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# Woven disease: friend or foe?

Salvatore Cito [1], PhD, Rishi Puri [2], MBBS, PhD, Jordi Pallarés-Curto[1], PhD, Omar Abdul-Jawad Altisent [3], MD, PhD, Antoni Bayes-Genis[3], MD, PhD, FESC, FHFA

1- Fluid Mechanics Section, Department of Mechanical Engineering, Rovira i Virgili University, Tarragona, Spain

2-Cardiology department, Cleveland Clinic, Cleveland, Ohio, USA

3- Cardiology department, Germans Trias University Hospital, Badalona, Barcelona, Spain

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**Address for correspondence:**

Omar Abdul-Jawad Altisent, MD, PhD

Germans Trias University Hospital

Carretera de Canyet s/n, 08916, Badalona, Barcelona, Spain

Tel num. +34 934978989, Fax num +34934978988

Email: oabduljawadaltisent@gmail.com

Woven disease is a rare and under-diagnosed coronary disease that is characterized by multiple thin channels bifurcating and weaving along the epicardial coronary artery. The characteristic TIMI 3 flow in the distal segment of the artery, where the conduits reassemble again into a single lumen, usually renders this anomaly as benign clinical entity [1] (Figure 1A). However, some controversy appeared recently after the description of a case of Woven disease causing ischemia and angina [2]. We decided to decode the underlying physiopathology of woven disease and the probability of causing ischemia. For these purposes we analyzed the channel morphology of a case of Woven disease affecting the right coronary artery (RCA), and we built and compared numerical simulations of the flow and a theoretical model using fluid dynamic principles.

Morphology characterization of the model was performed using the DICOM files of the coronary angiography and optic coherence tomography (Dragonfly®, Abbott) of the artery. The digital images were processed by the software ITK-SNAP 3.8, which was used to segment and extrapolate the 3D structure of the artery. The area and wetted perimeter of the artery and each channel at different axial positions were computed using a Matlab script.

Fluid dynamic principles define the hydraulic diameter as four times the total cross-sectional area available for the flow divided by the wetted perimeter [3]. The segmented 3D artery structure was used to perform a Computational Fluid Dynamic (CFD) numerical simulation (ANSYS Fluent R.19) which was carried out, assuming Newtonian fluid behavior, with density 1050 $kg/m^3$ and viscosity $4 \cdot 10^{-3}$ $Pa \cdot s$, and rigid vessel walls. The time averaged values of the measured aortic and intracoronary pressures were imposed as boundary conditions at the inlet and outlets, respectively. For this purpose, a Fractional Flow Reserve (FFR) wire (Volcano®) was used.

For the theoretical model, we considered the conventional relation between the pressure drop and the flow rate for a fully developed, laminar, steady pipe flow of a Newtonian fluid with constant physical properties. Under these hypotheses, the ratio between the pressure drop produced by the channels $(dp/dz)_B$ and the pressure drop produced by a vessel of constant diameter $(dp/dz)$ can be written as,

$$\frac{(dp/dz)_B}{dp/dz} = \frac{1}{\sum_1^N A_i^{*2}} \tag{1}$$

where N is the number of channels at a given axial position and $A_i^*$ is the ratio between the total cross-sectional area available for the flow and the area of a single channel.

Figure 1 shows three different views of the segmented artery (Figure 1B) together with the number of channels (Figure 1C), vessel connectivity (Figure 1D) and the hydraulic diameter (Figure 1E) and along the axial direction (z or flow direction). The initial portion of the vessel (N=1, z<5 mm had a hydraulic diameter of about 2.6 mm and it was successively divided into two, three and up to four channels. However, there were locations along the axial position in which the different channels merged into a single vessel (N=1 at z=11.5 mm, 31.5 mm, 42.0 mm and 48.5 mm, Figure 1D). Nonetheless, the hydraulic diameter was reduced from about 2.6 mm at the initial portion of the vessel down to about 1.5 mm in most of the length (5 mm>z> 48.0 mm) of the Woven segment (Figure 1E).

FFR along the Woven segment showed a pressure drop of ⍰P=-15.1 mmHg. The computed pressure drop of the Woven segment, $(dp/dz)_B$, using Eq. 1 was calculated using the flow rate predicted by the CFD simulation. Q=1.48 mL/s, and the average diameter ($D$=2.6 mm) of the initial portion of the vessel (N=1, z<5.0 mm). shows a $dp/dz$=37.7 mmHg/m in the initial portion of the vessel (N=1, z<5.0mm, average diameter 2.6mm,

Figure 1F shows the axial decreases of pressure predicted by the numerical simulation (red lines), by theoretical model (green line), and that assuming no channels along the artery (blue line) (i.e. the theoretical value of the post stenting woven segment, $dp/dz$=-37.7 mmHg/m). The theoretical model under-predicted the measure pressure drop by about 25%.

This is the first time that the morphology and the underlying physiopathology of Woven disease for causing myocardial ischemia were assessed. The segmentation of a RCA with Woven disease revealed truly complex channel morphology. The hydraulic diameter decreased significantly into the affected segment (Figure 1E). As a consequence, the numerical simulation and the theoretical model showed a significant pressure drop. However, compared with the numerical simulation, the theoretical model under-predicted the measured pressure drop by about 25% (Figure 1F). This could be explained because Equation 1 neglects entrance and exit effects of the channeling and the curvature of the vessels, and assumes fully developed flow conditions. Therefore, the effect of branching for causing pressure drop and ischemia in Woven disease is, for the case considered, not negligible.

