoiled gradient was selected and applied in 3D acquisition. Three-dimensional source images obtained with a 10% gradient are shown in Fig. 3. The diastolic images (Fig. 3, A) show bright blood for both arteries and veins, whereas the systolic images (Fig. 3, B) show bright blood for the veins and black blood for the arteries. Subtraction of the diastolic images from the systolic images, followed by MIP, provides an image that shows bright blood for the arteries (Fig. 3, C).

The RVOs on FBI and PC-MRA images for 14 subjects are shown in Table III. The distribution of grading scores for separating arteries from veins on FBI are shown in Table IV. In the majority of fresh blood images, the RVO was low and the grading score was judged as good. Typical flow-spoiled FBI images from the carotid arteries to the maxillary, lingual, and facial arteries are shown in Fig. 4. The RVO of this image was ~5% and scored as good. However, in 2 subjects, 1 had an RVO of 30% and the other an RVO of 40% (Fig. 5), and both were judged as fair. In the majority of FBIs, much thinner vessels that could be judged as continuous from the carotid arteries were depicted (Fig. 4), but not in the 2 latter cases (Fig. 5).

**DISCUSSION**

Magnetic resonance angiography commonly uses a bright-blood method, in which the signal from the moving protons is accentuated relative to the stationary
protons through the pulse sequence and measurement parameters. Other bright-blood methods include time-of-flight (TOF) and PC methods.20 New noninvasive FBI, which uses 3D half-Fourier FSE triggered with ECG gating, is one of the new nonenhanced MRA techniques.9-12 FBI permits the depiction of slow-flow blood vessels in T2-weighted images and of fast-flow blood vessels by acquiring the images with ECG triggering during the slow-flow cardiac phase.10 In the present study, we demonstrated that 3D-FBI could visualize the 3D vasculature of relatively thinner blood vessels in the oral and maxillofacial regions, including lingual and facial arteries, better than 3D-PC-MRA, just as in the thoracic and abdominal regions.10 This is because FBI can depict slow-flow vessels owing to the T2 effects, unrelated to the flow rate of blood vessels, so that even relatively static blood vessels can be depicted on images, unlike imaging with PC-MRA. In addition, the depiction level of thick blood vessels by using FBI was the same as that by using PC-MRA. Therefore, the clear depiction of blood vessels in the oral and maxillofacial regions by using FBI can range from thick vessels to thinner vessels.

Moreover, the mean acquisition time using FBI was 5 minutes and that using PC-MRA was 10 minutes. Phase-contrast MRA needs a long acquisition time, and artifacts from patients’ movements may reduce the quality of the images. One more advantage of FBI is that it has fewer pulsational artifacts than PC-MRA. We speculate that the higher visual scores on thinner blood vessels by using FBI reflect the synergistic effect of technical improvement and shortened acquisition time. Most importantly, the method is easy and fast to use, and it permits repeated imaging, because no contrast medium is required.

Regarding the present parameters of FBI, a relatively long TE of 60 ms was applied, as in abdominal studies.17 The contrast between blood and background was problematic with a TE of 30 ms, because the background contributed a high signal due to a sufficient presence of fat tissues in the oral and maxillofacial regions. The short TR of 5 R-R intervals was applied because inflow blood, replaced with every heartbeat, can be acquired in late diastole when flow is quite slow or stable. An ECG delay time of ~400-800 ms was usually applied in FBI scanning, depending on the heart rate. To minimize the short FBI acquisition time, the coronal slice direction was selected by using an appropriate ECG delay, as in other regions, determined from the ECG prep scan.9,14,17 In the venous phase of the oral and maxillofacial regions, 500-600 ms was selected as the ECG delay time applied in FBI scanning, depending on the subject, but 100 ms was selected in the arterial phase. In the present study, there was no case of failure with MRA using FBI due to the inappropriate selection of an ECG delay time. However, this manipulation is an operator-dependent

| Table III. Rates of venous overlap (RVO; mean % ± SD) on both fresh blood imaging (FBI) and phase-contrast magnetic resonance angiography (PC-MRA) in all subjects |
|-------------|----------------|----------------|
| FBI (n = 14) | PC-MRA (n = 19) |
| 16 ± 13     | 40 ± 23        |

Table IV. Distribution (n) of grading scores for separating arteries from veins in oral and maxillofacial region on magnetic resonance angiography using fresh blood imaging

<table>
<thead>
<tr>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2</td>
<td>0</td>
<td>14</td>
</tr>
</tbody>
</table>

Fig. 3. Three-dimensional source images of contiguous sections obtained with a 10% flow-spoiled gradient. A, Images acquired during diastole. B, Images acquired during systole. C, Maximum intensity processing image after diastolic and systolic subtraction.
technique based on the selected ECG delay time. Selection of the wrong ECG delay time results in failure with MRA. In particular, because blood vessels in the oral and maxillofacial regions have a wide range of flow rates from high flow to static flow, it is difficult to select appropriate flow-spoiled gradient pulses. Therefore, training in the technique of MRA using FBI is essential, with hospitals requiring experts in this field to facilitate such training programs. The single-slab excitation technique with 3D half-Fourier FSE could significantly reduce intrinsic magnetization transfer contrast effects compared with the 2-dimensional multislice technique, owing to no off-resonance slice effect.18

