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Paradoxical Computed Tomography-Derived Fractional Flow Reserve Changes Due to Vessel Morphology and Constituents

Damar Morfolojisi ve Bileşenlerine Bağlı Bilgisayarlı Tomografi Kaynaklı Fraksiyonel Akım Rezervinde Paradoksal Değişiklikler

CASE REPORT

OLGU SUNUMU

ABSTRACT

Computed tomography-derived fractional flow reserve decreases from the proximal to the distal with coronary stenosis. According to the principles of fluid dynamics, paradoxical computed tomography-derived fractional flow reserve changes require an unconventional vessel morphology and specific site of the vessels with a high driving force. Therefore, only a few articles have reported a paradoxical increase of computed tomography-derived fractional flow reserve. We present a case report of marked computed tomography-derived fractional flow reserve elevation in the middle left anterior descending artery with a severe coronary stenosis. Computed tomography-derived fractional flow reserve was 0.94 just proximal to the stenotic lesion and decreased to 0.65 at the maximum stenosis area but recovered to 0.80 in the distal segment. We speculated that the vessel morphology could have caused a pressure recovery phenomenon, resulting in paradoxical computed tomography-derived fractional flow reserve changes.

Keywords: Coronary computed tomography, funnel, pressure recovery

ÖZET

Bilgisayarlı tomografi kaynaklı fraksiyonel akım rezervi koroner stenozda proksimalden distale doğru azalır. Akışkanlar dinamiği ilkelerine göre, bilgisayarlı tomografi kaynaklı fraksiyonel akım rezervinde paradoksal değişiklikler, alışılmadık bir damar morfolojisi ve yüksek itici güce sahip spesifik damar bölgeleri gerektirir. Bu nedenle, yalnızca birkaç makalede bilgisayarlı tomografi kaynaklı fraksiyonel akım rezervinde paradoksal bir artış bildirilmiştir. Bu yazıda, ciddi bir koroner stenozu olan orta sol ön inen arterde bilgisayarlı tomografi kaynaklı belirgin fraksiyonel akım rezervi elevasyonu olan bir olgu sunmaktayız. Bilgisayarlı tomografi kaynaklı fraksiyonel akım rezervi stenotik lezyonun hemen proksimalinde 0,94 idi ve maksimum darlık bölgesinde 0,65'e düştü, ancak distal segmentte 0,80'e tekrar yükseldi. Damar morfolojisinin, bilgisayarlı tomografi kaynaklı fraksiyonel akım rezervinde paradoksal değişikliklere yol açan bir basınç geri kazanım fenomenine neden olabileceğini tahmin etmekteyiz.

Anahtar Kelimeler: Bilgisayarlı tomografi, huni, basınç geri kazanımı

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Computed tomography (CT)-derived fractional flow reserve (FFR_{CT}) values typically decrease from the proximal to the distal across a stenotic lesion.[1-4] According to the principles of fluid dynamics, potential energy is converted into kinetic or thermal energy across the stenotic lesion and dissipated. Paradoxical FFR_{CT} changes occur in unconventional vessel morphology, with kinetic energy recovered into potential energy (pressure recovery phenomenon). Such paradoxical FFR_{CT} changes have been reported in proximal vessels in only a few cases.[5,6] To our knowledge, there have been no reports of marked FFR_{CT} elevation except for proximal vessel segments. This report presents a patient with a paradoxical increase of FFR_{CT} at the middle segments of the vessels.

Case Report

A 63-year-old woman was admitted with chest discomfort at exertion. Coronary CT was performed for this patient. Vessel morphology and components of each segment were measured using GE AW server 3.2 software and Colour Code Plaque

