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ORIGINAL ARTICLE

Prevalence of myocardial bridges in the Mexican population: A morphometric and histological analysis

A. Rojas-Granados[a], E. Pérez-Campos[b], M. Sanchez-Sanchez[c], M.A.M. Chávez[d], L. Pérez-Campos-Mayoral[d], M. Ángeles-Castellanos[a,e,*]

[a] *Departamento de Anatomia, Facultad de Medicina. Universidad Nacional Autónoma de México, México, Mexico*
[b] *Tecnológico Nacional de México/IT, Oaxaca, Oaxaca City, Mexico*
[c] *Posgrado Facultad de Odontologia, Universidad Autónoma Benito Juárez de Oaxaca, Oaxaca, Mexico*
[d] *Facultad de Medicina y Cirugia, Universidad Autónoma Benito Juárez de Oaxaca, Oaxaca, Mexico*
[e] *Departamento de Innovacion en Material Biologico Humano, Facultad de Medicina, Universidad Nacional Autonoma de Mexico, México, Mexico*

KEYWORDS
Myocardium;
Coronary arteries;
Human heart;
Heart attack;
Dissection

Summary
Background. — Myocardial bridge (MB) is described as an abnormal band of myocardium covering a variable portion of any coronary artery.
Methods. — The current study explores the presence of MB throughout the coronary arterial system and provides a morphometric description through instrumented dissection of a sample of 100 human hearts. The study shows a higher prevalence of MB in the Mexican population than in previous reports.
Results. — In the total sample ($n = 100$), MB was identified in 96% of it. A total of 421 MBs were observed, with a mean of 4.38 mm ($\pm$0.28) per dissected heart. The most frequently affected vessel is the anterior interventricular artery where a total of 52 MBs were found, of the total sample studied.
Discussion. — The high prevalence of MB among Mexican patients could be the result of a genetic association for this population or the neoformation of MB after birth due to lifestyle-associated factors. Further studies are required to better understand the high prevalence of MB among Mexican subjects.

* Corresponding author. Departamento de Anatomía, Edificio B 4° Piso, Fac. of Medicine UNAM, DF 04510 México, Mexico.
E-mail address: mangeles_castellanos@unam.mx (M. Ángeles-Castellanos).

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Introduction

The main coronary arteries usually cross an epicardial position, however, the partial or total overlay of cardiac muscle fibers that covers a variable length of the vessels has been previously described as a myocardial bridge (MB) [1]. This alteration has been described frequently in the left anterior descending coronary artery [2], MB has been described as a congenital anomaly or variation in the coronary circulation; it represents a relatively frequent anatomical finding with an incidence that varies according to the screening method [3,4], by anatomical dissection, MBs are identified in 5%—86% of samples, and by angiography, the identification of MBs ranges between 0.5%—33% [4,5]. The presence of MBs has been associated with a transient systolic constriction of a segment of the coronary vessel known as the ''milking'' effect. The clinical importance derived from this compression will depend on the length, thickness, and direction of the myocardial fibers [6,7]. Anatomically, the MB can be classified into two distinct categories: superficial and deep. The latter can compress the affected vessel during systole, thereby compromising the diastolic blood flow and resulting in transitory ischemia [3,7]. The presence of MB should be considered in patients presenting angina without a history of risk factors and evidence of ischemia [7,8]. Also, MB represents an important risk factor in patients undergoing coronary interventions as they are associated with angina, myocardial ischemia, arrhythmias, acute failure in patients with heart transplantation, ventricular dysfunction, ventricular fibrillation, and even sudden death [7,9—11]. Previous reports have described the presence of MB mainly in the anterior interventricular artery. This study aimed to explore the presence of MB throughout the entire coronary arterial system. To achieve this, we performed a comprehensive morphometric description, including localization, of MBs by instrumented dissection in a sample of 100 human hearts. We also evaluated the prevalence of MB in the population.

