# Imaging Aortic Dissections and Aneurysms with MRI: The Clinical Value of Advanced Angiography and 4D Flow Sequences

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## Introduction

Ascending aortic aneurysms are characterized by dilation of the ascending aorta that progressively develops over several years and may ultimately result in aortic dissection or aortic rupture. The only curative treatment is surgical, involving replacement of the aneurysmal segment with a Dacron prosthetic graft. Currently, surgical recommendations are based on the maximum diameter of the ascending aorta (between 45 and 55 mm depending on the presence of potential associated risk factors for rupture, such as connective tissue disease, bicuspid aortic valve, or rapid aneurysm progression) [1]. However, this criterion is imperfect, and for personalized management of this disease, the generation of new biomarkers (including aorta shape, movement, and constrain flow) that allow personalized treatment of thoracic aortic aneurysms (TAA) is essential. These new biomarkers can be obtained from ex vivo biomechanical tests [2], angiography from MRI, or 4D flow MRI. In this context, MRI of the aorta done at 3T is a cornerstone for assessing these parameters. This is the objective of the MECATHOR project [3] (registered on clinicaltrials.gov under NCT03746964), which is studying 200 patients presenting with an ascending aorta aneurysm.

In addition, aortic dissection is a serious condition in which a tear occurs within the inner layers of the aorta. This allows blood to enter the aortic wall and leads to the formation of a true lumen and a false lumen, with the main risk being aortic wall rupture. According to the Stanford classification, there are two types of aortic dissections depending on the region of the aorta where the tear occurs [1, 4]. In this classification, Type A corresponds to a dissection involving the ascending aorta (immediately after the heart), whereas Type B refers to a dissection affecting the descending aorta. Type A dissections are a surgical emergency. Type B dissections are a medical emergency requiring regular follow-up and are considered to be a chronic aortic dissection. Type A could be present as a residual Type B aortic dissection to the descending aorta. It is now recognized that anatomy, and particularly diameter alone, does not allow prediction of the progression of chronic aortic dissection toward an aneurysm that requires surgical management [5]. The objective of the ADEPT project (registered on clinicaltrials.gov under NCT07315178) is to develop a patient-specific digital twin that enables multifactorial modeling of high-risk regions and prediction of the aneurysmal evolution of chronic aortic dissection. This digital twin will be based on 3D modeling of the aorta from MRI data and will integrate all parameters obtained from biomechanics, histology, imaging, and blood biomarkers.

In these two projects (MECATHOR and ADEPT), the MRI protocol incorporates two key sequences: angiography of the aorta and 4D flow MRI. Angiography is used to obtain basic anatomical information and a precise shape of the aorta, with excellent contrast between the vessel lumen and wall. Flow imaging is used to characterize blood flow and its interaction with the aortic wall (such as wall shear stress (WSS)). However, both techniques are inherently time-consuming and remain sensitive to motion artifacts, particularly due to respiratory variability and prolonged acquisition times, which may lead to heterogeneous image quality in clinical practice. These limitations represent a major barrier, especially in patients requiring repeated longitudinal follow-up. In this context, the compressed sensing (CS) technique is applied to both MR angiography (MRA) and 4D flow imaging to offer a promising solution [6]. By enabling highly accelerated acquisitions, CS has the potential to reduce scan duration, improve robustness

to motion, and increase overall workflow efficiency. Furthermore, CS-based approaches make it feasible to implement the multi-velocity encoding (VENC) acquisition in a clinically acceptable duration. This allows accurate depiction of a broader range of flow velocities, from high-velocity jets to slow recirculating flow, which is particularly relevant in complex aortic pathologies, such as the flow in false lumen in cases of dissection. This paper therefore evaluates the clinical relevance and added value of these advanced CS-accelerated MRA and 4D flow MRI techniques in the initial assessment and longitudinal follow-up of patients with severe aortic diseases and therefore complex anatomy.

## Methods and protocols

### MRI acquisitions and study population

All examinations were performed on a clinical 3T scanner (MAGNETOM Vida Fit, Siemens Healthineers, Erlangen, Germany) equipped with multi-channel cardiac and thoracic coils (18-channel body coil), allowing extended coverage of the thoracic and abdominal aorta. Acquisitions of the sequences with CS were conducted during free breathing with electrocardiographic (ECG) gating and respiratory motion synchronization.

The overall imaging protocol was designed to enable a comprehensive assessment of both vascular morphology and aortic hemodynamics within a single examination, relying on two research sequences: an advanced MRA sequence (non-CE MRA and CE-MRA)* and an advanced 4D flow MRI acquisition*. Complementary sequences such as 3D T1 SPACE (also called blackblood in cases of dissection) and 2D phase-contrast sequence were included in the protocol. The detailed protocol is illustrated in Figure 1.

