Functional Versus Anatomic Assessment of Myocardial Bridging by Intravascular Ultrasound: Impact of Arterial Compression on Proximal Atherosclerotic Plaque

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Background—The presence of a myocardial bridge (MB) has been shown to promote atherosclerotic plaque formation proximal to the MB, presumably because of hemodynamic disturbances provoked by retrograde blood flow toward this segment in cardiac systole. We aimed to determine the anatomic and functional properties of an MB related to the extent of atherosclerosis assessed by intravascular ultrasound.

Methods and Results—We enrolled 100 patients with angina but no significant obstructive coronary artery disease who had an intravascular ultrasound–detected MB in the left anterior descending artery (median age 54 years, 36% male). The MB was identified with intravascular ultrasound by the presence of an echolucent band (halo). Anatomically, the MB length was 22±13 mm, and halo thickness was 0.7±0.6 mm. Functionally, systolic arterial compression was 23±12%. The maximum plaque burden up to 20 mm proximal to the MB entrance was significantly greater than the maximum plaque burden within the MB segment. Among the intravascular ultrasound–defined MB properties, arterial compression was the sole MB parameter that demonstrated a significant positive correlation with maximum plaque burden up to 20 mm proximal to the MB entrance ($r=0.254$, $P=0.011$ overall; $r=0.545$, $P<0.001$ low coronary risk). In multivariate analysis, adjusting for clinical characteristics and coronary risk factors, arterial compression was independently associated with maximum plaque burden up to 20 mm proximal to the MB entrance.

Conclusions—In patients with an MB in the left anterior descending artery, the percentage of arterial compression is related directly to the burden of atherosclerotic plaque located proximally to the MB, particularly in patients who otherwise have low coronary risk. This may prove helpful in identifying high-risk MB patients. (*J Am Heart Assoc*. 2016;5:e001735 doi: 10.1161/JAHA.114.001735)

Key Words: angina • angiography • atherosclerosis • intravascular ultrasound • myocardial bridge

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A myocardial bridge (MB) is a common anatomic variant that predominantly involves the mid- or distal coronary segments of the left anterior descending artery (LAD).[1–3] An MB has traditionally been considered a benign condition because contraction of the bridging muscles alters blood flow within the underlying LAD during systole, whereas coronary flow in the LAD occurs predominantly in diastole. A number of studies, however, have indicated that an MB can lead to significant clinical symptoms, arrhythmia, or adverse cardiac events (ie, myocardial ischemia,[4,5] myocardial infarction,[6] and sudden death[7]) in a subset of patients.

In addition to the reduced blood flow reserve and decreased blood perfusion derived from delayed arterial relaxation in diastole, progression of atherosclerotic plaque frequently reported in the segment proximal to the MB has been proposed as another potential mechanism of poor clinical outcomes in a subset of MB patients.[6,8–10] Consequently, accurate identification of high-risk MB patients susceptible to this complication may not only provide prognostic information but also help determine the indication and strategy for therapeutic approaches.

To date, several autopsy reports and multidetector computed tomography studies have indicated that the anatomic properties of an MB, such as its length and thickness (depth), play decisive roles as regulators of atherosclerosis in the LAD segment proximal to the MB.[11] Considering its mechanisms involving abnormal hemodynamics, it may be hypothesized that functional or dynamic properties of the MB may be more directly associated with

the atherosclerotic plaque formation in this segment. Among several clinical diagnostic tools, intravascular ultrasound (IVUS) has the unique capability to provide both anatomic and functional information about an MB. This study aimed to determine anatomic and functional properties of an MB related to the extent of atherosclerosis assessed by IVUS in a clinical setting.

Methods

Participants

All patients were recruited at Stanford University Medical Center between March 2005 and July 2012. We included patients with angina and a clinical suspicion of coronary artery disease who were referred for coronary angiography and were found to have an MB in the LAD, identified by IVUS. Exclusion criteria were significant coronary artery stenosis ≥50% by visual estimation, acute coronary syndrome, prior coronary artery bypass grafting or percutaneous coronary intervention, and heart transplantation. Patient characteristics were obtained using hospital chart reviews at the time of the procedure, including clinical cardiovascular risk factors, such as hypertension (medically treated only), hyperlipidemia (medically treated or total cholesterol >240 mg/dL), diabetes mellitus (controlled by diet, oral agent, or insulin), and current smoking. This study was approved by the institutional review board at Stanford University, and written informed consent was obtained from all patients before study entry.

