Myocardial bridge over coronary arteries and myocardial coat lining coronary sinus: clinical implications

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SUMMARY

Myocardial Bridge (MB) on the coronary artery and myocardial coat (MC) on the cardiac veins are usually detected in angiography and cadaveric dissection. Left anterior descending branch (LAD) of the left coronary artery is the most frequent site of MB. Rarely MB is also seen over the right coronary arterial branches. MB has proven association with ischemic heart disease and other critical cardiac consequences like myocardial infarction (MI) (Alegria et al., 2000; Soran et al., 2000). MC, on the other hand has not gained enough attention in previous studies. Large MB can be readily identified in angiograms, but minutes MB can be picked up by newer imaging studies like multidetector computed tomography (MDCT) and optical coherence tomography (OCT) scan (Tiryakioglu and Aliyu, 2020). Cadaveric dissection, however, holds its unique place in direct visualization and studying the macro and micro-anatomical characteristics. To study the prevalence and anatomical attributes of MB and MC in Indian population, ten adult cadaveric hearts (6 male and 4 female) were dissected as part of a routine undergraduate teaching at the Anatomy Department, All India Institute of Medical Sciences, New Delhi, India. MB over the coronary artery and MC over the cardiac vein were identified. Data pertaining to the MB and MC dimensions were measured with a digital vernier calliper. Histology of the MC was carried out to confirm its presence and observe the cyto-architecture pattern. Relevant gross macroscopic and microscopic images were photographed and photomicrographed.

20% of the dissected cadavers revealed MB involving LAD in first heart while LAD and RCA both in second heart with lengths 5 mm, 18 mm and 2 mm respectively. MC was noted over coronary sinus and proximal few millimeters of great and middle cardiac veins. Histological examination revealed cardiac striated muscle in MC with typical cyto- architecture. The mean myocardial muscle index (MMI) of MBs ranged from 1.6 to 21.6. The present study highlights 20% prevalence of MBs in Indian population involving both right and left coronary artery. 10% of the subjects had histologically confirmed MC over cardiac veins. MC over the coronary sinus and other cardiac veins need more elaborate explorative studies to quantify the anatomic properties and to examine the possible association with cardiovascular disease. Nevertheless, anatomic attributes should be kept

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in mind to better appreciate MI in evolution and MI at evaluation in a case with MB.

Key words: Myocardial bridge – Myocardial coat – Myocardial cover – Coronary artery – Coronary sinus

