

# Identification of the Facial Colliculus in Two-dimensional and Three-dimensional Images

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## Abstract

The facial colliculus (FC), an important landmark for planning a surgical approach to brainstem cavernous malformation (BCM), is a microstructure; therefore, it may be difficult to identify on magnetic resonance imaging (MRI). Three-dimensional (3D) images may improve the FC-identification certainty; hence, this study attempted to validate the FC-identification certainty between two-dimensional (2D) and 3D images of patients with a normal brainstem and those with BCM. In this retrospective study, we included 10 patients with a normal brainstem and 10 patients who underwent surgery for BCM. The region of the FC in 2D and 3D images was independently identified by three neurosurgeons, three times in each case, using the method for continuously distributed test results (0–100). The intra- and inter-rater reliability of the identification certainty were confirmed using the intraclass correlation coefficient (ICC). The FC-identification certainty for 2D and 3D images was compared using the Wilcoxon signed-rank test. The ICC (1,3) and ICC (3,3) in both groups ranged from 0.88 to 0.99; therefore, the intra- and inter-rater reliability were good. In both groups, the FC-identification certainty was significantly higher for 3D images than for 2D images (normal brainstem group; 82.4 vs. 61.5,  $P = .0020$ , BCM group; 40.2 vs. 24.6,  $P = .0059$  for the unaffected side, 29.3 vs. 17.3,  $P = .0020$  for the affected side). In the normal brainstem and BCM groups, 3D images had better FC-identification certainty. 3D images are effective for the identification of the FC.

Keywords: brainstem cavernous malformation, facial colliculus, marching cubes algorithm, surface rendering, three-dimensional images

## Introduction

In the telovelar approach for surgical management of brainstem cavernous malformation (BCM), such as Spetzler's two-point method, priority for entry to the BCM is given to the location that is nearest to the surface of the brainstem.<sup>1,2</sup> It is important to gather the information on the safe entry zone during the preoperative examination.<sup>3</sup> The supra/infra facial colliculus (FC) approach through the

floor of the fourth ventricle is frequently used; therefore, identification of the FC is important in this operation.<sup>3,4</sup>

The FC is a microstructure with a rostrocaudal length of approximately 3 mm and a ventrodorsal elevation of  $0.73 \pm 0.30$  mm.<sup>5,6</sup> It is not easy to accurately identify the FC by magnetic resonance imaging (MRI).<sup>7,8</sup> Although there are no reports on the identification methods or their accuracy in identifying the FC on preoperative MRI of patients with BCM, it has been reported that three-dimensional (3D) images are useful for visualizing the structure of the brainstem surface.<sup>9,10</sup> In this study, the FC-identification certainty in the normal brainstem and BCM groups was validated in two-dimensional (2D) and 3D images.

Received December 11, 2020; Accepted March 1, 2021

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## Materials and Methods

### Patient population

This retrospective study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. The study included 10 patients (Cases 1–10, three men, seven women) without a structural disorder in the brainstem (normal brainstem group) and 10 patients (Cases 11–20, three men, seven women) who had been diagnosed with BCM and were treated surgically using the telovelar approach at our hospital (BCM group).

### Ethical approval

All procedures involving human participants were in accordance with the ethical standards of the institutional research committee and the 1964 Helsinki declaration and its later amendments.

### Informed consent

Written informed consent was obtained from all individual participants included in the study.

### Image processing

MRI of the head was performed using a 3.0 T system (Signa 3.0 T, General Electric). Contrast-enhanced fast imaging with steady-state acquisition (CE-FIESTA) images were acquired using an 8-channel head coil. The main imaging parameters for CE-FIESTA were as follows: repetition time, 4.2 ms; echo time, 1.6 ms; slice thickness, 0.4 mm; field of view (FOV), 20 cm; matrix size, 512 × 512; and flip angle 45°. The 2D images obtained using CE-FIESTA were used for FC identification in this study.

