ESC European Society of Cardiology

European Heart Journal - Case Reports (2024) **8**, 1–4
https://doi.org/10.1093/ehjcr/ytae005

CASE REPORT
Cardiovascular imaging

Normalization of FFR_{CT} after surgical unroofing of a myocardial bridge: a case report

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Received 16 May 2023; revised 19 December 2023; accepted 3 January 2024; online publish-ahead-of-print 11 January 2024

Background Cardiac computed tomography angiography derived fractional flow reserve (FFR_{CT}) is a diastolic measurement and has emerged as a valuable non-invasive alternative to FFR in patients with stable coronary artery disease. It has, unlike FFR during coronary angiography, not been validated for the physiological evaluation of an isolated myocardial bridge (MB) so far.

Case summary Our patient, previously known with a long myocardial bridge of the mid-segment of the left anterior descending artery, presented with a non-ST-segment elevation myocardial infarction that was treated by surgical unroofing of the MB. FFR_{CT} after surgery confirms a major amelioration of coronary blood flow.

Discussion Myocardial bridge may rarely present as a non-ST-segment elevation myocardial infarction. FFR_{CT} has thus far been accepted as a useful diagnostic tool in stable coronary artery disease. Our case report suggests that cardiac computed tomography angiography may be considered a useful technique for anatomical and physiological evaluation of MBs.

Keywords Case report • Cardiac computed tomography angiography • Fractional flow reserve • Myocardial bridge

ESC curriculum 2.1 Imaging modalities • 2.4 Cardiac computed tomography • 3.1 Coronary artery disease • 3.2 Acute coronary syndrome

Learning points

- A myocardial bridge may in rare cases be a cause of angina and even an acute coronary syndrome.
- A diastolic-specific index seems particularly attractive in the functional evaluation of a myocardial bridge since 85% of coronary blood flow occurs during diastole.
- Cardiac computed tomography angiography derived fractional flow reserve may be considered a useful technique for anatomical and physiological evaluation of MBs.

Introduction

A myocardial bridge (MB) is usually considered a benign condition but may be responsible for acute coronary syndrome.[1] Cardiac computed tomography angiography (CCTA) derived fractional flow reserve (FFR_{CT}) has not been validated for the physiological evaluation of an isolated MB so far. Our case demonstrates an amelioration in coronary blood flow through FFR_{CT} before and after surgical unroofing of the MB.

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Handling Editor: Christoph Jensen
Peer-reviewers: Amardeep Ghosh Dastidar; Giampiero Vizzari
Compliance Editor: Polyvios Demetriades

Summary figure

Time	Event
24 November 2017	Presentation at the urgency department with complaints of anginal pain on exertion with normal troponin level.
25 November 2017	Coronary angiography confirms a long myocardial bridge (MB) in the middle segment of the left anterior descending artery (LAD). The patient is treated with bisoprolol 5 mg once daily.
24 August 2018	Rehospitalization due to a post-exertional prolonged episode of angina with elevated high sensitivity troponins.
	Repeat coronary angiography demonstrated no significant changes.
27 August 2018	Discussion on heart team. Decision for surgical treatment.
28 August 2018	Cardiac computed tomography angiography (CCTA) demonstrating a long MB of the LAD with a CCTA derived fractional flow reserve (FFR_{CT}) value of 0.76 in the apical portion.
21 September 2018	Surgical unroofing (supra-arterial myotomy) of the MB.
18 January 2019	Normalization of FFR_{CT} value. No new complaints of anginal pain occurred.

Case presentation

This 55-year-old patient without relevant medical history and unremarkable physical examination underwent diagnostic coronary angiography for progressive complaints of angina on exertion. There were no obstructive atherosclerotic lesions. However, a MB at the mid-portion of the left anterior descending coronary artery (LAD) was seen with visually important 'systolic milking' (>70% luminal reduction) and a clear step down-step up phenomenon due to systolic compression of the tunnelled segment (*Figure 1A and B*). Transthoracic echocardiography was normal. The patient was treated medically with bisoprolol 5 mg and acetylsalicylic acid 80 mg once daily.