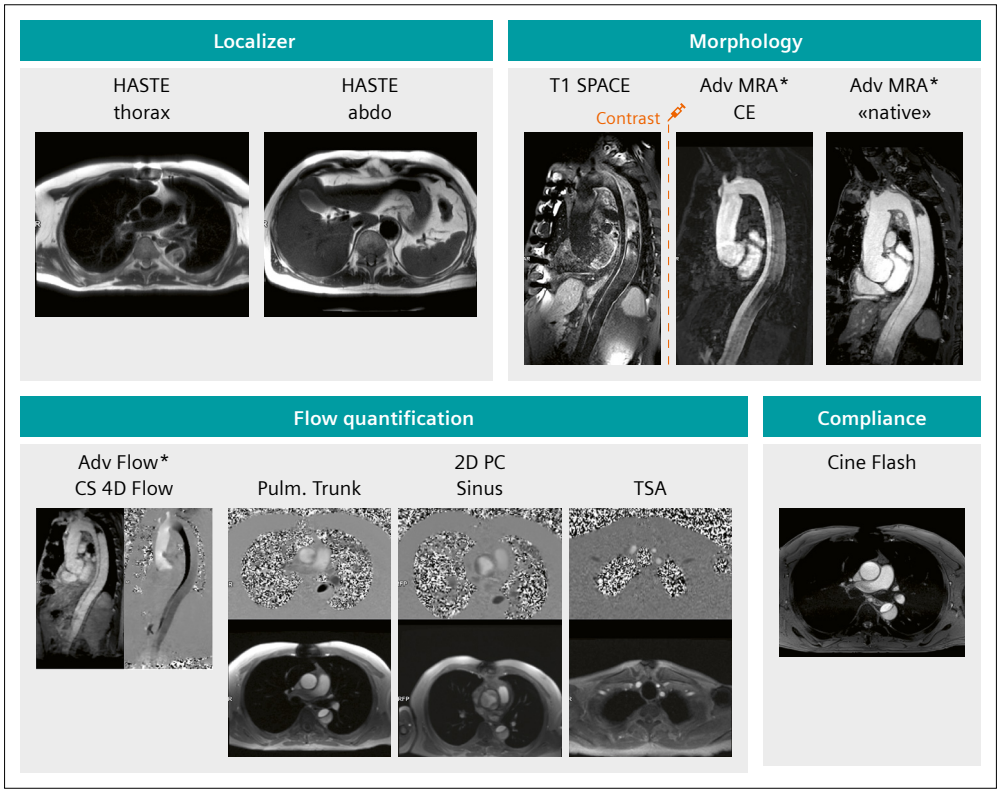
To date, over 80 exams for patients with aortic aneurysm (from the total of 200 exams involved in the MERCATHOR project) and 15 exams for patients with aortic dissection (the ADEPT project has just started) have been performed with these sequences.

### MR angiography (Advanced MRA*)

Morphological assessment of the aorta was based on a three-dimensional native MRA sequence (non-CE MRA), relying on a T2-prepared gradient-echo acquisition with fat suppression.

To reduce acquisition time and motion-related artifacts, a CS acceleration strategy was implemented. This approach relies on the undersampling of *k*-space combined with iterative reconstruction, enabling high spatial resolution with significantly reduced scan times.

** Work in progress. The application is still under development and not commercially available. Its future availability cannot be ensured.*




**1** Overview of the proposed imaging workflow and sequence acquisition order. When contrast agent administration was indicated, CE-MRA was performed first, followed by CS 4D flow MRI and native MRA acquisitions. This acquisition strategy was designed to take advantage of the residual intravascular contrast enhancement, thereby improving SNR for both native angiographic imaging and subsequent 4D flow analysis.

Fat–water separation was achieved using a two-point Dixon technique, which provides improved robustness to magnetic field (B0) inhomogeneities compared to conventional fat saturation methods.

Native MRA was acquired in two steps to cover both the thoracic and abdominal aorta for Type B aortic dissection while limiting off-center induced artifacts. To reduce overall examination time, abdominal native MRA was acquired without respiratory triggering (ECG gating), as motion artifacts in this region were considered less critical than in the thoracic aorta, where respiratory motion plays a more significant role in image quality degradation.

For patients eligible for contrast material administration, and particularly in the context of initial evaluation of aortic aneurysm or dissection, a CE-MRA acquisition was incorporated into the protocol. The administration of a gadolinium-based contrast agent was leveraged to both improve morphological assessment and enhance the signal characteristics of subsequent native angiographic sequences and 4D flow MRI acquisitions. Although breath-holding would have led to better image quality, CE-MRA was deliberately performed with free-breathing for patient comfort. Acquisition of CE-MRA took between 8 and 12 seconds on average.

**4D flow MRI (Advanced Flow*)**

Hemodynamic analysis was performed using a time-resolved three-dimensional phase-contrast MRI acquisition, referred to as 4D flow MRI. This technique enables both visualization and quantification of blood flow velocities throughout the entire volume of interest, providing a comprehensive characterization of flow patterns within the aorta and its true and false lumens.

To overcome the conventional limitations of 4D flow MRI — particularly the prolonged acquisition times and restricted velocity sensitivity — a combined strategy using CS and multi-VENC acquisition was implemented. This approach enables simultaneous encoding of multiple velocity ranges (dual VENC in our case), allowing accurate depiction of both high-velocity flow (e.g., in the true lumen or entry jets) and low-velocity flow (e.g., within the false lumen), which may otherwise be underestimated with a single VENC setting.

Sequence parameters for both Advanced MRA and Advanced 4D Flow sequences can be found in Table 1.

** Work in progress. The application is still under development and not commercially available. Its future availability cannot be ensured.*

| Sequences | CE-MRA | Native MRA | 4D Flow |
|---|---|---|---|
| FOV (readout × phase) | 350 × 263 mm | 350 × 295 mm | 450 × 313 mm |
| In-plane spatial resolution | 1.4 x 1.4 mm (recon. 0.7 mm) | 1.0 × 1.0 mm | 2.0 × 2.0 mm |
| Slice thickness | 1 mm | 1 mm | 2 mm |
| Slice resolution | 50% | 100% | 68% |
| Phase resolution | 100% | 100% | 75% |
| Acceleration factor | CS – 9 | CS – 7 | CS – [7.5-7.8] |
| Bandwidth | 781 Hz/px | 799 Hz/px | 531 Hz/px |
| Flip angle | 30° | 15° | 10° |
| TR/TE | 492.8 ms/1.78 ms | 219.2 ms/1.48 ms/3.07 ms | 45.5 ms/2.41 ms |
| Segments | 128 | 25 | 2 |
| Specific parameters | – | Prep. T2 35 ms (2 × MLEV4)<br>Dixon fat saturation | Flow mode: Free<br>VENC: 4<br>Vit. 1 = 250 cm/s<br>Vit. 2 = 250 cm/s<br>Vit. 3 = 250 cm/s<br>Vit. 4 = 100 cm/s<br>Dir. 1 through plane<br>Dir. 2 A >> P<br>Dir. 3 F >> H<br>Dir. 4 F >> H |