Cardiac Catheterization Procedure

Cardiac catheterization was performed in a standard fashion, and 200 µg of intracoronary nitroglycerin was administered prior to angiography and IVUS imaging. IVUS image acquisition was performed during an automated pullback at 0.5 mm/s using a 40-MHz mechanical IVUS system (Atlantis SR Pro2; Boston Scientific Corp), which was placed as far distally as safely possible in the LAD. All images were stored on DVD for offline analysis.

Image Analysis

All images were analyzed at an independent core laboratory (Cardiovascular Core Analysis Laboratory, Stanford University). Quantitative coronary angiography was performed using a validated computer-assisted method (QAngio XA7.3; Medis Medical Imaging Systems Inc). Measurements of interest included reference vessel diameter, minimum lumen diameter, and percentage diameter stenosis at tunneled coronary segments at end–diastole and –systole after administration of intracoronary nitroglycerin. The quantitative coronary

angiography boundaries (entrance and exit) of the tunneled segments were confirmed by corresponding IVUS images of the MB segments.

All IVUS images were reviewed frame by frame using validated IVUS analysis software (echoPlaque 3.0.60; Indec Systems Inc). According to our previous IVUS report with histological validation, an MB was defined as an echolucent band (halo) partially surrounding the artery (Figure 1).[5,12–14] Anatomic IVUS assessment of the MB included length of the MB segment, halo thickness, location of the MB, and the presence of branches arising within the MB segment. The MB length was measured from the first proximal appearance of the halo (MB entrance) to its distal end (MB exit), and the halo
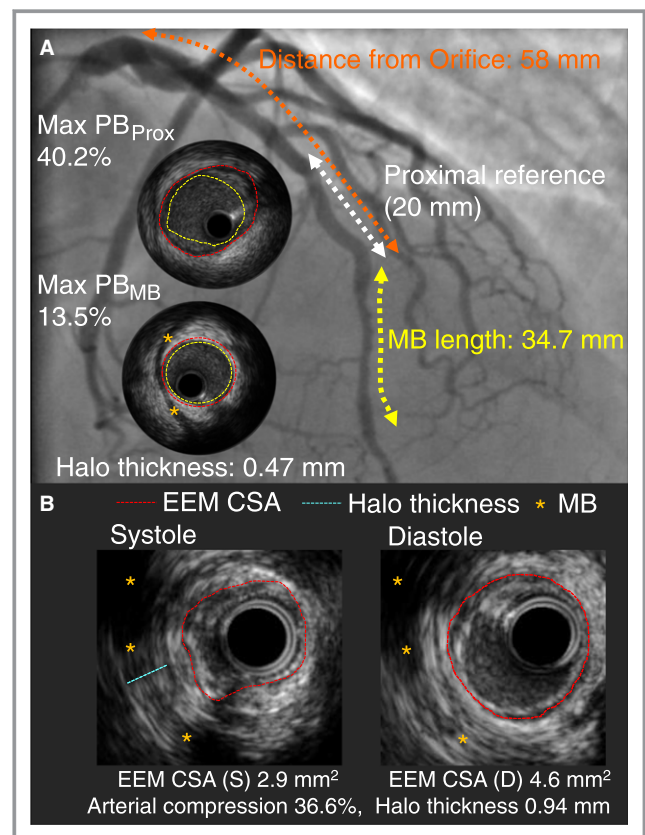

Figure 1. Intravascular ultrasound assessment of myocardial bridging. An MB was defined as an echolucent band (halo: orange asterisk) partially (or completely) surrounding the artery. The proximal reference was defined as a 20-mm segment immediately proximal to the MB entrance. Max PB was measured in the proximal reference (Max PB$_{Prox}$) and in the MB segment (Max PB$_{MB}$). The location of the bridge was also measured, defined by the length from the orifice of the left anterior descending artery to the entrance of the MB (A). Within the MB segment, EEM-CSA (red dotted line), arterial compression, and halo thickness (blue dotted line) were measured (B). CSA indicates cross-sectional area; EEM, external elastic membrane; Max PB$_{MB}$, maximum plaque burden with the myocardial bridge segment; Max PB$_{Prox}$, maximum plaque burden within a 20-mm segment immediately proximal to the myocardial bridge entrance; MB, myocardial bridge.