ABBREVIATIONS

CAD – Coronary artery disease

CCTA – Coronary computed tomographic angiography

CS – Coronary sinus

CTA – Computed tomography angiography

IHD – Ischemic heart disease

IVUS – Intravascular ultrasound

LAD – Left anterior descending

LCA – Left coronary artery

MB – Myocardial bridge

MC – Myocardial coat

MDCT – Multidetector computed tomography

MI – Myocardial infarction

MMI – Myocardial muscle index

OCT – Optical coherence tomography

RCA – Right coronary artery

INTRODUCTION

The myocardial bridge is a clinical entity characterized by the presence of a portion of the epicardial coronary artery lying under cover of the myocardium. Ever since its description by Reyman in 1737 and Black in 1805, it has constantly fascinated cardiac physicians and surgeons (Reyman, 1737; Black, 1805; Möhlenkamp et al., 2002). Later, during 1951, Geiringer presented his extensive research findings in autopsy samples. The entity became more vivid after Portmann and Iwig narrated their angiographic observations in 1960 (Geiringer, 1951; Portman, 1960; Ishii et al., 2014). The cardiac muscle fibers running over the coronary artery embedded in the epicardium are conventionally called the “myocardial bridge (MB)”. The coronary artery passing under the bridge is termed “tunneled artery”. Other terminologies – viz., muscular cardiac bridge, intramural coronary, myocardial loop, mural coronary – are also used synonymously. It is primarily encountered and thought to be more frequent in the anterior interventricular artery (also known as left anterior descending or LAD artery). Other coronary artery branches – e.g., posterior descending, circumflex, right and left marginal and diagonal arteries – are also reported to be affected by MB. The MB covering LAD is a fairly common occurrence, as detected in heart autopsies, and the incidence is as high as 50% (Lujinović et al., 2013). Thus, some authorities believe it to be a normal variant rather than an instance of aberrant anatomy, and it correlates well as majority of such MBs remain asymptomatic. However, in some subjects with MBs, grave clinical consequences like ischemic angina, arrhythmia and acute coronary syndrome have been constantly reported. MBs occurring at special sites such as LAD are also linked with the risk of myocardial infarction (MI) and even sudden death. The overall risk of occurrence of critical cardiac events becomes higher in cases of pre-existing heart disease. Different schools of thought prevail as to whether presence of MBs can lead to critical cardiac events (Alegria et al., 2005; Soran et al., 2000; Michel et al., 2014; Zeina et al., 2007) or whether they are merely an asymptomatic benign anatomic entity (Alegria et al., 2005; Soran et al., 2000; Tiryakioglu et al., 2020; Nasr et al., 2014; Rogers et al., 2017). Coronary artery angiogram is a useful tool for detecting the presence of MBs. However, the reported angiographic detection rate is as low as 5%. The angiographic study utilizes the principle of compression of coronary artery by the MB musculature typically described as ‘milking’ during the systole. Many times a small muscular bridge of less than 1mm is not detected, as they cannot produce a milking effect large enough to get picked up. Invasive diagnostic methods like intracoronary ultrasound coupled with Doppler can increase the detection rate marginally, but multidetector computed tomography (MDCT) scan is an efficient visualization technique to visualize and detect a MB in a non-invasive manner, whose detection rate is comparable with that of autopsy. It is now well known that the right coronary artery (RCA) and the other unnamed small coronary arteries can also get covered by MB fibres, all of which have the potential for increasing the preponderance of atherosclerosis and consequent MI. The detection of MB over a large coronary artery is relatively easy in imaging studies, as changes in the blood flow in the burrowing artery distal to the site of MB fibres can be well visualized. With advanced radio- imaging technology, especially coronary computed tomographic angiography (CCTA) and MDCT, data pertaining to the detailed anatomic attributes of MBs in other coronary arteries have been gradually accumulating in literature (Tiryakioglu et al., 2020). Recently, optical coherence tomography (OCT) has emerged as a superior high resolution imaging modality successful for minute MBs not detectable even in intravascular ultrasound (IVUS) and routine angiography (Okamura et al., 2022). It was the gradual understanding of clinical correlation of MB with myocardial ischemia and resultant ischemic heart disease (IHD) that fueled more organized and in-depth research to explore the entity. Because MDCT and other newer techniques can accurately identify and functionally quantify the MB fibers, now it has been possible to guide the clinicians in evaluating a case of IHD or coronary artery disease (CAD) by providing functional correlation between MB fibers and resultant milking effect during systole, and link these data with clinical presentations which might adequately help in instituting prompt and adequate therapy.

The coronary sinus (CS) is a notable structure on the posterior coronary sulcus serving as the predominant terminal pathway of venous drainage of the left ventricle and inter-ventricular septum. A myocardial coat (MC) has been consistently seen over the coronary sinus, which has been attributed to the embryological development of the CS from the left horn of the sinus venosus and a small part of the right atrium. Despite being a more or less consistent structure, detailed study on MC over CS is long overdue in medical literature. The MC not only covers the CS but also wraps around variable adjoining portions of the draining tributaries: viz., middle and great cardiac veins. In up to one fifth of the MCs, it has been described in few different forms like myocardial belts, cuffs, adhesions, etc., which definitely have the potential to behave like a sphincter in the chief draining channel junction with the great cardiac vein (von Ludinghausen et al., 1992). Emphasis has been made on the surgical elimination of the consistent but variable morphological connections existing between left atrial myocardium with CS (Chauvin et al., 2000). A unique atrial macro-entry phenomenon culminating in atrial flutter was identified due to MC over CS, which is subsequently seen to be a direct connection between left atrial myocardium and MC over CS. The route of macro re-entry phenomenon was shown to be through the MC over CS via the left atrium to the interatrial septum, and then retuning back to CS (Olgin et al., 1998). The morphological aspect of MC over CS has to be seen from a different perspective in view of the increasingly performed invasive cardiac procedures through the CS.

