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Technical notes & surgical techniques

# A minimally invasive approach for the treatment of isolated type intracranial dural arteriovenous fistula in a neurosurgical hybrid operating room

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A R T I C L E I N F O

*Keywords:*
Dural arteriovenous fistula
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A B S T R A C T

*Objectives:* Isolated-type intracranial dural arteriovenous fistulas (DAVFs) could hinder the effective use of the transvenous approach. Direct trans-sinus embolization (dTSE) with craniotomy remains the treatment method for isolated-type DAVFs. We report our experience in using a neurosurgical hybrid operating room (NHOR) to treat cases of isolated-type DAVFs by dTSE using a single burr hole.

*Patients and methods:* Between April 2007 and March 2017, 189 DAVFs were treated by an endovascular procedure at our institution. Among these cases, 27 patients (14.3%) had isolated-type DAVF and 7 patients (3.7%) were treated by dTSE. The procedure accuracy and invasiveness of dTSE were compared with those of the transvenous embolization (TVE) group.

The NHOR was equipped with a biplane angiography system and used to perform 3D rotational angiography (3DRA). The burr hole site was precisely determined by 3DRA. Only one burr hole was made to expose the target sinus and allow for direct puncture. The target sinus was occluded by using coils and liquid embolic material.

*Results:* The NHOR allowed the accurate placement of the burr hole. Only a single burr hole and small skin incision (with minimal bleeding) were required for each dTSE case. The mean total contrast volume was significantly reduced in the dTSE group compared with that in the TVE group. Moreover, the dTSE group required shorter operation times and lower total radiation doses compared with the TVE group.

*Conclusion:* Using dTSE could be performed with a single burr hole using a NHOR equipped with biplanar fluoroscopy. This approach is a minimally invasive and effective treatment for isolated-type DAVFs.

## 1. Introduction

Intracranial dural arteriovenous fistulas (DAVFs) are direct pathologic connections between arteries and veins in the interjacent dura matter. Management alternatives for this condition include observation, open surgery, endovascular embolization, and radiosurgery. The management approach is chosen on the basis of various factors, including lesion location and venous drainage [13]. Venous drainage patterns are commonly classified by using the classification criteria of Borden and Cognard [1,5]. High-grade DAVFs, which are classified as Borden II and III/Cognard IIb–V, feature cortical venous drainage and are associated with a high risk of bleeding; therefore, this type of DAVF should be treated immediately [7,13,18]. DAVFs with an isolated sinus are referred to as isolated-type DAVFs and are typical examples of high-grade DAVFs. Open surgery, direct trans-sinus embolization (dTSE) with craniotomy, and radiosurgery are considered appropriate treatment methods for isolated-type DAVF. However, while surgical approaches have high cure rates, they are also very invasive procedures [9,14,17]. The radiosurgaical approach has low cure rates and requires long durations before obliteration is accomplished [11,16]. Onyx (Covidien, Plymouth, MN, USA) was recently developed, and the effectiveness of transarterial embolization (TAE) with Onyx for DAVF has been reported, particularly in cases of isolated-type DAVF. However, the efficacy of TAE with Onyx for other neurological complications has not been established [6,19]. Compared with other procedures, transvenous embolization (TVE) is the curative treatment of choice.

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Nevertheless, TVE is frequently difficult to perform in cases of isolated-type DAVFs. Combination therapy including surgery and TVE may involve craniectomy with direct sinus cannulation; however, these procedure are complex and invasive [2,8,10,20].

Neurosurgical hybrid operating rooms (NHORs) were recently developed to perform both neurosurgical and endovascular procedures. An NHOR allows the real-time imaging and 3D reconstruction of complex vascular lesions during cerebrovascular surgery [4,12]. In the current paper, we report our experience in using an NHOR to treat cases of isolated-type DAVFs by dTSE using a single burr hole and minimally invasive surgical procedures.

## 2. Patients and materials

### 2.1. Criteria for treatment

The first-line procedure for isolated-type DAVFs at our institution until October 2012 was TVE with the piercing technique or TAE depending on the number of feeding arteries and the length of shunt points. We changed therapeutic measures on account of bleeding complications and prolonged operation times in November 2012. We believe dTSE to be a good option for treating isolated-type DAVFs located on the transverse sinus (TS) or superior sagittal sinus (SSS) with a long sinus occlusion at both ends (> 20 mm). Patients who were treated by other procedures resulting in remaining shunt and those who had severe renal function impairment were considered eligible for this procedure.