Materials and methods

Ethical considerations

The biological material used as samples in the present study was obtained from the Institute of Forensic Sciences of Mexico City (INCIFO) from 2006 to 2008, through an agreement celebrated in 2006 between this institution and the Department of Anatomy of the Faculty of Medicine of the National Autonomous University of Mexico (UNAM). The institutional agreement was approved by the Jurisdiction of Mexico City (Of. No. 1908-2006). All the procedures and manipulation of the biological material performed for this study were aligned with the established Regulations and the Federal Health Law in terms of the sanitary control and disposal of human tissues and human corpses, chapter V (DOF 26-03-2014). The study was also approved by the institutional ethics and research committee of the Faculty of Medicine, UNAM (UNAM-030/17).

Study design

This was designed as a prospective, cross-sectional and descriptive study. The sample consisted of 100 cadaveric human hearts belonging to the Department of Anatomy of the Faculty of Medicine of the UNAM. These belonged to men and women with an age range of 14 to 93 years, who had died of causes not associated with cardiovascular diseases and that did not require a forensic autopsy. All hearts included in this study had no apparent lesions.

Exclusion criteria included hearts that were lacerated during extraction or those that presented a suboptimal state of conservation. Hearts from subjects with infectious diseases (confirmed or with reasonable clinical suspicion) including human immunodeficiency virus (HIV) infection or hepatitis were also excluded.

Conservation and dissection

All hearts were extracted and immediately immersed in a 10% phosphate-buffered formalin (PBF) solution for fixation. The time frame for extraction and fixation was 8 to 12 hours post-mortem. All were immersed in the fixative solution for at least 72 hours, or until dissection. Each heart was evaluated by instrumented dissection to assess the entire coronary arterial system. Although the coronary system is very variable, the most frequent collaterals were chosen, 11 arteries from the right coronary circulation and 13 arteries from the left coronary circulation. A total of 24 collateral arteries per heart were dissected. (Fig. 1, Table 1). Epicardia fat tissue was removed to visualize the trajectory of the coronary vessels and their main ramifications. After dissection, the criterion for the recognition of MB was the identification of partially or overlapping cardiac muscle fibers across the coronary artery. Proximal/distal arterial coronary length and diameter were measured using a digital vernier, as well as the angle of the MB regarding to the traverse myocardial fibers, and were classified as previously reported, superficial if the coronary artery ran through the corresponding coronary sulcus and was crossed by the muscle bundle perpendicularly or at an acute angle, and deep bridges, if the coronary artery was located deeply and was crossed. transversely, obliquely, or helically by a longitudinal bundle of myocardium [7].

Histology

A sample of 20 hearts with MB was randomly selected for histological studies. A segment of the anterior interventricular artery containing the MB was extracted. The sample included the affected section of the vessel containing the MB, as well as at least 0.5 cm of myocardial tissue. As a control, a similar section was taken from the middle third of the right coronary artery of the same heart, to maintain the same morphophysiological variables but without the presence of MB. The acquired samples were embedded