MATERIALS AND METHODS

The study was conducted at the All India Institute of Medical Sciences, New Delhi, India, during routine cadaveric dissection for undergraduate medical students. The institutional guidelines for procurement of human cadavers and their use for medical teaching and research were strictly adhered. Relevant ethical clearance and consent from the relatives of the deceased was obtained beforehand. The hearts were dissected out from the middle mediastinum of the embalmed cadavers, which were routinely kept in weak formalin solution. Subsequently, meticulous dissection for the coronary vasculature was carried out keeping in mind the presence of the MBs. The epicardium was carefully stripped off from the underlying myocardium and the epicardial fat and vessels. Proper care was taken not to damage the vascular architectural pattern. Using blunt forceps, the epicardial fat was removed bit by bit and the specimens were cleared off from additional loose connective tissues obscuring the coronary vasculature. The various anatomical attributes of the myocardial bridges and tunneled arteries – viz., location, thickness, length, etc. – were measured using a digital vernier caliper. All cadavers were of voluntary body donors (age ranging from 36 years to 73 years). The death certificates collected at the time of body donation revealed that none of the individuals died of cardiac cause.

RESULTS

Two out of the total 10 dissected cadavers revealed MB over LAD and right ventricular branch of the RCA. Data pertaining to the myocardial bridges and / or tunneled arteries were recorded, and specimens were photographed. MB muscle indexes were calculated as follows: MB muscle index (MMI) = Length of MB in millimeters x Thickness of MB in millimeters.

Case 1:

In the first heart specimen from a male cadaver aged 62 years, MB was noted in the proximal segment of the LAD artery (Fig. 1A). The dimensions of the MB were 5 mm x 3 mm x 0.8 mm in length, breadth and thickness respectively. MMI of the MB was 4. The MB was positioned in the same plane as that of the adjoining myocardium. The left coronary artery (LCA) after originating from the left aortic sinus runs anterior to pulmonary trunk and after sprouting other branches lie for a short distance in the anterior interventricular groove, hooked beneath the MB to reappear in the groove and then turned backwards to the diaphragmatic surface running in the posterior interventricular groove. No other coronary artery or their branches were seen to be afflicted by MBs. The course of both the coronary arteries and their branches appeared normal. The segment of the LCA which was not covered by the MB had an average diameter of 3.35 ± 0.35 mm and the diameter of RCA at origin was of normal caliber (3.86 ± 0.28 mm).