A few months later, he was re-hospitalized after a post-exertional prolonged episode of angina. A diagnosis of non-ST-segment elevation myocardial infarction was made based on T-wave flattening in the precordial leads and elevated high sensitivity troponins (0.552 μg/L with normal reference value < 0.005 μg/L). Repeat coronary angiography showed unchanged findings. After discussion in heart team, it was decided to treat this patient by means of surgical unroofing (supra-arterial myotomy) of the MB because of failed medical treatment. This was done successfully off pump through median sternotomy without any complication after which no more symptoms of angina nor coronary events occurred during follow-up. Before surgery, CCTA was done for further characterization of the MB. This confirmed the presence of a deep (3.7 mm) and a long (57 mm) MB of the mid-LAD. Cardiac computed tomography angiography derived fractional flow reserve (FFR_{CT}) was also measured (Heartflow Inc., CA, USA) and repeated after surgery (*Figure 1C and D*). On both occasions, the patient received nitroglycerine 0.4 mg sublingually. All images were acquired with a 320 slice GE Revolution™ scanner. As becomes clear from the images, surgical unroofing caused a major amelioration of coronary blood flow based on FFR_{CT}.

Discussion

A MB is a congenital coronary anomaly in which a segment of the coronary artery (the tunnelled segment) traverses through the myocardium at different degrees of length and depth. Most MBs are located in the LAD (>75% of cases), left circumflex and right coronary artery are less commonly affected. Arbitrarily, a tunnelled segment with a length > 25 mm is considered long and a depth of >2 mm is considered deep. Prevalence is high: one in three adults based on autopsy studies, ~5% on coronary angiography and 20% on CCTA.[1] As a consequence, it is generally considered a benign condition but in rare instances, MB can be a cause of angina and even an acute coronary syndrome as in our case.[1] Therefore, there is a clear clinical need for additional testing to identify the 'vulnerable' MB. Functional assessment of coronary lesions represents an essential tool for both epicardial and microvascular circulation.[2] Fractional flow reserve (FFR) has been used for this purpose but given the peculiar physiology of MB, its measurement and interpretation are cumbersome. Previous studies showed that diastolic FFR using dobutamine is more accurate in identifying MB-related ischaemia (with an ischaemic cut-off point of 0.76) compared to whole cycle mean FFR using adenosine as is routinely done in fixed atherosclerotic stenosis.[3] This is explained by an intracoronary systolic pressure overshoot caused by the systolic compression interfering with measurements based on mean pressures. Due to this coronary compression, the distal coronary pressure can even exceed proximal aortic pressure leading to a reversed systolic pressure ratio. In fixed stenosis, the differences between diastolic and mean pressure gradients are non-significant.[4] However, diastolic FFR with dobutamine challenge is time-consuming and difficult to obtain and is therefore not routinely performed in most laboratories.

Nevertheless, a diastolic-specific index seems particularly attractive in the functional evaluation of a MB. From a physiological point of view, this makes sense since 85% of coronary blood flow occurs during diastole.[1] Intuitively when looking at the often-impressive milking effect of a MB, one could believe that this compression is the primary cause of myocardial ischaemia. During systole, there is indeed very limited to no flow in the MB segment. It needs to be recognized that during diastole, there is a continued impairment of flow due to a delay in the increase in luminal diameter caused by persistence of some degree of systolic compression into mid-to-late diastole. This hampered diastolic flow is most prominent in the subendocardium that is more subject to ischaemia. Both systolic and predominantly diastolic flow impairment contribute thus to myocardial supply–demand mismatch in a MB.[1]

FFR_{CT} uses computational fluid dynamics to calculate 3-vessel virtual FFR. Patiespecific coronary geometries are derived from conventional CCTA images. Numerical solution of the Navier–Stokes equations that govern the fluid dynamics of blood flow results in a 3-dimensional pressure map across the entire coronary tree.[5] It is per definition a purely diastolic measurement since CCTA images are acquired in mid-diastole (diastasis). FFR_{CT} has emerged as a valuable non-invasive alternative to FFR in patients with stable coronary artery disease.[6] It has not been validated for the physiological evaluation of an isolated MB so far.

This case shows for the first time by using FFR_{CT} that there is a clear diastolic impediment of coronary flow due to the presence of a deep and long MB. This impaired flow causes ischaemia with FFR_{CT} values < 0.80 showing a gradual pressure drop along the vessel comparable to what we see in diffuse coronary artery disease. Clinically, this led to a non-ST-segment elevation myocardial infarction. Surgical unroofing has a profound beneficial effect with restoration of coronary flow to normal FFR_{CT} values. Cardiac computed tomography angiography could be considered the preferred technique for anatomical evaluation of MBs permitting accurate measurement of length and depth but it could also become a one-stop test incorporating physiological

