TOMORROW TODAY

Eight clinical cases demonstrating the diagnostic value of ViosWorks 4D powered by Arterys™

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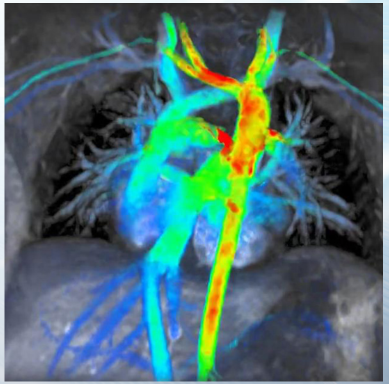
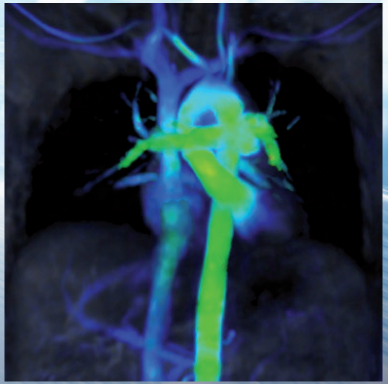
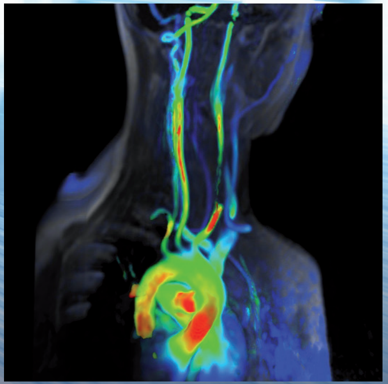

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Dr. Paul has been performing CMR exams for over a decade and is now responsible for cardiac imaging at IMM. During the last 2 years, he has performed 500 ViosWorks examinations on an Optima™ MR450w 1.5T scanner.

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Dr. Rohnean has over a decade of CMR experience. She has been collaborating with Dr. Paul on Cardiac MR since 2007 and reports several 4D Flow clinical cases every week.

Cardiology at Institut Mutualiste Montsouris (IMM)

Cardiac surgeons at IMM in Paris perform the impressive amount of 800+ interventions per year. Almost 10% of these surgical procedures consist in valve sparing surgery, a highly specialized type of procedures that aim at repairing defective valves rather than replacing them with prostheses. This strong cardiology service, which naturally includes an experienced team of echocardiographers, has also established strong links with the Radiology department, where Dr. J.-F. Paul and Dr. A. Rohnean perform 3000 cardiac CT and 800 cardiac MR examinations annually.

In the last two years, all patients referred to MR with valvular dysfunction, congenital heart disease or aortic disease have benefited from a 4D Flow scan within the cardiac MR protocol at IMM (1.5T MR450w GEM). This represents around 500 clinical cases, out of which this document presents eight typical examples.

While Doppler echocardiography is the first line modality for the pathologies mentioned above, it cannot always provide a precise answer on whether the patient should undergo surgery mainly due to a poor acoustic window. For this reason, current guidelines encourage a multi-modality approach (Ultrasound + CMR) to the assessment of, for example, aortic regurgitation [(1)] or congenital heart disease [(2)]. Today, ViosWorks 4D Flow routinely provides a view of the whole anatomy of the heart, including the flows within the four chambers and large vessels, helping to make patient management decisions on solid, operator-independent data. As Dr J.-F. Paul puts it, “I can study flow patterns throughout the cardiac cycle, visualize turbulences and vortexes, and quantify flows such as regurgitations. No other imaging modality, not even the classic 2D flow MRI, can provide such a complete picture.”

The eight cases that follow fall into three wide categories: Cases 1 to 4 demonstrate the ability of ViosWorks to assess aortic and mitral regurgitant flow rates and visualize valvular structure and surrounding tissue. Cases 5 and 6 present two congenital malformations, where echocardiography struggled with poor acoustic windows while ViosWorks could provide precise quantification of complex abnormal flows prompting surgical intervention in one, and non-surgical follow-up in the other. Finally, cases 7 and 8 show aortic pathology with unprecedented detail of anatomy and flow.

1. Recommendations for Noninvasive Evaluation of Native Valvular Regurgitation. ASE GUIDELINES AND STANDARDS. 2017. http://dx.doi.org/10.1016/j.echo.2017.01.007.
2. Congenital Heart Disease and Multi-modality Imaging. R. Puranik, V. Muthurangu, D. S. Celermajer, A.M. Taylor. Heart, Lung and Circulation. Vol. 19, Issue 3, March 2010, Pages 133-144. https://doi.org/10.1016/j.hlc.2010.01.001.

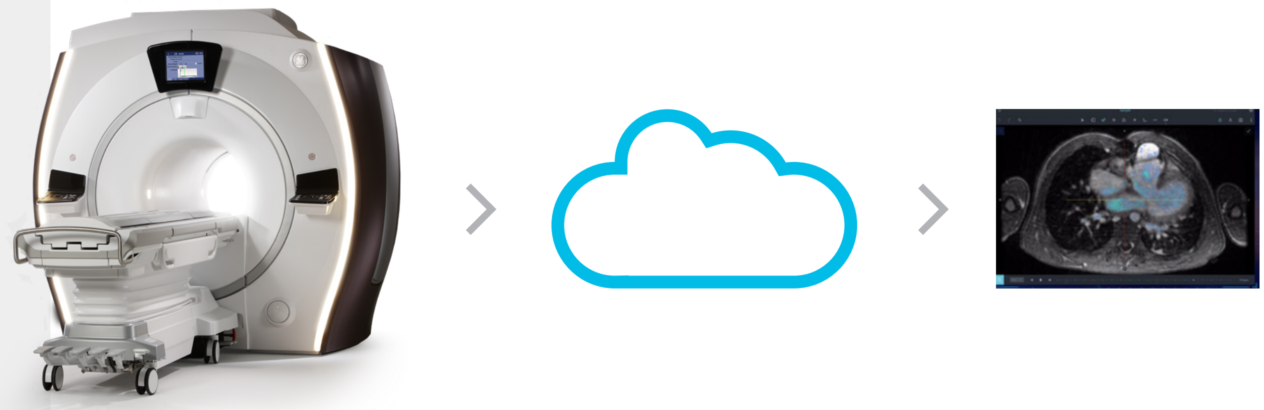
ViosWorks 4D
a game changer in cardiac MR

ViosWorks 4D, GE’s latest innovation in MR, extends cardiac MR assessment beyond the anatomy. For the first time, an MR application can provide 3D cardiac anatomy and 3D flow over the cardiac cycle with unprecedented resolution in one free-breathing scan of 10 minutes or less. Data is sent to the Arterys™ cloud post-processing software directly from the scanner for a seamless workflow. With cloud computation and Artificial Intelligence, Arterys can process these large files rapidly and provide deep learning automation for fast cardiac MRI report. The web-based platform can be accessed anywhere.

In a single free-breathing scan, ViosWorks 4D generates image data containing 7-dimensional information: 3 space directions, 3 velocity directions and time.

Cloud post-processing provides unlimited GPUs to process images of any size without additional infrastructure. Data can be accessed and analyzed anytime, anywhere.

ViosWorks powered by Arterys, provides a real-time visualization platform that delivers quantitative data and structured reporting.



Quantification of aortic regurgitation

A 44-year-old man, referred to our center for severe aortic regurgitation (AR) diagnosed on trans-thoracic echocardiography, presented with dyspnea during exertion. MRI was requested to evaluate LV dilatation before the surgical intervention. The protocol included long-axis and short-axis cine SSFP sequences, and a contrast-enhanced 4D Flow free-breathing acquisition to assess the morphology of the aortic root and valve and quantify the AR more precisely.

Cardiac cine images showed a dilated left ventricle, with an indexed telediastolic volume of 130 ml/m² measured on short-axis views.

