The Prevalence and Anatomical Patterns of Intramuscular Coronary Arteries
A Coronary Computed Tomography Angiographic Study

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Objectives
This study sought to report prevalence and radiologic patterns of intramuscular coronary arteries (myocardial bridging) on coronary computed tomographic angiography (CCTA).

Background
Reported prevalence of intramuscular coronary arteries varies between 5% and 86% in autopsy and 0.8% and 4.9% in coronary angiography. Intramuscular coronary arteries can cause technical problems during coronary bypass surgery, including inadvertent perforation of the right ventricle.

Methods
One hundred and eighteen consecutive patients were studied with CCTA using Brilliance 40/64 multidetector computed tomography (Philips Medical Systems, Cleveland, Ohio). Parameters evaluated were number, length, and depth of intramuscular coronary segments; diameter and evidence of atherosclerosis in the involved artery proximal and within the intramuscular segment; and its course in relation to the interventricular septum and right ventricular wall.

Results
Forty-seven intramuscular segments were identified in 36 of 118 (30.5%) patients. Most were located in mid left anterior descending coronary artery (LAD), 27 of 47 (57%), and distal LAD, 7 of 47 (15%). The CCTA features in the LAD showed 3 patterns: superficial septal, 10 of 34 (29.4%); deep septal, 14 of 34 (41.1%); and right ventricular type, 10 of 34 (29.4%). Intramuscular segment length ranged from 13 to 40 mm. Coronary diameter proximal and within the affected segment was 2.2 ± 0.5 mm versus 1.6 ± 0.6 mm for the LAD, and 1.9 ± 0.3 mm versus 1.5 ± 0.6 mm for the remaining arteries, respectively. Depth ranged from 0.1 to 5.6 mm.

Conclusions
Prevalence of intramuscular coronary arteries on CCTA is in concordance with most pathological reports and higher than in angiographic series. The CCTA clearly showed presence, course, and anatomical features of intramuscular coronary arteries. Coronary computed tomographic angiography may provide potentially useful information in the preoperative evaluation of candidates for coronary bypass surgery. (J Am Coll Cardiol 2007;49:587–93) © 2007 by the American College of Cardiology Foundation

Coronary arteries in the human characteristically have an epicardial course. Not infrequently, however, segments of these arteries run intramuscularly. This variant is known as myocardial bridging and is most commonly seen in the left anterior descending coronary artery (LAD) (1–5). The clinical significance of myocardial bridging is controversial. In most of the cases, myocardial bridging represents an incidental finding that may be considered a normal variant or a benign coronary anomaly (4–5). Cases have been reported, however, of myocardial bridging causing myocardial ischemia, myocardial infarction, arrhythmias, or sudden death (6,7). Reduced coronary flow reserve and altered vasoreactivity has been documented in arteries with an intramuscular segment (3–5,8). In addition, myocardial bridging may present a technical challenge during coronary arterial bypass because surgical exposure of the intramuscular coronary artery may be difficult and may require the use of intraoperative echocardiography (9,10). Accidental opening of the right ventricle during dissection of intramuscular LAD is an undesired complication (11,12).

The true prevalence of myocardial bridging is not known. In autopsy series, myocardial bridging was found in 5% to 86% of the cases (3–5). It is commonly recognized that myocardial bridging is underdiagnosed in vivo. In vivo diagnosis is usually made with coronary angiography showing the characteristic “milking” effect (13). Additionally, a typical intravascular ultrasound (IVUS) appearance (the half-moon sign) and a characteristic spike-and-dome pat-
tern of diastolic flow with intracoronary Doppler wire have been reported (14). The incidence of myocardial bridging reported in angiographic series ranged from 0.8% to 4.9%. Few reports in cardiac surgery literature suggested the presence of an intracavitary subtype with an estimated prevalence of 0.2% to 0.3% (12).