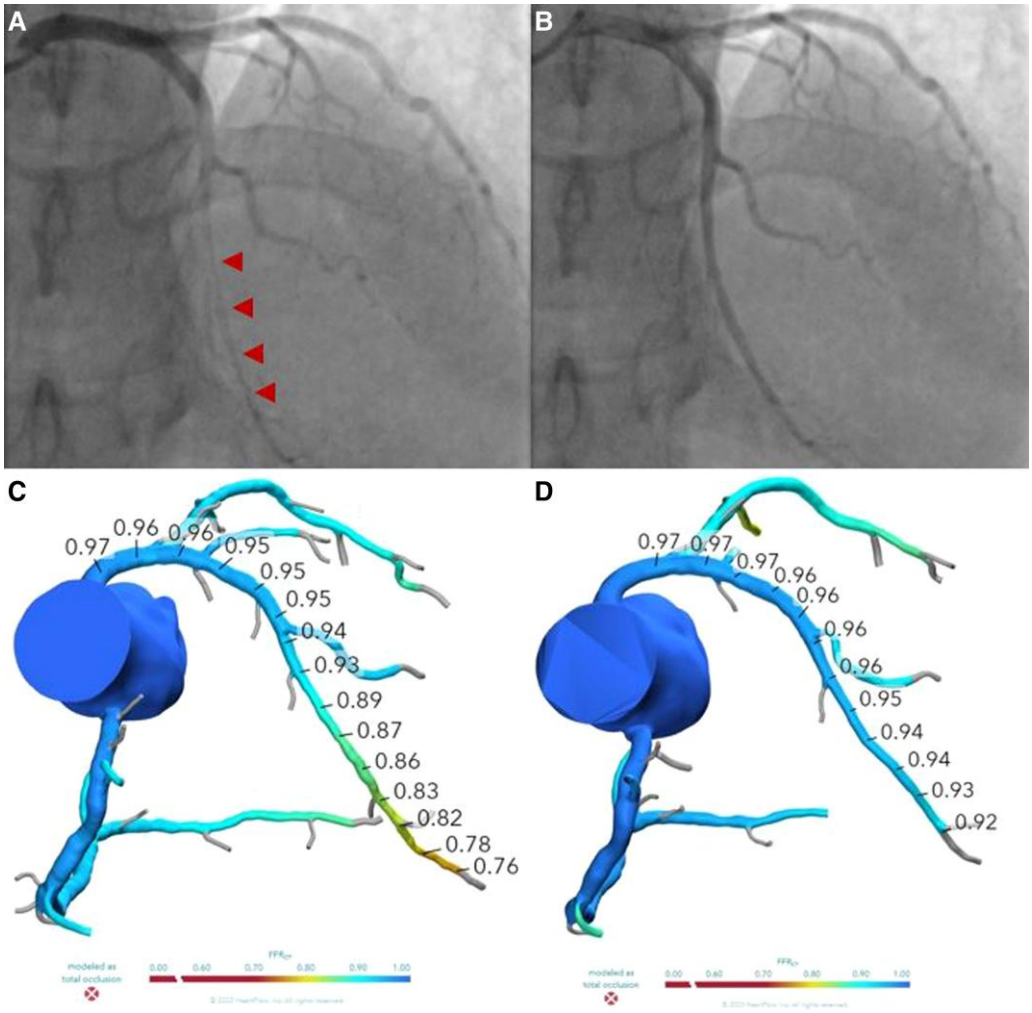

Figure 1 Diagnostic coronary angiography showing marked systolic compression (delineated with arrows), indicative of myocardial bridging (*A*); apparent normal course of the LAD in diastole (*B*); FFR$_{CT}$ prior to surgical unroofing, with FFR values shown along the LAD (*C*); FFR$_{CT}$ after surgical unroofing with normalization of FFR$_{CT}$ values (*D*).

evaluation. A limitation in our case is that no invasive assessment was done post-surgery to compare with the FFR$_{CT}$ values. Evidently, validation studies against other coronary physiological indices and studies with clinical endpoints need to be done before this translates into clinical practice.

Lead author biography

Martens Broes is a cardiology resident in the University Hospital Brussels. He will finish his residency in one year and has a great interest in all aspects of cardiology. He is being trained and supervised by, among others, the co-authors on both a clinical and scientific level.

Acknowledgements

The content is solely the responsibility of the authors.

Consent: The authors confirm that written consent for submission and publication of this case including images and associated text has been obtained from patient in line with COPE guidance.

Conflict of interest: None declared.

Funding: No financial support was received.

Data availability

The data underlying this article are available in the article.

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