The 4D Flow (ViosWorks) sequence and Arterys™ cloud post-processing allowed us to estimate the regurgitant volume in two different and independent ways:

1- Direct estimation of the aortic regurgitation in the left ventricle by tracing a ROI around the regurgitant flow on the diastolic phase of the cycle. Regurgitation volume (Qrv) was estimated at 7.4 l/min (Fig.1.1), corresponding to 95 ml/beat.

2- Indirect estimation by calculating the difference between systemic (Qs) and pulmonary (Qp) flows. The ROIs were drawn at the level of the LVOT and the main pulmonary artery. Results were as follows: Qs = 12 l/min, Qp = 4.8 l/min, hence Qs-Qp = 7.2 l/min, in excellent agreement (< 3%) with the direct estimation.

4D Flow magnitude images showed a regular and non-dilated ascending aorta and excluded coarctation of the aortic arch or the descending aorta. Bicuspid aortic valve was disclosed (Fig.1.2), with eccentric regurgitation suggesting a prolapse of a leaflet (Fig.1.3). In addition, 4D Flow showed a holodiastolic flow reversal within the descending aorta consistent with severe AR (Fig.1.4).

Analysis of 4D Flow provided precise quantification of regurgitation due to prolapse of the aortic bicuspid valve with dilated left ventricle. The patient underwent successful valve-sparing aortic surgery.

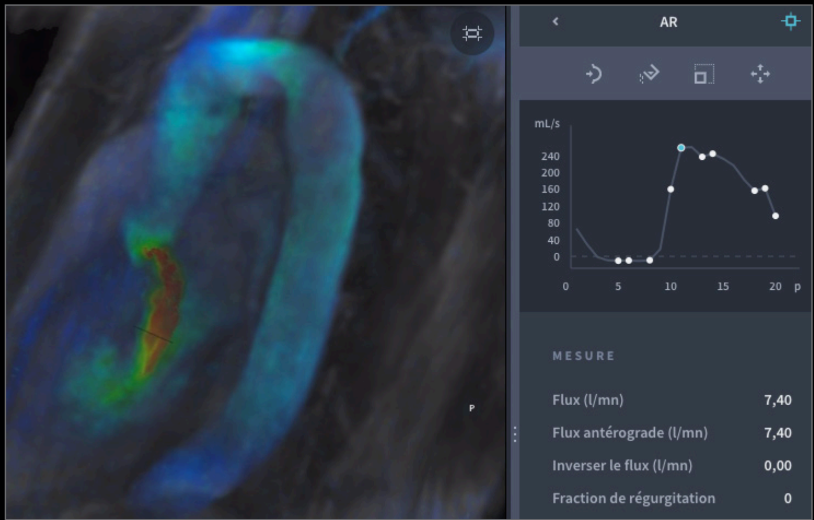


Fig.1.1

An estimate of AR flow was obtained by tracing a ROI directly across the regurgitant flow, perpendicular to the streamlines. The ROI was only traced on the diastolic phase and modified to contour the flow shape along cardiac phases.

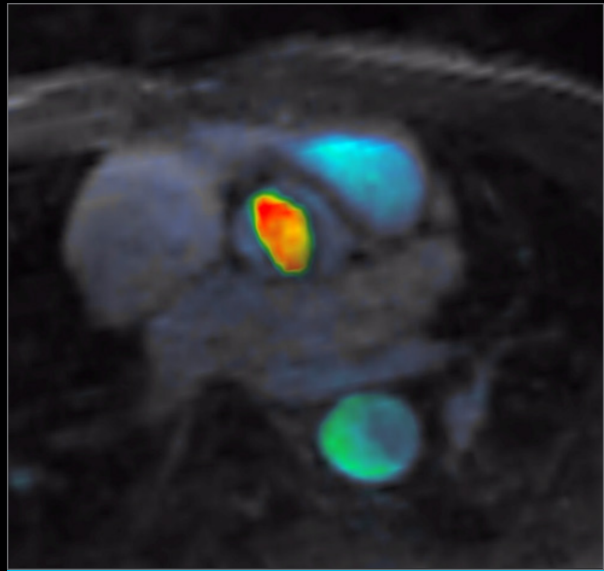


Fig.1.2

< Aortic valve in systole clearly shows 2 leaflets instead of 3, confirming a bicuspid, non-stenotic aortic valve.

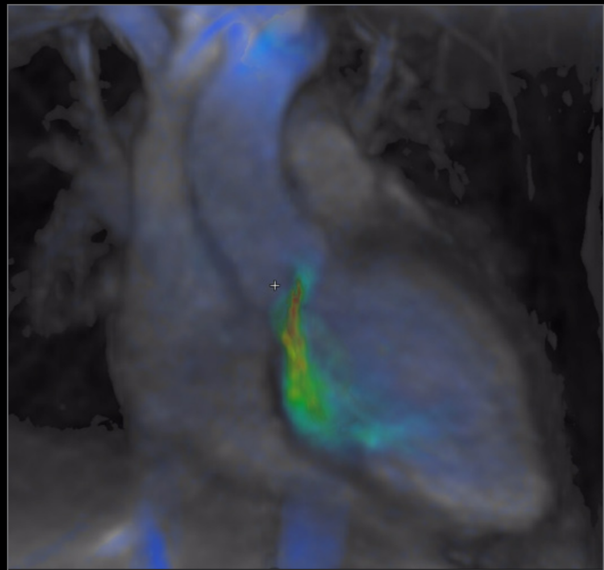


Fig.1.3

> Frontal view of aortic flow in diastole showing eccentric regurgitation and suggesting a prolapse of the bicuspid valve.

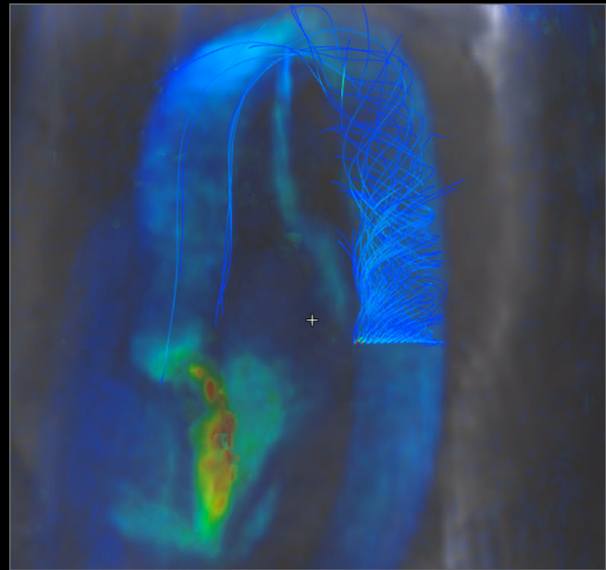


Fig.1.4

Sagittal streamline view of the aortic flow in diastole, demonstrating holodiastolic flow reversal in mid descending aorta suggestive of severe AR. Note helical reverse flow demonstrated by streamlines.

Mitral and aortic regurgitation

A 48-year-old man presented with recent onset of dyspnea, fatigue, tachycardia, and a systolic murmur at auscultation. Cardiac echography detected insufficiency of both mitral and aortic valves associated with a large left ventricle.

A cardiac MRI examination was performed for further evaluation, with a protocol that included long-axis and short-axis cine SSFP sequences and a contrast-enhanced 4D Flow free-breathing acquisition.

Cardiac cine images confirmed a very large left ventricle, with an indexed telediastolic volume of 200 ml/m2 and a stroke volume of 14 l/min.

4D Flow MRI (ViosWorks) demonstrated a severe mitral regurgitation (6.91 l/min) (Fig.2.1 & 2.2) and a mild aortic regurgitation (1.61 l/min) (Fig.2.3 & 2.4). The aortic forward flow was 6.75 l/min.

The patient underwent successful mitral valve replacement.