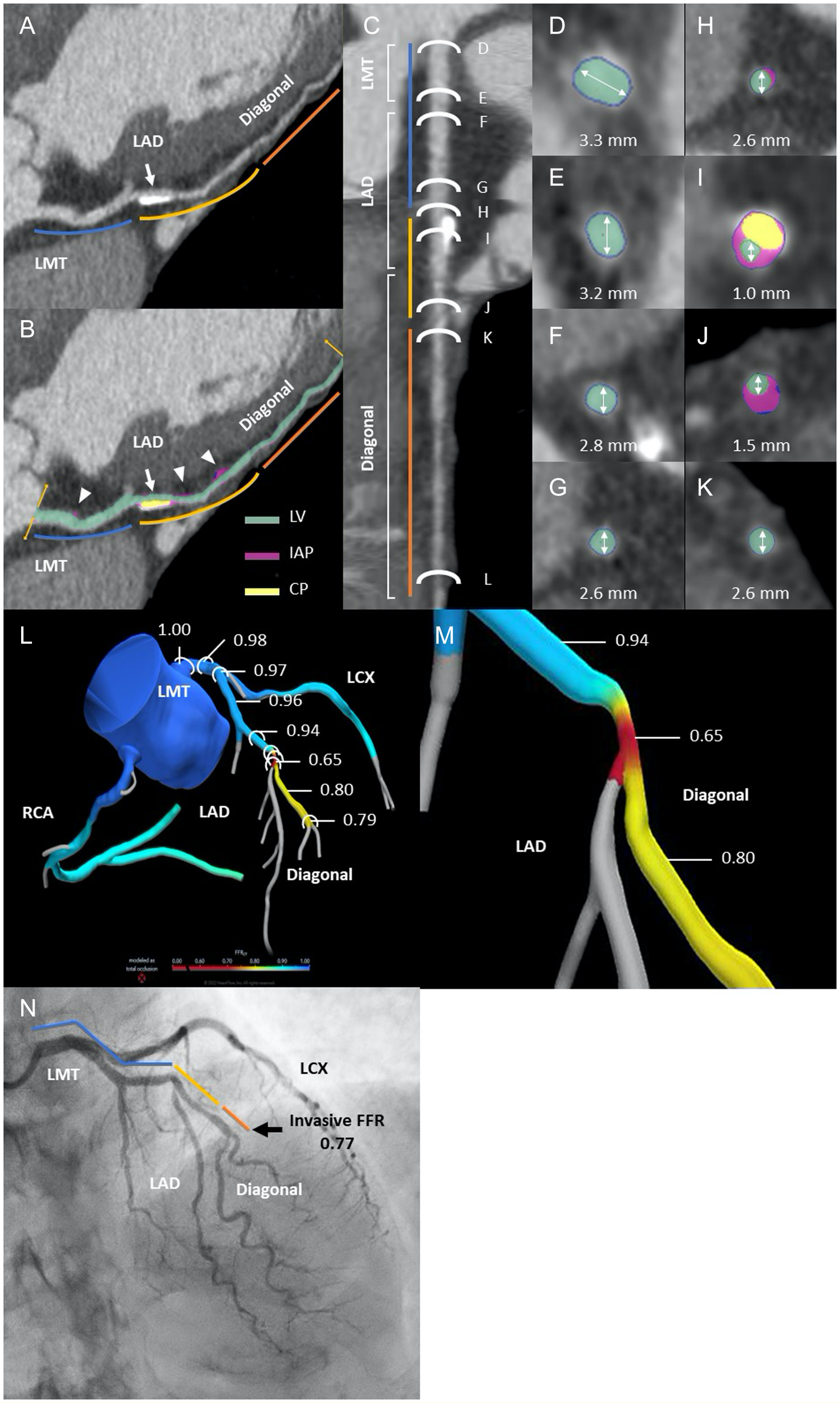

Figure 1. CTA: (A) Curved multiplanar reformat showing a severe stenotic lesion (yellow line) with calcified plaque (arrow) in the bifurcation between the LAD and diagonal branch. (B) Vessel components are indicated with the following colors: green is LV, red is IAP (arrowhead), and yellow is CP (arrow). (C) Stretched multiplanar reformation. (D-K) Each axial image corresponds to a stretched multiplanar reformat. FFR_{CT}: (L). FFR_{CT} changes in LMT, LAD, and diagonal branch. (M) Zoomed view of a stenotic lesion. Invasive coronary angiography: (N) Invasive FFR is 0.77. Blue, yellow, and orange lines indicate proximal lesion, stenotic lesion, and distal stenotic lesion, respectively. Blue, yellow, and orange lines indicate proximal lesion, stenotic lesion, and distal stenotic lesion, respectively. CP, calcified plaque; CTA, computed tomography angiography; IAP, intermediate-attenuation plaque; LAD, left anterior descending; LCX, left circumflex artery; LMT, left main trunk; LV, lumen volume; RCA, right coronary artery.

Table 1. Vessel Morphology and Components at Proximal Stenotic Lesion, Stenotic Lesion, and Distal Stenotic Lesion

	Total	Proximal Segment	Stenotic Lesion	Distal Segment
Absolute value of vessel components at each segment				
Vessel length (mm)	94.3	26.1	26.2	42.0
Proximal lumen diameter (mm)	3.3	3.3	2.6	2.6
Distal lumen diameter (mm)	1.2	2.6	1.5	1.2
Lumen volume (mm^3)	327.1	172.8	64.2	90.1
LAP volume (mm^3)	4.2	0	4.1	0.1
IAP volume (mm^3)	76.4	4.3	67.2	4.9
CP volume (mm^3)	24.8	0.1	24.7	0.1
Proportion of vessel components at each segment				
Lumen volume (%)	75.6	97.5	40.1	94.7
LAP volume (%)	1.0	0	2.6	0.1
IAP volume (%)	17.7	2.4	41.9	5.2
CP volume (%)	5.7	0.1	15.4	0

CP, calcified plaque; IAP, intermediate-attenuation plaque; LAP, low-attenuation plaque.