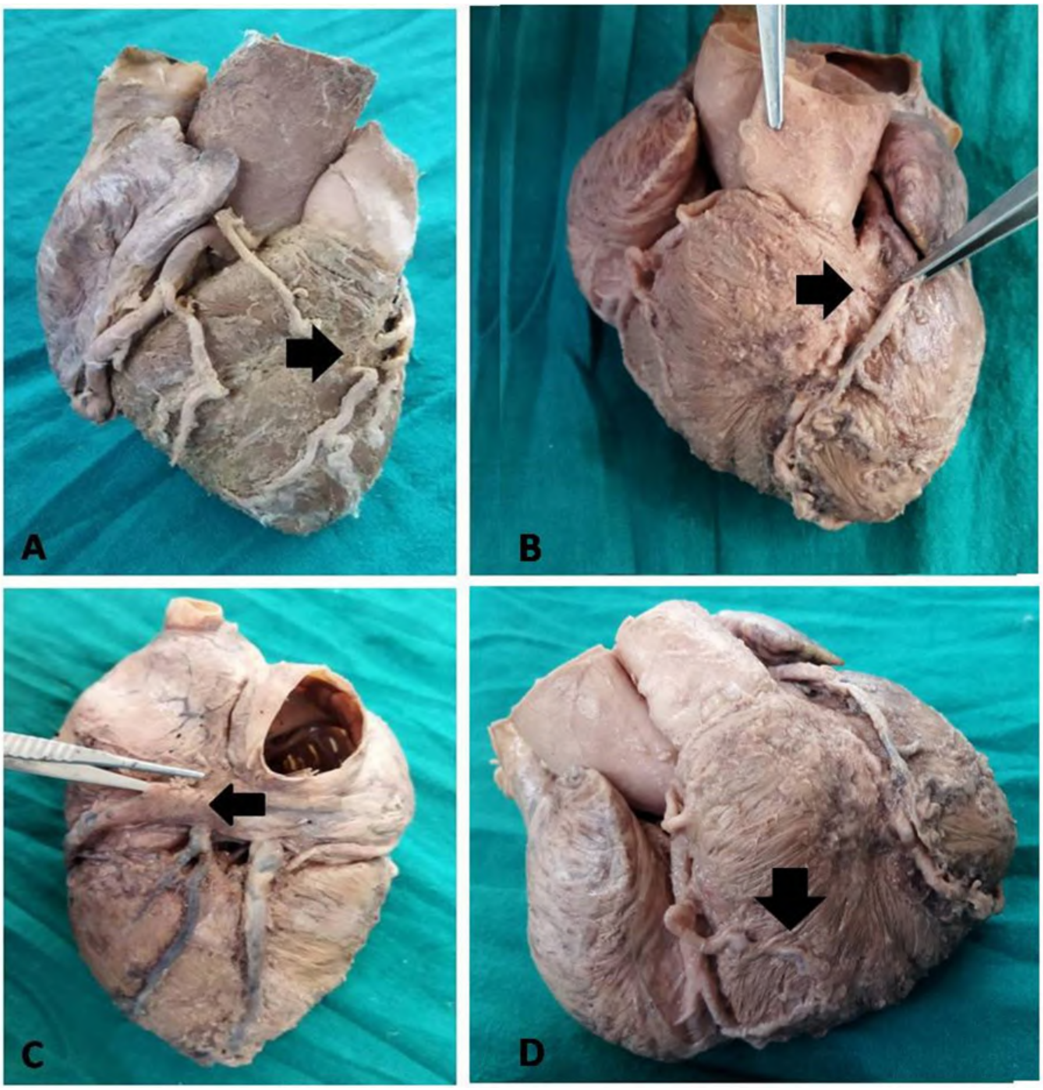

Fig. 1.- A- Myocardial Bridge (MB) over proximal segment of LAD in the first heart specimen; **B**- MB over proximal segment of LAD in the second heart specimen; **C**- MC over the coronary sinus in the second heart specimen; **D**- MB over the right ventricular branch of RCA in the second heart specimen.

Case 2:

In the second heart specimen of the male cadaver aged 57 years, two MBs were noted in the proximal segment of the LAD artery and in the right ventricular branch arising from the RCA just to the left of the anterior coronary sulcus slightly above the inferior border of the heart (Fig. 1B and 1D). The LCA originated normally from the left aortic sinus and runs in the anterior interventricular groove after giving circumflex and diagonal branches. The dimensions of the MB on LAD artery were 18 mm x 4 mm x 1.2 mm in length, breadth and thickness respectively. The MMI of this MB was 21.6. The MB appeared slightly elevated than its adjoining myocardium so that the LAD artery did not appear to be hooking in a deeper plane. The RCA originated from the anterior aortic sinus and after giving the conus and atrial branches it traversed in the anterior coronary sulcus. The second MB was noted over the right ventricular branch of the RCA whose dimensions were 2 mm x 2 mm x 0.8 mm in length, breadth and thickness respectively; and it appeared to be in the plane of the adjoining myocardium. The MMI of this MB was 1.6. The RCA and LCA were of normal caliber (average diameter of RCA at origin was 3.73 ± 0.25 mm; average diameter of main LAC at origin was 4.30 ± 0.32 mm) and had a normal course and branching pattern except the noted MBs.