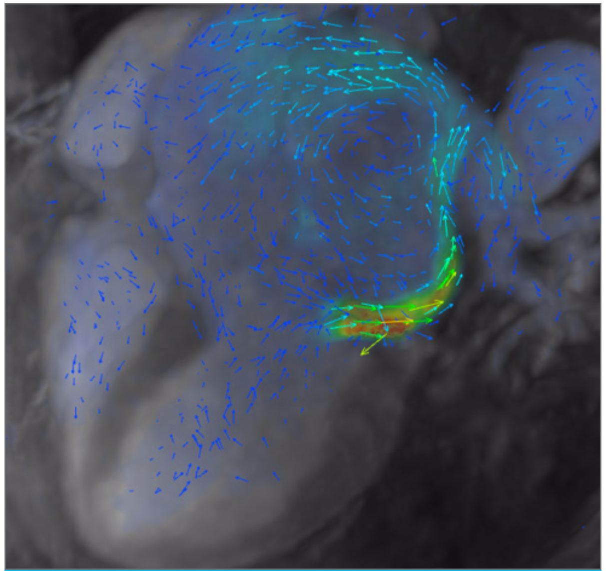


Fig.2.1-A

4D Flow MRI at systolic phase shows an eccentric mitral regurgitation along the wall of the left atrium. Note that both the left ventricle and the left atrium are severely dilated. Vectors indicate the direction of the regurgitant flow.

ViosWorks 4D powered by Arterys can provide, with only one acquisition, coherent flow estimates even in complex situations such as the double aortic and mitral regurgitation presented here.

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Tracing a ROI around the mitral regurgitant flow makes it possible to estimate the severity of the regurgitation. Here, the regurgitant volume is 6.91 l/min or 86 ml/beat, corresponding to severe regurgitation.

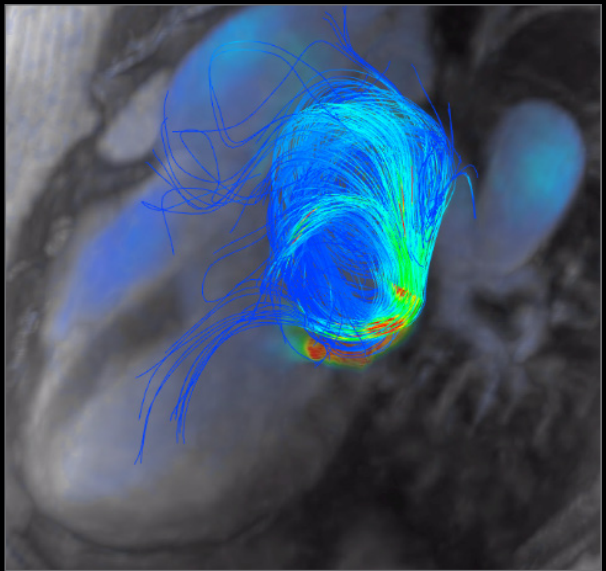

Fig.2.1-B

Same slice as 4.1-A, with streamlines showing a large vortex within the dilated atrium.

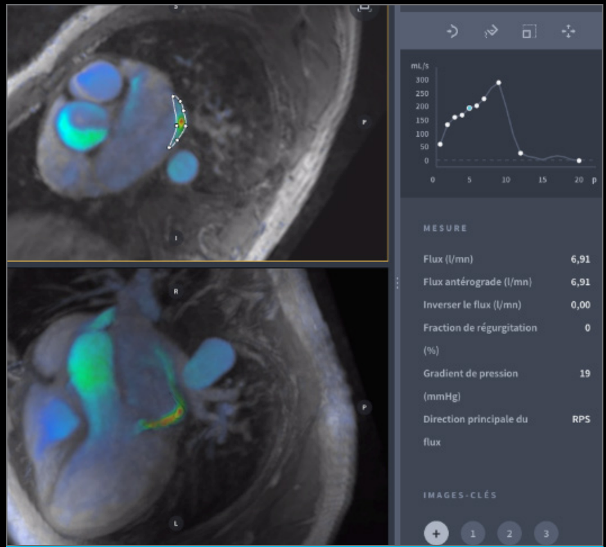

Fig.2.2

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4D Flow MRI at diastolic phase shows a central aortic regurgitation. Vectors indicate the direction of the regurgitant flow in the left ventricle.

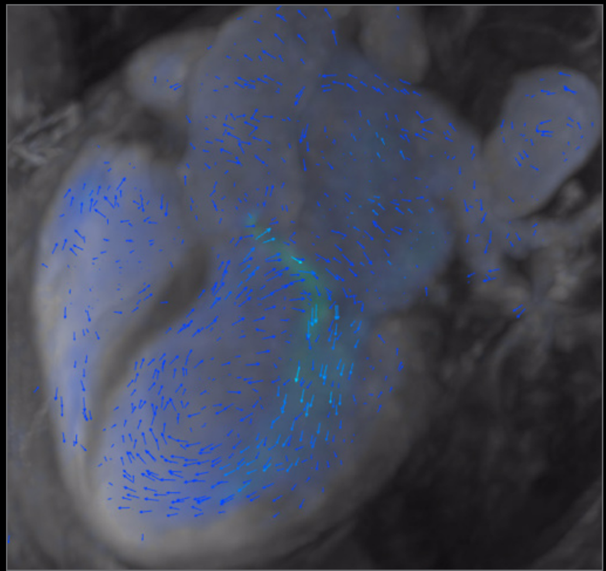

Fig.2.3

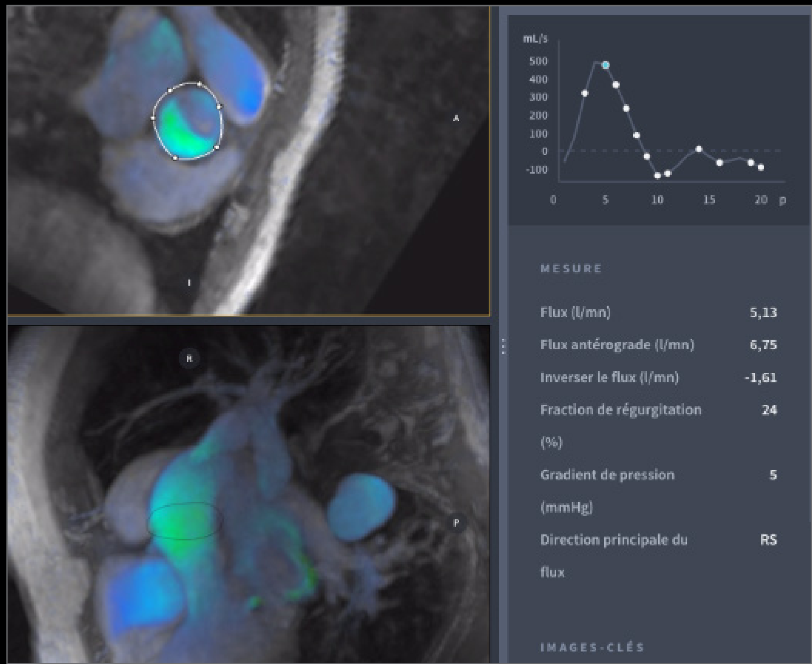

Fig.2.4

After tracing ROI across the proximal aorta, the aortic outflow was measured equal to 6.75 l/min with a volume of regurgitation of 1.61 l/min or 20 ml/beat, corresponding to mild aortic regurgitation.

Mitral dysfunction

A 60-year-old man presented with progressive dyspnea and a history of mitral annuloplasty for Barlow disease 5 years earlier. Echocardiography detected soft tissue surrounding the prosthesis, with a significant trans-mitral pressure gradient (16 mmHg) and a moderate mitral regurgitation.

The MRI protocol included long-axis and short-axis cine SSFP sequences and a contrast-enhanced 4D Flow (ViosWorks) free-breathing acquisition that was performed for further assessment of the mitral valve dysfunction before treatment decision.

On 4D Flow, both mitral stenosis (Fig.3.1) and mitral regurgitation (Fig.3.2) were clearly depicted. Trans-mitral mean pressure gradient was 16 mmHg (Fig.3.3) and was associated with a grade 3 (moderate to severe) mitral eccentric regurgitation (regurgitant volume: 50 ml/beat) (Fig.3.4) which prompted surgical valve replacement.

After surgery, histopathology revealed infectious tissue surrounding the annuloplasty. Infectious tissue and mitral valve were removed, and mitral bioprosthesis inserted.