### 2.2. Subjects

Between April 2007 and March 2017, 189 patients with DAVFs were treated by an endovascular procedure at a single center (Saitama Medical University International Medical Center, Saitama, Japan). Among these patients, 27 (14.3%) had isolated-type DAVF and 7 (3.7%) were treated by dTSE. Among the 11 isolated-type DAVFs treated until October 2012, five patients were treated by TAE and six patients were treated by TVE. Among the 16 isolated-type DAVFs treated since November 2012, eight patients were treated by TAE, one patient was treated by TVE, and seven patients were treated by dTSE only. The seven patients treated by dTSE included three males and four females with a mean age of 71.0 years (range, 44–89 years). Six DAVFs had a TS location, and one DAVF was located in the SSS. Of these seven cases, two cases had previously received treatment but TVE had failed in one case and TAE was incomplete in another case. Besides these two cases, four cases had long occluded sinus and another case had severe renal dysfunction (Table 1).

Informed consent was obtained prior to treatment. The protocol for endovascular treatment was approved by the Institutional Review Board of Saitama Medical University International Medical Center. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. No competing interests are declared.

**Table 1**
Characteristics of the patients and DAVF cases.

| | Age (years) | Sex | Location | Borden classification | Characteristics |
|---|---|---|---|---|---|
| 1 | 75 | F | TS | 3 | Long occluded sinus |
| 2 | 83 | M | TS | 3 | TVE failure, Retreatment after TAE |
| 3 | 44 | F | SSS | 3 | Additional treatment after TAE in one session |
| 4 | 73 | F | TS | 3 | Long occluded sinus |
| 5 | 66 | M | TS | 3 | Long occluded sinus |
| 6 | 89 | F | TS-SS | 3 | Long occluded sinus |
| 7 | 47 | M | TS | 3 | Long occluded sinus |
| 8 | 67 | M | TS | 3 | Severe renal dysfunction |

TS: transverse sinus; SS: sigmoid sinus; SSS: superior sagittal sinus; TVE: transvenous embolization; TAE: transarterial embolization; M: male; F: female.

### 2.3. Methods

The NHOR at our institution is equipped with a biplane angiography system (AXIOM Artis dBA, Siemens, Munich, Germany). Both neuroendovascular procedures and open surgery can be performed in the NHOR without patient transfer.

All treatments were performed under general anesthesia. The patient lay supine on the treatment table. First, we punctured the femoral artery and then inserted a catheter. Next, we fixed the cranium with a three-pin fixture and placed the patient in the prone position (Fig. 1). The diagnostic catheter was guided into the feeding artery, i.e., the external carotid artery in most cases. 3D rotational angiography (3DRA) was performed, and the operator decided the position of the burr hole position using the 3D digital subtraction angiography (3D DSA). The 3D cranium images obtained by the 3DRA were combined with those obtained by 3D DSA to achieve 3D images providing a clear location and direction of sinus puncture. The vertical angulation allowed by the 3DRA enabled clear visualization of the site of the cranium in which the burr hole was to be drilled. 3D DSA simultaneously showed the feeding artery in the subcutaneous tissue, which is helpful for avoiding bleeding into the operative field. Only one burr hole was drilled, and the target sinus was exposed and directly punctured with a 3-French sheath with a check valve connector or an 18-gage needle cannula with a 15 cm extension tube and Y-connector. The sheath or needle cannula was tied with skin edge part. A micro catheter with an internal lumen diameter of 0.0165–0.017 in. could meet the needs of the operator. Coils and liquid embolic materials were then inserted through the microcatheter, and the AVF was completely occluded. Finally, the skin incision was sutured.

### 2.4. Data analysis

The treatment policy of our institution was modified in November 2012. Statistical analysis of the results of patients treated by TVE with dTSE inclusion criteria until October 2012 and patients treated by dTSE since November 2012 was performed.

Analysis was carried out by using JMP V.12 (SAS Institute, Cary, NC, USA). The Fisher's exact probability test was used for statistical comparisons of the treatment results. The average total operation time, total radiation dose, and total contrast volume were expressed as mean ± standard deviation and analyzed statistically by using the Wilcoxon test. P-values $< 0.05$ indicated a statistically significant difference.