Data were provided as image stacks coded in Digital Imaging and Communications in Medicine (DICOM) format. The 3D images were obtained using CE-FIESTA and by visualizing the floor of the fourth ventricle by surface rendering using the image processing software LIVRET (Kompah Inc., Tokyo, Japan) on a Windows personal computer. Image thresholding was used to establish a single threshold value at which the FC was most visible for standardized/unified segmentation. Thresholding operations utilized/Segmentation was obtained using the full width at half maximum (FWHM) of the brainstem and cerebrospinal fluid. All structures except the floor of the fourth ventricle were deleted. The author (TU), a neurosurgeon, created all the 3D images. The workflow for image processing is shown in Supplementary Fig. 1 (All supplementary figures and tables are available Online).

### Assessment

The region of the FC in the 2D and 3D images was independently identified by three certified neurosurgeons of the Japan Neurosurgical Society. They were not informed of the patient's background or surgical method to obtain continuously distributed test results (0–100) and they were not co-authors. In the BCM group, the FCs were identified on the unaffected and affected sides. Observers could view 2D images in the axial, sagittal, and coronal planes and could freely change the slice number, window level, and window width. In the case of 3D images, observers could rotate, translate, and scale the images and could view them from any angle. In all cases, the region of the FC was identified in 2D and 3D images shown randomly. Observers evaluated each case three times. The identification of the FC was performed in the order of the normal brainstem group and, subsequently, the BCM group. There was no time limit for identification.

### Statistical analysis

The reliability of the obtained identification certainty was verified using the intraclass correlation coefficient (ICC).<sup>11)</sup> In both the normal brainstem and BCM groups, the ICC (1,3) and ICC (3,3) were calculated and the intra- and inter-rater reliability were confirmed. The ICC indicating good reliability was set to 0.8 or higher.

In both the normal brainstem and BCM groups, the FC-identification certainty using 2D and 3D images was compared using the Wilcoxon signed-rank test. In the BCM group, the average evaluation time of each observer was compared using the t-test. The statistical significance level was set at 5% in this study. Statistical analyses were performed using JMP 15 (SAS Institute Inc., Cary, NC, USA).

## Results

3D images were successfully created for all patients. In the normal brainstem group (Cases 1–10), the ICC (1,3) for each of the three observers was 0.94, 0.98, and 0.99, respectively, for 2D images and 0.96, 0.97, and 0.99, respectively, for 3D images (Table 1). The ICC (3,3) was 0.97 for 2D images and 0.92 for 3D images (Table 1). The intra- and inter-rater reliability were good. The FC-identification certainty was significantly higher for 3D than for 2D images (82.4 vs. 61.5,  $P = .0020$ ; Table 2; see Supplementary Table 1 and Supplementary Fig. 2). An illustrative case (Case 7) from the normal brainstem group is presented in Supplementary Fig. 3.

The demographic characteristics of the BCM group are summarized in Table 3. The average age of

**Table 1** Intra- and inter-rater reliability evaluated using the ICC in the normal brainstem group and BCM group

		Intra-rater reliability ICC (1,3)			Inter-rater reliability ICC (3,3)
		Observer 1	Observer 2	Observer 3	
Normal brain stem					
2D		0.94	0.98	0.99	0.97
3D		0.96	0.97	0.99	0.92
BCM cases					
2D	Unaffected side	0.92	0.98	0.96	0.95
	Affected side	0.91	0.97	0.89	0.89
3D	Unaffected side	0.92	0.95	0.93	0.92
	Affected side	0.93	0.95	0.91	0.88

ICC (1,3) was 0.8 or higher for all categories for each of the three observers, indicating that good intra-rater reliability was obtained. ICC (3,3) was also 0.8 or higher for all categories, indicating good inter-rater reliability. Statistical analyses were performed using JMP 15 (SAS Institute Inc., Cary, NC, USA). BCM: brainstem cavernous malformation, ICC: intraclass correlation coefficient, 2D: two-dimensional, 3D: three-dimensional.