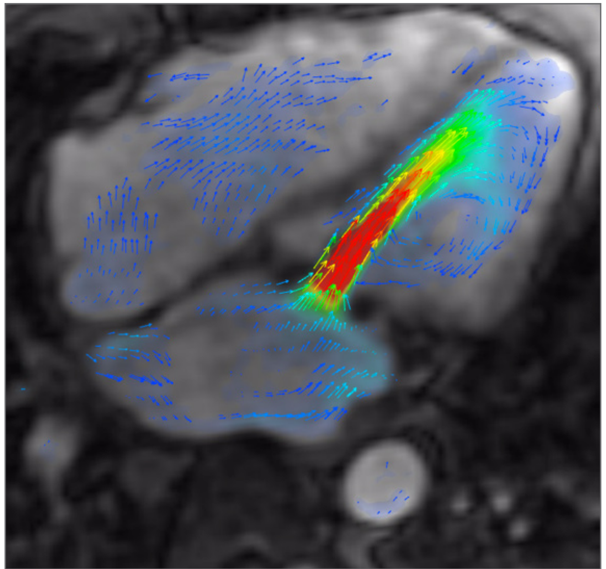

Fig.3.1

4D Flow showed high-velocity mitral flow (in red) entering the left ventricle during the diastolic phase. Note thick tissue around the mitral valve.

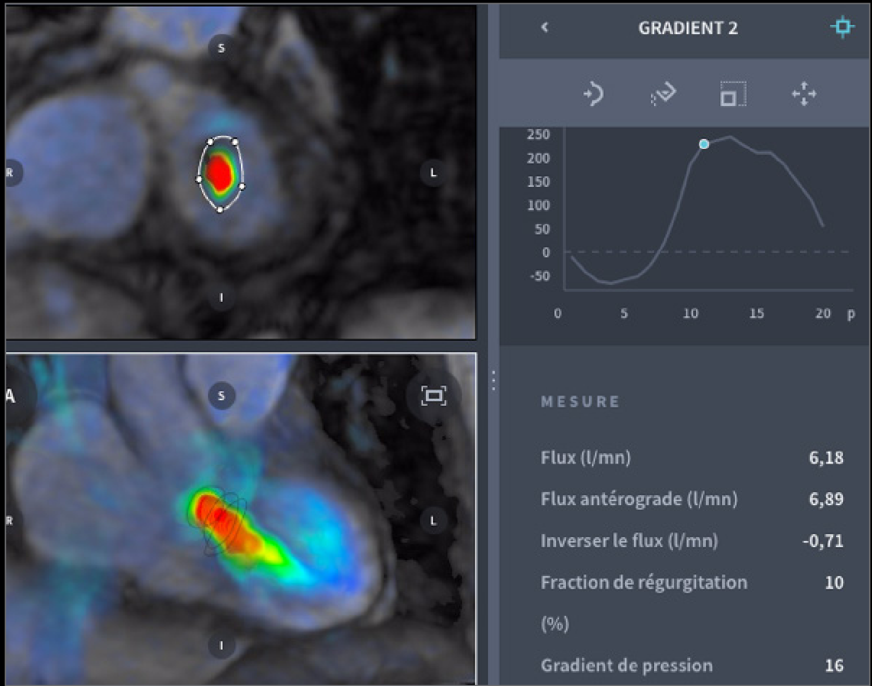

Fig.3.3

4D Flow estimates the mean gradient based on user-defined contours around the high-velocity flow entering the left ventricle. The value found here (16 mmHg) was identical to the previous echocardiographic finding.

ViosWorks 4D powered by Arterys provided a complete assessment of a mitral valve despite the presence of an MR Conditional metallic prosthesis.

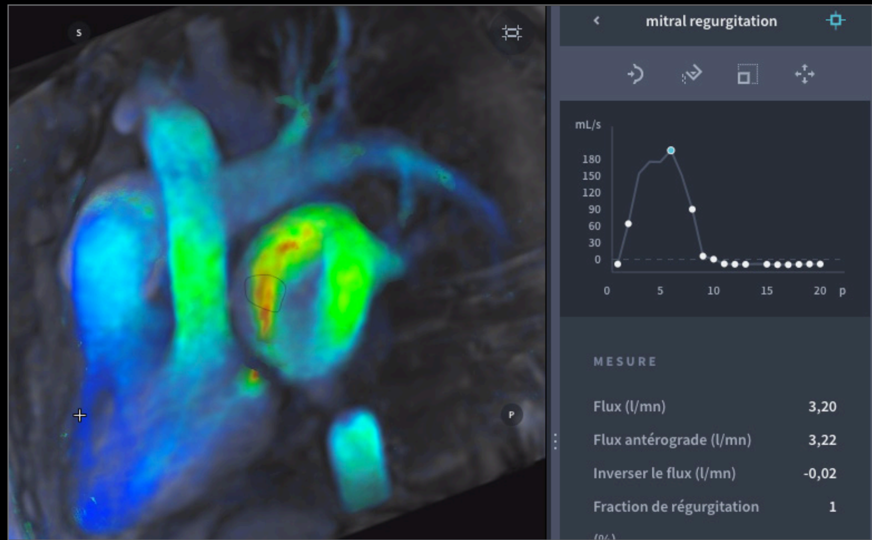

Fig.3.4

4D Flow provides estimates of mitral regurgitation based on user-defined contours around backflow entering the left atrium. The value found here (3.2 l/min or 50 ml/beat) was a step higher than the one estimated at echocardiography.

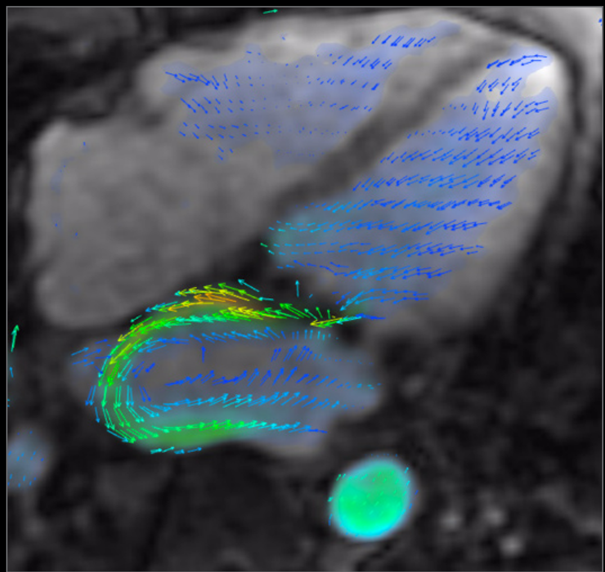

Fig.3.2

4D Flow showed eccentric regurgitant flow leaking back into the left atrium during the diastolic phase.

Characterization of prosthetic regurgitation

An 83-year-old man was referred to our center for progressively worsening dyspnea.

The patient, who had had an aortic bioprosthesis implanted 10 years before, also presented with a moderate-to-severe aortic regurgitation diagnosed by transthoracic echocardiography. But a poor acoustic window and artefacts from the bioprosthesis made it impossible for echocardiography to determine if the leakage was intra-prosthetic or para-prosthetic.

A 4D Flow MRI was scheduled with the aim of visualizing the leakage through the prosthesis in order to choose the most appropriate therapeutic intervention: Either surgical reintervention in case of para-prosthetic leakage, or percutaneous TAVI procedure (valve in Ring) in case of intra-prosthetic leakage.

The MRI protocol consisted of a contrast-enhanced 4D Flow (ViosWorks 4D) free-breathing acquisition that lasted 11 minutes on this patient.

A direct visual check of the images, without the need of any further analysis or quantification, allowed us to clearly locate the origin of the aortic regurgitation in the middle of the bioprosthesis (Fig.4.1), leading to the decision of a TAVI procedure. TAVI was attempted and succeeded in the aortic ring without residual leakage. Two-month follow-up was uneventful.

This case illustrates the ability of ViosWorks 4D powered by Arterys to visualize flow through a defective bioprosthesis.