Indeed, Woven disease may not be as benign as previously described. Indeed, the complex three-dimensional channel structure of an artery of Woven disease makes it difficult to angiographically assess the effective area of the arterial segment affected. It seems that the probability of pressure drop is proportional to the effective area, the number of channels and to the length of the segment with channels. The greater number of channels and length, the more flow drop and resultant ischemia (figure 1D, E, F). For these reasons the functional assessment with FFR of each case of woven disease, not conventional angiography, is likely the most appropriate method to assess the risk of ischemia.

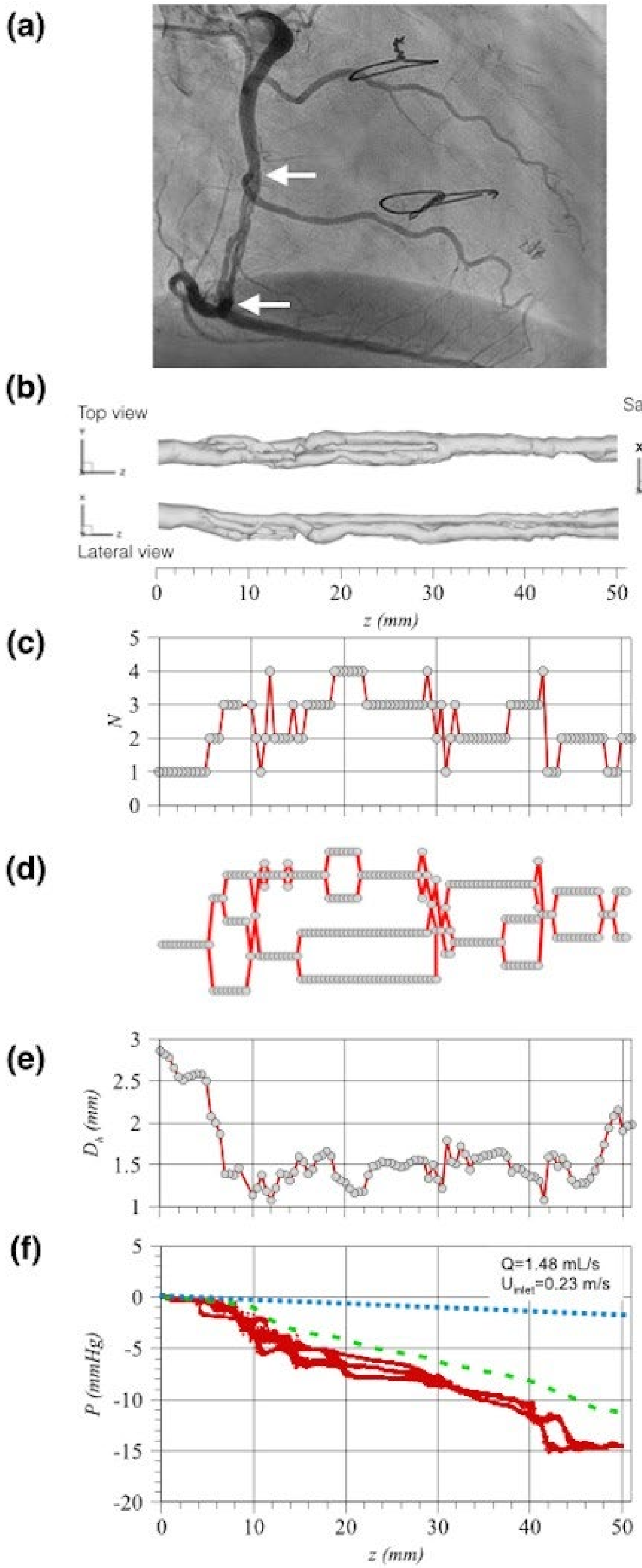
## Disclosures

Authors had no conflict of interest to disclose.

## FIGURE LEGENDS

Figure 1. (A) Angiography of a patient with woven disease affecting the right coronary artery (segment affected between white arrows). (B) Top, lateral and sagittal view of the segmented artery affected by woven disease. (C) Number of individual channels at each axial (z) position. (D) Connectivity of the channels along the axial direction. (E) Hydraulic diameter. (F) Pressure drop in each channel estimated by numerical simulation (red lines), by theoretical model (dash-dotted

line) and by Poiseuille flow with constant diameter (blue line, with D=2.6 mm, Q=1.48 mL/s). (z) indicates flow direction.


(a)
(b)
Top view
Sagital view
Lateral view
x
y
z
0
10
20
30
40
50
z (mm)
(c)
N
0
1
2
3
4
5
(d)
(e)
$D_h$ (mm)
1
1.5
2
2.5
3
(f)
P (mmHg)
5
0
-5
-10
-15
-20
Q=1.48 mL/s
$U_{inlet}$=0.23 m/s
0
10
20
30
40
50
z (mm)

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