**Table 2** Comparison of average FC identification certainty between 2D and 3D images in the normal brainstem group and BCM group

Normal			BCM	Unaffected side		Affected side	
Case No.	2D	3D	Case No.	2D	3D	2D	3D
1	51.7	80.7	11	29.2	57.7	12.8	42.4
2	62.6	80.7	12	25.6	38.7	13.8	24.6
3	62.6	72.6	13	21.2	48.2	23.6	31.4
4	53.1	85.1	14	20.4	43.1	11.9	29.0
5	75.8	82.9	15	21.2	32.2	14.6	26.0
6	70.7	86.4	16	18.0	38.2	20.0	30.0
7	57.1	92.7	17	16.8	35.8	15.1	20.6
8	64.3	71.0	18	17.0	33.8	20.8	29.1
9	54.0	92.2	19	37.0	29.6	19.2	22.6
10	63.0	79.3	20	40.0	45.1	21.6	37.7
Avg.	61.5	82.4	Avg.	24.6	40.2	17.3	29.3
<i>P</i> value	.0020		<i>P</i> value	.0059		.0020	

The FC-identification certainty in the normal brainstem group was significantly higher in 3D images (82.4 vs. 61.5,  $P = .002$ ). Even in the BCM group, the FC-identification certainty was significantly higher in 3D images (40.2 vs. 24.6,  $P = .0059$  on the unaffected side, 29.3 vs. 17.3,  $P = .0020$  on the affected side). Statistical analyses were performed using JMP 15 (SAS Institute Inc., Cary, NC, USA). BCM: brainstem cavernous malformation, FC: facial colliculus, 2D: two-dimensional, 3D: three-dimensional.

the BCM group was 34.9 years (range: 18–57 years), and the average lesion volume was 5.0 mL (range: 0.9–10.4 mL). In the BCM group, the average threshold for the visualization of the floor of the fourth ventricle was 4732.9 (range: 3591–6149), the average 3D image creation time was 505.4 s (range: 327–663 s), and

the average evaluation time by each observer was 113.3 s for 2D images and 35.1 s for 3D images ( $P < .0001$ ; Table 3).

In the BCM group (Cases 11–20), the ICC (1,3) for each of the three observers was 0.92, 0.98, and 0.96, respectively, for the unaffected side and 0.91,

**Table 3 Summary of the 10 patients in the BCM group**

Case No.	Age (y), Sex	Localization	Size (mm)	volume (mL)	Threshold	3D image creation time (s)	Average evaluation time of 2D images (s)	Average evaluation time of 3D images (s)
11	26, F	Pons (Rt)	22 × 25 × 22	6.1	5008	455	149.1	25.0
12	18, F	Pons (Lt)	11 × 12 × 13	0.9	4379	427	120.7	29.4
13	28, F	Pons (Lt)	25 × 26 × 25	8.1	5465	610	95.4	31.0
14	26, M	Pons/medulla (Rt)	18 × 14 × 20	2.5	4592	445	125.2	26.2
15	37, M	Pons (Lt)	20 × 24 × 27	6.5	6149	606	133.9	44.8
16	57, M	Pons (Rt)	28 × 24 × 31	10.4	3946	336	107.9	38.3
17	42, F	Pons (Lt)	22 × 27 × 20	5.9	3733	640	85.2	38.7
18	53, F	Pons/medulla (Lt)	16 × 18 × 30	4.3	4923	663	119.4	46.8
19	37, F	Pons (Rt)	16 × 18 × 18	2.6	5543	327	94.9	36.7
20	25, F	Medulla (Rt)	14 × 16 × 22	2.5	3591	545	101.3	33.8

The 10 patients (cases 11–20, three men, seven women) had been diagnosed with BCM and were treated surgically using the telovelar approach. The average age of the patients was 34.9 years and the threshold at which the FC is most visible was set by image thresholding using the full width at half maximum of the brainstem and cerebrospinal fluid. The author, neurosurgeon (TU), created all the 3D images; the average 3D image creation time was 505.4 s. The average evaluation time by each observer was 113.3 s for 2D images and 35.1 s for 3D images. BCM: brainstem cavernous malformation, FC: facial colliculus, 2D: two-dimensional, 3D: three-dimensional.