Recently, coronary computed tomographic angiography (CCTA) using multidetector computed tomography (CT) has been introduced for the noninvasive visualization of coronary arteries. At variance with conventional coronary angiography, CCTA is able to visualize in the same image not only the lumen of coronary arteries but also their walls, the neighboring myocardium, and the heart chambers. A CCTA therefore should be able to visualize myocardial bridging in a more sensitive and comprehensive way than coronary angiography, in which the diagnosis is not made by the direct visualization of the intramuscular course but the indirect finding of systolic compression of the coronary artery indicated by the milking effect. A few case reports of myocardial bridging diagnosed by CCTA have been recently published (15–17). The goal of this study is to report the prevalence and the morphologic characteristics of myocardial bridging diagnosed at CCTA in a consecutive series of 118 patients.

**Methods**

One hundred eighteen consecutive patients who underwent CCTA for suspected or known coronary artery disease were studied for the presence of intramuscular coronary arteries. Two additional patients were excluded from analysis because of poor image quality. A beta-blocker drug was administered to all patients with heart rate >65 beats/min (metoprolol 100 mg orally or 5 to 10 mg intravenously, 1 h or immediately before scanning, respectively). A CCTA was obtained with a 40-slice (72 patients) or 64-slice (46 patients) multidetector CT scanner (Brilliance 40/64, Philips Medical Systems, Cleveland, Ohio). Scanning was performed with both scanner types at 120 kV, using 600 to 800 mA, with a detector collimation of 0.625 mm and gantry rotation speed of 0.42 s. Minimal slice thickness was 0.67 mm, and the reconstruction interval was 0.4 mm. A volume of 80 to 120 ml of contrast media (Iomeron 400, Bracco Imaging SpA, Milan, Italy) was injected intravenously at a rate of 4 to 5 ml/s. Using retrospective electrocardiographic gating, reconstructions were performed routinely at 40%, 70%, 75%, and 80% phases of the R-R interval period. Additional reconstructions during the end-systolic phase (20% to 30% of the R-R interval) were excluded from analysis because of their limited image quality, which did not allow reliable measurements of vessel caliber and anatomical delineation. Analysis of scans was performed on a dedicated workstation (Philips Extended Brilliance Workspace). Reconstructed images were viewed using the original axial slices, curved multiplanar reformations (MPR) along the axis of each vessel, and volume-rendered images. Scans were analyzed by a consensus of an experienced radiologist (4 years of experience with CCTA) and a cardiologist (30 years of experience in cardiac catheterization).

Myocardial bridging was diagnosed and evaluated when an intramuscular segment of a coronary artery was visualized on axial and MPR images. Arterial segments located in a deep gorge but covered only by a thin layer of muscle or fibrous–fatty tissue were included because it was reported that they also may be compressed during systole by the surrounding muscle (4).

For each intramuscular segment, the following parameters were recorded: the coronary artery and the segment involved, the length and the diameter of the intramuscular segment, the diameter of the artery immediately proximal to the intramuscular entry, presence of atherosclerosis in the intramuscular segment, and in a 2-cm-long segment proximal to the entry of the intramuscular segment. The ability to correlate the myocardial bridging localization in multiplanar reformats with the display in volume-rendered images was also evaluated. In addition, for intramuscular segments in LAD, the following anatomical findings were analyzed: the depth of the intramuscular segment (≤1 or >1 mm), its course within the interventricular septum (proximity to the right or left ventricular endocardium), and its relationship with the right ventricular anterior wall. All scans were analyzed for a hypodense myocardial segment suggestive of myocardial infarction. Values are represented as mean ± SD.