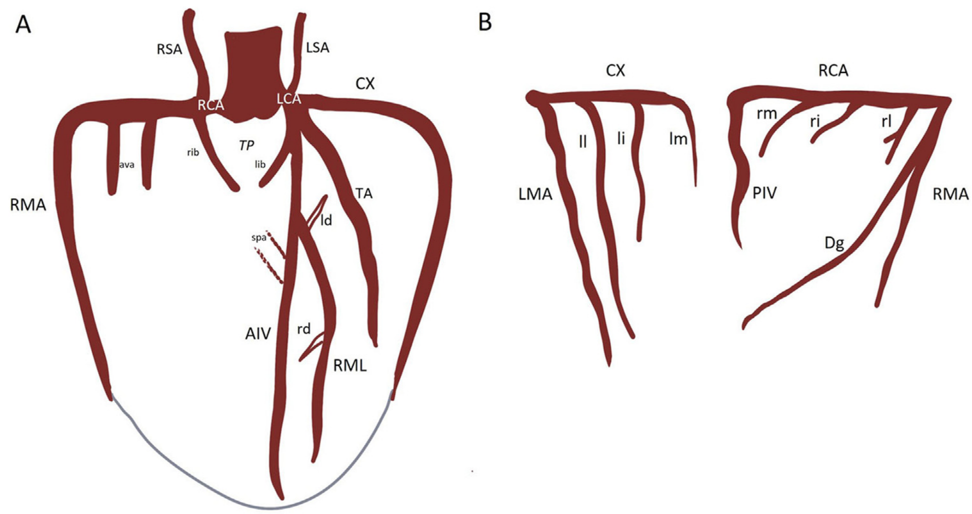

Figure 1 Scheme showing the principal and collateral branches of the coronary system that were studied by dissection in this study. A. represents the anterior view and B. The posterior view. RCA: right coronary artery; RMA: right marginal artery; Dg: posterior diagonal; IVP: posterior interventricular; IVA: anterior interventricular; Cx: circumflex; TA: third artery or intermediate artery; LMA: left marginal artery; rib: right infundibular branch; lib: left infundibular branch; AVA: anterior ventricular branches; rm: right medial; ri: right intermediate; rl: right lateral; lm: left medial; li: left intermediate; ll: left lateral; d: diagonal branches; rd: right diagonal; ld: left diagonal; spa: septal perforating arteries; RSA: right sinoatrial; LSA: left sinoatrial; RML: lateral branch; LCA: left coronary artery; PT: pulmonary trunk.

Table 1 Distribution of myocardial bridges (MB) among the dissected hearts ($n = 100$).

Location	Number of MB	Average length of MB (mm)
Right coronary artery (RCA)	2	15.52 ± 3.1
Right marginal artery (RMA)	33	17.02 ± 1.4
Posterior diagonal (Dg)	23	19.85 ± 1.8
Posterior interventricular (IVP)	15	20.24 ± 2.9
Anterior interventricular (IVA)	52	20.90 ± 1.9
Circumflex (Cx)	4	7.84 ± 2
Third artery or intermediate artery (TA)	20	29.45 ± 3.1
Left marginal artery (LMA)	29	26.55 ± 2.4
Right infundibular branch (rib)	26	18.88 ± 1.9
Left infundibular branch (lib)	1	5.71
Anterior ventricular branches (AVA)	34	21.49 ± 1.3
Right medial (rm)	9	15.06 ± 1.9
Right intermediate (ri)	4	16.59 ± 3.6
Right lateral (rl)	10	17.13 ± 3.1
Left medial (lm)	0	0
Left intermediate (li)	5	25.79 ± 10
Left lateral (ll)	4	17.82 ± 5.3
Diagonal branches (d)	5	17.22 ± 2.5
Right diagonal (rd)	6	21.91 ± 2.6
Left diagonal (ld)	5	17.38 ± 4.3
Septal perforating arteries (spa)	2	21.60 ± 3.2
Right sinoatrial (RSA)	27	19.90 ± 2.6
Left sinoatrial (LSA)	46	50.02 ± 5.1
Lateral branch (RML)	3	11.26 ± 2.6

in paraffin and cut into a series of 4 slides, in 5 μm thick sections. The samples were processed and stained using three different techniques: hematoxylin and eosin (HE), Masson's trichrome stain, and Reyes-Mota stain [12,13].

Image acquisition and analysis

All histological samples were analyzed using a Microscope GmbH, Primo Star (Carl Zeiss Germany), and a 5 MP