0.97, and 0.89, respectively, for the affected side in 2D images, and 0.92, 0.95, and 0.93, respectively, for the unaffected side and 0.93, 0.95, and 0.91, respectively, for the affected side in 3D images (Table 1). The ICC (3,3) was 0.95 for the unaffected side and 0.89 for the affected side in 2D images, and 0.92 for the unaffected side and 0.88 for the affected side in 3D images (Table 1). The intra- and inter-rater reliability were good. The FC-identification certainty was significantly higher for 3D than for 2D images (40.2 vs. 24.6,  $P = .0059$  for the unaffected side, 29.3 vs. 17.3,  $P = .0020$  for the affected side; Table 2; see Supplementary Table 2). Figure 1 shows the 2D and 3D images of all cases in the BCM group (Cases 11–20).

#### **Illustrative case: Case 17—a 42-year-old woman**

This patient had right hemiplegia, left abducens nerve palsy, and left facial nerve paralysis due to four past episodes of brainstem hemorrhages. The BCM had spread widely around the left pons, and the lesion volume was 5.9 mL. Preoperative 2D images showed that the median sulcus had deviated to the right, but the region of the FC could not be identified on the unaffected or the affected side (Fig. 2A). Surgical resection of the BCM using the telovelar approach was planned. It was possible to identify the region of the FC on both sides in 3D images using the proposed method, and the anatomical structure of the dorsal brainstem (such as the obex,

median sulcus, and lateral recess) could be observed in detail (Fig. 2B). The location of the BCM, and the part of the BCM that is nearest to the surface of the brainstem, was determined three-dimensionally, and it was also confirmed that the developmental venous anomaly could be preserved. The infra FC approach was considered as the most suitable surgical approach (Fig. 2C). During the operation, the cerebellomedullary fissure was widely opened to the outer area of the lateral recess, and the region of the FC was identified by direct electric stimulation. After confirming that the region of the FC matched that identified in the preoperative 3D image, the BCM was resected using the infra FC approach (Fig. 2D). There were no surgical complications and the postoperative course was uneventful. In this case, the average FC-identification certainty was 16.8 for the unaffected side and 15.1 for the affected side in the 2D image, and 35.8 for the unaffected side and 20.6 for the affected side in the 3D image (Table 2). The 3D image had a higher FC-identification certainty for both sides than the 2D image.

## **Discussion**

In this study, in the normal brainstem group, the FC-identification certainty was 61.5 in 2D images and 82.4 in 3D images. In this group, identification was often difficult using 2D images; however, using 3D images, identification was possible in many cases.