thickness was measured at the thickest part above the artery during systole (Figure 1B). The location of the MB was assessed as a distance from the LAD orifice to the MB entrance. Functional IVUS assessment of the MB included arterial compression, which was calculated as a decrease in external elastic membrane cross-sectional area (CSA) at systole standardized by external elastic membrane CSA at end-diastole, expressed as a percentage. Atherosclerotic plaque was assessed by calculating plaque burden as (external elastic membrane CSA−lumen CSA/external elastic membrane CSA)×100. Maximum plaque burden was obtained within the MB segment (Max PB$_{MB}$) and in the proximal reference (Max PB$_{Prox}$), defined as a 20-mm nontunneled segment immediately proximal to the MB entrance (Figure 1A). In addition, plaque types were categorized into fibrous, soft, calcified, or mixed, according to the "American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, Measurement and Reporting of Intravascular Ultrasound Studies."[15] The reproducibility of IVUS measurement of arterial wall compression was verified using randomly selected patients (10% of study participants). For the assessment of inter- and intraobserver variability, IVUS measurements were performed by 2 independent investigators who were blinded to each other's results, and then measurements were repeated at least 1 month later by 1 investigator who was blinded to his initial results.

Statistical Analysis

Statistical analysis was performed using StatView 5.0 (SAS Institute). Categorical variables are presented as percentages, and continuous variables are reported as mean±SD. The paired Student *t* test was used to differentiate 2 sets of data with normal distribution. A *P* value of <0.05 was considered statistically significant. Bonferroni correction was used to adjust a *P* value of significance for multiple comparisons between arterial compression and 2 anatomic MB parameters (a *P* value of <0.025 was considered statistically significant). Similarly, a *P* value of significance was adjusted for multiple comparisons between plaque burden and 4 MB parameters (a *P* value of <0.0125 was considered statistically significant). The Pearson correlation coefficients were calculated in simple linear regression analysis. Clinical risk factors and MB properties with *P*<0.20 found in simple regression analysis were inserted into multivariate linear regression analysis.

Results

Patient Demographics

From 185 patients with angina in the absence of obstructive coronary artery disease, a LAD MB was identified in 100

Table 1. Clinical Characteristics

Variable	n=100
Patient characteristics	
Age, y	53±13
Body mass index	28.9±7.2
Male, n (%)	36 (36.0)
Risk factors	
Hypertension, n (%)	53 (53.0)
Diabetes mellitus, n (%)	15 (15.0)
Hyperlipidemia, n (%)	67 (67.0)
Current smoker, n (%)	3 (3.0)
Lipid profile	
Total cholesterol, mg/dL	169.6±37.4
LDL cholesterol, mg/dL	100.9±31.1
HDL cholesterol, mg/dL	49.6±13.9
TG, mg/dL	92.3±50.2
Medications	
Aspirin, n (%)	59 (59.0)
Clopidogrel, n (%)	8 (8.0)
β-blockers, n (%)	41 (41.0)
ACEI/ARB, n (%)	14 (14.0)
Diuretics, n (%)	17 (17.0)
Statins, n (%)	59 (59.0)
Nitrates, n (%)	28 (28.0)

Continuous variables are expressed as mean±SD. ACEI indicates angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride.

patients who fulfilled the inclusion and exclusion criteria of this study. Table 1 summarizes the clinical characteristics of the enrolled participants. The median age was 54 years, and 36% were men. Hyperlipidemia was present in 67% of the patients, the majority of whom were adequately controlled by statin therapy. More than half of the patients had hypertension (or were on an antihypertensive medication), whereas only 15% had diabetes, although all cardiac medications were routinely withdrawn ≥48 hours before the catheterization.

Anatomic and Functional Properties of Myocardial Bridging

Quantitative coronary angiography and IVUS findings of myocardial bridging analyzed by the core laboratory are summarized in Table 2. By quantitative coronary angiography, the minimum lumen diameter of the tunneled segment was 1.66±0.37 mm in diastole, and the percentage

Table 2. Angiographic and IVUS Findings

Variable	n=100
QCA results at MB segment	
RVD (D), mm	2.28±0.57 (1.33–4.32)
RVD (S), mm	2.40±0.50 (0.93–4.71)
MLD (D), mm	1.66±0.37 (0.95–3.23)
MLD (S), mm	1.37±0.42 (0.01–2.48)
%DS (D), %	25.7±13.0 (0.00–58.89)
%DS (S), %	42.0±17.8 (3.77–99.78)
IVUS results	
Bridge length, mm	21.6±13.4 (4.7–76.9)
Arterial compression, %	22.9±12.1 (0.4–50.7)
EEM CSA (D), mm^2	7.0±2.8 (2.8–15.1)
EEM CSA (S), mm^2	5.4±2.4 (2.1–12.7)
Halo thickness, mm	0.66±0.58 (0.11–3.17)
Distance from LAD ostium, mm	37.7±12.7 (5.3–77.5)
Presence of branches within MB, n (%)	81 (81.0)
Max PB$_{Prox}$, %	38.6±15.1 (11.3–76.9)
Max PB$_{MB}$, %	21.7±7.0 (10.1–45.3)
Plaque type (fibrous/soft/ calcified/mixed), %	49/33/10/8