**Results**

**Patient population.** Patient characteristics are shown in Table 1. Patients were referred to CCTA because of chest pain and equivocal test results 26 (22%) 8 (22%)

<table>
<thead>
<tr>
<th>Patient Data</th>
<th>All Patients, n (%)</th>
<th>Myocardial Bridging Patients, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>118</td>
<td>36 (30.5%)</td>
</tr>
<tr>
<td>Mean age, yrs</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>Male gender</td>
<td>107 (91%)</td>
<td>32 (89%)</td>
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<tr>
<td>Referral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest pain and equivocal test results</td>
<td>26 (22%)</td>
<td>8 (22%)</td>
</tr>
<tr>
<td>Risk factors</td>
<td>62 (52%)</td>
<td>15 (50%)</td>
</tr>
<tr>
<td>Known coronary disease</td>
<td>30 (25%)</td>
<td>10 (30%)</td>
</tr>
<tr>
<td>Coronary arteries</td>
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<tr>
<td>Normal</td>
<td>52 (44%)</td>
<td>18 (50%)</td>
</tr>
<tr>
<td>&lt;50% stenosis</td>
<td>40 (34%)</td>
<td>12 (33%)</td>
</tr>
<tr>
<td>&gt;50% stenosis</td>
<td>26 (22%)</td>
<td>6 (17%)</td>
</tr>
<tr>
<td>Hypertrophic cardiomyopathy</td>
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<td>1</td>
</tr>
</tbody>
</table>
pain with or without equivocal noninvasive diagnostic test results, follow-up of known coronary artery disease, or multiple risk factors but no symptoms. One hundred seven patients (91%) were male, with an average age of 53 ± 11 years.

**CT diagnosis.** The average heart rate during CT scan was 62 ± 8 beats/min (range 45 to 85 beats/min). A normal pattern of epicardial coronary artery or the presence of an intramuscular segment could be identified clearly both on axial views and on MPR images (Figs. 1 to 4). In all cases, the intramuscular segment could also be identified on volume-rendering reformations, allowing a 3-dimensional anatomical evaluation of its location (Fig. 5).

**Prevalence.** Myocardial bridging was found in 36 of 118 (30.5%) patients. Intramuscular segments totaled 47, thus, in 8 patients more than 1 intramuscular segment was found. Most of the intramuscular segments were in the mid LAD (n = 27) (Figs. 2 to 4) followed by distal LAD (n = 7), diagonal branches (n = 6), intermediate artery (n = 4), and obtuse marginal artery (n = 3). No myocardial bridging was detected in the right coronary artery.

**Anatomical and pathological features.** The length of the intramuscular segments ranged from 13 to 50 mm (average 23 ± 9 mm). The mean diameter of the intramuscular segments was 2 ± 1.8 mm and 1.5 ± 0.6 mm for LAD and the remaining arteries, respectively. The diameter of the proximal segments was significantly larger than that of the intramuscular segment, being 2.8 ± 0.5 mm for the LAD and 1.9 ± 0.3 mm for the remaining arteries (p > 0.001). The depth of the intramuscular segments ranged from 0.1 to 6.2 mm.

For the LAD, 3 anatomical patterns of intramuscular segments were identified according to the depth and the course of the intramuscular segment: 1) the superficial type (Fig. 2), seen in 10 of 34 (29%) of all intramuscular LAD segments, in which the intramuscular artery had a superficial course along the interventricular septum and was covered by a thin layer of tissue (<1 mm thick); 2) the deep type (Fig. 3), seen in 14 of 34 (41%) of all intramuscular LAD segments, in which the intramuscular segment penetrated the interventricular septum at a depth between 1 and 6.2 mm (In the deeper segments of this group the intramuscular artery tended to deviate toward the right ventricular aspect of the interventricular septum.); and 3) the right ventricular type (Fig. 4) seen in 10 of 34 (29%) of all intramuscular LAD segments, in which the intramuscular artery crossed through the right ventricular anterior wall adjacent to the interventricular septum.

