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CASE REPORT

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Evaluation of flow dynamics in distal stent graft-induced new entry using 4D flow MRI

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Key Clinical Message

Distal stent graft-induced new entry may occur after stent grafting for aortic dissection. Four-dimensional magnetic resonance imaging is useful for predicting outcomes, showing accelerated flow and increased wall shear stress, indicating further false lumen expansion.

KEYWORDS

4D flow MRI, aortic dissection, dSINE, stent graft insertion

1 | INTRODUCTION

In recent years, for the management of chronic false lumen-persistent type aortic dissections, percutaneous stent graft placement or open-chest surgery with the insertion of a stent graft, specifically the frozen elephant trunk (FET) technique, has been employed to close the primary entry. The insertion of a stent graft leads to the closure of the entry, followed by thrombosis in the false lumen and a consequent reduction in the aortic diameter. However, as the number of cases has increased, a complication known as distal stent graft-induced new entry (dSINE), characterized by the formation of a new entry at the distal end of the implanted stent graft, has been observed. The circumstances under which dSINE leads to further enlargement of the false lumen remain unclear. Consequently, noninvasive four-dimensional (4D) flow magnetic resonance imaging (MRI) was used for blood flow assessment within the false lumen to establish a treatment strategy for this case.

4D flow MRI enables the visualization and analysis of blood flow within the aorta, allowing for the assessment of parameters such as flow velocity and wall shear stress (WSS). In this case, blood flow evaluation revealed an accelerated flow into the false lumen and an elevation in WSS, suggesting a risk of further enlargement and rupture of the false lumen. Therefore, additional stent graft insertion was performed. This report presents a case in which postoperative thrombosis of the false lumen occurred, leading to a reduction in its diameter and successful prevention of rupture.

2 | CASE PRESENTATION

2.1 | Case history/examination

The patient, a man in his sixties, was admitted with persistent dull pain in his left chest with no skin lesions. He

had a history of hypertension and had been treated with calcium channel blockers. He also had dyslipidemia and been managed with statins. He had a 20-year history of smoking 20 cigarettes per day. Eight years previously, he had undergone Bentall's operation for acute Stanford Type A aortic dissection. Four years ago, due to persistent entry into the distal aortic arch and an increase in aortic diameter, he underwent reoperation with the insertion of a stent graft (FET) and total arch replacement under direct vision. Subsequently, the false lumen in the descending thoracic aorta was successfully thrombosed, leading to a reduction in the aortic diameter, as shown in Figure 1A.

Chest auscultation revealed clear breath and mechanical valve sounds. No significant differences in blood pressure were observed between the arms. Electrocardiography revealed sinus rhythm without ST segment changes. Echocardiography confirmed that the aortic valve had been replaced with a mechanical valve that functioned adequately. Left ventricular wall motion was normal, and no pericardial effusion was detected. Blood tests revealed elevated D-dimer levels. These findings ruled out ischemic heart disease, however, they suggested a recurrent aortic dissection. Contrast-enhanced CT imaging showed distal dSINE at the distal end of the inserted stent graft (FET), with blood flow resuming into the previously thrombosed false lumen of the descending thoracic aorta, as depicted in Figure 1B,C.

2.2 | Methods (investigations and treatment)

Thoracic and back pain were caused by the influx of blood into the false lumen from the newly formed entry at the distal end of the stent. Intensive antihypertensive therapy was then administered. Additionally, blood flow was evaluated using 4D flow MRI to assess the potential future expansion of the aorta. 4D flow MRI revealed accelerated flow from the true lumen to the false lumen at the distal end of the FET (Figure 2A,B) (Video S1), accompanied by an increase in WSS at the site where the flow from the true lumen to the false lumen occurred (Figure 2C) (Video S1). These findings indicate that the diameter of the false lumen is likely to increase further.

2.3 | Conclusion and results (outcome and follow-up)

Consequently, the decision was made to insert an additional stent graft to close the entry. Aortic angiography performed during stent graft insertion confirmed the flow from the true lumen to the false lumen, consistent with the 4D flow MRI findings (Figure 3A,B) (Video S2).