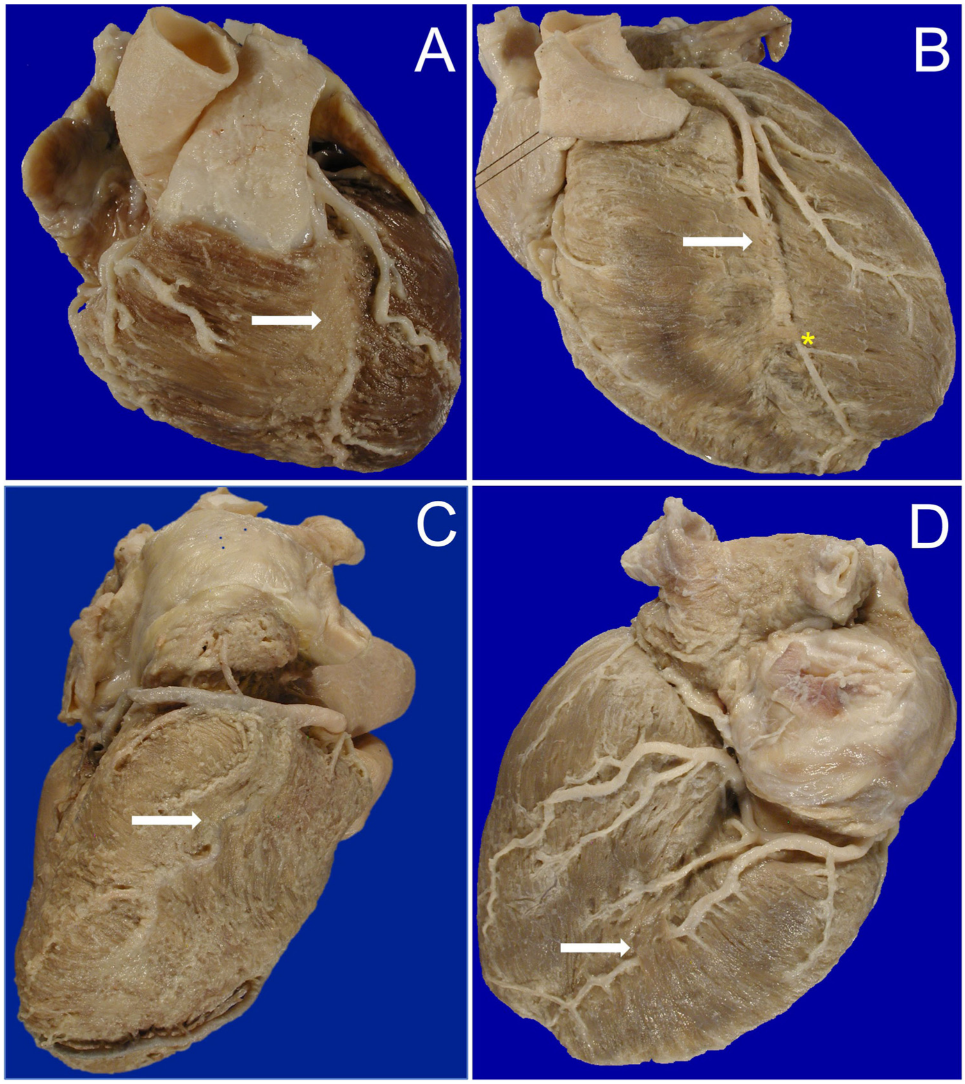

Figure 2 Representative photographs of hearts showing deep myocardial bridge (MB). A. Heart with MB on the anterior interventricular artery which when leaving the bridge is outside the anterior interventricular groove. B. Anterior view of a heart showing torsion of the anterior interventricular artery in the prepontine segment and a decrease of more than 70% of its diameter in the post-pontine segment (*). C. Right view showing MB at the right margin coronary artery. D. Heart showing MB over the posterior interventricular artery.

microscope camera (Carl Zeiss model ERc 5c, Germany) with Labscope analysis software (Carl-Zeiss, Germany) adapted to the equipment. Images were processed using Adobe Photoshop CS4 software. Measurements of the coronary layers, internal (intima) and media (muscular), were performed on histological images taking 4 different points in each coronary section. The MB results were contrasted against the control tissue in each sample and compared using a student's *t*-test. Data are presented as means ± standard deviation (SD).