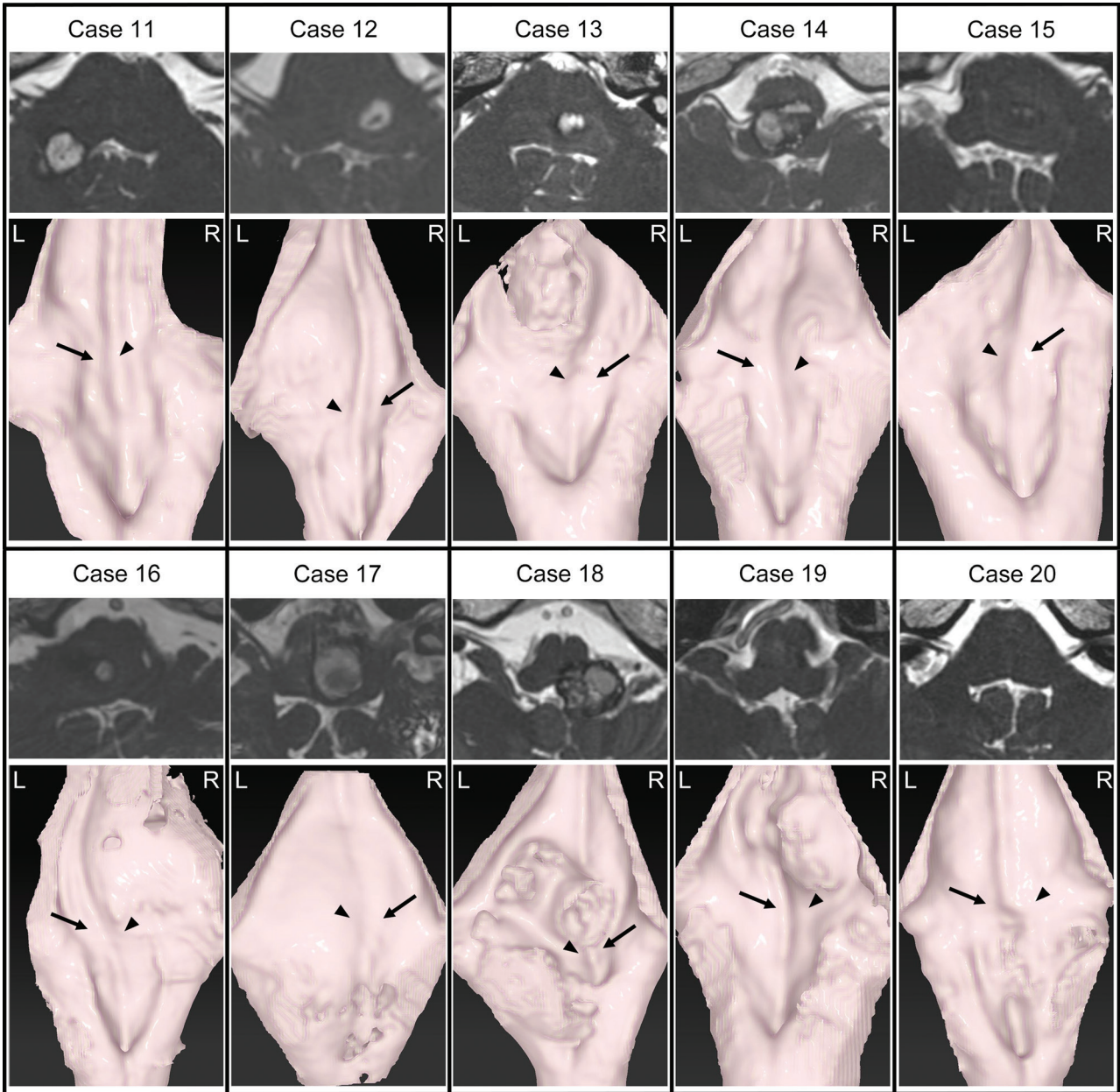


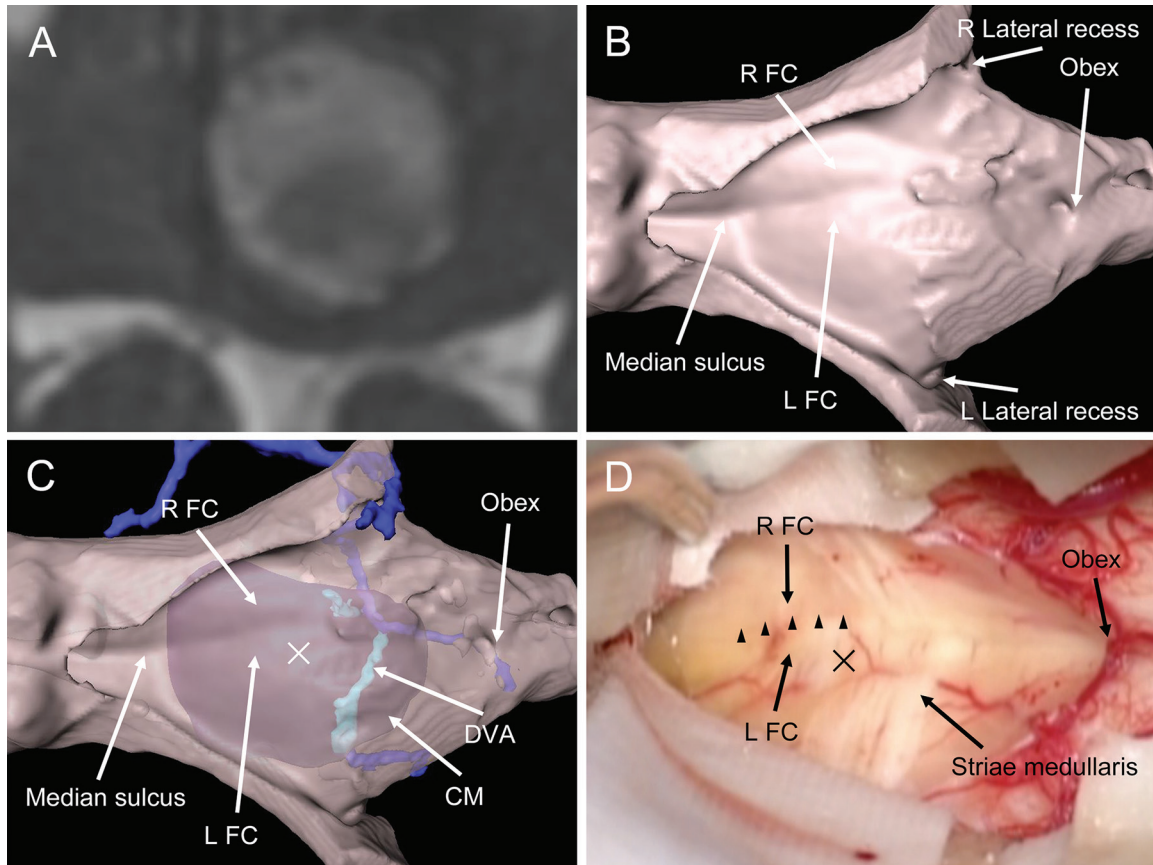
Fig. 1 All 2D (axial) and 3D MRI of the BCM group. It was difficult to identify FC on 2D images, and the FC-identification certainty was low. The 3D images had a higher identification certainty than the 2D images. Arrows indicate the FC on the unaffected side, and arrowheads indicate the FC on the affected side. BCM: brainstem cavernous malformation, FC: facial colliculus, L: left, MRI: magnetic resonance imaging, R: right, 2D: two-dimensional, 3D: three-dimensional.

In the BCM group, the FC-identification certainty was 24.6 for the unaffected side and 17.3 for the affected side in 2D images, and 40.2 for the unaffected side and 29.3 for the affected side in 3D images. In the presence of BCM, the identification of the FC in 2D images was almost impossible, even on the unaffected side. Some 3D images could be identified on the unaffected side, but this was shown to be extremely difficult on the affected side.

There are no reports that verify the identification accuracy and identification rate of the FC in 2D and 3D images.

#### Identification of the FC in the normal brainstem and BCM groups

The BCM group had a lower identification certainty than the normal brainstem group in both 2D and 3D images. In this group, the FC-identification



**Fig. 2** Case 17: MRI, interactive computer graphics, and actual operative view of a 42-year-old female patient with a BCM. (A) Axial image obtained using contrast-enhanced fast imaging with steady-state acquisition. The FC cannot be identified on the 2D image. (B) Dorsal view of the brainstem on the 3D image. The anatomical structure of the dorsal brainstem can be observed in detail. (C) Dorsal view of the brainstem with the brainstem rendered translucent using 3D fusion imaging. The nearest position of the BCM (indicated by X) to the surface of the brainstem was located caudal to the left FC. This position was the incision site used during surgery. (D) Actual operative view. The BCM was resected using the infra FC approach. X indicates the incision site. Arrowheads indicate the median sulcus. BCM: brainstem cavernous malformation, CM: cavernous malformation, DVA: developmental venous anomaly, FC: facial colliculus, L: left, MRI: magnetic resonance imaging, R: right, 2D: two-dimensional, 3D: three-dimensional.