Continuous variables are expressed as mean±SD (range). %DS indicates percentage diameter stenosis; CSA, cross-sectional area; D, diastole; EEM, external elastic membrane; IVUS, intravascular ultrasound; LAD, left anterior descending artery; Max PB$_{MB}$, maximum plaque burden with the myocardial bridge segment; Max PB$_{Prox}$, maximum plaque burden within a 20-mm segment immediately proximal to the myocardial bridge entrance; MB, myocardial bridge; MLD, minimum lumen diameter; QCA, quantitative coronary angiography; RVD, reference vessel diameter; S, systole.
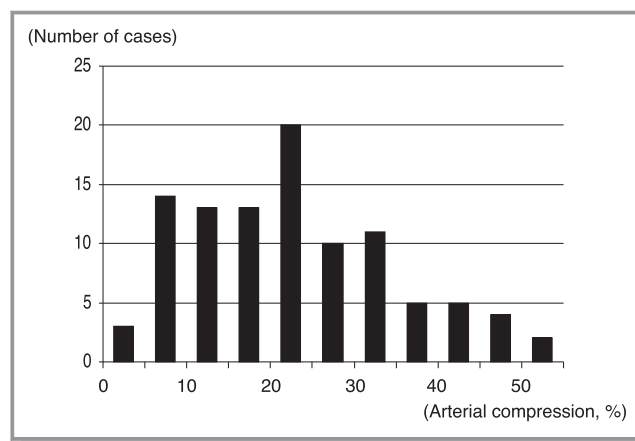

Figure 2. Histogram of arterial compression by myocardial bridging. Systolic arterial compression was 22.9±12.1%, ranging from 0.4% to 50.7%.

Atherosclerotic Plaque Related to Myocardial Bridging

The tunneled arterial segment under the MB was relatively spared from plaque, whereas the proximal segment adjacent to the MB showed a significantly larger amount of plaque, ranging from 11.3% to 76.9% (Max PB$_{Prox}$ 38.6±15.1% versus Max PB$_{MB}$ 21.7±7.0%, *P*<0.001) (Figure 3). Although no anatomic or functional MB properties were related to the plaque burden within the MB, the degree of arterial compression showed a weak but significant positive correlation with the proximal plaque burden (Max PB$_{Prox}$ *r*=0.254, *P*=0.011; with the Bonferroni correction, a *P* value of <0.0125 was considered statistically significant) (Figure 4). In contrast, the degree of angiographic "milking" by quantitative coronary angiography was not related to the proximal plaque burden by either correlation or categorical analysis. With respect to the plaque characteristics, fibrous and soft plaques were the dominant plaque types in the proximal segment, but no relationship was observed between plaque type and the degree of arterial compression.

Determinants of Atherosclerotic Plaque in the Proximal Segment

Table 3 shows the results of univariate and multivariate analyses looking for determinants of the maximum plaque burden in the adjacent proximal segment, including patient demographics, clinical characteristics such as baseline medications, and angiographic and IVUS imaging variables. The univariate analysis identified age, male sex, hyperlipidemia, and arterial compression as significant variables related to Max PB$_{Prox}$. The multivariate analysis confirmed systolic arterial compression as an independent determinant of Max

diameter stenosis increased from 25.7±13.0% to 42.0±17.8% during the cardiac cycle. When angiographically detectable MBs were defined as angiographic arterial compression of >20%, >30%, and >40%, the detection rates of MB by angiography were 42%, 23%, and 16%, respectively. By IVUS, the tunneled segment measured 21.6±13.4 mm in axial length, and the halo thickness was 0.66±0.58 mm, ranging from 0.11 to 3.17 mm. The MB entrance was located 37.7±12.7 mm distally to the orifice of the LAD. From diastole to systole, external elastic membrane CSA decreased from 7.0±2.8 to 5.4±2.4 mm^2, and calculated arterial compression ranged from 0.4% to 50.7% (Figure 2). Intra- and interobserver differences for IVUS-defined arterial compression were 0.3±3.1% and 2.2±5.7%, respectively. The degree of arterial compression had a weak but significant positive correlation to both MB length (*r*=0.288, *P*=0.004) and halo thickness (*r*=0.295, *P*=0.003; with the Bonferroni correction, a *P* value of <0.025 was considered statistically significant).
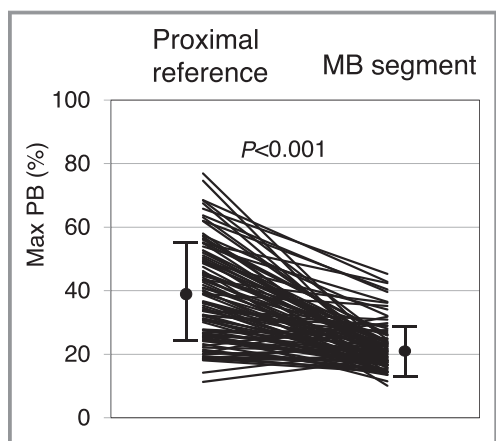
Figure 3. Maximum plaque burden in the proximal reference vs myocardial bridge segment. In the majority of the enrolled patients, the proximal reference segment adjacent to the MB showed a significantly larger amount of plaque, ranging up to 76.9%, compared with the MB segment (Max PB$_{Prox}$ 38.6±15.1% vs Max PB$_{MB}$ 21.7±7.0%, $P<0.001$). Max PB$_{MB}$ indicates maximum plaque burden with the myocardial bridge segment; Max PB$_{Prox}$, maximum plaque burden within a 20-mm segment immediately proximal to the myocardial bridge entrance; MB, myocardial bridge.