The insertion of the stent graft led to cessation of blood flow into the false lumen and a reduction in its

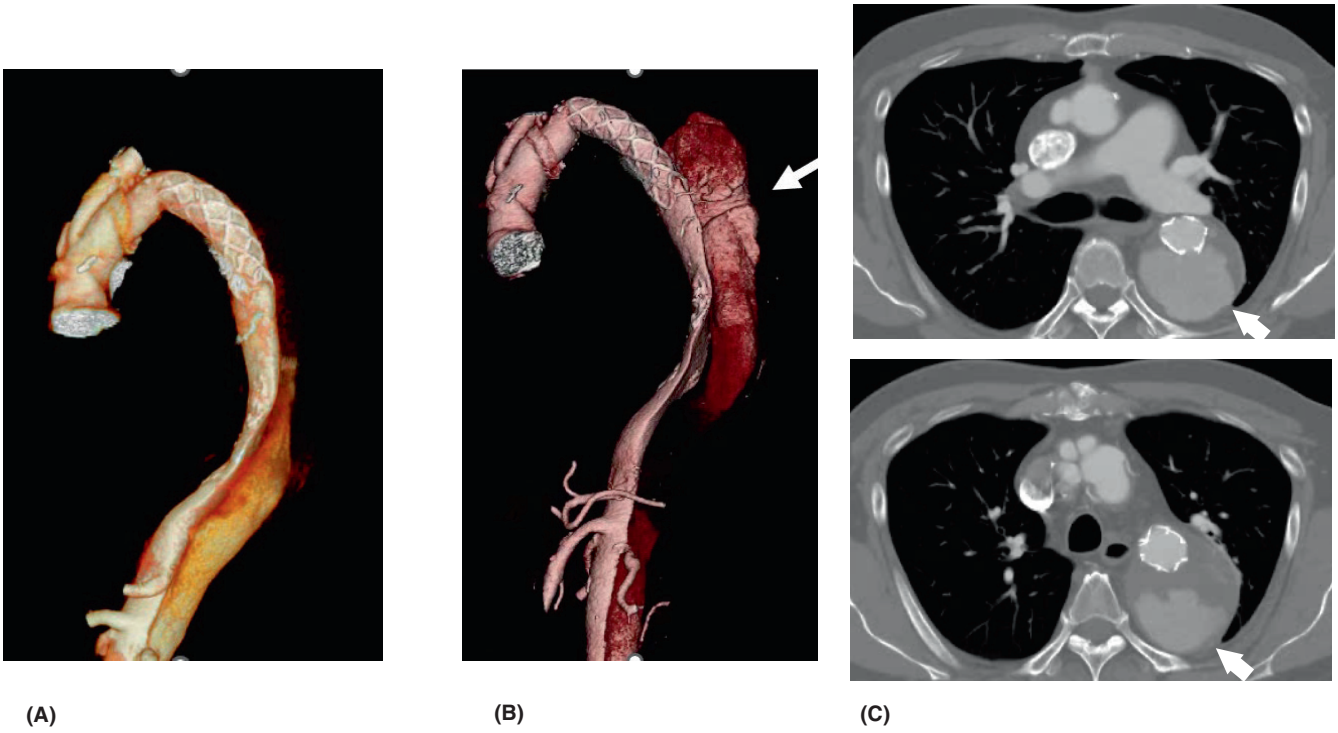

FIGURE 1 Three-dimensional computed tomography (3D-CT) showed the false lumen in the descending thoracic aorta was successfully thrombosed, leading to total arch replacement with a stent graft (A). 3D-CT (B) and contrast-enhanced CT (C) revealed blood flow in the previously thrombosed false lumen and an enlargement of the false lumen diameter.