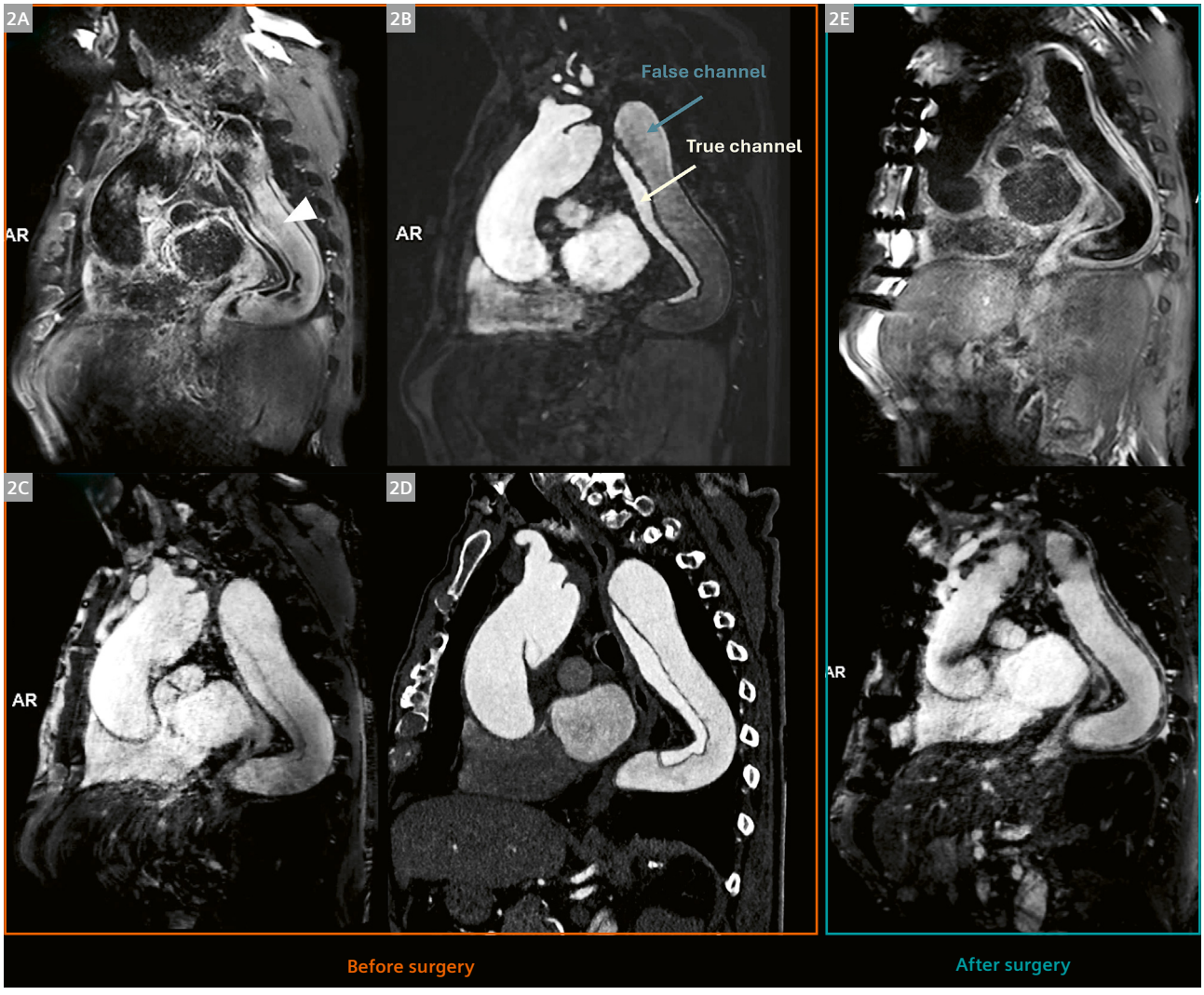
**Table 1:** 3T sequence parameters for Advanced MRA* and Advanced 4D Flow*.

