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Anatomical characteristics of myocardial loops in the adults

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Abstract

Aim. To establish structural features and adjacent anatomy of myocardial loops in the adult and elderly human hearts.
Methods. We studied 100 hearts obtained from adult and elderly people who died from non-cardiac causes. We dissected subepicardial blood vessels and their intramural segments on 60 formalin-fixed hearts. The rate of the cone artery directly originating in the aorta (third coronary artery) was recorded. The number of myocardial loops, their localization and length were determined. We made histological sections from 40 heart specimens from areas of the coronary groove containing myocardial loops. The shortest distances from the coronary sinus and myocardium of the left atrium to the artery, the thickness of the loops, the cross-sectional area of the artery and perivascular space and the ratio of these parameters were measured. The statistical significance of differences was assessed by using the Mann–Whitney U-test. The relationship between the two qualitative features was identified using the Pearsons χ^2 test. The Spearman's rank correlation coefficient (R) was used for the correlation analysis.
Results. Macroscopically, myocardial loops were found in 12 (20%) hearts out of 60. More often, they were determined on specimens where the cone artery directly originating in the aorta. Histological examination revealed myocardial loops in 10 (25%) hearts out of 40. They were located above the arteries accompanying the coronary sinus. Their length varied from 8.5 to 44.53 mm (Me=16.68 mm), thickness from 0.16 to 0.58 mm (Me=0.31 mm). Two types of myocardial loops (arterial and arteriovenous), differing in thickness (p=0.045), were distinguished.
Conclusion. The myocardial loops are predominantly located on the diaphragmatic surface of the heart in the left half of the coronary groove over the arteries accompanying the coronary sinus, while the artery can pass in the myocardial loop separately from the veins or in the "sleeve" of the coronary sinus; the presence of myocardial loops is associated with the independent aortic origin of the cone artery.
Keywords: heart, coronary arteries, myocardial loops, coronary sinus, left atrium.

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Background. In Russia and other developed countries, atrial fibrillation is one of the most frequently recorded cardiac arrhythmias [1]. In atrial fibrillation ablation (the maze procedure), it is important to consider the peculiarities of the relationship between the vessels present in the coronary sulcus and the atrial myocardium [2]. When the lines of the impulse conduction block are formed in different parts of the left atrium, the failure of ablation may be associated with the intramyocardial location of the coronary sinus in the "sleeve" of the myocardium [3].

Individual sections of the coronary arteries (CA) can also have an intramyocardial course, where the ventricular branches may pass under myocardial bridges. Many authors studied their distribution and morphometric characteristics [4, 5].

P. Polacek and H. Kralov (1961) identified the atrial myocardium bundles, covering the arteries in the coronary sulcus, and called them myocardial loops (ML) [6]. Most of the studies on ML were conducted using radiation for examining the patients. Anatomical studies are sporadic [7].

ML frequency is presented in many publications, but literature analysis showed that its frequency varied from 0.1%, according to coronary angiography [8], to 49%, according to the results of studying the autopsy material [7]. There are no data in the literature on ML local topography and the relationship between ML and the variants in CA branching patterns.

It is crucial to study the anatomy and topography of ML to not only understand the heart structure but also choose the optimal approach when performing surgeries on the posterior and inferior parts of the atria.

The study aimed to establish the anatomy and topography of ML using heart specimens of middle-aged and elderly individuals.

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Materials and methods of research. We examined 100 heart specimens obtained from the pathomorphological departments of the clinical bases of the Ural State Medical University in accordance with cooperation agreements. We obtained specimens from the deceased whose bodies were not requested for burial, so no informed consent was obtained. The requirements of Article 5 of the Federal Law No. 8 “On burial and funeral business” of 01/12/1996 (with amendments and additions of 01/01/2017) were considered.

The local ethics committee of the Ural State Medical University of the Ministry of Health of Russia (protocol no. 5, dated May 24, 2019) approved the study.

Study inclusion criteria were as follows:

1) middle-aged or elderly deceased individuals,
2) death from noncardiac diseases,
3) a typical left-sided position of the heart,
4) normal heart,
5) concordant ratio of the chambers of the heart and near-cardiac vessels,
6) weight of the heart: 200–420 g.

Exclusion criteria were as follows:

1) heart defects and CA anomalies,
2) a history of heart surgery or CA,
3) macroscopic signs of complications of coronary heart disease,
4) damage and deformity of research objects.