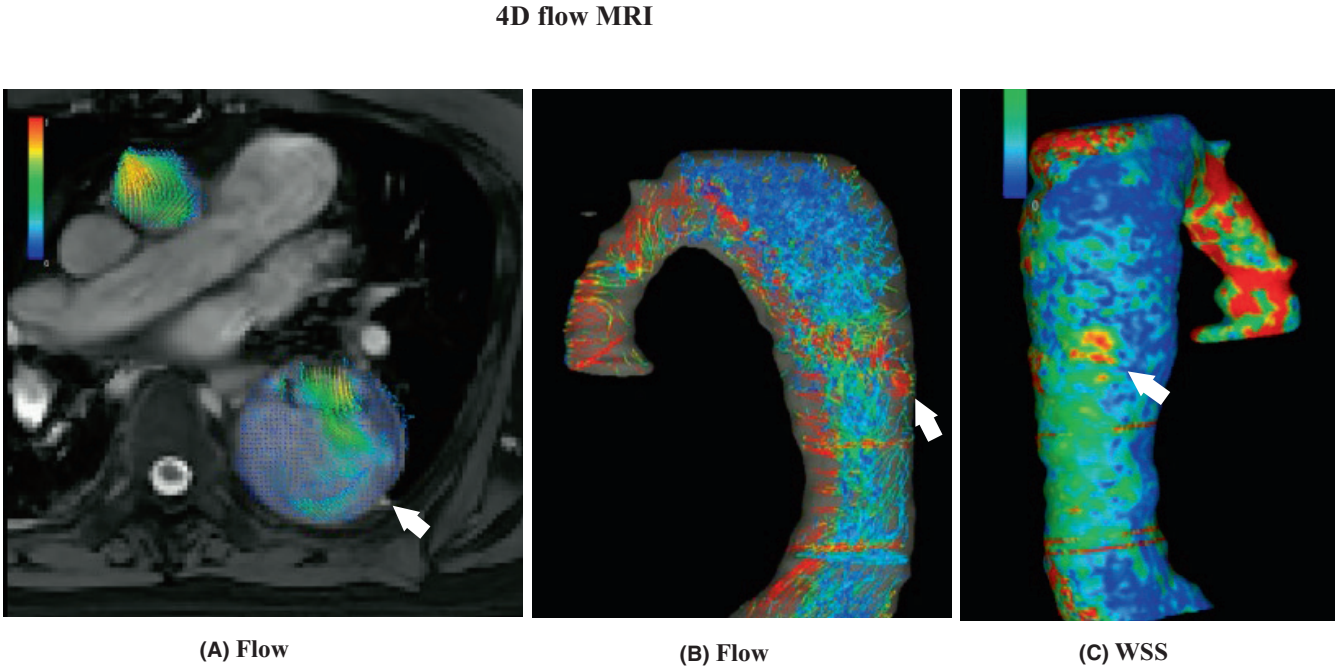

FIGURE 2 Four-dimensional (4D) flow magnetic resonance imaging (MRI) revealed accelerated flow from the true lumen to the false lumen at the distal end of the stent graft. Axial image (A). Three-dimensional (3D) view (B). An increase in wall shear stress (WSS) at the site where the flow from the true lumen to the false lumen is reached (C).

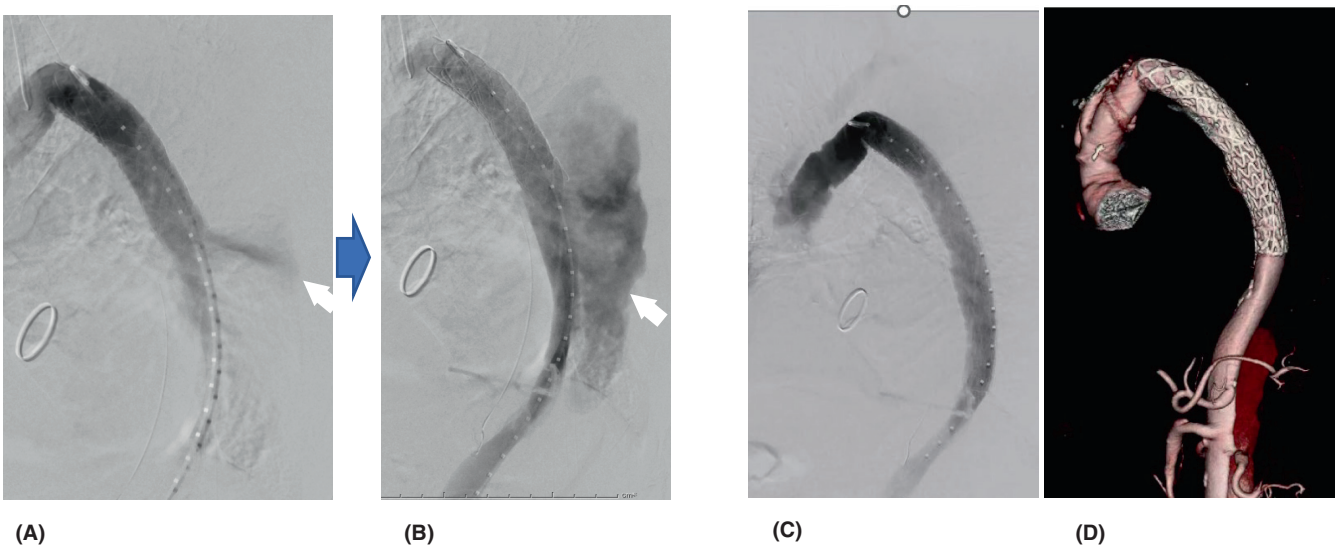

FIGURE 3 Aortic angiography showed high-velocity blood flow from the true lumen to the false lumen at the distal end of the stent graft (A, B). Thoracic endovascular aortic repair (TEVAR) was performed for distal stent graft-induced new entry (dSINE), resulting in the disappearance of blood flow into the false lumen, and the surgery was concluded (C). Postoperative computed tomography (CT) showed thrombosis of the false lumen and a reduction in its diameter (D).

diameter (Figure 3C) (Video S2). Furthermore, the chest and back pain experienced upon admission improved. The postoperative course was uneventful. Fourteen days after surgery, he was successfully discharged from our hospital. Six months postoperatively, CT imaging showed that the false lumen remained thrombosed and the aortic diameter was maintained at a reduced size (Figure 3D).