## Results

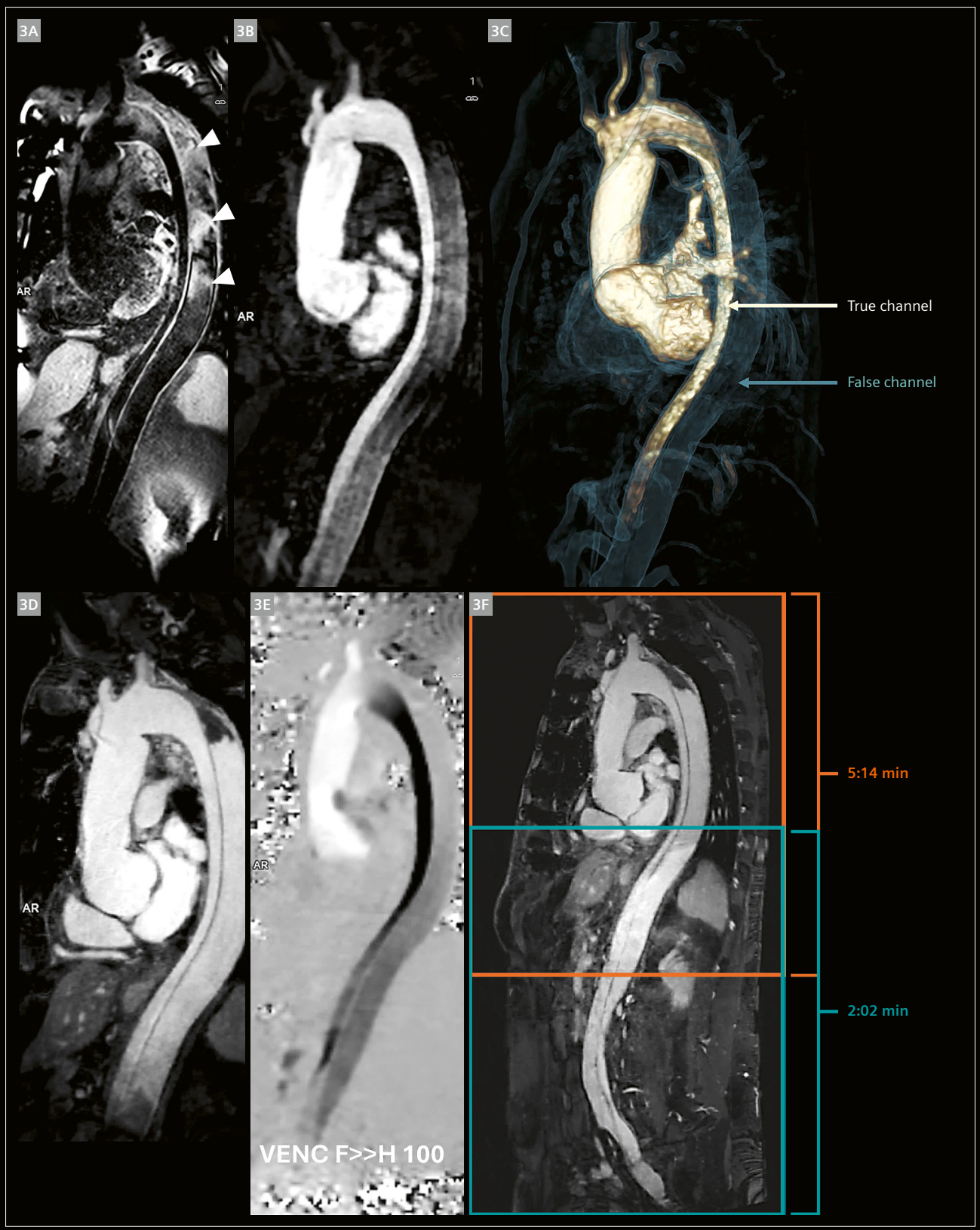
### Aortic dissection

An example of Type A aortic dissection (male patient, 77 years old) is shown in Figure 2 with results from T1 SPACE (2A), CE-MRA (2B), and native angiography (acquired after contrast agent, 2C). On CE-MRA, the resulting contrast between perfused and non-perfused regions facilitates more accurate identification of true and false channels, thereby improving diagnostic confidence. In addition, T1 SPACE imaging provides complementary information to further refine morphological assessment. The arrowhead shows the area of stagnant flow in the false lumen. These findings are consistent with observations from computed tomography angiography (CTA, 2D), supporting the robustness and clinical reliability of CE-MRA and non-CE MRA for initial assessment. The longitudinal follow-up of this patient after surgery is shown in Figure 2E. False lumen is no longer visible.

Another example of residual Type B aortic dissection after surgery for Type A (male patient, 55 years old, ascending aorta replacement) is reported in Figure 3, showing T1 SPACE (3A), CE-MRA (3B and 3C, maximum intensity projection (MIP)), native MRA (3D, acquired after contrast injection), and CS 4D flow (3E). Here again, the combination of angiographic imaging and blackblood acquisition strengthens the anatomical characterization of aortic dissections and contributes to a more accurate evaluation of disease extent and morphology. Of note, T1 SPACE demonstrates areas of incomplete blood signal suppression within the false lumen (arrowheads), corresponding to stagnant flow and resulting in a heterogeneous or partially blurred appearance. In addition, the use of contrast agent contributes to increased signal-to-noise ratio (SNR) in 4D flow MRI acquisitions, which may be advantageous for the analysis of complex flow patterns. A fused reconstruction combining native MRA of the thoracic and abdominal