The specimens were divided into two groups: n_1, including 60 hearts, and n_2, including 40 hearts. Group n_1 was macroscopically examined. For this purpose, the hearts were fixed in a 10% formalin solution, and the subepicardial blood vessels and myocardial formations (bridges and loops) above their sites were dissected using the classical method with a scalpel and forceps without preliminary injection. The number and position of MLs were compared with similar characteristics of myocardial bridges. Attention was drawn to the independent separation of the conus artery from the aorta. The type of blood supply to the cardiac ventricular complex was determined based on whether the posterior interventricular branch belonged to the left or right CA system. ML length was measured using a ShTsTs-2-250 0.05 caliper (Chelyabinsk Instrument Plant, the resolution step of the reading device of 50 µm, with verification).

Group n_2 was microanatomically examined. Sections were made across the coronary sulcus with an interval of 0.5 cm. Areas with ML were taken as histological specimens. The material was fixed in a 10% solution of neutral buffered formalin and prepared according to the standard technique. After preparation, the fragments were embedded in paraffin. Three-micrometer-thick sections were made from paraffin blocks, which were stained with Ehrlich’s hematoxylin and eosin and Van Gieson's picrofuchsin. An Olympus CX31RTSF microscope (Japan) was used to study them.

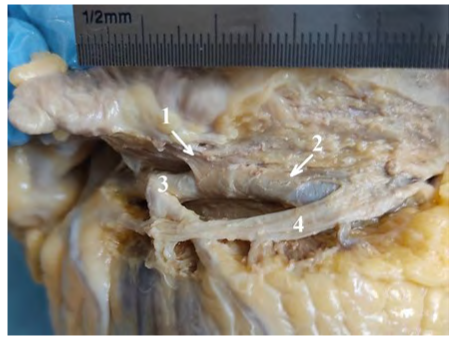

Fig. 1. Myocardial loop (indicated by arrows), formed by the myocardium of the left auricle (1) and the posterior wall of the left atrium (2), surrounding the circumflex branch of the left coronary artery (3). The great cardiac vein (4) is located behind the artery.

For morphometry, photographs of the microslides were taken using the “stitching” option in the ADF Image Capture 4.7 (2019) program. Using the images from the ImageJ 1.53e software (2020), we measured the shortest distances from the artery located in the ML to the coronary sinus and myocardium of the left atrium; ML thickness; the cross-sectional area of the intraloop artery and the perivascular space. The ratio of these parameters was determined.

Statistica 13.3 software (StatSoft Inc., USA) was used for statistical processing. The results were presented as medians (Me) and extreme values. For the correlation analysis, Spearman’s coefficient (R) was used. The Mann–Whitney U-test was used to assess the significance of differences, and the Pearson χ^2 test was used to identify the relationship between two qualitative signs. Significance level α was 0.05.

Results. MLs were macroscopically found in 12 (20%) of 60 hearts. MLs were located above the circumflex branch of the left CA in 10 specimens and above the artery at the base of the left auricle in two specimens. In the remaining eight specimens, the circumflex branch was located between the posterior wall left atrium and a great cardiac vein or coronary sinus (Fig. 1).

MLs were rarely detected over the terminal section of the right CA, which entered the myocardial “sleeve” of the coronary sinus at its entry site in the right atrium. In nine specimens, where the circumflex branch of the left CA passed into the ML, myocardial bridges were found above the ventricular branches of the left CA. Bridges were present over the anterior interventricular (n = 9), left marginal (n = 2), and diagonal (n = 1) arteries. Their

Table 1. Morphometric characteristics of myocardial loops in different formations

Indicator	Range of values		p
	Arterial variant, n = 6	Arteriovenous variant, n = 7	
Myocardial loop thickness, mm	0.30–0.44	0.16–0.58	0.045*
Cross-sectional area of the artery, mm^2	2.15–13.65	1.76–10.98	0.941
Cross-sectional area of the perivascular space, mm^2	2.71–6.35	0.79–12.38	0.164
Index of the ratio of the cross-sectional areas of the artery and perivascular space	0.39–2.15	0.14–3.77	0.213

numbers varied from one to three in one specimen. MLs were isolated in three specimens. They were located above the right CA in two specimens. They were above the circumflex branch at the base of the left auricle in one specimen. No relationship existed between the loops and myocardial bridges ($\chi^2 = 0.21$; $p = 0.64$).

The type of blood supply to the ventricular complex was determined in all specimens. The presence of ML was associated with a right-sided blood supply in 10 specimens, a left-sided blood supply in one specimen, and a uniform bloody supply in one specimen.