Results

The presence of MB was identified in 96 human hearts, with a total of 421 bridges evaluated in the total sample, the mean number of MB per heart was 4.38 ± 0.28. Three hundred sixty-five coronary arteries presented at least one MB, on average 3.8 ± 0.2 arteries were affected with MB in each heart, and each artery presented on average 1.12 ± 0.019 MB. Eighty percent of the identified MB were classified as superficial, while the remaining twenty percent were considered deep.

Among these 24 dissected arteries, the anterior interventricular artery was the most commonly affected by MB and at least one in 54.1% of the total sample. The sinoatrial node artery was the second most affected, with the presence of MB in 47.9% of the sample. The anterior ventricular coronary arteries presented MB in 35.4% of the total. The left medial artery was the only vessel that lacked MB in this study (Fig. 2).

The systematic dissection presented in this study revealed that MB can affect more than one artery in each heart, as in most of the hearts included in this sample. Among these, ten hearts presented only one coronary artery

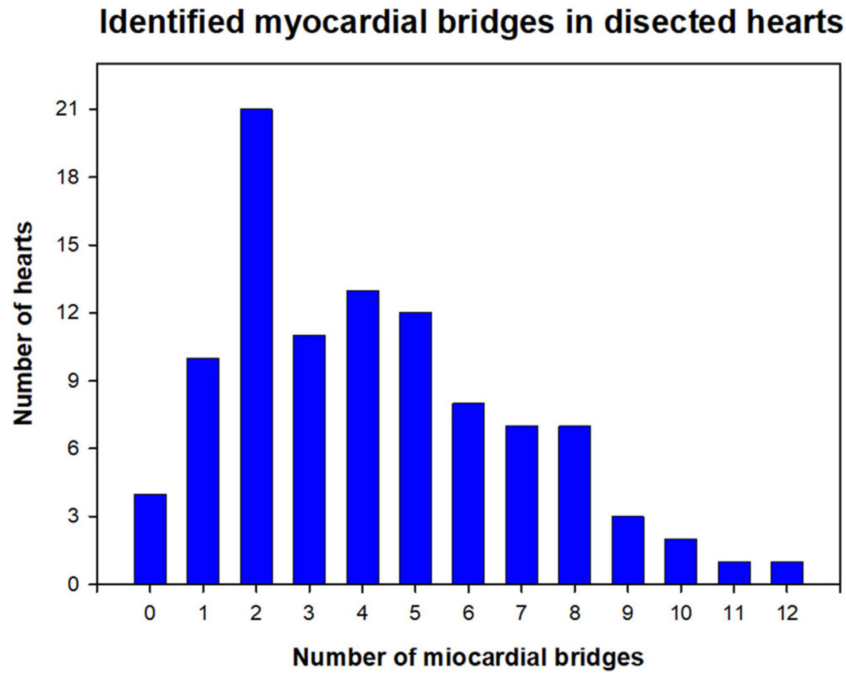

Figure 3 The number of myocardial bridges (MBs) found per heart. One hundred hearts were analyzed, 4 of them did not show MB, in 10 hearts only one artery was compromised with MB, and the remaining 86 hearts had two or more arteries compromised by MB. One heart showed 12 arteries compromised with MB.

affected by MB, whereas eighty-six had two or more arteries that presented MB ($n = 100$). The maximum number of arteries affected by MB in one heart was 12 (Table 1, Fig. 3).

Regarding the length of the MB, the intramural extension varied from 5.7 to 65.2 mm, with an average of 20.4 ± 2.4 mm in the total 421 MB identified in this study. The prepontine arterial diameter presented a statistically significant reduction compared to the post-pontine diameter ($P < 0.008$). Finally, the direction angle of the myocardial fibers concerning the artery axis was $63.6 \pm 5.2°$ (Table 1, Fig. 4).