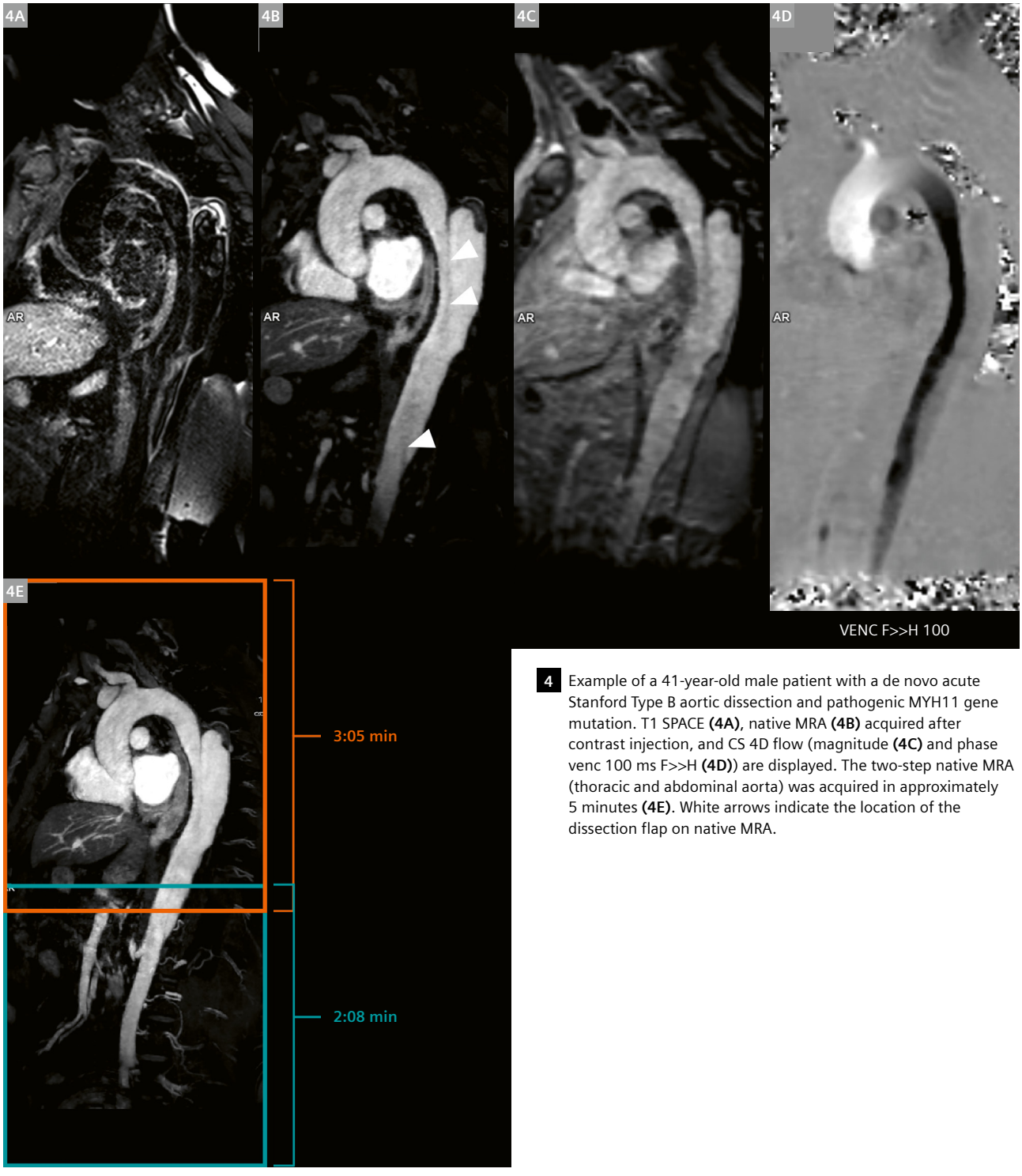

**2** Example of aortic dissection of Type A before surgery **(2A–2D)** and after surgery **(2E)**.




**3** Example of residual Type B aortic dissection after surgery for Type A. T1 SPACE **(3A)**, CE-MRA **(3B and 3C MIP)**, and native MRA **(3D)** acquired after contrast injection and CS 4D flow **(3E)** are displayed. The two-step native MRA (thoracic and abdominal aorta **(3F)**) was acquired in approximately 7 minutes.

aorta (3F) highlights the full extent and longitudinal propagation of the dissection in this patient, along with the acquisition time of each step.

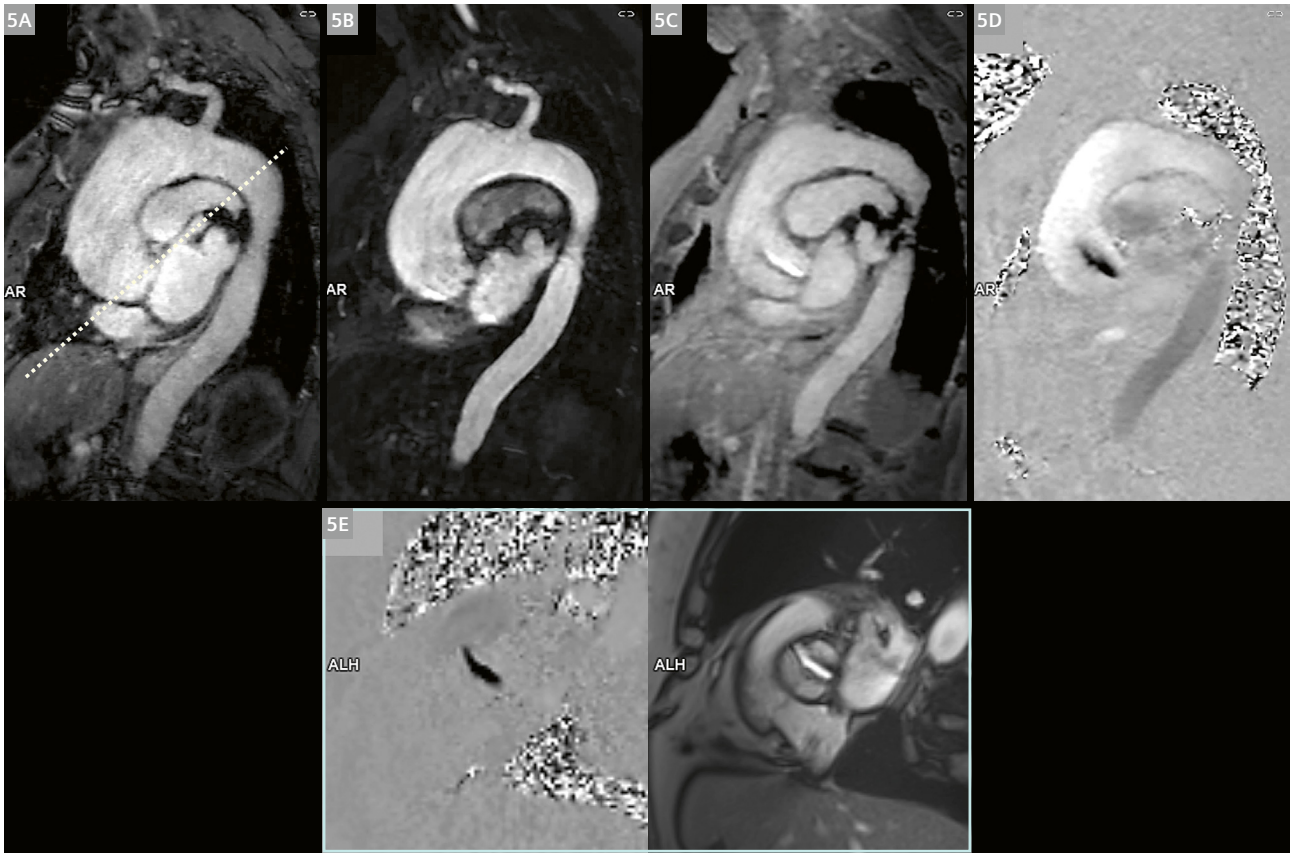
A third example of dissection is provided in Figure 4, which illustrates the case of a 41-year-old male patient with a de novo acute Stanford Type B aortic dissection and pathogenic MYH11 gene mutation [7]. The acceleration provided by CS allowed acquisition of thoraco-abdominal native MRA within a scan time of approximately 5 minutes, while maintaining sufficient image quality. Such coverage is particularly valuable in patients with extensive aortic dissections, where accurate visualization of the longitudinal propagation of the disease is essential for diagnosis and follow-up.