There are potential disadvantages with FBI. The FBI technique has less temporal resolution and generally requires 4-6 minutes for data acquisition. Because the superior-inferior phase-encode direction is selected to improved delineation, a slight loss of signal may occur at the apex of an arch, such as the aortic arch. Because ECG triggering is used, patients with arrhythmia or tachycardia are not suitable candidates for FBI examination. Because FBI allows not only the depiction of fast-flow blood vessels during periods of slow flow but also T2-weighted image contrast, effusions are depicted as areas of high signal intensity. Therefore, a massive effusion may degrade the image quality of FBI. In the present study, MRA images using FBI could not be visualized in 6 of the 20 subjects despite the subjects’ good health, because a normal ECG could not be obtained. We speculate that our MR system for FBI might respond to even slight changes in ECG. In 1 case of PC-MRA, there was no effect of fat suppression owing to a prominent dental metal artifact. Therefore, we could not necessarily insist that MRA using FBI is better than that using PC. We selected the 3D-PC-MRA for comparison with the FBI in the present study. In a previous study, we reported that the main external

Fig. 4. Maximum intensity processing images with a 0% flow-spoiled gradient (A) and illustration of indicated vessels (B) of the maxillary arteries (arrows) in a 36-year-old healthy male volunteer. The visualization score of 3 was judged as good.

Fig. 5. Maximum intensity processing images with a 30% flow-spoiled gradient (A) and the illustration of indicated vessels (B) of the maxillary arteries (arrows) in a 31-year-old healthy male volunteer. The visualization score of 2 was judged as fair.
carotid artery and its branches, including the lingual and facial arteries, could be shown using 3D-PC-MRA with the MR system that is currently used in our hospital, but the branches could not be shown by using 3D TOP. Because a limited region was selected for the acquisition of the MRA images, the reduced number of partitions, which is a limitation of the PC technique, was not a problem in the present study.

As the other very interesting result, we succeeded in our initial attempt to differentiate arteries from veins in the oral and maxillofacial regions. Flow-spoiled gradient pulses do not affect the signal intensity of stationary background tissues. Veins are similarly less affected by the flow-spoiled pulses during diastole and systole as a result of their relatively constant slow flow throughout the cardiac cycle. By applying the flow-spoiled pulses, the signal intensity difference between diastole and systole in arteries is increased. Thus, diastolic and systolic subtraction provides better delineation of the arteries. In fact, blood vessels depicted on MRA by using our combination technique are most of the arteries depicted in textbooks of head and neck anatomy. In the present study, we judged blood vessels having continuity with carotid arteries as the main thinner arteries in each subject. The blood vessels other than these thinner arteries were determined to be veins. We evaluated the RVOs on both FBI and PC-MRA in each subject. The RVO of FBI in 12 of 14 subjects was <25%, and we judged that the combination technique of FBI and subtraction was successful in our initial attempt to differentiate arteries from veins in the oral and maxillofacial regions in 14 subjects.

The TOF-PC technique has been used to evaluate peripheral arteries in the oral and maxillofacial regions. However, the acquisition time is longer than that with our present technique. Flow-independent angiography with T2 preparation shows promising results, but discernment of arteries from veins is limited. Our technique is based on simple subtraction and maximum intensity processing; these techniques are readily available in the main MRI console. Therefore, neither additional software nor an offline processing system is required for image processing. In the present study, acquiring thick sections allowed a further reduction in acquisition time.

Flow preparation imaging is a fast and useful method for determining the appropriate flow-spoiled gradient strength without acquiring the 3D data. It has been reported that for relatively fast blood flow, such as in the abdominal aorta and the iliac arteries, a 0% flow-spoiled gradient was applied, which resulted in slight N/2 artifacts in the phase-encode direction. A small negative flow-spoiled readout pulse may be required. Therefore, selection of the appropriate flow-spoiled gradient is also an important factor in determining image quality in the oral and maxillofacial regions, as in the lower extremities. In addition, even a slightly stronger flow-spoiled gradient affects the visualization of slow-flow branch arteries, including maxillary arteries. Particularly for the extremely slow flow in the oral and maxillofacial regions, such as in the lingual arteries and facial arteries, stronger flow-spoiled gradient pulses were applied to improve the arterial images.

The most important limitation of the present study is that our new technique cannot be directly compared with MRA using contrast medium. Although subjects in the present study were all healthy volunteers, we could not expose them to diagnostically unnecessary contrast medium. In addition, the extent of discernment of arteries from veins could not be precisely evaluated, because of the lack of a criterion standard. Further study is therefore needed.

Although FBI cannot completely replace angiography in the investigation of many kinds of vascular-related diseases in the head and neck regions, we would recommend performing this examination before angiography. FBI, which does not require contrast medium, is easy to perform in patients with limited kidney function and associated contrast media problems, and it yields important information regarding the status of the disease, including the 3D relationship of any tumor and its blood vessels. In this regard, FBI is much more valuable than earlier methods. In addition, we confirmed that modified FBI sequences could depict both tumor-like diseases and thinner blood vessels in 1 image without the fusion of multiple images. The clinical use of FBI has not yet been fully established, but future applications of this approach for the detection of thinner blood vessels are very attractive and further investigation in this field is expected.

**REFERENCES**


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