PB$_{Prox}$, whereas other univariate variables were also independently associated with Max PB$_{Prox}$. Consequently, when focusing on younger patients (age <54 years as the median value) with ≤1 coronary risk factor, arterial compression and Max PB$_{Prox}$ demonstrated stronger correlation ($r=0.545$, $P<0.001$) than in the overall population (Figure 5).

Discussion

The present study adds to and extends the current literature regarding atherosclerotic plaque in the presence of an MB by demonstrating that (1) arterial compression, more than MB length, depth (halo thickness), or location, is correlated with the burden of atherosclerotic plaque proximal to the MB and (2) this is particularly true for patients with low coronary risk who otherwise are not expected to manifest a large plaque burden. This latter finding may help identify those patients for whom MB confers atherosclerotic risk beyond traditional cardiac risk factors.

Effects of Myocardial Bridging on Atherosclerotic Plaque Formation

Similar to previous autopsy,[1,16] angiographic,[5] and multidetector computed tomography[17] reports, we found a greater plaque burden in the LAD segment proximal to the MB than

within the tunneled LAD segment. This preferential location of atherosclerotic plaque in relation to the MB is attributed partially to hemodynamic disturbances caused by MB muscle contraction. In particular, the distribution of wall shear stress in relation to the tunneled segment may play a role because lower sheer stress has been postulated to predispose patients to enhanced lipid transfer across the endothelium and to more atherosclerosis. A report using a computational fluid dynamics model of the LAD in a patient with a symptomatic MB revealed areas of relatively low wall shear stress proximal and distal to the MB and high wall sheer stress within the tunneled segment.[18] Likewise, a case–control study of MB patients also demonstrated that the wall shear rate⸺the velocity gradient perpendicular to the wall, which relates to the wall shear stress by the factor of blood viscosity⸺was lower in the segment proximal to the MB than within the tunneled segment.[19]

Other potential mechanisms for proximal plaque formation include abnormal flow profiles at this segment, such as oscillatory flow reversal with or without significant collision with antegrade coronary flow. A number of studies have indicated that arterial segments in which blood flow departs from a laminar unidirectional pattern are prone to the development of atherosclerotic plaques.[6,8–10] Another study using a catheter-based pressure measurement system demonstrated that the intracoronary pressure within the LAD segment proximal to the MB was significantly higher than the aortic blood pressure, suggesting potential augmentation of the intimal injury at this segment.[9] Finally, solid mechanical forces that result from the motion and deformation of the coronary tree and myocardial material properties may lead to a heterogeneous stress field at this segment.[6,9,20,21]

Anatomic Versus Functional Properties of Myocardial Bridging

Although previous studies have focused on the conventional anatomic properties of an MB with regard to proximal atherosclerotic plaque formation, the potential hemodynamic mechanisms discussed led us to believe that functional or dynamic properties of an MB may be associated more directly with the burden of proximal atherosclerotic plaque. To the best of our knowledge, the present study is the first to test this hypothesis in clinical patients by investigating the relationship between the degree of arterial compression and the amount of atherosclerotic plaque accumulated at the segment proximal to the MB.