Evidence of coronary artery atherosclerosis was found in 66 of 118 (55.9%) patients. Coronary arteriosclerosis was shown in 48 of 82 (58.5%) patients without bridging and in 18 of 36 (50%) of those with bridging. In 7 cases, athero-
sclerotic plaques were noted in a 2-cm-long segment proximal to the beginning of the intramuscular segment (Fig. 6), and in 1 patient (a 69-year-old man) the plaque extended into the proximal part of the intramuscular segment. Atherosclerotic plaques were not detected in the intramuscular segment in any of the other cases. No evidence of myocardial infarct was found in the myocardial territory subtended by the intramuscular artery.

**Discussion**

This study shows that the intramuscular course of coronary arteries can be detected and characterized by CCTA. Our data suggest that CCTA is an easy and reliable tool for comprehensive in vivo diagnosis of the intramuscular course of coronary arteries. It is generally estimated that the myocardial bridging can be detected in about one-third of the adults in autopsy series, whereas the reported incidence in angiographic series is much lower, <5% (4,5). The incidence of myocardial bridging in our study (30.5%) is in concordance with the reported incidence in autopsy series, but is at variance with the much lower incidence reported in angiographic series. Major differences from this incidence in some angiographic and autopsy series may be dependent on the selection of the cases studied in those series (4,18,19).

The present study was performed on a series of consecutive patients who underwent CCTA for known or suspected coronary artery disease. In most patients (55%), no evidence of coronary atherosclerosis was found, whereas significant coronary artery disease (>50%) was detected in only 22%. Two cases only were affected by hypertrophic cardiomyopathy, a condition that was associated with an increased prevalence of bridging (7,20–22). The incidence of myocardial bridging in the present series therefore may be closer to the incidence in the general population than reported previously in published clinical studies.

**Anatomical and pathological features.** In our series, in concordance with previous reports, the length of myocardial bridging was 2 to 3 cm on average (3). We have also found a significant decrease in the diameter of the intramuscular segment compared with the adjacent proximal segment. Similar observations were reported in the literature. Structural differences between intramuscular and epicardial segments and reduced diameter of the intramuscular segments have been detected in pathological studies (23,24). Moreover, a persistent diastolic reduction of 34% to 41% within the bridged segment after a systolic diameter reduction of 70% to 80% has been shown with angiography and IVUS (3,14,25,26). In addition, it cannot be excluded that normal tapering in the arterial diameter may have influenced our results.

Myocardial bridging was found in our series mainly in the LAD coronary artery. We were able to classify the intramuscular LAD segments into 3 distinct types according to their depth and their anatomical course in relation to the...
interventricular septum and the anterior right ventricular wall. In the first 2 types the tunneled arteries run their entire course in the interventricular septum, superficially or deeply, whereas in the third type the tunneled artery penetrated into the right ventricular anterior wall, sometimes crossing within the right ventricular cavity. This CCTA-based classification partially corresponds with previous studies that suggested various anatomical classifications for intramuscular LAD arteries (1,12,27). Ferreira et al. (27) divided the intramuscular LAD into 2 types: the superficial type, in which the intramuscular segment runs on the interventricular groove, and the deep type, in which the intramuscular segment deviates toward the right ventricle and is crossed by a muscle bundle arising from the right ventricle. An intracavitary course of a coronary artery is a rare condition that to date was diagnosed only in vivo at surgery (10–12). Our third type, defined as an intramuscular segment running in the right ventricular wall or in the right ventricular cavity, may partially correspond to the Ferreira deep type of myocardial bridging and/or to the intracavitary LAD described by Ochsner and Mills (10) and Tovar et al. (12). Our series represents the first noninvasive in vivo observation of a right ventricular intracavitary course of the LAD coronary artery.

We did not find any intramuscular segment in the right coronary artery. Bridging in the right coronary artery was less frequent than in the left system in the anatomical literature and exceptional in angiographic series (4,5). Absence of right coronary bridging in our moderately sized series was most probably incidental and not because of an intrinsic limitation of the CT technique.