The microscopic assessment identified changes in the coronary arteries walls of control sections, including irregular thickening of the intima (internal layer), and a loss of continuity of the internal elastic lamina, with an adequately conserved external elastic lamina, which allowed to unequivocal identify the muscular (media layer) (Fig. 5). The thickness of the intima was 10.20 ± 2.08 μm, while the muscular layer had an average thickness of 10.34 ± 1.07 μm. It is important to highlight that the arteries affected by MB presented an average thickness of the intima layer in the pontine region of 5.14 ± 0.56 μm, and a muscular layer with an average thickness of 5.91 ± 0.47 μm, both show a marked reduction when compared to the average thickness of the control. The thickness of the intima and muscular layers was compared between the control vessels and those affected by MB, with a statistically significant difference between the two groups ($P < 0.05$) identified for the muscular layer. In addition, the intima layer thickness was compared among the vessels with MB and by regions (prepontine region, pontine region, and post-pontine region). Also, a statistically significant reduction in the thickness of the intima was observed when comparing arteries with MB and control (Fig. 6).

Discussion

The presence of MB is a relatively frequent anatomical observation, but its assessment varies in precision [14]. The prevalence of MB varies considerably depending on the diagnostic method, which includes coronary angiography, multidetector computed tomography, or intravascular ultrasound. There is evidence that autopsy studies can identify the highest overall prevalence of MB, thus differences between autopsy studies compared to other methods for detecting MB can be highly significant [15]. In the present study, we identified a prevalence of MB of 96%, the presence of at least one MB was found in 96 of the 100 total hearts analyzed by instrumented dissection.

This reveals a higher prevalence of MB in this population compared to previous studies, including those by Kosinsky et al., [14], which identified a prevalence for MB of 41% and 31.3% in 2001 and 2004, respectively [14,16]. Importantly, the results we present come from a design that focused on a detailed morphological analysis and represents one of the few studies to evaluate the presence of MB from this point of view. Most of the published information on MB has focused on the anterior interventricular artery as the most frequently affected vessel [14,17—24].

Our results are very consistent with previous reports, with the anterior interventricular artery presenting 52% of the MB in this sample evaluated.

It is important to underline that most of the previous studies cited above focused on the dissection of the main right and left coronary arteries, with conclusions deriving from this limited dissection approach. In contrast, our results come from a very complete dissection of 24 arterial branches in each human heart, including the primary and secondary vessels. This methodology led us to identify

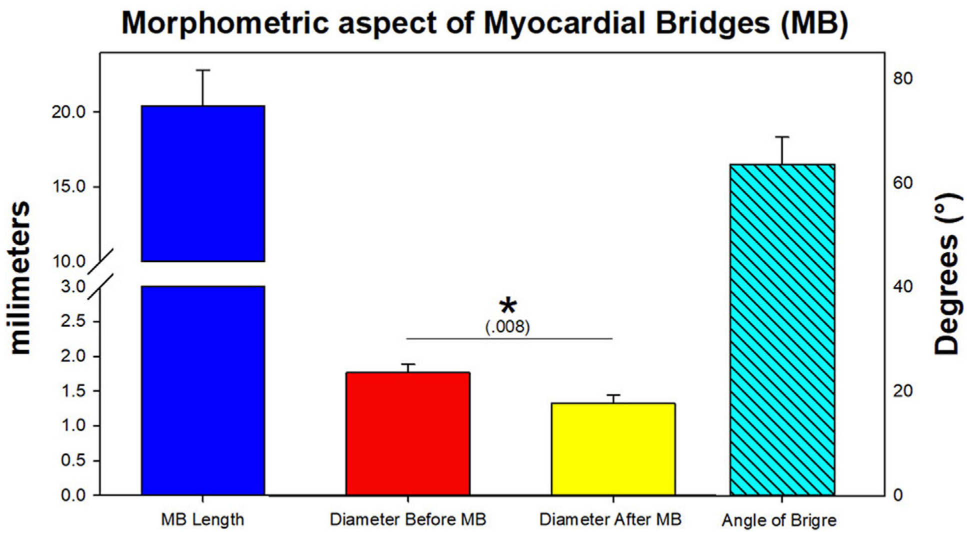

Figure 4 Measurements in mm of the length of the myocardial bridges, the prepontine arterial diameter, and the arterial diameter posterior to the bridge. Comparing both diameters, a statistically significant decrease was found. The bar on the right shows the direction angle of the myocardial fibers concerning the axis of the artery. All values correspond to the mean ± SE; (*) ($P < 0.008$).

