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Helical Velocity Patterns in a Human Coronary Artery

A Three-Dimensional Computational Fluid Dynamic Reconstruction Showing the Relation With Local Wall Thickness

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A 74-year-old man was referred to our catheterization laboratory for elective angioplasty of the right coronary artery (RCA). One year earlier, he had suffered an acute inferior myocardial infarction, which was successfully treated with intravenous streptokinase. Only minor creatinine phosphokinase elevations were found. Since that time, however, the patient had frequently experienced exertional angina, Canadian Cardiovascular Society class 2. Because maximal antianginal medical therapy did not end these episodes, diagnostic coronary and left ventricular angiograms were performed. These showed a normal left ventricular contraction pattern. The left coronary arteries revealed no significant stenoses. The RCA showed a proximal stenosis of 90%.

The lesion was crossed with a hydrophilic guidewire and was predilated. A 4.0×13-mm self-expandable Wallstent (Schneider Co) was implanted for optimization of the angioplasty result (as verified with intracoronary ultrasound [IVUS]). Because the stent was insufficiently appositioned, poststenting balloon inflations were applied to further optimize the angiographic and ultrasonic results. After this successful intervention, no rise in creatinine phosphokinase was seen. The day after the procedure, the patient was dismissed from the hospital.

Six months later, a control angiogram was performed. Since the original procedure, the patient had remained free of angina. Coronary anatomy was assessed through both biplane angiography and IVUS. No angiographic restenosis at the stented site was seen; IVUS revealed only mild neointimal hyperplasia (Figure 1).

Recently, we reported a novel technique combining IVUS and angiography (ANGUS) for 3D reconstruction of coronary arteries.[1] Through a combination of this technique with computational fluid dynamics, fluid particle behavior can be calculated at any site of interest and compared with the local wall thickness.[2] In the present patient, we applied this technique to the stented RCA. Figure 1 shows the angiographic left anterior oblique view of the RCA (A) with respective IVUS images, computed fluid particle dynamics of 3 hypothetical red blood cells entering the vessel (B), and a 3D reconstruction of the wall thickness color-coded on the lumen surface (C). The impression of neointimal hyperplasia seen on the angiogram was only partly confirmed by IVUS, which revealed a 1-mm neointimal thickness; this discrepancy may be caused by flow impairment induced by the IVUS catheter still present in the lumen. Furthermore, this picture shows that at the stented site, a small helical excursion of the particles can be observed, possibly influenced by the angulated vessel segment immediately preceding the stent location.

Figure 2 shows a detailed view of the proximal RCA (center). Panel A shows the IVUS image with a fibrocalcific plaque between the 9 and 12 o'clock positions; panel B highlights wall thickness, panel C the local wall shear stress (WSS) values, and panel D the velocity patterns of 3 hypothetical cells entering the vessel. From this image, it becomes clear that the eccentric plaque area shown on IVUS corresponds with a high-wall-thickness spot ("hot" red spot in B) and with a zone of low focal shear stress accompanied by flow abnormalities.

Disturbed flow patterns have been associated with oscillatory WSS, which has been implicated in plaque formation in the carotid artery.[3] Although investigation is ongoing as to whether oscillatory WSS, gradients in WSS, or low WSS is deleterious to the vascular wall, this frictional force exerted by the flowing blood at the endothelium of the artery has repeatedly been implicated in the pathogenesis of atherosclerosis[2] and vascular remodeling.[4] In human coronary arteries in vivo, the existence of helical flow has not yet been demonstrated. This case shows, for the first time, the presence of helical particle movement in a coronary artery and its relation to wall thickness and WSS. Because this patient is still symptom- and event-free 2.5 years after the initial stent implantation,

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it may be hypothesized that the absence of severe flow disturbances at the stented surface of the RCA (with possibly the presence of high shear stress) is an effective measure in the prevention of restenosis. Conversely, intensely disturbed flow patterns can sustain focal atherogenesis in other parts of the vessel.