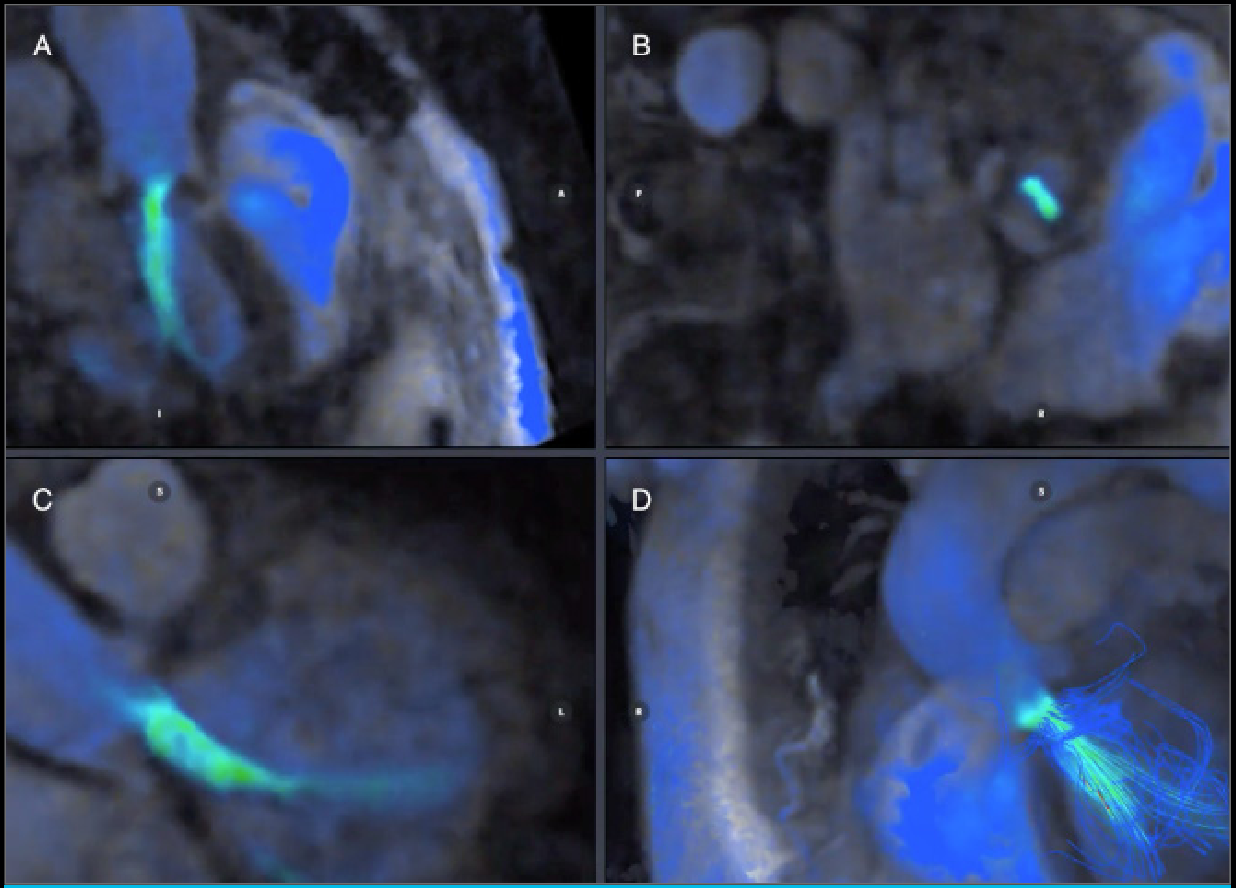

Fig.4.1-A, -B, -C, -D

Images at diastolic phase showing a central regurgitation from the middle of the prosthesis, as best seen in panel B.

Atrial septal defect

An 82-year-old woman was referred to our center for supra-ventricular arrhythmia.

Transthoracic echocardiography (TTE) identified a premature atrial complex associated with a secundum atrial septal defect. Both TTE and transesophageal echocardiography (TEE) could show overload of the right atrium but failed to conclusively evaluate the right ventricle volume and to quantify the shunt.

Because TEE was inconclusive and the relation to symptoms unclear, the patient underwent Cardiac MRI. The MRI protocol included long-axis and short-axis cine SSFP sequences, and a contrast-enhanced 4D Flow free-breathing acquisition.

Cardiac MRI showed a dilated right ventricle: indexed telediastolic volume was calculated at 110 ml/m² from cine short-axis views.

4D Flow (ViosWorks 4D) easily detected an abnormal flow between the left and right atria (Fig.5.1 and Fig.5.2). We could estimate the intra-cardiac shunt in two independent ways, with results closely matching:

1- Direct estimation of the blood flow through the interatrial defect by tracing a region of interest (ROI) around the septal defect across the whole cardiac cycle. Shunt estimated at 2.38 l/min (Fig.5.3).

2- Indirect estimation by calculating the difference between pulmonary flow (Qp) and systemic flow (Qs). ROIs were thus drawn on the main pulmonary artery (Fig.5.4) and the left ventricular outflow tract (LVOT). We obtained Qp = 5.73 l/min and Qs=3.4 l/min, and hence Qp-Qs=2.33 l/min and Qp/Qs=1.7.

Since Qp/Qs was greater than 1.5, the patient underwent percutaneous closure with Amplatzer (St. Jude Medical) n°18. Clearly, 4D Flow MRI provided essential information to confidently make the decision of closure.

The immediate post-procedural and post-one-month color Doppler TEE showed complete occlusion of the defect with no residual shunt.

Follow-up Cardiac MRI with 4D Flow analysis at 6 weeks exhibited no shunt through the Amplatz, a normalized right-ventricle volume, and a Qp/Qs = 1.

VíosWorks 4D powered by Arterys precisely estimated the intra-cardiac shunt after an inconclusive Doppler echocardiography.

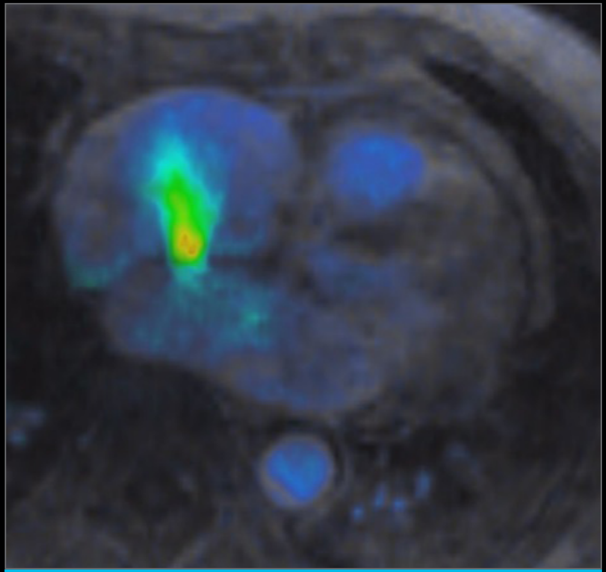

Fig.5.1

< 4D Flow axial view showing abnormal flow from the left atrium to the right atrium, corresponding to septum secundum atrial septal defect.

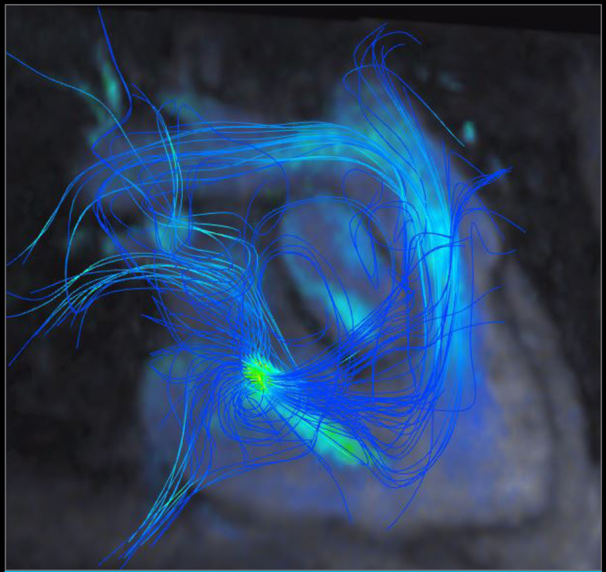

Fig.5.2

< 4D Flow sagittal view depicts streamlines crossing the septal defect, then going back into both pulmonary arteries through the right cavities.