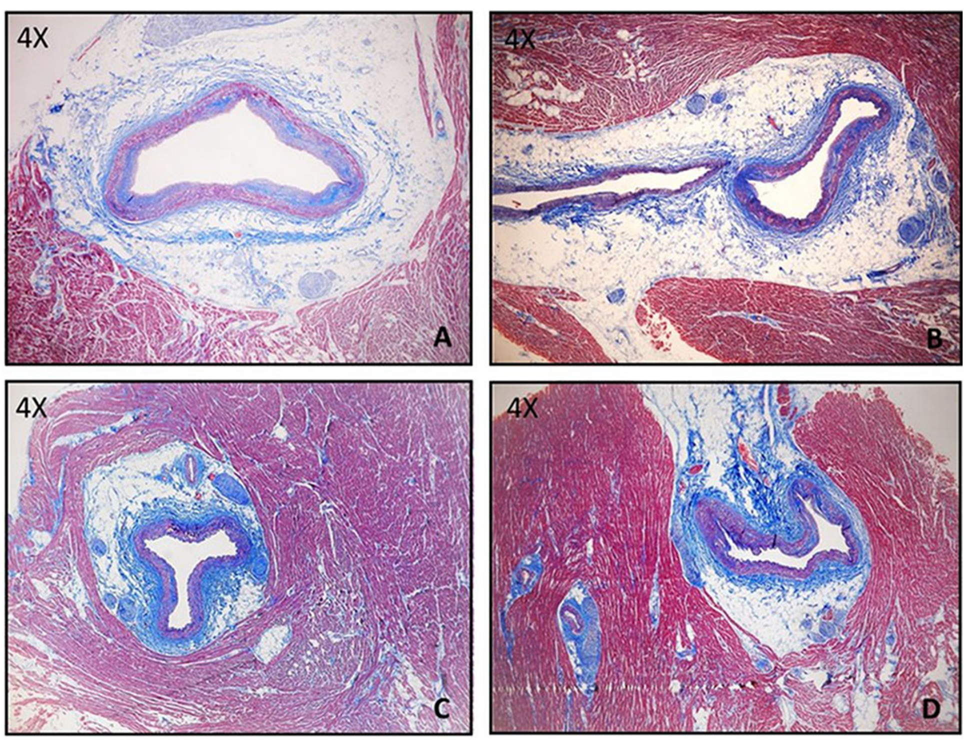

Figure 5 An anterior interventricular artery with a myocardial bridge (MB). Masson's trichrome stain. Representative histological section. A. Proximal segment. B. Middle segment. C. and D. Distal segment. There is thickening and irregularity of the intima in the proximal segment. A large sub-rhythmic space is observed in the proximal third of the pontine segment. The adventitia layer contains collagen fibers and elastic fibers, and abundant nerves are observed in the proximal and middle segments, and to a lesser extent in the distal segment of the pons.

a greater number of vessels affected by MB, including one heart which affected 12 arteries.

The results show that in this sample ($n = 100$) of a Mexican population, 96% have MB, of which 48% present one MB, 44% have two MB, and the remaining 4% have three or more MB.