## 3. Results

A single burr hole was drilled in the correct location, and the effective occlusion of the shunt was achieved in all cases treated by dTSE (Fig. 2). Consequently, a less invasive procedure compared with TVE was possible. Overall, the mean skin incision and mean operative blood loss for dTSE cases were approximately 4 cm and under 20 ml, respectively.

Six patients were treated by TVE using dTSE inclusion criteria until October 2012. Among seven patients treated by dTSE since November 2012, diagnostic angiography and treatment were performed in one session in one patient and TAE and dTSE were performed in one session in another patient. Thus, these two patients were excluded from the statistical analysis.

The slight remains of shunt were observed in only one case treated by TVE. All cases demonstrated complete shunt disappearance at the 3-month follow-up by DSA in both treatment groups. Two complications occurred in the TVE group, and one complication was occurred in the

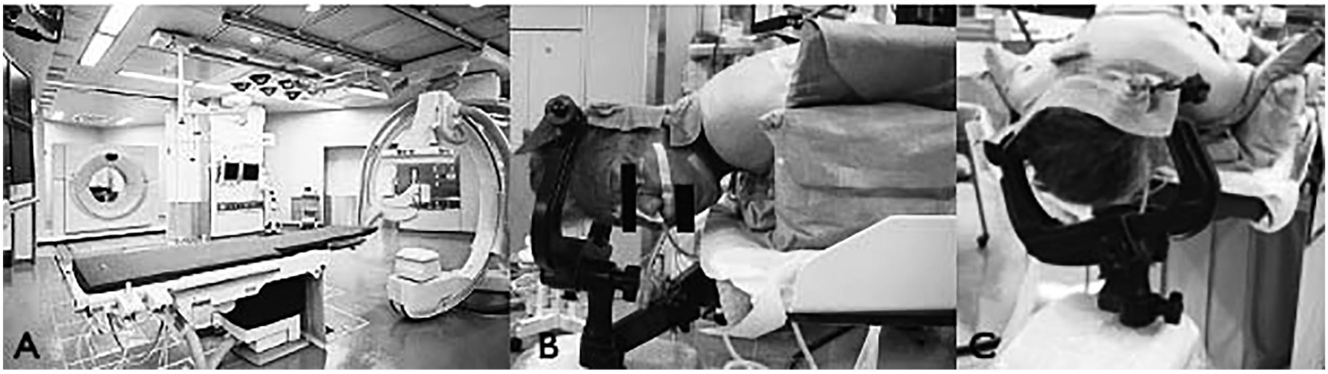


**Fig. 1.** (A) The Neurosurgical hybrid operating room at our institution. (B, C) A patient with dural arteriovenous fistula in the left transverse sinus was placed in the prone position, and was tightened with a three-pin fixture.

dTSE group. All complications were related to bleeding due to acute subdural hematoma and subarachnoid hemorrhage without neurological deficit.

The results of this analysis are detailed in Table 2. Among the 11 cases studied, those treated by dTSE had a lower total contrast volume than those treated by TVE (123.0 ± 52.8 ml vs. 283.8 ± 118.4 ml, $p = 0.023$). While the operation time (254.2 ± 50.5 min vs. 344.8 ± 128.8 min, $p = 0.171$) and total radiation dose (2300.4 ± 850.9 mGy vs. 3374.2 ± 2073.1 mGy, $p = 0.523$) between groups were not significantly different, dTSE revealed slightly shorter operation times and small reduction in total radiation dose compared with TVE.

**Table 2**
Comparison of the results between TVE and dTSE.

| | TVE (n = 6) | dTSE (n = 5) | *p* value |
|---|---|---|---|
| Age (yr) | 72.2 ± 7.1 | 72.8 ± 6.1 | |
| Shunt remain immediately after treatment | 1 | 0 | – |
| Shunt remain at 3 month DSA | 0 | 0 | – |
| Complications | 2 | 1 | – |
| Contrast volume (ml) | 283.8 ± 118.4 | 123.0 ± 52.8 | 0.023* |
| Operation time (min) | 344.8 ± 128.8 | 254.2 ± 50.5 | 0.171 |
| Total radiation dose (mGy) | 3374.2 ± 2073.1 | 2300.4 ± 850.9 | 0.523 |

*: significant difference, $p < 0.05$.