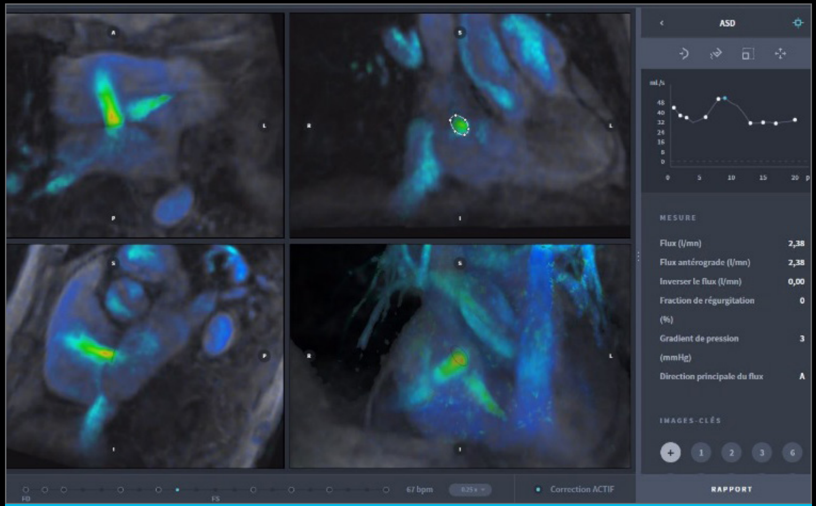

Fig.5.3

Panel view displays direct flow measurement through the shunt: a ROI was manually drawn around the septal defect (upper-right image) and adjusted for each phase of the cardiac cycle. The flow curve and flow measurements are automatically generated by the Arterys software (right column).

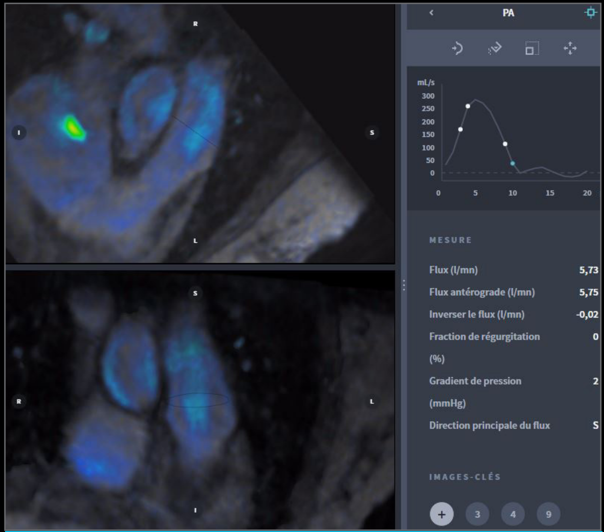

Fig.5.4

View describing indirect flow measurement. A ROI was manually drawn across the main pulmonary artery and adjusted for each phase of the cardiac cycle. Pulmonary flow was measured (Qp) at 5.73 l/min. Using the same method (not shown here), aortic flow (Qs) was found to be 3.4 l/min.

Scimitar syndrome - Evaluation of right to left shunt

A 34-year-old woman was referred to our center with fatigue and palpitations. During her childhood, the patient had been diagnosed with an anomalous right pulmonary venous return draining in the inferior vena cava, associated with a hypoplastic right lung and right-sided heart —a so-called Scimitar syndrome.

Since clinical symptoms were scarce, the need for surgical intervention was unclear. Given the complexity of the malformation, the patient was referred to CMR and benefitted from a precise quantification of the right-to-left shunt with 4D Flow MRI.

The MRI protocol included long-axis and short-axis cine SSFP sequences, and a contrast-enhanced 4D Flow free-breathing acquisition.

Cardiac cine images showed a dilated right ventricle with a telediastolic volume of 100 ml/m² assessed on short-axis views.

The 10-minute 4D Flow (ViosWorks 4D) acquisition provided both anatomical and functional information within the same dataset. Direct visualization of the data in the frontal plane clearly showed the congenitally abnormal drainage of the right pulmonary vein within the inferior vena cava (Fig.6.1). We could estimate the shunt in two independent ways with excellent matching results:

1- Direct estimation of the blood flow through anomalous pulmonary venous return by tracing a ROI across the abnormal vessel over the whole cardiac cycle: shunt estimated at 2.67 l/min (Fig.6.2).

2- Indirect estimation by calculating the difference between Qp and Qs. The ROIs were drawn at the level of the LVOT (Fig.6.3) and the main pulmonary artery (Fig.6.4). We obtained: Qp = 8.35 l/min, Qs = 5.64 l/min. Hence Qp-Qs=2.71 l/min, and Qp/Qs = 1.48, which prompted the decision of follow-up without surgical intervention.

In addition, blood flows in both the right pulmonary artery (Q-RPA) and the left pulmonary artery (Q-LPA) were calculated for a consistency check and the assessment of separate perfusion of each lung:
Q-RPA = 2.69 l/min, and Q-LPA = 5.6 l/min

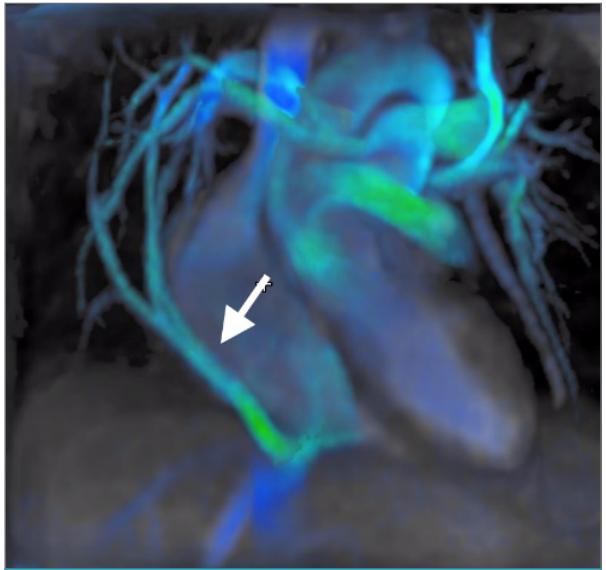

Fig.6.1

Frontal view showing abnormal drainage of the right pulmonary vein into the inferior vena cava (arrow).

Measurement of abnormal right pulmonary vein flow: a ROI is manually drawn across the congenitally abnormal vessel responsible for the left to right shunt. In this case, the L-R shunt flow is 2.67 l/min.

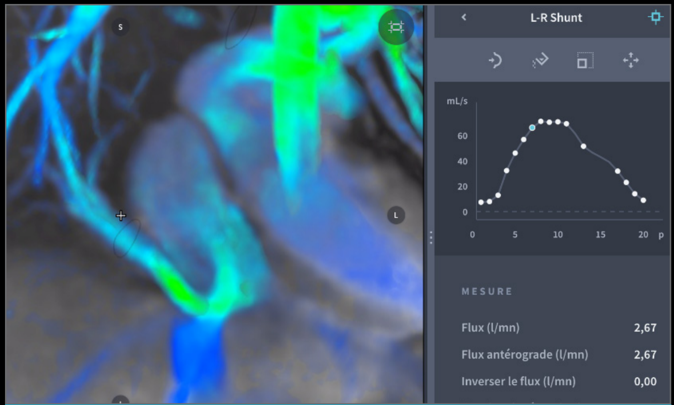

Fig.6.2

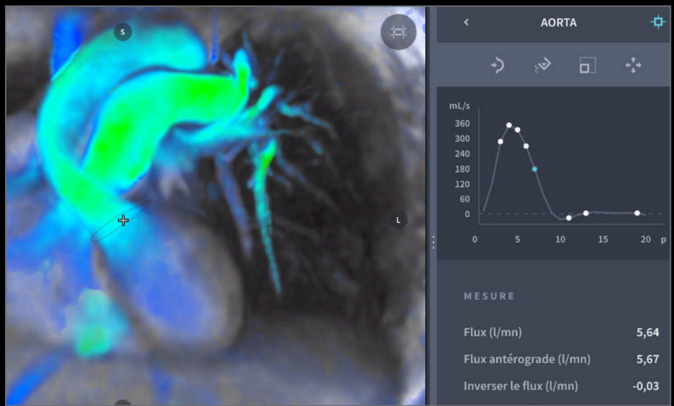

Fig.6.3

Left outflow tract flow measurement (Qs): a ROI is manually drawn across the LVOT and adjusted for each phase of the cardiac cycle. Qs flow measured value is 5.64 l/min.