The positive correlation of these 2 variables found in the present study supports the proposed mechanisms for the accelerated proximal plaque formation. As expected, however, other classic cardiac risk factors were also independently related to the amount of plaque in the LAD, presumably
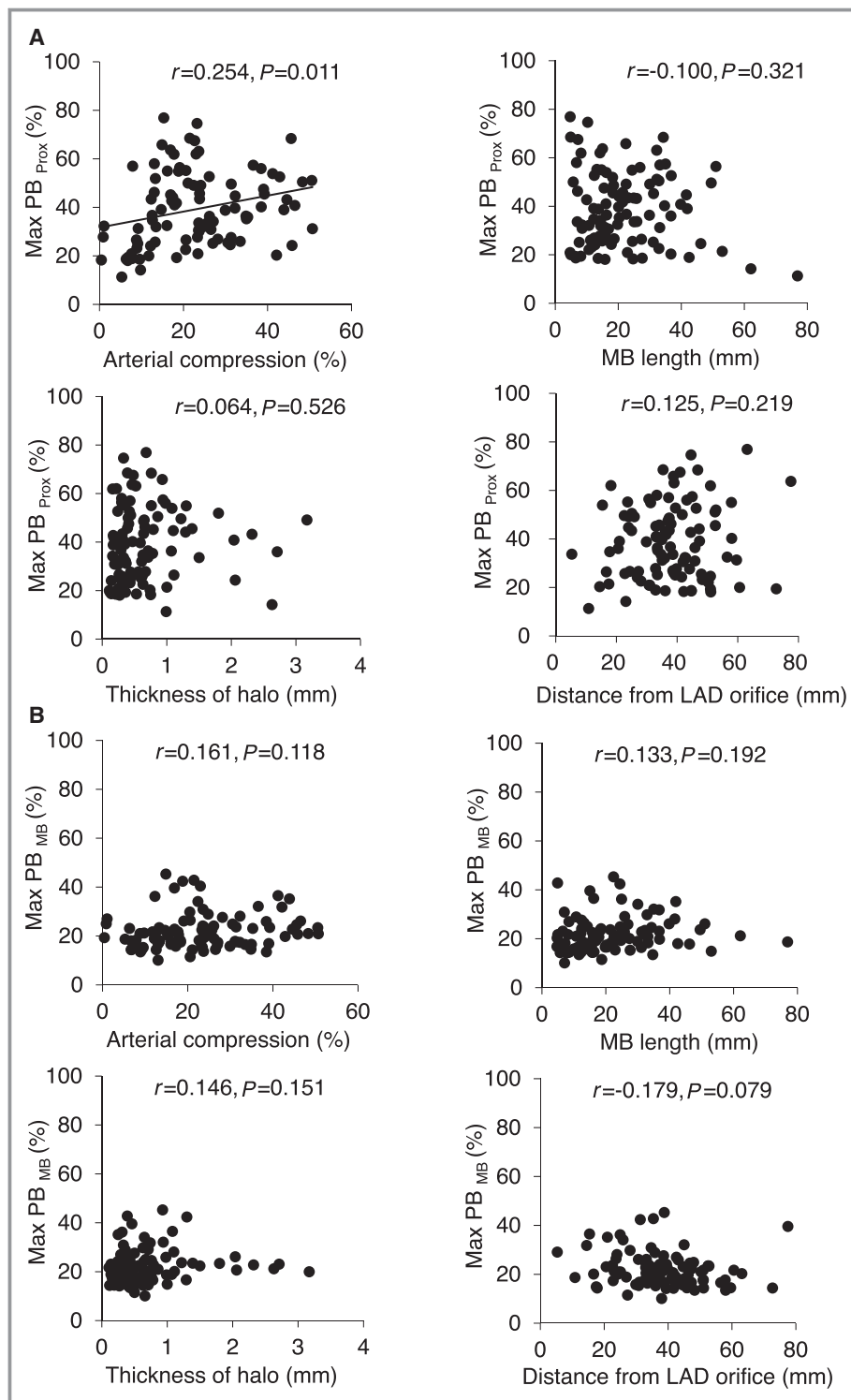
Figure 4. Correlations of anatomic and functional MB properties with maximum plaque burden at the proximal reference and the myocardial bridge segment. At the proximal reference (A), arterial compression showed a weak but significant positive correlation with maximum plaque burden. In contrast, no correlation was observed in anatomic properties of an MB, including MB length, thickness of halo, and the location of the MB based on its distance from the LAD orifice. At the MB segment (B), maximum plaque burden showed no association with any MB properties. LAD indicates left anterior descending artery; Max PB$_{MB}$, maximum plaque burden with the myocardial bridge segment; Max PB$_{Prox}$, maximum plaque burden within a 20-mm segment immediately proximal to the myocardial bridge entrance; MB, myocardial bridge.