We also noticed a myocardial coat (MC) over the coronary sinus (CS), extending to the proximal part of the great and the middle cardiac veins in the second cadaveric heart (Fig. 1C). There is mention of MC covering coronary sinus and other large diameter cardiac veins draining into coronary sinus in the literature. The MC extended from the point where the oblique vein of the right atrium drained into the CS till the point at which CS itself drained into right atrium. The proximal portion of the great cardiac vein and middle cardiac veins had similar muscle coat. Histological examination of the same revealed that the CS had a coating of spirally arranged cardiac striated muscle fibers (Fig. 2). Loose areolar tissue with intervened in space between CS wall and MC coat. On gross examination, the MC coat appeared to be in continuity with the cardiac muscle fibers of the left atrium. All the dimensions of MBs (length, breadth and thickness) along with MMIs and dimensions of MC (length, breadth and thickness) have been tabulated (Table 1).

DISCUSSION

The MB results in systolic compression of burrowing coronary arterial segment and is the underlying pathophysiology in myocardial ischemia (Bourassa et al., 2003). In fact, the clinical research did commence on MB due to the increased predilection to myocardial ischemia in subjects harboring MB (Houstiuc et al., 2017; Michel et al., 2014). In the late 20th century, morphologic study involving 642 hearts

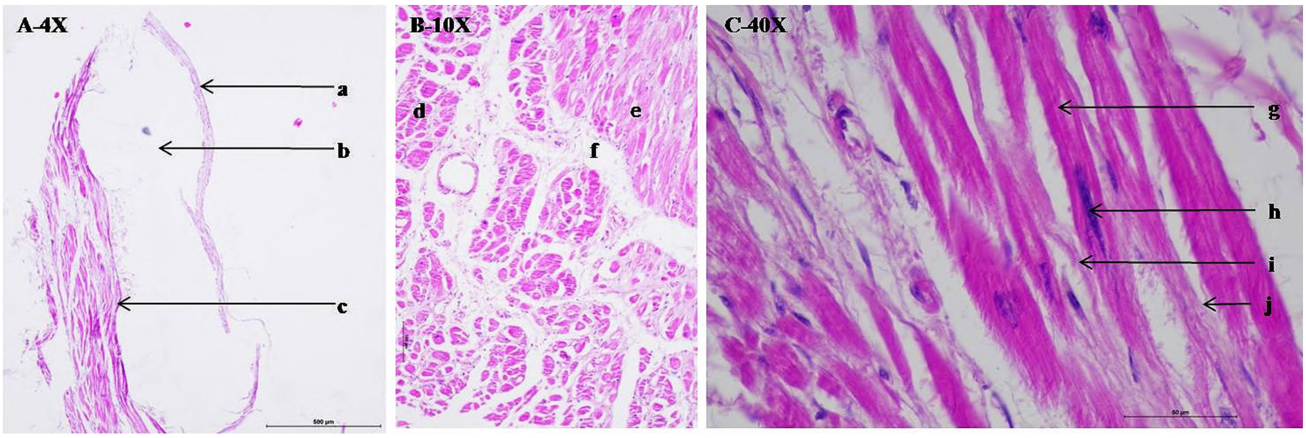

Fig. 2.- Histological features of MC over coronary sinus. **A:** myocardial coat with wall of coronary sinus. Scale bar = 500 µm. **B:** cardiac muscle fibres in transverse and longitudinal section. Scale bar = 200 µm. **C:** characteristic of MC showing branching pattern of muscle fibre, central nucleus and intercalated disc. Scale bar = 50 µm. a- endothelium of the coronary sinus wall, b-adipose tissue between coronary sinus and surrounding cardiac striated muscle coat, c-striated cardiac muscle coat, d-cardiac muscle fibre bundle in a fascicle, e-cardiac muscle fibres seen in longitudinal section, f-perimysium, g-intercalated disc, h-central nucleus of cardiac muscle fibre, i-branching carding muscle fibre, j-endomysium of cardiac muscle.

Table 1. Anatomical parameters of MBs and MC.