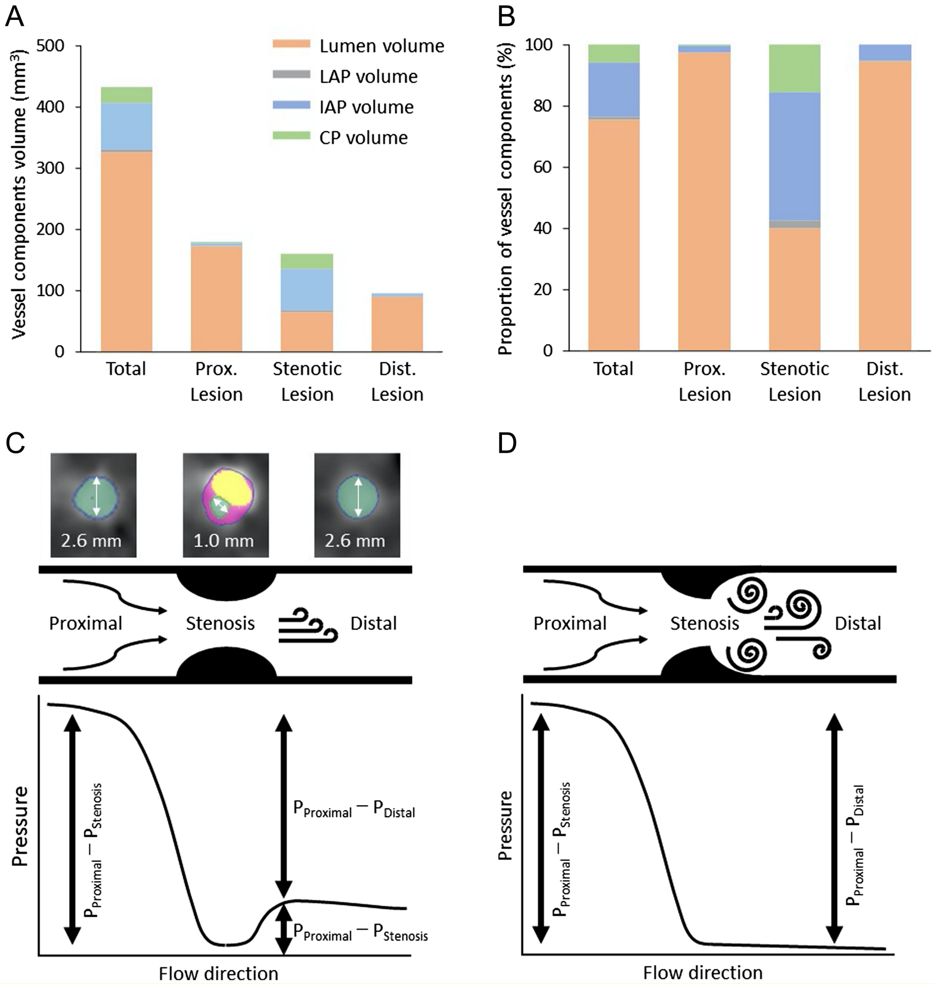

Figure 2. Vessel components at the proximal stenotic lesion, stenotic lesion, and distal stenotic lesion: (A) Absolute value of vessel components at each segment. (B) Proportion of vessel components at each segment. Schematic of energy dynamics in different stenotic lesions: (C) Model of streamlined stenotic lesion. (D) Model of orifice-like stenotic lesion. CP, calcified plaque; Dist., distal; IAP, intermediate-attenuation plaque; LAP, low-attenuation plaque; Prox., proximal.

Table 2. Proportion of Each Segment to Vessel Components at Proximal Stenotic Lesion, Stenotic Lesion, and Distal Stenotic Lesion

	Lumen Volume	LAP Volume	IAP Volume	CP Volume
Proximal segment (%)	52.9	0	5.6	0.4
Stenotic lesion (%)	19.7	97.6	88.0	99.6
Distal segment (%)	27.6	2.4	6.4	0

CP, calcified plaque; IAP, intermediate-attenuation plaque; LAP, low-attenuation plaque.