Spontaneous branching of the conus artery from the aorta was noted in 25 (42%) hearts, with ML in eight of them. The presence of ML over CA was associated with spontaneous branching of the conus artery ($\chi^2 = 3.64$; $p = 0.05$). ML length ranged from 8.5 to 44.53 mm (Me = 16.68 mm). ML length ranged from 11.73 to 18.5 mm at the base of the left auricle; from 8.5 to 44.53 mm where the artery passed in the anterior wall of the coronary sinus; from 10.0 to 15.0 mm at the entry of the coronary sinus into the right atrium.

Histological examination revealed MLs in 10 (25%) of 40 hearts. MLs were located mainly in the left coronary sulcus on the diaphragmatic surface in 13 areas. MLs were found above the artery accompanying the coronary sinus in seven specimens, at the base of the left auricle in four specimens, and above the artery in the "sleeve" of the coronary sinus at its entry in the right atrium in two specimens. The data obtained on the number and location of MLs are consistent with the results of a macroscopic study.

In most cases, the artery located in the left coronary sulcus was in close contact with the coronary sinus. Most often, this artery was located anteriorly (5 of 13) or inferiorly (4 of 13) to the coronary sinus and passed in the tight space between it and the posterior wall of the left atrium. The distance from the intraloop artery to the coronary sinus ranged from 0.14 to 2.54 mm (Me = 0.73 mm), and the distance from the artery to the left atrial myocardium ranged from 0.07 to 2.32 mm (Me = 0.33 mm).

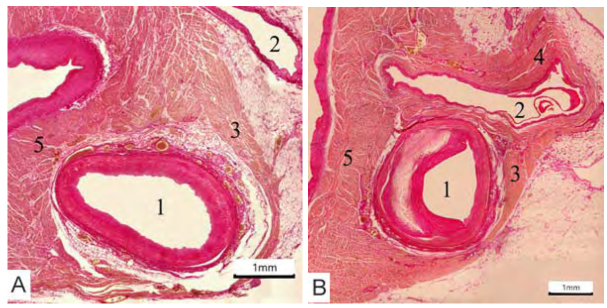

Fig. 2. A segment of the coronary sulcus at the level of the coronary sinus formation. Variants of the formation of myocardial loops. (A) Arterial variant. (B) Arteriovenous variant. (1) coronary artery; (2) coronary sinus; (3) myocardial loop; (4) "sleeve" of the coronary sinus; (5) posterior wall of the left atrium. Van Gieson's picrofuchsin staining. Magnification ×40.

Two variants of ML formation were identified: arterial and arteriovenous (Fig. 2). In the arterial variant, the circumflex branch of the left CA or right CA passed inside the ML, separately from the veins (great cardiac vein or coronary sinus) located in the subepicardial tissue of the coronary sulcus. In the arteriovenous variant, the artery passed in the "sleeve" of the coronary sinus.

Table 1 presents the morphometric characteristics of the ML and the intraloop of the artery.

The results of the analysis showed that only the ML thickness differed in the two groups (p = 0.045). An inverse correlation (R = −0.785) was found between ML thickness and the distance from the intraloop artery to the left atrial myocardium; the closer the distance to the left atrium, the thicker the ML. In both the arterial and arteriovenous variants, the atrial myocardium formed MLs. The myocardial bundles that formed the ML were separated from the posterior wall of the atrium, covering at least two-thirds of the artery's circumference or covering the artery completely and returning.

Cardiomyocytes exclusively formed MLs. The connective tissue fibers were located only around the arterioles and venules. In 76.9% of the specimens (10 of 13), cardiomyocytes within one ML were located codirectionally. They were perpendicular to the long axis of the artery in six specimens and were located obliquely in four specimens. In three specimens only, the layers in the ML tended to separate: inner (transverse and circular) and outer (oblique). Around the artery, there was a perivascular space filled with adipose tissue, containing microvessels and nerves of the periarterial plexus. At the macromicroscopic level, these vessels and nerves predominated in the dilated areas of the perivascular space where the myocardium transferred from the posterior wall of the atrium to the artery.

Discussion. ML's detection rate was 20% according to the macroanatomical examination and 25% according to the histological examination. According to the literature, ML incidence has a wide range. Watanabe et al. (2016) detected ML above the circumflex branch of the left CA in only one of 60 specimens [9]. Meanwhile, I.I. Kagan and N.N. Tyutyunnikova (2017) studied 55 specimens, where 27 loops were noted (21 above the circumflex branch of the left CA and 6 above the trunk of the right CA) [7].