Main pulmonary artery flow measurement: a ROI is manually drawn across the main pulmonary artery and adjusted for each phase of the cardiac cycle. Main pulmonary flow (Qp) is 8.35 l/min.

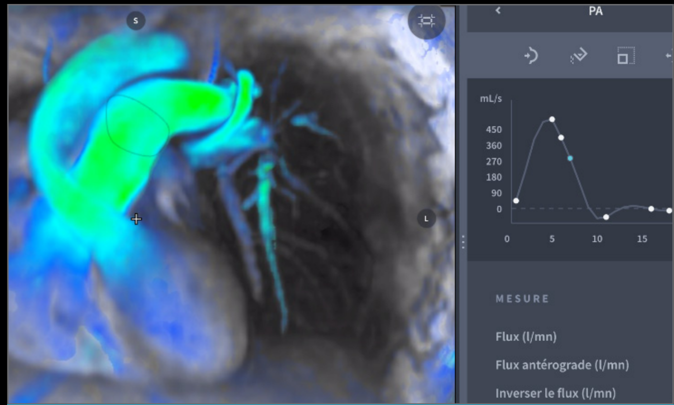

Fig.6.4

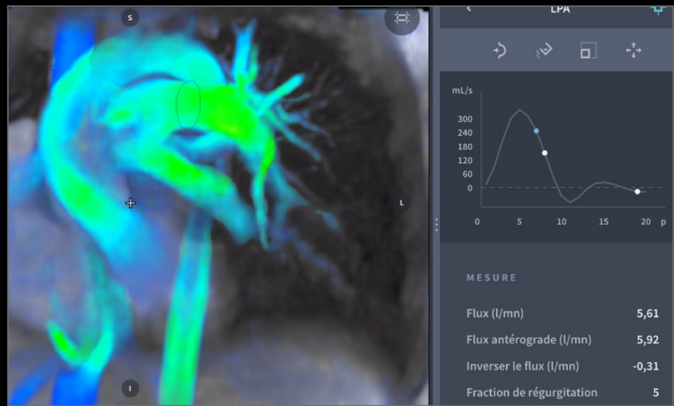

Fig.6.5

Left pulmonary flow measurement: a ROI is manually drawn across the left pulmonary artery and adjusted for each phase of the cardiac cycle. Left pulmonary flow (R-Qp) is 5.61 l/min.

Direct visualization of the data in the frontal plane clearly showed the congenitally abnormal drainage of the right pulmonary vein within the inferior vena cava (Fig.6.1)

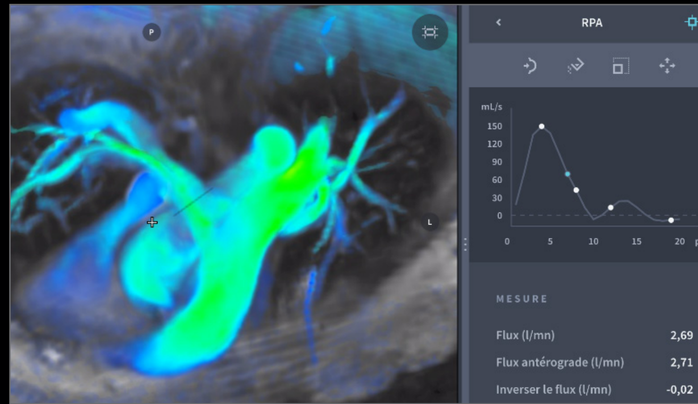

Fig.6.6

Right pulmonary flow measurement: a ROI is manually drawn across the right pulmonary artery and adjusted for each phase of the cardiac cycle. Right pulmonary flow (L-Qp) is 2.69 l/min.

Giant aneurysm

A 42-year-old woman was admitted for sudden onset of repeated discomforts and orthostatic hypotension. She reported a thoracic traumatism during a car accident at the age of 26, without any immediate complication at that time.

The initial physical examination detected tachycardia and cyanosis. Electrocardiography showed a right ventricular overload, and transthoracic ultrasound visualized a voluminous compressive cavity.

Given the atrial compression and the risk of rupture, the patient underwent an emergency surgery, a reconstitution of non-coronary Valsalva sinus with a prosthetic patch and a plication of the aneurysmal cavity. The evolution was simple.

Giant and compressive aneurysms of the non-coronary Valsalva sinus are rare, often asymptomatic, and sometimes post-traumatic.

ViosWorks 4D powered by Arterys showed a circulating giant aneurysm (100 mm) rising from the non-coronary sinus of Valsalva (Fig.7.1), with significant compression of the right atrium (Fig.7.2).

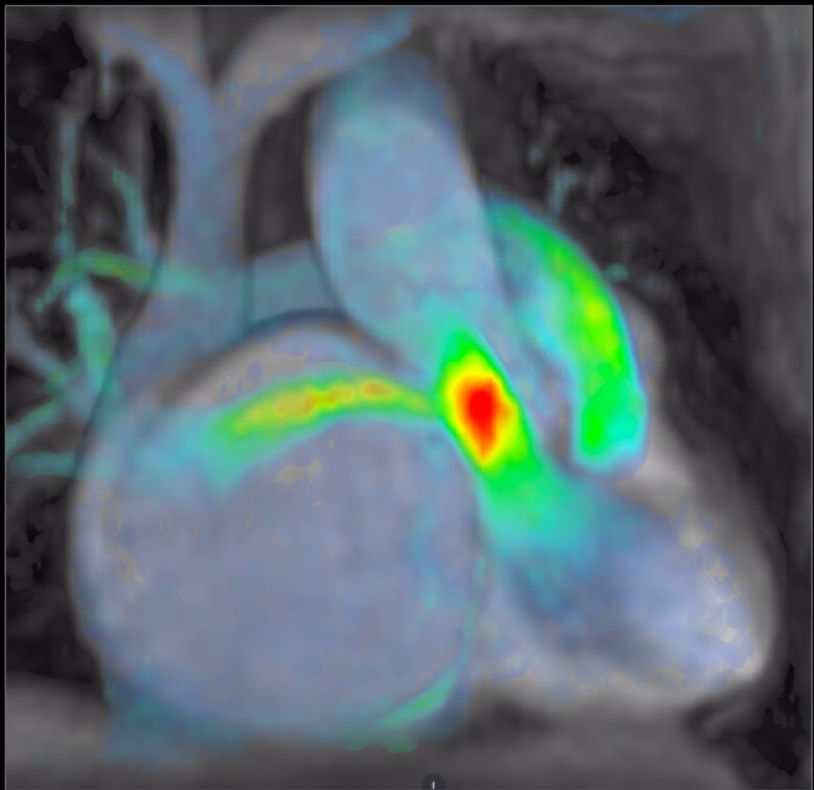

Fig.7.1

< 4D Flow MRI (frontal view at systolic phase) showing a giant aneurysm on the right side of the aorta, fed with flow originating in the non-coronary sinus of Valsalva.