Table 3. Determinants of Maximum Plaque Burden in the Proximally Adjacent Segment

Variable	Simple Regression Analysis			Multiple Regression Analysis		
	r	95% CI	P Value	β	95% CI	P Value
Age	0.424	0.28 to 0.69	<0.001	0.290	0.12 to 0.54	0.003
Male	0.328	4.38 to 16.33	<0.001	0.230	1.72 to 12.77	0.011
Hyperlipidemia	0.384	6.41 to 18.33	<0.001	0.221	1.25 to 12.96	0.018
Hypertension	0.155	−1.30 to 10.72	0.123	0.075	−3.26 to 7.80	0.418
Current smoker	−0.065	−23.51 to 12.02	0.523	—	—	—
Diabetes mellitus	0.114	−3.61 to 13.29	0.258	—	—	—
Arterial compression	0.254	0.08 to 0.56	0.011	0.192	0.02 to 0.46	0.031
Length from LAD orifice	0.125	−0.09 to 0.39	0.219	—	—	—
MB length	−0.100	−0.34 to 0.11	0.321	—	—	—
Halo thickness	0.064	−3.56 to 6.93	0.526	—	—	—

R^2=0.343, $P<0.001$ for multivariate model. LAD indicates left anterior coronary artery; MB, myocardial bridge.

accounting for wide scatter of the correlation in the unadjusted overall population. The analysis of an adjusted population with low coronary risk unmasked the direct effect of arterial compression on proximal plaque formation by demonstrating a moderately strong correlation between the 2 variables.
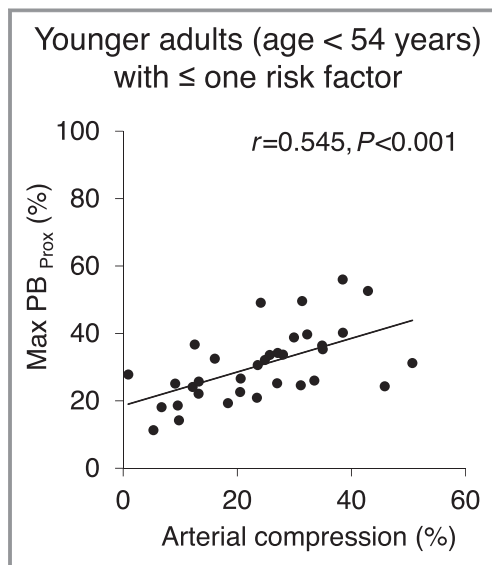

Figure 5. The correlation between arterial compression and Max PB$_{Prox}$ in younger adults with ≤1 coronary risk factor. The analysis using the adjusted (low coronary risk) population demonstrates a moderately strong correlation between the 2 variables, unmasking the effect of arterial compression on the proximal plaque formation. Max PB$_{Prox}$ indicates maximum plaque burden within a 20-mm segment immediately proximal to the myocardial bridge entrance.

Unlike previous studies, the conventional anatomic MB properties, such as axial MB length, halo thickness, and the distance from the LAD orifice, were not significantly related to the amount of proximal plaque in the current study. In addition to the limited statistical power of the current study, this may be related in part to the relatively large variability in correlations between the anatomic and functional MB properties found in our study population. Indeed, patients with a long or thick MB did not necessarily show strong arterial compression that could cause significant hemodynamic disturbances. In contrast, some patients who had only a short or thin MB demonstrated a considerable degree of arterial compression, presumably depending on the variable function and anatomic direction of bridging muscle cells, as well as the 3-dimensional geography of the tunneled artery and the surrounding cardiac structures. Systolic arterial compression, for example, is known to occur even without an MB when the coronary segment is located deep within the interventricular groove.[22] Possible independent effects of anatomic factors have yet to be investigated; however, adding the direct assessment of arterial compression, rather than simply using the anatomic MB properties alone as surrogate markers, may be beneficial to better estimate the severity of hemodynamic disturbances caused by MB.

Clinical Implications

Although most patients with an MB are presumed to be asymptomatic, MB has been shown to cause myocardial ischemia, conduction disturbances, and myocardial infarction, possibly leading to sudden cardiac death in some cases.[4–7] These adverse effects likely result from 2 distinct mechanisms: (1) accelerated plaque formation in the segment

proximal to the MB, as investigated in the current study, and (2) alteration in the effective blood perfusion of the affected myocardial territory owing to delayed arterial relaxation in diastole or the Venturi effect on the septal branches that can cause functional ischemia of the septal wall.[4] Furthermore, external systolic compression and endothelial dysfunction frequently observed in the tunneled artery could stimulate coronary vasospasm and platelet aggregation resulting in acute coronary syndrome in certain clinical settings.[16,21,23,24]