certainty for the affected side was lower than that for the unaffected side. This could be explained by the fact that the floor of the fourth ventricle irregularly bulges due to the BCM and the deviation from the normal structure makes the identification of the FC difficult. Moreover, since the affected side is more strongly affected by the BCM bulge than the unaffected side, it could be inferred that the identification certainty would be lower.

#### Identification of the FC in 2D images

In this study, in both the normal brainstem and BCM groups, the FC-identification certainty was lower in 2D images than in 3D images. For FC identification on 2D images, we focused on the MRI sequence, the structure of the FC, and the resolution of 2D images.

In recent years, high-resolution imaging has become possible with balanced steady-state free precession such as CE-FIESTA, which has dramatically improved diagnostic imaging.<sup>12)</sup> The sequence used in this study for obtaining 2D images was CE-FIESTA using a 3.0 T MRI scanner. CE-FIESTA is extremely suitable for imaging around the brainstem given that structures other than cerebrospinal fluid (all cranial nerves, arachnoid membranes, etc.) appear hypointense, the contrast ratio between the cerebrospinal fluid and brain parenchyma region is high, and there are only a few pulsation artifacts.<sup>13,14)</sup> CE-FIESTA is the best sequence for obtaining 2D images which are used clinically for the identification of the FC.<sup>12,15–17)</sup> Nevertheless, the FC-identification certainty was low for 2D images because the FC is an anatomical microstructure.

A morphometric study of the surface structure of the brainstem showed that the rostrocaudal length of the FC was approximately 3 mm and the ventrodorsal elevation was  $0.73 \pm 0.30$  mm.<sup>5,6)</sup> In patients with a structural disorder of the brainstem, the average length between the median sulcus and the medial border of the FC was reported to be 1.9 mm (0.3–7.9 mm).<sup>7)</sup>

The CE-FIESTA used in this study had a FOV of 20 cm and a matrix size of  $512 \times 512$ ; therefore, the size of one pixel was 0.39 mm. However, the resolution was not 0.39 mm. To completely reproduce the original signal digitally, it is essential to sample at a frequency that is at least twice the spatial frequency of the original signal (signals sampling theorem).<sup>18)</sup> Specifically, when observing with CE-FIESTA, grasping is limited to structures with a size up to 0.8 mm. Therefore, it is difficult to grasp the FC with sufficient accuracy with CE-FIESTA for surgical planning, given a ventrodorsal elevation of approximately 0.73 mm and a minimum length from the median sulcus of 0.3 mm. It is more difficult to identify the FC on the affected side because the anatomy on the surface of the brainstem is deranged due to the lesion.<sup>7,19)</sup>

### Identification of the FC on 3D images

The probable explanation for a 3D image being better able to reveal the FC, despite using the same CE-FIESTA as used for a 2D image, is described below.

Generally, when creating 3D images by surface rendering, the marching cubes algorithm is used to extract the outer wall of the organ by displaying the isosurface from the CE-FIESTA voxel data. This algorithm is one of the methods used to convert voxels into polygons,<sup>20)</sup> and the converted polygon model is subsequently displayed using the surface rendering method. With this display method, the vertex coordinates of the patch are not affected by the voxel size, so that the fineness is maintained even when enlarged.<sup>20)</sup> The marching cubes algorithm can clearly display a slight difference in pixel values, visualize the anatomical structure of the brainstem surface as a smooth continuous surface, and enable visualization beyond resolution. The marching cubes algorithm is recognized as excellent for identifying microstructures on the surface of the brainstem, such as the FC.<sup>21)</sup>

In addition, improving the quality of images when creating the 3D images to make it easier to recognize structures also contributed to the superiority of the 3D images. Specifically, the optimal threshold was set by image thresholding using FWHM for each case to improve the visibility, and unnecessary

structures and noise were removed. Furthermore, in 3D images, visualization techniques such as lighting and shading are also considered to contribute to the recognition of microstructures.<sup>22,23)</sup> Another advantage of a 3D image is that it is easier to estimate the dimensions of the FC with respect to the positions of surrounding structures (median sulcus, obex, foramen of Luschka, etc.) compared with 2D images.