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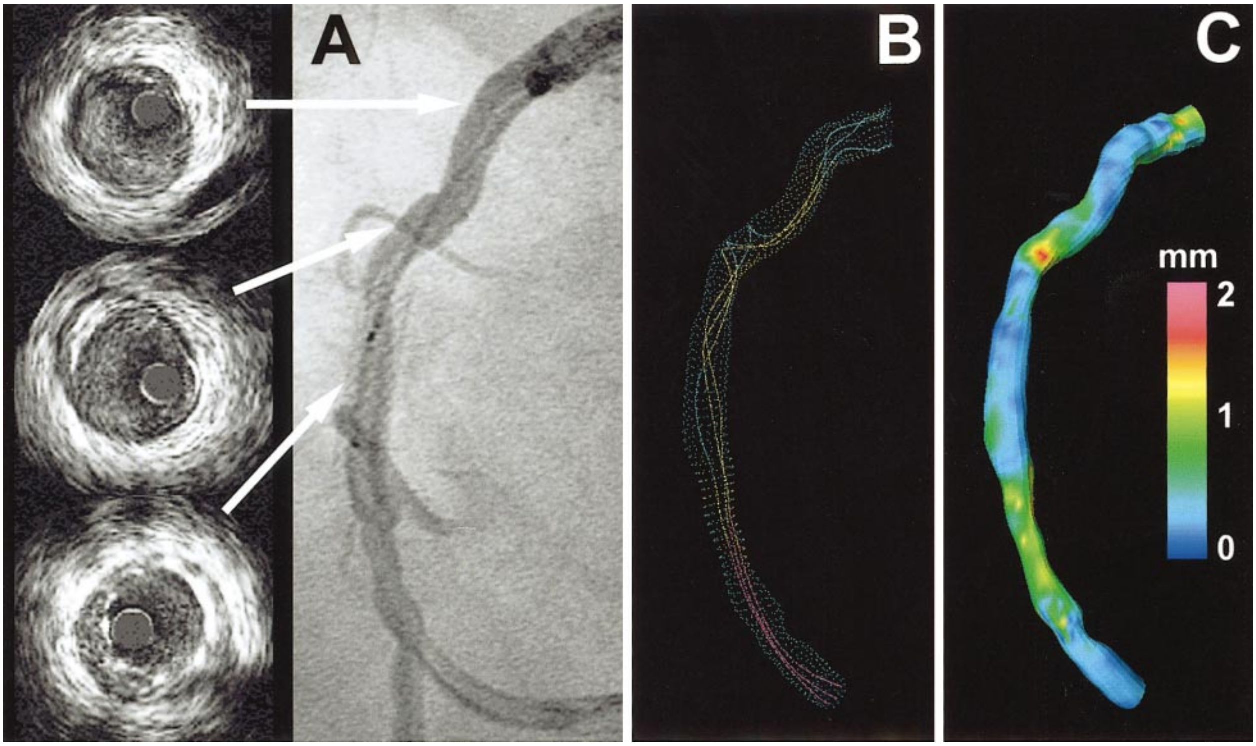

Figure 1. Left anterior oblique view of a stented right coronary artery (A) with IVUS images showing (from top to bottom) reference segment with slight intimal hyperplasia, focal fibrocalcific plaque, and stented segment (with only discrete neointimal formation). B, Flow paths of hypothetical red blood cells inside 3D reconstructed vessel. C, Local wall thickness, with color code ranging from 0 mm (blue) up to 2 mm (purple-red).

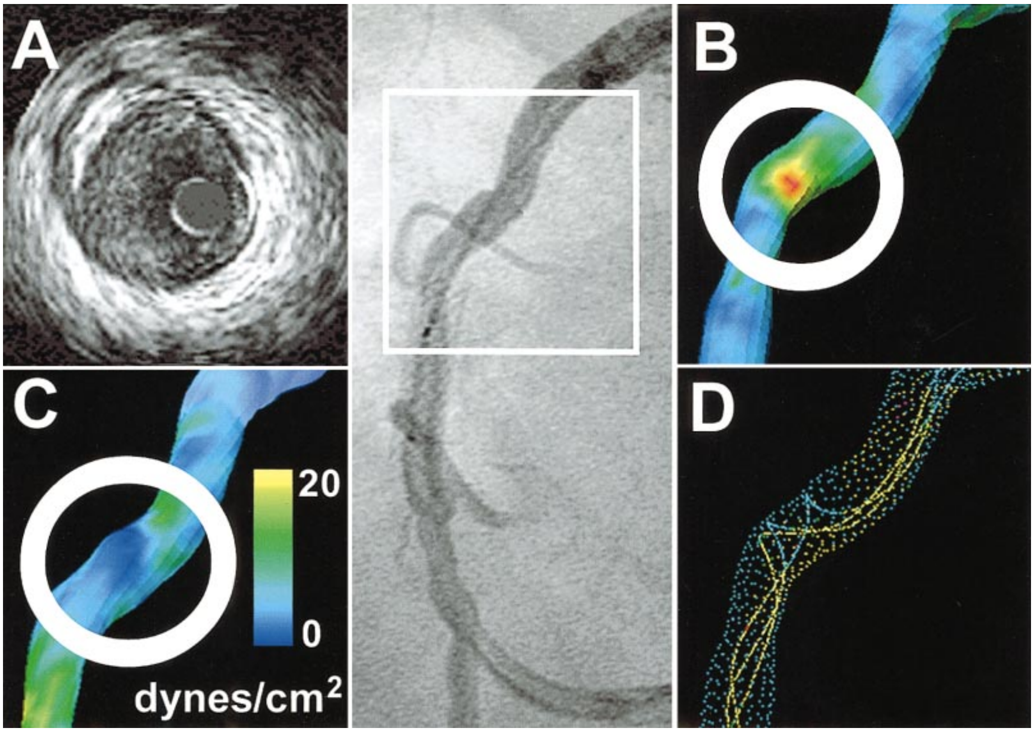

Figure 2. Detailed view of proximal part of RCA (white box) with IVUS image of a fibrocalcific plaque in a nontreated region (A), local wall thickness clearly demonstrating a "hot" (red) spot with increased thickness (B), computed local WSS with color code ranging from 0 to 20 dyne/cm^2 showing lower WSS values at site of interest (C), and helical flow patterns derived from computational fluid dynamics at site of increased vessel wall thickness (D).