	Length (in mm)	Breadth (in mm)	Thickness (in mm)	MMI
MB over LAD (Case 1)	5	3	0.8	4
MB over LAD (Case 2)	18	4	1.2	21.6
MB over branch of RCA (Case 2)	2	2	0.8	1.6
MC over CS	45	6.6	0.2	Not applicable

revealed that the atherosclerosis of the RCA is more extensive than the left in presence of MB, whereas no significant difference was noted between both coronary arteries in absence of MB. Furthermore, atherosclerotic lesions were noted to be more pronounced in the proximal segment of the LAD just preceding the MB with both macroscopic raised lesions and microscopic intimal thickenings. The most frequent segment of the LAD artery with atherosclerotic changes was also the proximal segment irrespective of the presence of any other additional MBs over LAD artery. It was in contrast to the prior observation of the international atherosclerosis project which stated that the RCA had more predilection for atheroma formation (Ishii et al., 1986). One of the two mechanisms by which MB leads to CAD is direct compression on the coronary artery at systole producing decreased coronary blood flow, reduced myocardial perfusion and impeding relaxation of coronaries during diastole. The other operating mechanism is acceleration of the atherosclerotic process at the segment of the artery just proximal to the MB location due to endothelial injury incited by altered hemodynamic processes with retrograde blood flow (Ishikawa et al., 2009). These mechanisms have evolved through the knowledge gathered from cadaveric and imaging studies with regard to their various anatomic attributes. Some of the relevant studies looking at the MB with its different attributes are summarized (Table 2).

A morphological study on MB was done to primarily focus on the MB thickness and the MMI and address its predictive value in context with

Table 2. Myocardial bridges and afflicted arteries across different population groups.

Authors	Study type	Number of specimens	Frequent artery involved	Population group
Bezerra et al., 1989	Cadaveric	90	LAD	Brazilian
Channer et al., 1990	Angiographic	1102	LAC	British
Ferreira et al., 1991	Cadaveric	90	LAD	Brazilian
Lima et al., 2002	Cadaveric	30	LAD	Brazilian
Ballesteros et al., 2008	Cadaveric	86	LAD	Colombian
Bandyopadhyay et al., 2010	Cadaveric	42	LAD	Indian
Saidi et al., 2010	Cadaveric	109	LAD	African
Saini et al., 2012	Cadaveric	100	Posterior interventricular branch of both coronaries	Indian
Lujinovic et al., 2013	Cadaveric	30	LAD	Bosnian
Ashraf et al., 2014	Cadaveric	60	LAD	Arab
Tiryakioglu et al.,2019	Angiographic	1	RCA	Nigerian
Zhu et al., 2021	CTA	106	LAD	Diagnosed HOCM cohort of Chinese
Cai et al., 2022	CTA	1	Right coronary artery and total absence of left coronary artery	Chinese
Alexandre et al., 2022	CTA	1	LAD	Portuguese
Bai et al., 2022	CTA	1	LAD	Chinese
Okamura et al., 2022	OCT	1	Only LAD was included	Japanese

CAD and IHD. These parameters are found to be directly correlating with the risk of atheroma formation and subsequent CAD severity in (Ishikawa et al., 2009; Pargaonkar et al., 2018). We noticed that 20 % (2 out of 10 cadavers) of the studied cadavers possess MBs involving both the RCA and the LAD branch of LCA. Comparison of percentage prevalence of myocardial bridge in different studies has been tabulated (Table 3). The average MMI in these two cases was 1.39, which corroborated the existing literature and is significant enough for critical cardiac events. In addition to it, we have also observed a fairly large MB over the coronary sinus, which on gross examination revealed to be coating and might be constricting the sinus at systole. Former studies described similar MC over coronary veins, which were considered a benign finding (Hazirolan et al., 2007; Mohlenkamp et al., 2002). Nonetheless, the observed large MC encircling the coronary sinus in our case might worsen pre-existing the myocardial ischemia due to other causes at the time of systole and might aggravate myocardial ischemia & damage due to myocardial toxicity from ongoing waste product accumulation. It might also create a difficult situation in coronary sinus atrial pacing procedures, when the MC is close to the coronary ostium (Olgin et al., 1998). The histological examination of the segment of the MC over the CS confirmed the presence of myocardium. The MC was external to the epicardium in which the CS was embedded. The MC entirely composed of striated cardiac muscle fibers arranged spirally with characteristic central nuclei, branched muscle fibers and intercalated disc. The earliest extensive report of MC over myocardium along with a proposed classification system is seen in a cadaveric case series of late 1990s (von Ludinghausen et al., 1992). The targeted research to unfold the mystery of MC over CS seems to have been somewhat neglected in comparison to broad and extensive areas of medicine looking at coronary artery MB. The increasing importance of MC over CS can be understood from the cardiac interventions requiring cannulation of CS for drug delivery for retrograde cardioplegia, cardiac pacing and also in instances where coronary artery stenosis hinders the desired access. The same route is now employed for stem cell delivery to revive a degenerated myocardium which suffered recent MI (Kassem et al., 2021; Singh et al., 2005). There is a description of atrial macro-re-entry pathway through the MC over CS in atypical atrial flutter in a patient with obvious structural heart disease (Olgin et al., 1998).