## 4. Illustrative case

The patient was diagnosed with Parkinson's syndrome secondary to isolated-type TS DAVF. In this case, congestion of the deep cerebral venous system occurred with retrograde venous flow from the straight sinus. Two shunt points were located on the lateral side of the TS, and the other was close to the confluence. A smaller shunt with only anterograde sinus flow was located on the anterior condylar confluence (Fig. 3). Treatment was indicated for this isolated-type TS DAVF, but the patient had severe renal failure. Thus, dTSE was performed in the NHOR.

The 3D DSA images were obtained, and the burr hole location was identified. We decided the angulation of the X-ray, and the burr hole site and skin incision were maintained in the vertical direction in relation to the cranium. The occipital artery was identified as the feeding artery, and detected under a scar (Fig. 4). Skin incision, ligation of the occipital artery, and creation of a single burr hole were performed with little bleeding and excellent accuracy. An 18-gage needle cannula was inserted into the TS toward the confluence (Fig. 5). Coils were inserted

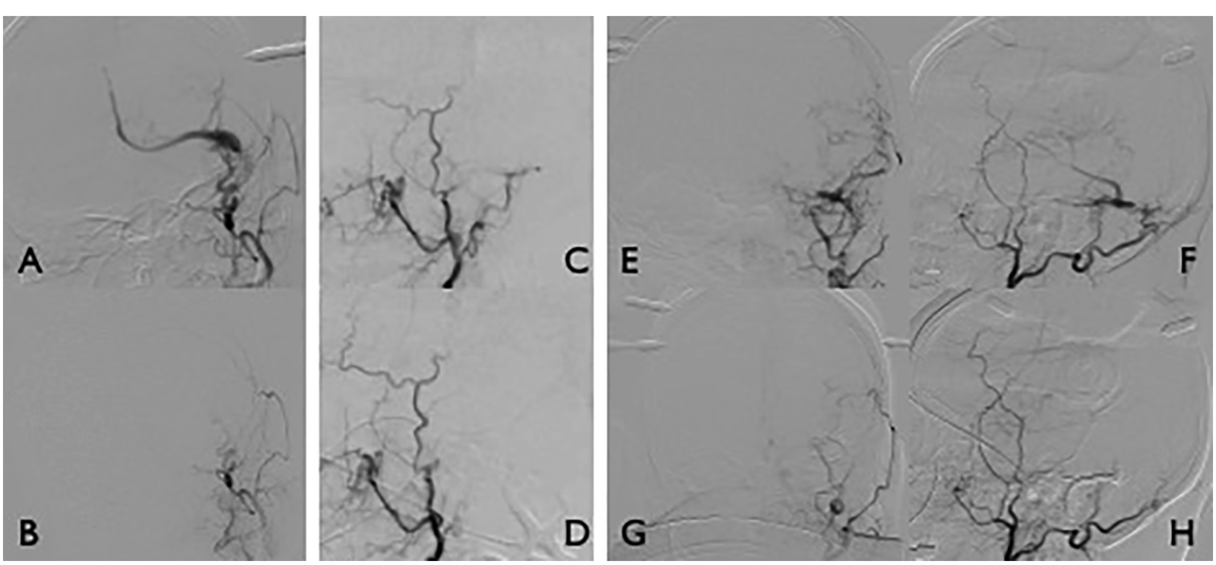


**Fig. 2.** Imaging findings of the three cases. Case 1: (A) Preoperative DSA anteroposterior view of an isolated-type dural arteriovenous fistula (DAVF) in the left transverse sinus (TS) with venous reflux in the straight sinus. (B) Postoperative DSA view shows no remaining shunt. Case 2: (C) Preoperative DSA lateral view of an isolated-type DAVF in the left TS with venous reflux in the superior petrosal sinus. (D) Postoperative DSA view shows no remaining shunt. Case 3: (E, F) Preoperative DSA anteroposterior and lateral views of an isolated-type DAVF in the TS with venous reflux in the vein of Labbe. (G, H) Postoperative DSA view shows no remaining shunt.