(General Electric Healthcare, Chicago, Ill, USA). Vessel components were characterized based on Hounsfield units into low-attenuation plaque (LAP) (<30 HU), intermediate-attenuation plaque (IAP) (30-150 HU), and calcified plaque (CP) (>150 HU).[1,3,7] Computed tomography-derived fractional flow reserve (HeartFlow Inc., Redwood City, Calif, USA) was calculated based on a 3-dimensional anatomic model synthesized from CT angiographic data.[1,3,7] Coronary CT angiography revealed severe coronary stenosis (coronary artery disease reporting and data system classification:[8] 4A) at the level of the left anterior descending artery (LAD) and the first diagonal branch bifurcation. The lumen diameter was 3.3 mm at the ostium of the left main trunk (LMT) and gradually tapered to 2.6 mm proximal to the stenotic lesion. The lumen diameter was 1.0 mm at the stenotic lesion and dilated to 1.5 mm, forming a streamlined shape (Figure 1A-K). Virtually no plaque components were observed in the peri-stenotic lesions, whereas the proportion of plaque components (LAP, IAP, and CP) in the stenotic lesion was as much as 59.9% (Table 1 and Figure 2A and B). The LAP, IAP, and CP were more abundant in stenotic than peri-stenotic lesions (stenotic vs. peri-stenotic: LAP, 97.6 vs. 2.4%; IAP, 88.0 vs. 12.0%; CP, 99.6 vs. 0.4%) (Table 2). Computed tomography-derived fractional flow reserve at the proximal LMT was 1.00 and gradually decreased to 0.94 proximal to the stenotic lesion. It dropped to 0.65 at the maximum stenosis which corresponded to the level of LAD diagonal branch bifurcation but recovered to 0.80 at the distal segment (Figure 1L and M). Invasive coronary angiography showed severe coronary stenosis (yellow line) at the bifurcation between LAD and diagonal branch. Invasive FFR was measured 20 mm distal to the stenotic lesion, and its value was 0.77 (Figure 1N). A drug-eluting stent was implanted at the level of the stenotic lesion. During 1 year following intervention, the patient had an uneventful clinical course and had not developed any cardiovascular symptoms.

Table 3. Previous and Present Case of Paradoxical FFR_{CT} Location

	Significant Coronary Stenosis (+)	Significant Coronary Stenosis (–)
Location of paradoxical FFR_{CT} (proximal segments)	LMT/ramus[6]	LMT/ramus[5]
Location of paradoxical FFR_{CT} (middle segments)	LAD/diagonal branch	N/A

FFR_{CT}, computed tomography-derived fractional flow reserve; LAD, left anterior descending; LMT, left main trunk; N/A, not available.

Discussion

According to the principles of fluid dynamics, a paradoxical increase of FFR_{CT} cannot occur unless unconventional conditions exist. To our knowledge, the present case is the first to show FFR_{CT} elevation in a middle segment of a vessel with severe stenotic lesion. In the present study, the paradoxical FFR_{CT} might be explained by the interaction of structural and functional factors. Pressure recovery phenomenon may be a possible mechanism of the observed FFR_{CT} elevation. Vessel flow velocity is accelerated at the stenotic lesion, resulting in potential energy being converted into kinetic energy. A small number of turbulent eddies generated at the stenotic lesion resulted in a smaller thermal energy loss and a larger reconverted into potential energy (pressure recovery phenomenon) (Figure 2C). A large amount of turbulent eddies generated at the stenotic lesion lead to high thermal energy loss generated by flow separation; thus, a pressure recovery occurs (Figure 2D).[9,10] We recently reported such a phenomenon of paradoxical mild FFR_{CT} elevation (proximal FFR_{CT} 0.92 ± 0.01, distal FFR_{CT} 0.96 ± 0.07) at the LMT –ramus artery junction in patients without apparent coronary stenosis. Since the relative narrowing of the vessel diameter was noted in the ramus compared to LMT, this mild FFR_{CT} elevation may be related to pressure recovery phenomenon accompanied by this structural factor.[5] In the present case, pressure recovery phenomenon might be affected not only by the structural factors but also by other factors. The stenotic lesion had a streamline-shaped morphology. Streamlined forms generate less turbulent eddies and a large pressure recovery.[10] Of note, the components of the stenotic lesion were abundant in LAP, IAP, and CP, whereas those of the peri-stenotic lesion contained little plaque components (LAP, IAP, and CP) (Figure 2A and B). Inadequate vasodilation resulted in reduced flow velocity and pressure gradients in the vessel before and after the stenotic lesion; thus changes in FFR_{CT} were smaller than expected. The contrast of plaque components between stenotic lesion and peri-stenotic lesions reinforced the streamlined vessel morphology functionally and structurally. In previous reports,[5,6] paradoxical FFR_{CT} changes occurred at the proximal segments of the vessels with high vessel flow velocity which had a high driving force (kinetic energy).

Conclusion

The difference of plaque burden between the stenotic and non-stenotic regions may contribute to a marked FFR_{CT} elevation due to structural and functional factors.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Universitair Ziekenhuis Brussel (Approval No: B.U.N. 143202000302).

Informed Consent: Written informed consent was obtained from the patient for the publication of the case report and the accompanying images.

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