3 | DISCUSSION

In the acute phase of aortic dissection treatment, artificial blood vessel replacement surgery aimed at closing the entry is performed for Stanford Type A aortic dissections, whereas intensive antihypertensive therapy is conducted in the intensive care unit for Stanford Type B aortic dissection. There is a possibility of enlargement or redissection

of the remaining dissected aorta in the chronic phase. Therefore, post-discharge follow-up using CT scans is recommended. In particular, reports on the prognosis of chronic aortic dissections suggest that cases with a persistent false lumen have a poorer life prognosis than those with closed false lumens, indicating a potential association between the blood flow within the false lumen and chronic enlargement or rupture of the aorta.[1]

In cases of chronic aortic dissection with observed enlargement of the false lumen, treatment is performed by closing the entry through percutaneous or open-chest stent graft insertion, aiming for thrombotic occlusion of the descending thoracic aorta and subsequent reduction in aortic diameter. However, with an increase in the number of cases, the formation of dSINE, allowing blood flow from the true to the false lumen, resulting in false lumen enlargement, has been reported. After open-chest stent graft placement, dSINE occurs in 6.5% of chronic patients. This is attributed to the selection of oversized stent grafts relative to the true lumen diameter and the spring-back force of the stent graft contributing to dSINE formation.[2]

Generally, dSINE is asymptomatic and is often incidentally discovered during routine follow-up CT examinations. However, similar to the present case, approximately 5% of patients present with symptomatic thoracic or back pain and further arterial dilation.[3] In typical CT images of dSINE cases, the entry forms at the distal part of the stent graft inserted into the true lumen, with the distal part of the stent graft protruding into the false lumen, leading to resumed blood flow into the false lumen. To date, there have been no reports indicating which CT findings are associated with an increased risk of aortic expansion or rupture. Recently, blood flow analyses have been performed to predict outcomes of brain aneurysms, aortic aneurysms, and aortic dissections, and 4D flow MRI has emerged as a prominent noninvasive blood flow evaluation method.[4]

The main advantages of 4D flow MRI include: the ability to extract blood flow information at any section from volumetric data, the ability to visualize three-dimensional (3D) blood flow using representation methods such as streamlines, and the computation of parameters such as WSS utilizing 3D velocity vectors. In blood flow analyses of aortic dissections and brain aneurysms, an uneven distribution of WSS at the aneurysm wall and accelerated flow into the false lumen with an uneven distribution of WSS in the false lumen have been reported as risk factors for expansion.[4] Additionally, 4D flow MRI analyses of aortic dissections suggest that acceleration of blood flow and localized elevation of the WSS in the remaining dissected area from the true to the false lumen are factors for distal expansion.

In this case, accelerated flow from the true to the false lumen was observed at the newly formed entry site, along with an elevation in WSS at the arterial wall, indicating the likelihood of further arterial diameter enlargement. Reports indicate that for cases such as dSINE, thoracic endovascular aortic repair (TEVAR) leads to successful thrombosis of the false lumen, controlling its diameter and preventing rupture.[5,6] Therefore, a stent graft was inserted at the newly formed entry site, resulting in thrombosis of the false lumen, arterial diameter reduction, and the disappearance of thoracic symptoms. Six months postoperatively, the patient was symptom-free, with no observed arterial diameter enlargement. However, a risk of new dSINE formation remains, so regular follow-up observations with CT imaging are necessary.

4 | CONCLUSIONS

Following stent graft insertion, new entry at the distal end can lead to expansion of the false lumen as a complication. In this case, 4D flow MRI revealed accelerated flow into the false lumen and an increase in WSS. Therefore, a blood flow analysis predicted further enlargement of the false lumen. In response to this situation, the addition of a new stent graft resulted in thrombotic occlusion of the false lumen and cessation of blood flow, effectively preventing rupture due to expansion of the false lumen. The use of 4D flow MRI for blood flow analysis proved invaluable in determining treatment strategies.

AUTHOR CONTRIBUTIONS

Kenji Sakakibara: Writing – review and editing. **Hiroyuki Nakajima:** Supervision. **Yudai Hagihara:** Writing – original draft. **Chie Nakamura:** Writing – original draft. **Daichi Shikata:** Writing – original draft. **Yuki Takesue:** Writing – original draft. **Satoru Shiraiwa:** Writing – original draft. **Yoshihiro Honda:** Supervision. **Shigeaki Kaga:** Supervision. **Masahiro Hamasaki:** Formal analysis. **Hisashi Johno:** Formal analysis.

FUNDING INFORMATION

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data regarding this case have been reported in the manuscript. Please contact the corresponding author if you are interested in any further information.

CONSENT

Written informed consent was obtained from the patient to publish this report in accordance with the journal's patient consent policy.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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