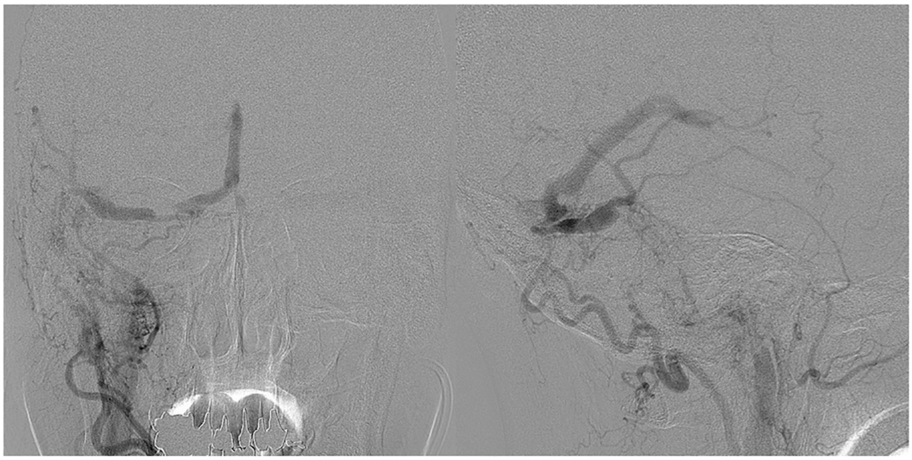

**Fig. 3.** External carotid arteriography showing an isolated-type dural arteriovenous fistula (DAVF) in the transverse sinus (TS) and small DAVF at the anterior condylar confluence. The venous reflux is observed in the straight sinus. Shunt points are observed on the lateral wall of the TS and on the TS near the confluence.

**Fig. 4.** Combination of a 3D cranial image and a 3D digital subtraction angiograph into a single 3D image to decide the angulation of the X-ray. The burr hole site was identified on the basis of this image (marked with a circle). The existence of an occipital artery under the skin incision was noted.

through the straight sinus into the TS, and the direction of the cannula was changed toward the lateral wall of the TS. A total of 18 coils were used to fill the sinus, and a small dose of liquid embolic material (*n*-butyl-2-cyanoacrylate) was injected. The surgical incision was closed after ascertaining the complete occlusion of the TS DAVF (Fig. 6).

## 5. Discussion

The dTSE we described herein may be used in the noninvasive curative correction of isolated-type DAVFs. Isolated-type DAVFs are usually associated with cortical refluxes and a high risk of bleeding; therefore, this type of DAVF must be surgically treated [7,13,15,18]. The main purpose of treating high-grade DAFs is to obliterate the shunt and relieve the pressure on the normal venous system. While TVE is a curative treatment, the procedure is sometimes not feasible because of access difficulties. Surgical treatment, radiosurgical treatment, and TAE are adopted for complex DAVFs. On the one hand, the surgical approach has high cure rates, but it is a very invasive procedure [9,14,17]. On the other hand, the radiosurgaical approach has low cure rates and requires long durations before obliteration is achieved [11,16]. Onyx was recently developed, and the effectiveness of TAE with Onyx for DAVF has been reported, particularly in cases of isolated-type DAVF [6,19]. The risk of TAE with Onyx includes the migration of Onyx from the sinus to the arterialized draining veins; this phenomenon may cause venous infarction, reflux, and subsequent cranial nerve injury and cerebral infarction via dangerous anastomoses. Treatment procedures other than TVE generally require considerable invasion or have low cure rates. Combination therapy including surgery and TVE may involve craniectomy with direct sinus cannulation [2,8,10,20]. The methods currently used to determine craniectomy and burr hole location, as well as the size of the craniectomy, are not well established. Caplan et al. [3] introduced a combined surgical approach and TVE using neuronavigation that resulted in the successful single burr hole craniectomy for direct sinus cannulation. Neuronavigation is very useful for identifying the most accurate location of the burr hole, which could also be accomplished by using 3DRA. Whereas neuronavigation provides limited information on the burr hole, 3DRA provides detailed information about the entire structure of the shunt and the burr hole. Mobile single fluoroscopy can be combined with neuronavigation in operating rooms other than the NHOR. Biplanar fluoroscopy is often