All but one intramuscular artery were without evidence of atherosclerosis. Atherosclerotic plaques immediately proximal to the beginning of the intramuscular segment were found in 7 of 36 cases (19%). It has been reported that intramuscular arteries are protected from the atherosclerotic process and that the immediately proximal segments are at
higher risk of arteriosclerosis (4,5,23). Although our data correspond with the reported rarity of atherosclerosis in the intramuscular artery, they do not allow statistical analysis or understanding of a possible protection mechanism.

**Clinical implications.** Most of the reported cases of myocardial bridging had no clinical consequences, thus in most cases myocardial bridging could be considered a normal variant or a benign coronary anomaly. Some reports have suggested that bridging may merely represent an evolutionary remnant, being rare or missing in mammalians (28). However, it has been reported that myocardial bridging may be responsible for flow disturbances and myocardial ischemia (3–8). Current CT technology allows precise anatomical delineation but is lacking the ability of physiological evaluation. Thus, the physiological significance of myocardial bridging and its specific subtypes, detected by CCTA, remains elusive.

Occasionally myocardial bridging has caused technical problems during coronary bypass surgery (10,11). A deep intramuscular artery may be difficult to localize, therefore the use of intraoperative echocardiographic Doppler has been proposed to visualize the artery (9,29,30). An intracavitary course of the LAD has been the cause of complications during coronary surgery, including perforation of the right ventricular wall during attempts of isolation of the intramuscular artery (11,31–33). Preoperative knowledge of this abnormal course, as detected on CCTA, may theoretically help surgeons to overcome such a complication. However, none of our patients with myocardial bridging underwent surgery, so we do not have any objective confirmation of the practical usefulness of our findings. In addition, an intramuscular coronary artery is considered a relative contraindication to minimally invasive coronary surgery. It has been suggested that a preoperative diagnosis of myocardial bridging on CCTA may help in making the decision between coronary artery bypass grafting through the midsternotomy with or without cardiopulmonary bypass (coronary artery bypass graft or off-pump coronary bypass graft, respectively) or a minimally invasive approach through the small left anterior thoracotomy, but no data are available to support this hypothesis (34,35).

**Study limitations.** This study is a descriptive one because comparison of our findings with other modalities was not available. None of our patients with myocardial bridging underwent cardiac catheterization or coronary surgery after CCTA. Nevertheless, CCTA has been validated as a reliable modality for coronary artery imaging, therefore it is highly unlikely that our findings represent artifacts and not true and faithful imaging of the coronary artery course.

Coronary arteries are best evaluated on CCTA during the end-diastolic phase. The current limited temporal resolution of CT scanners does not allow reliable coronary anatomical delineation during the end-systolic phase. For this reason we could not evaluate in this study the presence or degree of systolic compression of the intramuscular coronary artery, and we could not produce the milking sign as seen on coronary angiography. Future studies using scanners with improved temporal resolution should address this issue.

**Conclusions.** A CCTA clearly showed the presence, the course, and the anatomical features of myocardial bridging. Prevalence of intramuscular coronary arteries on CCTA in the present study is in concordance with most pathological reports and higher than in angiographic series. A CCTA offers several advantages over other techniques (coronary angiography, IVUS, and intracoronary Doppler) used for in vivo diagnosis of myocardial bridging, including increased sensitivity, ability to diagnose those cases without overt systolic compression, and recognition of right ventricular intracavitary course. Additionally, CCTA is a noninvasive procedure with a minimal rate of complications. It seems that CCTA may become the technique of choice for in vivo diagnosis of myocardial bridging. However, CCTA is unable to determine the physiological significance of an intramural coronary artery; thus, functional tests for ischemia may be needed to assess the clinical impact of the bridged segments.

Further data are needed to establish the usefulness of this technique in the preoperative evaluation as a guide to the surgeon in localizing intramuscular and/or intracavitary segments of the coronary artery during coronary bypass surgery.

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**REFERENCES**