Because these mechanisms are all linked to hemodynamic abnormalities caused by arterial compression, it is reasonable to add functional assessment to the conventional diagnosis of an MB. The combined assessment of MB anatomy and degree of arterial compression with consequences for proximal plaque burden, as performed with IVUS in the present study, may enhance our understanding of this common coronary variant and provide us with prognostic information in given patients to guide the indication and strategy for treatment. Particularly important is that the percentage of arterial compression is notably correlated with the burden of proximal plaque in a population with low coronary risk. It may be that such patients need more aggressive primary prevention than we would typically offer through current cardiac risk prediction models. The quantitative assessment of arterial compression may also be useful in evaluating the results of pharmacological (ß-blockers)[25] or surgical (unroofing of the intramural coronary with myotomy)[26] interventions, although a noninvasive method of making such an assessment would be preferred. Unfortunately, angiography is also not sufficient; we and others[5,20] have shown that the majority of MBs are angiographically silent. We also note that the present study assessed the degree of arterial compression only at a resting state in the setting of cardiac catheterization. Exercise or pharmacological stress might help estimate the maximum physiological impact of a given MB.[4]

Another clinically relevant question regards the stability of the atherosclerotic plaque located proximally to the MB. A recent autopsy series of 150 patients with LAD-related infarction (with or without MB) and 100 normal hearts with MB suggested that plaques in the LAD proximal to the MB are prone to rupture, resulting in myocardial infarction at a younger age.[27] Although the present study demonstrated noncalcified plaques in the majority of the enrolled patients, detailed assessment of plaque vulnerability using advanced tissue characterization techniques, including radiofrequency IVUS analysis,[28,29] or hybrid IVUS with near-infrared diffuse reflectance spectroscopy[30] may be informative. Optical coherence tomography is also commercially available to provide detailed tissue-type information, such as thin-cap fibroatheroma[31] or plaque erosion.[32] Nevertheless, its limited signal penetration and the need for contrast flush with ultrafast pullback preclude the direct visualization of an MB

beyond the artery and, more important, the functional assessment of arterial compression under baseline conditions. Further studies with long-term clinical follow-up are needed to address the clinical impact of MB-induced arterial compression on atherosclerotic plaque vulnerability.

Limitations

Several limitations should be noted in this study. First, this study was used a single time point with a relatively small sample size. In particular, the sample size was not large enough to deny the possible correlations between anatomic MB properties and proximal atherosclerotic plaque burden. Second, the rate of MB appears higher in the current study compared with past angiographic reports (prevalence 0.4–16%) in the literature.[20] This might be attributed to the higher image resolution of IVUS and its ability to directly visualize MB muscle or may suggest that MB itself is a substantial contributor to anginal symptoms without obstructive coronary artery disease. Of note, this was a retrospective analysis of a selected group of patients with angina in the absence of obstructive coronary artery disease who were recruited in a nonconsecutive fashion; therefore, the study was not designed to determine the exact prevalence of MB within this population or within the general population at large. Third, all IVUS measurements were obtained in the resting state. There could be unaccounted-for variability in the measurements based on blood pressure or heart rate, and the measurements tell us little about the influence of these anatomic and functional properties on proximal plaque during states of exertion, such as exercise. Moreover, the current study design did not allow us to evaluate possible drug effects on arterial compression because all cardiac medications were routinely withdrawn ≥48 hours before the cardiac catheterization. Although none of the baseline medications, including the use of β-blockers, was related to the plaque burden in the current study, this issue is notable and needs to be addressed in subsequent investigations with dedicated study designs. Fourth, plaque types were assessed by conventional gray-scale IVUS with no advanced tissue characterization techniques. Fifth, although the majority of the current study participants had a sufficient MB length for IVUS evaluation, measuring arterial compression by IVUS may be difficult in patients with a short MB. In addition, the percentage of arterial compression may be underestimated by the presence of the IVUS catheter in small vessels or segments with extreme compression. Lastly, measurements were not compensated for transducer movement during the cardiac cycle. This issue is common and nearly inevitable for all catheter-based coronary diagnostics and can compromise the precision of measurements, although it is unlikely that the catheter motion itself could artificially create the correlation observed in the current study.

Conclusion

In patients with a LAD MB, the percentage of arterial compression correlates with the burden of atherosclerotic plaques located proximal to the MB. This is particularly true in patients who are otherwise at low risk for developing coronary atherosclerosis. In addition to the conventional anatomic assessment, a functional assessment may provide further information with regard to the clinical import of an MB in certain patient subsets.

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Disclosures

None.

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