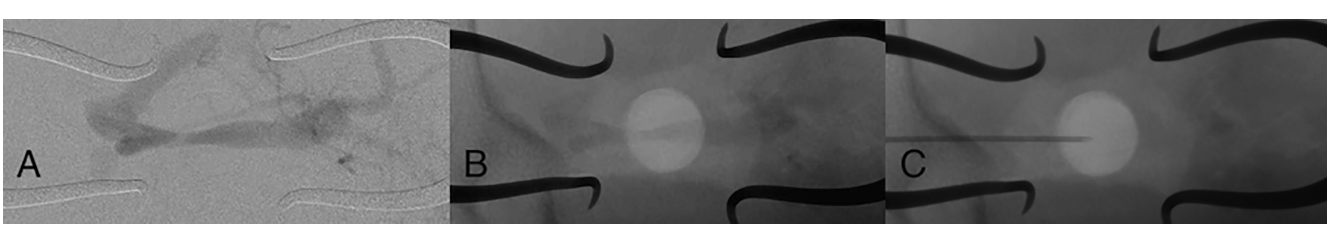


**Fig. 5.** (A) Site of the burr hole after making the skin incision. (B) Accurate creation of a single burr hole on the site. (C) Insertion of an 18-gage needle cannula into the transverse sinus toward the confluence.

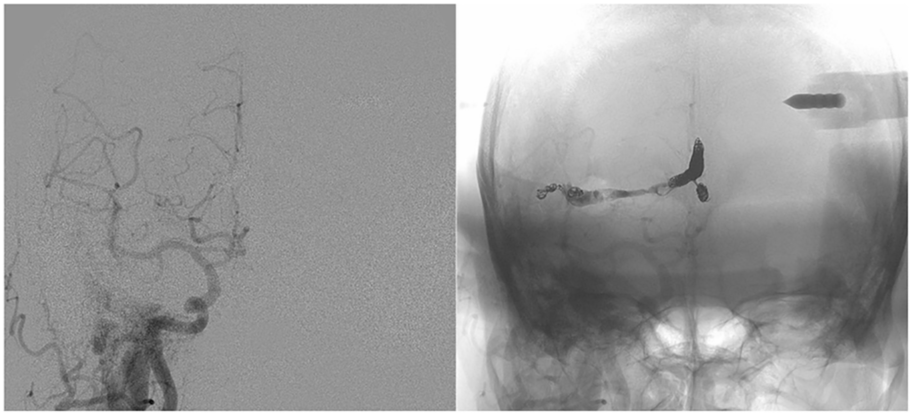

**Fig. 6.** Insertion of 18 coils and *n*-butyl-2-cyanoacrylate into the transverse sinus. The dural arteriovenous fistula was completely occluded.

applied to sinus embolization because single fluoroscopy renders embolization cumbersome. Therefore, the NHOR presents clear advantages over neuronavigation because the former is useful for the accurate identification of the location of the burr hole and direction of cannulation without the use of other equipment. Additionally, both the surgical and endovascular approaches can be performed without patient transfer using NHORs.

The procedure we described herein may be used in the noninvasive curative correction of DAVF. This procedure is expected to reduce contrast usage. Because only one puncture is needed to reach the target sinus in all cases, dTSE shortens the operation time and reduces the total radiation dose, as expected for minimally invasive procedures. Indeed, while the operation time and total radiation dose between procedures were not significantly different in this study, dTSE demonstrated slightly shorter operation times and small reductions in total radiation dose compared with TVE. This finding may be attributed to the regular use of 3DRA and other imaging modalities during dTSE.

Our study has several limitations. This study employs a retrospective design and includes a relatively small number of patients. The procedure we developed requires validation over time, and the operator must have knowledge of open surgery and endovascular surgery.

## 6. Conclusion

This report describes dTSE for intracranial isolated-type DAVF performed in the NHOR equipped with biplanar fluoroscopy. The proposed procedure is minimally invasive and highly effective.

## Funding

No funding was received for this research.

## Ethical approval

The protocol for endovascular treatment was approved by the Institutional Review Board of Saitama Medical University International Medical Center. Formal consent was not required for this type of study.

## Informed consent

This retrospective study was approved by the Institutional Review Board of Saitama Medical University International Medical Center. The requirement to obtain informed consent was waived.

## CRediT authorship contribution statement

**Hiroaki Neki:** Methodology, Investigation, Resources, Writing - original draft, Visualization. **Azusa Yonezawa:** Investigation. **Aoto Shibata:** . **:** Investigation. **Eisuke Tsukagoshi:** . **Fumitaka Yamane:** Writing - review & editing. **Shoichiro Ishihara:** Conceptualization, Supervision. **Shinya Kohyama:** . **:** Validation, Formal analysis, Data curation, Writing - review & editing, Project administration.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inat.2020.100762.

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