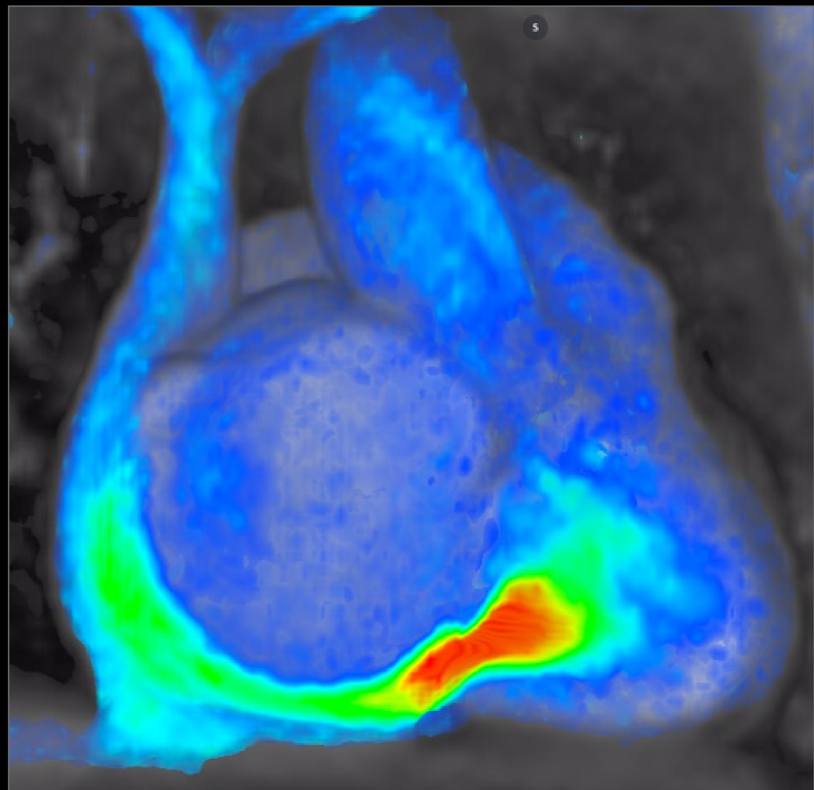

Fig.7.2

< 4D Flow MRI (frontal view at diastolic phase) showing a severe compression of the right atrium with high-velocity flow (in red) entering the right ventricle.

Ascending aorta dilatation

A 24-year-old woman presented with a systolic murmur and high blood pressure.

At transthoracic echocardiography, a bicuspid valve associated with a dilatation of the ascending aorta was suspected. An aortic MRI was recommended for further evaluation.

The MRI examination consisted of an 8-minute 4D Flow (ViosWorks 4D) free-breathing acquisition. The magnitude images showed a dilated tubular aorta, with its distal part reaching 44 mm of maximal diameter. Bicuspid valve was visually confirmed (Fig.8.1) as well as high-velocity flow (peak velocity=250 cm/sec). An aortic flow jet strikes the aortic wall at its most dilated part (Fig.8.2), suggesting flow jet as the cause of dilatation.

ViosWorks 4D powered by Arterys provides a comprehensive visualization of aortic disorders, associating anatomic information with hemodynamic insights. Shear stress on the aortic wall can be estimated from these data, and flow disturbances over the whole cardiac circle may be visually analyzed. Although therapeutic decisions are guided exclusively by the aortic diameter at present, the new insights offered by ViosWorks may soon be useful for a refined prognosis and the selection of optimal treatment for each patient with aortic dilatation.

ViosWorks 4D powered by Arterys provides a comprehensive visualization of aortic disorders, associating anatomic information with hemodynamic insights.

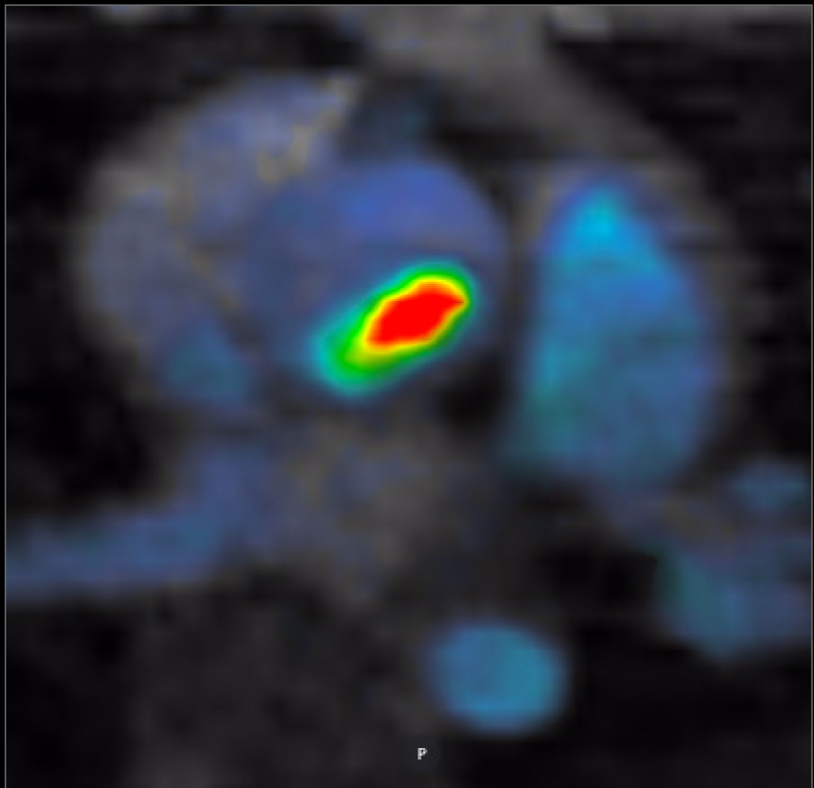

Fig.8.1

< Cross-sectional aortic view in the systolic phase showing a bicuspid valve with restricted aperture.

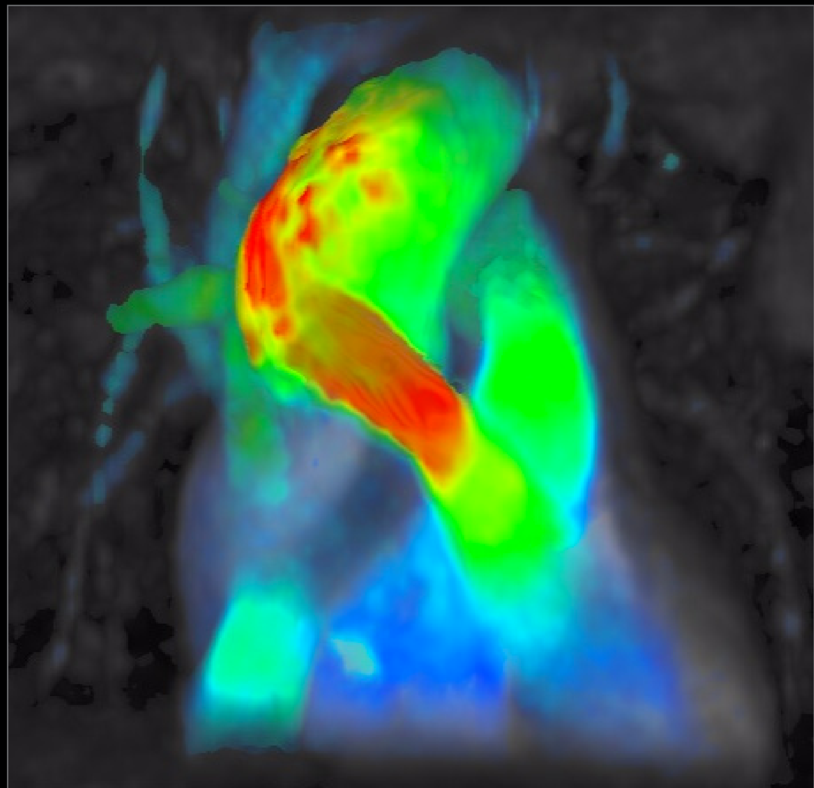

Fig.8.2

< Frontal view in systole showing high-velocity flow (in red) striking the right side of the tubular aorta.

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