By instrumented dissection, we analyzed a sample of hearts using light microscopy; the results of this additional evaluation showed an irregular decrease in the thickness of the intima layer for the segment of the vessel directly below the MB. In general, the thickness of the intima layer decreases compared to the prepontine and

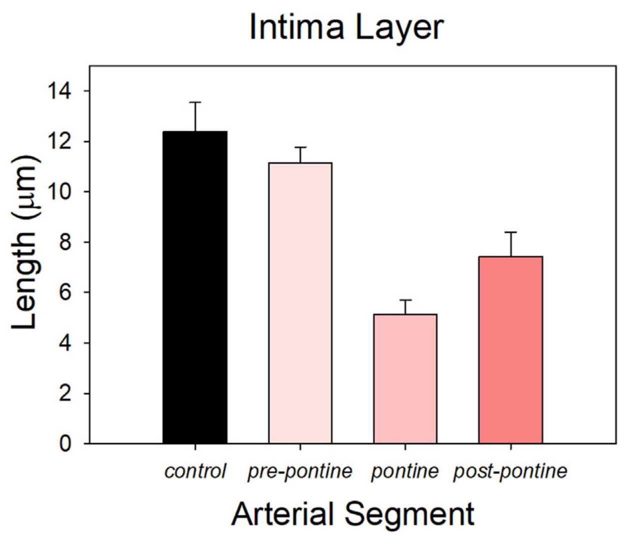

Figure 6 Measurement of the average thickness ± SE of the evaluated arterial segments, showing the statistical difference between groups (different letters) ($P < 0.03$).

post-pontine segments, which is consistent with previous studies [17,22–26]. This observation has been explained through hemodynamics. Briefly, during systole, the arterial lumen below the MB is smaller compared to the prepontine and post-pontine distal arterial segments, resulting in a decreased thickness of the intima and muscular layers, due to the exerted tension on the arterial wall.

The mechanism of damage to the intima layer has been associated with a turbulent flow that is produced by the blood exerting pressure on the prepontine arterial walls, favoring the development of a thicker intima layer in the prepontine arterial segment. As the exerted force decreases when the blood flow reaches the segment below the MB, this mechanism is subdued, making it more difficult to injure the intima layer. This proposed mechanism would imply that the MB can act as a protective element of the pontine segment of the coronary vessel, which has been suggested in previous studies.

An interesting finding of our study is the observation that the morphological characteristics of the vessel affected by the MB differ when evaluating the proximal segment, the medial segment, and the distal segment in terms of the bridge, e.g., the adventitia is initially irregular and presents numerous nerve fibers that dimmish as it reaches the distal segment. An important advantage of the present study is the analysis of not only the artery affected by MB but also its comparison with a control vessel not affected by MB in the same organ; we used the right coronary artery from the dissected heart.

Overall, our results show that the prevalence of MB in the Mexican population is 96%, with the anterior interventricular artery being the most frequently affected vessel. The evidence in this study shows that there are MBs in other arteries of the coronary system that had not been previously studied systematically. This information suggests that MB can be distributed in any of the branches of the coronary system. It is also important to highlight that it was observed that the arterial diameter of the segment posterior to the pontine bridge decreased.

These observations have potential implications for clinical and interventional purposes and prompt consideration of the high prevalence of MB in Mexican subjects that could be associated with clinical manifestations of coronary pathologies. Further studies should focus on determining the cause for this high prevalence of MB among Mexican subjects, including whether they are the result of a genetically susceptible population or a phenomenon that occurs postnatally due to environmental exposures, including lifestyle and nutritional habits. At this point, these represent options for exploring in further studies, and should not be considered actual explanations to the difference in prevalence.

In addition, it is necessary to improve the methods for detecting MB while the patient is alive, to try to correlate it with myocardial pathologies.

The limitations of this work are that the age ranges are very wide and due to the number of hearts, it was not possible to stratify the presence of bridges by age; furthermore, the histological analysis focused only on the anterior interventricular artery.

Disclosure of interest

The authors declare that they have no competing interest.

Author contributions

A.R.G: study design, data collection, data analysis, data interpretation, supervision, writing; E.P.C: data analysis, data interpretation, writing; M.S.S.: data analysis, data interpretation, writing; M.A.M.C: data analysis, data interpretation, writing; L.P.C.M.: data analysis, data interpretation, writing; M.A.C.: formal analysis, funding acquisition, investigation, methodology, project administration, writing.

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