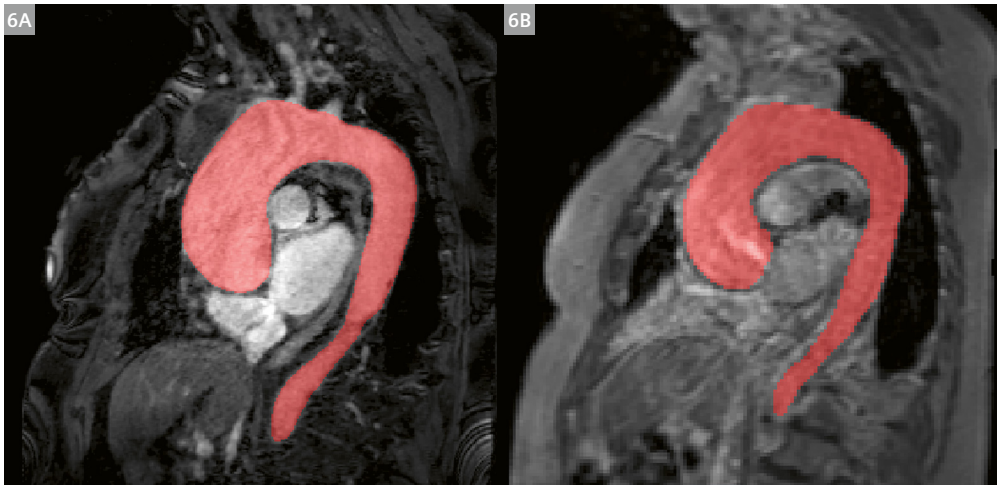

**4** Example of a 41-year-old male patient with a de novo acute Stanford Type B aortic dissection and pathogenic MYH11 gene mutation. T1 SPACE **(4A)**, native MRA **(4B)** acquired after contrast injection, and CS 4D flow (magnitude **(4C)** and phase venc 100 ms F>>H **(4D)**) are displayed. The two-step native MRA (thoracic and abdominal aorta) was acquired in approximately 5 minutes **(4E)**. White arrows indicate the location of the dissection flap on native MRA.

**Thoracic aortic aneurysm**

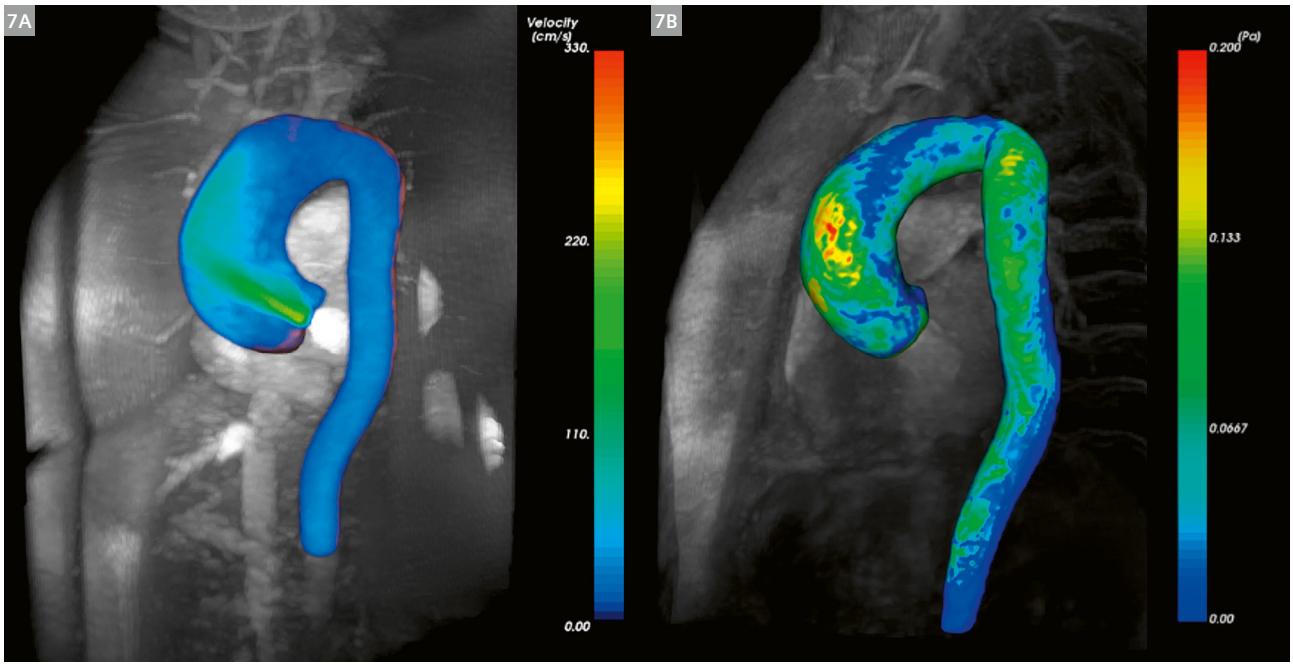
Figure 5 illustrates a patient (female, 82 years old) with an aneurysm of 51 mm, a bicuspid valve (seen on the 2D phase-contrast image in 5E) and a Grade 1 aortic insufficiency. The exam was performed the day before surgery. This figure shows native angiography (non-CE MRA without contrast agent, 5A), CE-MRA (5B), CS 4D flow MRI (magnitude and phase, 5C and 5D), with the segmentation automatically done on the native angiography and on the CS 4D flow MRI. It clearly depicts the strength of the native angiography with CS. In addition, our method for automatic segmentation of the aorta, which is based on deep learning, allows for a precise segmentation of the aorta on this sequence (Fig. 6) but also on the magnitude images of the CS 4D flow MRI [8] (6B). Figure 7 displays the resulting blood velocity at peak systole (7A) as the wall