### Reliability of the FC-identification certainty

Many published scale validation studies determine the intra- and inter-rater reliability using the ICC.<sup>24)</sup> Kuwabara et al.<sup>25)</sup> consider an ICC of  $\geq 0.9$  to be excellent,  $\geq 0.8$  to be good,  $\geq 0.7$  to be normal,  $\geq 0.6$  to be possible, and  $< 0.6$  to need to be reconsidered. Landis et al.<sup>26)</sup> classify an ICC of 0.81–1.00 as almost perfect, 0.61–0.80 as substantial, 0.41–0.60 as moderate, 0.21–0.40 as fair, and 0.0–0.20 as slight. In this study, both the ICC (1,3) and ICC (3,3) were 0.8 or more, indicating that the FC-identification certainty was highly reliable.

### Evaluation time

In the BCM group, there was a significant difference in the average evaluation time between the 2D and 3D images (113.3 s vs. 35.1 s,  $P < .0001$ ). Evaluation of 3D images using the software was easy and required few operations. On the contrary, evaluation of 2D images was time-consuming, requiring various operations such as changing the slices and views (axial, sagittal, and coronal). It should be noted that the difference between these evaluation times is only due to operability and it does not affect the FC-identification certainty.

### Sample size

In this study, the sample size was limited to 20 cases (10 cases each in the normal brainstem group and the BCM group). FC-identification certainty in 3D images was clearly higher than that in 2D images in all cases. Hence, although it was possible to increase the number of samples in the normal brainstem group, we presumed that the results would not be changed by a larger sample size. Even though the number of samples in the BCM group was small and it was difficult to perform a statistically accurate test, we felt the statistical difference was obvious.

### 3D images in BCM surgery

The FC cannot be identified accurately only by evaluating 3D images, so it is important to perform direct electric stimulation of the facial nerve to determine its path during BCM surgery. Especially

when the normal structure strongly deviates due to BCM, the region of the FC can be estimated by electrical stimulation and its approach point determined. This study focused on FC anatomy visualized by 2D and 3D images. The role of the 3D images in the BCM surgery was such that the degree and direction of FC deviation might be predicted preoperatively. It will be necessary to increase the number of samples in the BCM group to verify the prediction of deviation and the identification rate of the FC in a prospective study.

### Limitations

Due to the small sample size, the evaluation of the 2D images may have affected the evaluation of 3D images. In addition, since the identification was performed three times, it is necessary to consider that the observers may have become familiar with the identification. As this study was retrospective, these 3D images were not used as a navigation system or assistance in the FC identification by direct electric stimulation.

### Conclusions

The FC-identification certainty in 2D and 3D images was validated in patients with a normal brainstem and BCM. It was found that 3D images had a higher FC-identification certainty in both the normal brainstem and BCM groups (unaffected and affected sides) compared with 2D images. Evaluation of 3D images is an effective method for the identification of the FC.

### Acknowledgment

Part of this research was supported by the Japan Agency for Medical Research and Development [AMED; grant number JP18he1602001]. The sponsor had no involvement in the planning or execution of the study, nor in the writing of the report or the decision to submit the article for publication.

We would like to thank Dr. Takuya Kawahara of the Clinical Research Promotion Center, University of Tokyo for statistical analysis.

We would also like to thank Editage (www.editage.jp) for English language editing.

### Conflicts of Interest Disclosure

None.

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