The CAD severity is the net effect of the two mechanisms mentioned above operating simultaneously which is dependent on the

Table 3. Prevalence of MBs in different population groups in angiographic and cadaveric studies.

Authors	Population group	Sample Size	Type of study	Incidence of MB (in percentage)
Geiringer, 1951	British	100	Autopsy	23
Noble et al., 1976	Canadian	5250	Angiographic	0.51
Kramer et al., 1982	American	658	Angiographic	12
Angelini et al., 1983	American	1100	Angiographic	4.5
Wymore et al., 1989	American	64	Angiographic	33
Ferreira et al., 1991	Brazilian	90	Autopsy	55.6
Baptista et al., 1992	American	82	Autopsy	54
Juillière et al., 1995	France	4767	Angiographic	0.82
Harikrishnan et al., 1999	Indian	3200	Angiographic	0.60
Ortale et al., 2001	Brazilian	37	Autopsy	56
Kosiński et al., 2001	Polish	100	Autopsy	41
Podolec et al., 2019	Polish	298556	Angiographic	0.81
Matta et al., 2021	Polish	35813	Angiography	1.42
Claudino et al., 2022	Brazilian	57	Autopsy	40.3

different anatomical dimensions of the MB segment viz. thickness, length, muscle mass etc. whose various properties actually govern it indirectly. We are reporting here two cases of MBs encountered during cadaveric dissections, one of which not only had MBs over the two major coronary arteries but also had fairly large MC over the CS which is a unique situation having tremendous clinical repercussions. Specific correlation between the presence of MB and MC, their anatomical attributes and resultant adverse cardiac event could not be established from the available clinical history. Nevertheless, we should not forget to pay attention to these anatomical attributes while dealing with a patient with IHD; as these have close correlation with the onset, progression and eventual management plan of the CAD patients. Therefore, a large pool of data gathered through newer high resolution, high precision techniques such as MDCT, CCTA or OCT can illuminate more in this relatively grey area of anatomical attributes of myocardial bridge.

CONCLUSIONS

Though not every myocardial bridge (MB) can become determinant of avoidable serious cardiac consequences, some of the MBs obviously have definite proven correlation, which is brought about either by direct coronary arterial compression or by mediating endothelial injury. MB significantly adds to the intimal proliferative lesions combined with subsequent rupture and / or fissure of atheromatous plaques. There can be grave consequences in the form of occurrence of MI in very young age also. Cadaveric anatomic study integrated with the newer more efficient and high-resolution imaging modalities coupled with the clinical research will be able to not only identify the presence of minute MBs but also can quantify its anatomic properties and other attributes. Thus, anatomic parameters should be kept in mind to better appreciate MI in evolution and MI at evaluation in a case with myocardial bridge. Furthermore, it is believed that the finding of MC over CS in one of the 10 cadaveric hearts will ignite anatomist, cardiologist to look for the same in a more inquisitive manner into this less explored entity.

Ethical Approval and Consent to Participate

The study protocol was designed as per the prevailing guideline of the institute on the use of human cadaver for teaching and research and relevant ethical clearance was obtained from donor at the time of whole-body donation.

Availability of data and materials

All data and materials can be procured from first (Dibakar Borthakur) and corresponding (Rima Dada) authors.

Authors Contributions

Dibakar Borthakur and Rajesh Kumar-carried out dissection, staining and wrote the main manuscript, Rima Dada-Reviewed and corrected the final manuscript. All authors reviewed the manuscript.

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