**5** An 82-year-old female patient with an aneurysm of 51 mm, a bicuspid valve (seen on the 2D phase-contrast image, **5E**) and a Grade 1 aortic insufficiency.



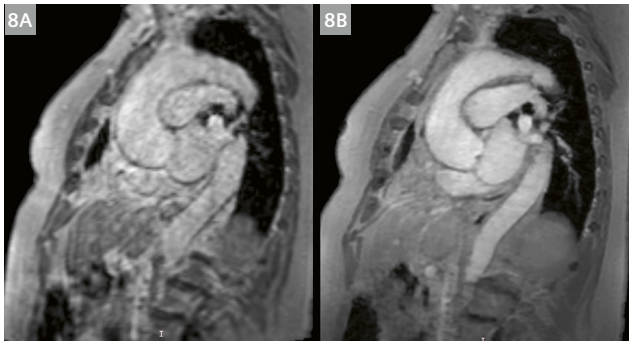

**6** Automatic segmentation of the aorta on native angiography **(6A)** and on magnitude images of 4D flow MRI **(6B)** in the same patient as in Figure 5 (female, 82 years old, aneurysm with bicuspid valve).




**7** Display of the blood velocity at peak systole (**7A**, scale [0–330] cm/s) as the wall shear stress (**7B**, pressure scale [0–0.2] Pa), in the same patient as in Figure 5 (female, 82 years old, aneurysm with bicuspid valve).

shear stress (7B) computed from the CS 4D flow series. Figure 8 illustrates the reduction in acquisition time (almost 50%) that was achieved with the CS 4D Flow* (6:31 min vs 12:46 min) while maintaining satisfactory image quality.

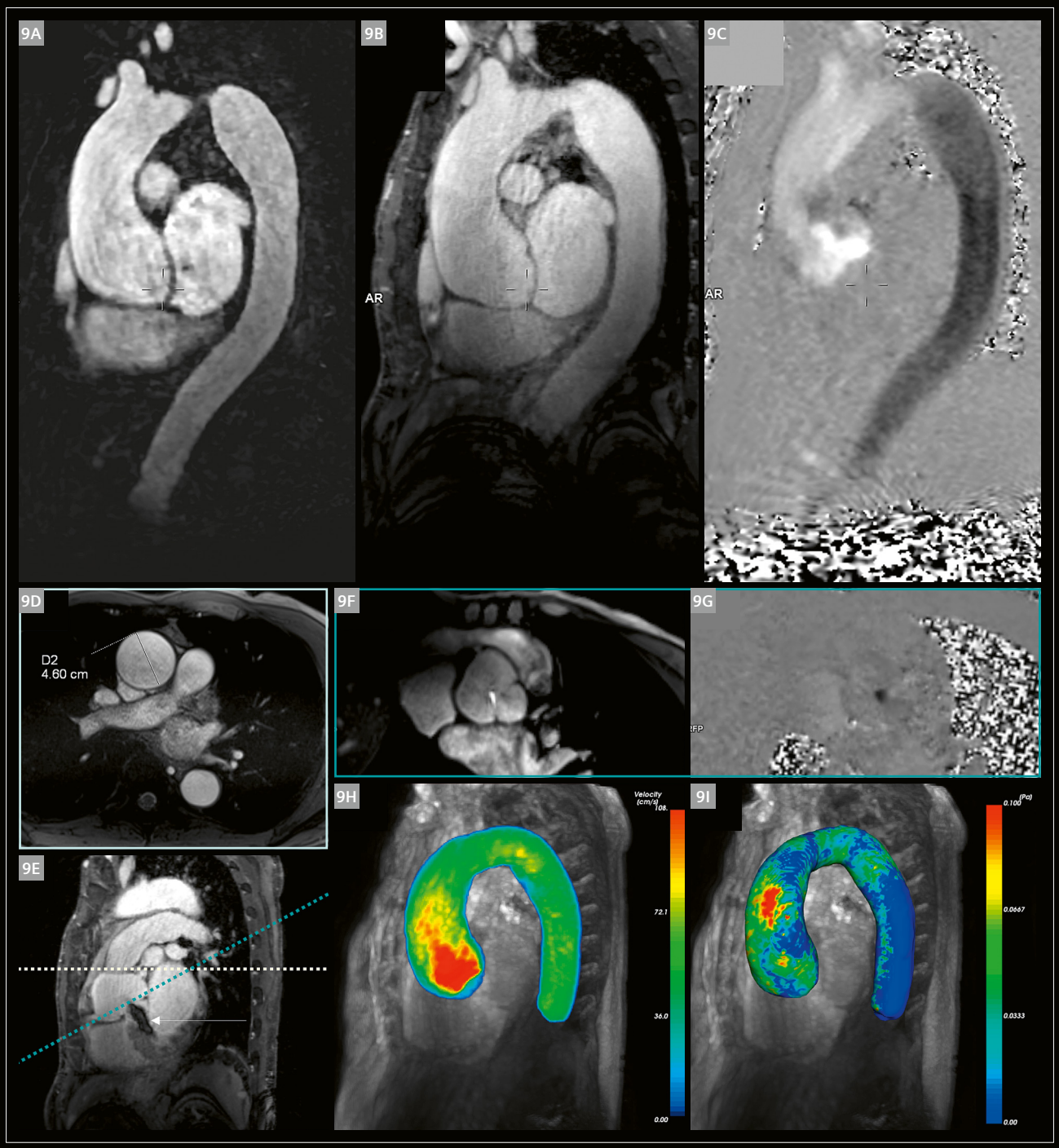
A further example of aortic root aneurysm is presented in Figure 9, in a patient with associated aortic regurgitation and Grade 2 aortic insufficiency. CE-MRA (9A) and native MRA with contrast material (9B and 9E) demonstrate the aneurysmal dilatation and provide comprehensive anatomical assessment of the thoracic aorta. Aortic dimensions could be measured on axial cine flash images (9D), although this sequence is used for aortic compliance assessment, while flow images magnitude (9F) and phase, venc 250 in-plane (9G) clearly depict the regurgitant jet associated with aortic valve insufficiency. Beyond conventional flow visualization, advanced hemodynamic biomarkers can also be derived from CS 4D flow MRI. Figures 9G and 9I illustrate the peak velocity distribution and WSS, respectively, providing complementary information on the interaction between blood flow and the aortic wall that may contribute to a more comprehensive assessment of aneurysmal disease.