In isolated cases, MLs were detected in patients using radiation for examination. According to 6774 coronary angiograms, MLs were detected over the circumflex branch of the left CA in four patients and above the right CA in four cases, which amounted to 0.1% [8]. In 2462 coronary angiograms obtained using multispiral computed tomography, other researchers detected ML in 14 (0.6%) patients in the same locations in equal proportions [10]. The complexity of visualizing intravital ML contributes to such a low frequency. Additionally, ML was not the focus of the aforementioned studies.

The presence of ML is often associated with the presence of myocardial bridges over the ventricular branches of the CA. According to our study, ML over the circumflex branch and myocardial bridges over the anterior interventricular branch of the left CA were often detected in one specimen.

The literature describes the simultaneous presence of loops and myocardial bridges over the branches of the right CA. M. Teryakioglu and M.N. Aliyu (2020) detected ML over the right CA and a myocardial bridge above the posterior interventricular branch [11]. N. Nishida and Y. Hata (2017) described a similar variant, but, besides the listed locations, they noted a myocardial bridge over the anterior interventricular branch of the left CA [12].

The results of our study showed that the presence of ML is not associated with the type of blood supply to the ventricular complex but is associated with the independent branching of the conus artery from the aorta. L.E.B. Acunã et al. (2009) revealed a similar aspect for myocardial bridges [13].

The main morphometric characteristics of MLs are their length and thickness. According to a study conducted on the autopsy material, ML length varied from 2 to 28 mm [7] and, on studying the macrospecimens, a wider range of values (8.5–44.5 mm) was obtained. G. Teofilovski-Parapid et al. (2017) showed that ML thickness ranged from 2.1 to 4.2 mm in histological sections [14]. In our study, ML thickness ranged from 0.3 to 0.58 mm. The differences in ML thickness in different works can be due to the heterogeneity of the sample sets. Particularly, G. Teofilovski-Parapid et al. (2017) in their study on specimens from patients with cardiac profiles showed that three of five patients with ML died from myocardial infarction [14].

We described, for the first time, the two variants of ML formation: arterial and arteriovenous. MLs were located on the diaphragmatic surface of the heart in the left coronary sulcus above the arteries accompanying the coronary sinus. With approximately equal frequency, these arteries passed into the ML separately from the veins or were located in the thickness of the myocardial "sleeve" of the coronary sinus.

A. Ishizawa et al. (2014) studied the different positions of the atrial branches of CA. They found that if the posterior atrial branches originating from the terminal section of the right CA were located over the coronary sinus, deep position was typical for the atrial branches of the left circumflex artery, specifically between the coronary sinus and the posterior wall of the left atrium [15]. As far as we know, the intraloop position of a great artery in the "sleeve" of the coronary sinus has not been described in the literature and was described for the first time in our study.

The preferred locations of ML are landmarks for *in vivo* detection using radiation for examination. Fixing a large artery in the posterior wall of the left atrium and the coronary sinus is important to consider when catheterizing the coronary sinus and performing surgical interventions to treat atrial fibrillation. The literature presents that MLs fix the arteries in the coronary sulcus, thereby ensuring the continuity of blood flow in both systole and diastole [6]. Meanwhile, MLs over CA, detected by coronary angiography, can cause systolic compression of the artery and cease blood flow.

Further studies are needed on the intravascular blood flow. Additionally, a comparative analysis of patients with ML in the left coronary sulcus with ischemic disorders in the lower left ventricle and patients with no ischemic disorders is needed. Developing a personalized management strategy for such patients may become possible when applying the results obtained from cardiac surgeries.

CONCLUSIONS

1. MLs are typically localized in the left coronary sulcus on the diaphragmatic surface of the heart above the arteries accompanying the coronary sinus. The presence of MLs is associated with spontaneous branching of the conus artery from the aorta.

2. Two variants of MLs have been identified: arterial and arteriovenous. The thickness of MLs covering only the artery is significantly greater than the thickness of MLs above the artery located in the "sleeve" of the coronary sinus.

Authors' Contributions. E.G.D. created the study concept and design, prepared and performed the morphometry of specimens, analyzed the results, and wrote the text. A.A.Ya. was the work supervisor, developed the concept and design of the study, and wrote the text.

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Conflicts of Interest. The authors declare no conflicts of interest.

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