**8** Difference between the 4D flow sequence without CS (**8A**, acquisition time 12:46 min) and with CS (**8B**, acquisition time 6:31 min) in the same patient during the same examination.

### Clinical value of Compressed Sensing

The application of CS to both MRA and 4D flow MRI represents a significant advancement in aortic imaging. By enabling substantial acceleration of data acquisition through undersampling of *k*-space combined with iterative reconstruction, CS effectively reduces scan duration, which is a critical limitation of conventional techniques. This reduction in acquisition time not only improves patient comfort and workflow efficiency but also mitigates the impact of respiratory variability and motion artifacts, which are common sources of image degradation in aortic imaging. Although acquisition time remains dependent on the patient's physiological condition, particularly their heart rate and respiratory pattern, in our experience the mean acquisition time for both MRA and 4D flow imaging was approximately 7 minutes, with the shortest acquisitions around 5 minutes. In addition, the intrinsic regularization associated with CS reconstruction contributes to improved image consistency and robustness, particularly in patients with complex or tortuous aortic anatomy. As a result,




**9** A 72-year-old male patient with an aneurysm of 46 mm and an aortic insufficiency. CE-MRA **(9A)**, native MRA **(9B and 9E)** acquired after contrast material, CS 4D flow venc 250 F>>H **(9C)**, transversal cine flash **(9D)**, 2D flow phase contrast (PC) (magnitude **9F** and phase venc 250 in-plane **9G**), peak velocity (**9H**, scale [0–108] cm/s), and wall shear stress (**9I**, scale [0–0.1] Pa). White arrow on native MRA **(9E)** depicts the regurgitant jet associated with aortic valve insufficiency.

high-quality morphological and hemodynamic datasets can be obtained even in challenging clinical scenarios.

**Combination of native MRA and 4D flow**
The isotropic resolution of the native angiographic sequence makes it easy to perform registration with 4D flow images (considering the diastolic phase). This may be relevant for evaluating parameters such as wall shear stress or for computational fluid dynamics (CFD) applications. Indeed, for the latter, the 3D modelling could be obtained from the native angiographic sequence, and the inlet as outlet conditions from 4D flow MRI. Plus, the advent of artificial intelligence (AI) should make it possible to automatically segment different structures (non-dissected aorta with or without aneurysm, true and false lumen), but it requires a sufficiently large database with the corresponding annotations to train a deep learning model. Our experience shows very good results [9] (Fig. 6).

## Conclusion

The combination of CS-accelerated MRA and 4D flow MRI represents a major step forward in the comprehensive imaging of complex aortic diseases, both for initial assessment and longitudinal follow-up. Compared to conventional contrast-enhanced MRA, the native angiographic sequence offers several key advantages: high signal-to-noise ratio, excellent lumen-to-wall contrast, no requirement for gadolinium-based contrast agents, free-breathing acquisition, and high isotropic spatial resolution. The addition of 4D flow MRI with multi-VENC acquisition further extends the diagnostic value of the examination. Beyond flow visualization, this sequence supports the quantification of biomechanical parameters such as wall shear stress — key biomarkers for predicting aneurysmal progression and guiding personalized surgical decision-making. The complementarity between these two sequences, combined with deep learning-based automatic segmentation, opens the door to a fully integrated workflow, from morphological assessment to hemodynamic quantification and wall-shear-stress mapping, within a single, clinically feasible examination. This dual-sequence approach has consistently demonstrated its clinical relevance across a broad spectrum of pathological presentations.

From a practical standpoint, the use of CS reduces mean acquisition time to approximately 5 to 7 minutes per sequence, improving both patient comfort and robustness to motion. Beyond their value in the MECATHOR and ADEPT research projects, these techniques are mature enough to be considered for broader clinical deployment, both at 1.5T and 3T, offering a reproducible, patient-friendly, and information-rich alternative to CT angiography-based follow-up in patients with severe aortic pathology.

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