Anatomy of the left atrial ridge (coumadin ridge) and possible clinical implications for cardiovascular imaging and invasive procedures

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Abstract
Background: The left atrial ridge is a structure located in the left atrium between the left-sided pulmonary veins ostia and the orifice of the left atrial appendage. Since it was commonly misdiagnosed as a thrombus, the ridge is also known as the “coumadin” or “warfarin” ridge. The left atrial ridge is a potential source of arrhythmias and can be an obstacle in ablation procedures. This study aimed to provide information about the occurrence and spatial morphometric characteristics of the left atrial ridge.

Methods and Results: The macroscopic morphology of the left atrial ridge was assessed in 200 autopsied human hearts. The ridge was observed in 59.5% of specimens and was absent in the remaining 40.5% of cases. The mean length of the ridge was 22.4 ± 5.1 mm. It was wider at its inferior sector when compared to its superior sector (9.1 ± 5.0 vs 7.9 ± 3.2 mm; \( P = .028 \)). The total wall thickness measured at the cross section of the ridge was significantly larger in the inferior than in superior sector (6.2 ± 3.5 vs 4.3 ± 1.8 mm; \( P < .001 \)), although the myocardial thickness was significantly larger at the superior sector (3.1 ± 1.4 vs 1.9 ± 0.9 mm in inferior sector, \( P < .001 \)).

Conclusion: The left atrial ridge is a variable structure, present in 59.5% of humans. The ridge is significantly wider and thicker at its inferior sector, although the actual myocardial layer present within the ridge is thinner at this location. Knowledge about the left atrial ridge morphology is key in avoiding unnecessary interventions or complications during invasive procedures.

Keywords: ablation, atrial fibrillation, coumadin ridge, endocardial ridge, left atrial appendage, left atrial lateral ridge, left atrial pseudotumor, left lateral ridge, pulmonary veins, warfarin ridge

1 | INTRODUCTION

The left atrial ridge (also known as the left lateral ridge, the coumadin ridge, the warfarin ridge, or the endocardial ridge) is an anatomical entity located in the left atrium between the left-sided pulmonary veins ostia and the orifice of the left atrial appendage. Formed during the development of the left-sided cardinal veins, it is the result of an invagination of the atrial wall. It was first described by Sir...
Arthur Keith in 1907 and continues to be the most noticeable and prominent endocardial left atrial structure.\cite{2,3,4}

Various imaging modalities such as echocardiography, computed tomography, and magnetic resonance imaging can detect the ridge.\cite{5,6} However, this structure can sometimes be mistaken for a tumor or a thrombus and patients may receive unnecessary treatment or anticoagulation. It is for this reason that the ridge has alternative names such as the “coumadin” or “warfarin” ridge.\cite{7} Fortunately, the typical morphology and location of the ridge allow physicians to easily distinguish it from pathological structures. Nonetheless, caution should still be exercised to not exclude other diagnoses, since tumors like papillary fibroelastomas or actual thrombi may be lodged in this specific location.\cite{8}

The left atrial ridge is of great clinical interest. It is a recognized source of supraventricular arrhythmias, mainly because its thick musculature contains the terminal branches of the Bachmann's bundle. It is also closely associated with the overlying vein of Marshall and/or ligament, contains an autonomic nerve bundle and has many direct interconnections with surrounding cardiac structures.\cite{9,10} Moreover, because the ridge is located near the left-sided pulmonary vein ostia, it may negatively affect electrophysiological procedures. Its presence may hinder the proper positioning of ablation catheters leading to unsuccessful ablations or pulmonary veins isolations. The left atrial ridge has even been described as the most challenging ablation site in the left atrium.\cite{11}

Our understanding of this structure is still incomplete and most of our knowledge stems from a few small studies. Therefore, using the largest to date sample size, we aimed to gather information about the occurrence and spatial morphometric characteristics of the left atrial ridge. Our results should be considered by clinicians performing cardiac imaging studies and/or planning and performing interventional procedures within this anatomical region.

2 | MATERIAL AND METHODS

This study was conducted at the Department of Anatomy of the Jagiellonian University Medical College and was approved by the Bioethical Committee of the Jagiellonian University in Cracow, Poland (1072.6120.144.2019). The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki. The methods were carried out in accordance with the approved guidelines.

2.1 | Study population

We examined 200 hearts dissected from human beings who died of noncardiac causes. Organs were collected during routine forensic medical autopsies. All hearts were dissected from adults (22.5% were female) who were on average 48.7 ± 4.9 years of age. The average body mass index (BMI) was 26.8 ± 17.3 kg/m², and the mean heart weight was 439.0 ± 96.0 g. The leading causes of death of the studied subjects were suicide, murder, and traffic/home accidents. Donors with known severe anatomic defects, past cardiac surgeries/interventions, or vascular or cardiac pathologies discovered during autopsy (aneurysms, storage diseases, trauma) were excluded from this study.

2.2 | Dissection and measurements

Each heart, along with the proximal portions of the great vessels, was dissected from the thoracic cavity. After removing excess blood, all specimens were weighed using a 0.5 g precision electronic laboratory scale (SATIS, BSA-L Laboratory, Poland). Subsequently, the hearts were placed in a 10% paraformaldehyde solution for a maximum of 2 months.

Heart cavities were opened in a routine manner. The anterior wall of the left atrium was dissected to expose the studied region. All the data was collected with hearts held in anatomical position using 0.03-mm precision electronic callipers (YATO, YT-7201, Poland). To reduce human bias, all measurements were recorded by two independent researchers. If any result differed by more than 10%, the specimen was remeasured.

The posterolateral region of the left atrial endocardial surface was studied in detail. First, we determined whether each specimen under examination had a left atrial ridge present. We defined the ridge as a prominent fold of tissue located between the left-sided pulmonary vein ostia and the orifice of the left atrial appendage (Figure 1). We also noted any additional variations in the left-sided pulmonary vein ostia and measured the following distances:

- the width of the ridge at the level of the superior margin of the left superior pulmonary vein ostium (Figure 1B),
- the width of the ridge at the level of the inferior margin of the left inferior pulmonary vein ostium (Figure 1B),
- the transverse diameter of the left-sided pulmonary vein ostia (parallel to the mitral annulus),
- the length of the ridge (Figure 1C),
- the transverse diameter of the orifice of the left atrial appendage (parallel to the mitral valve annulus),
- the length of the mitral isthmus (defined as the shortest line between the inferior margin of the left inferior pulmonary vein ostium and the margin of the mitral annulus, perpendicular to the mitral annulus),
- the length of the left atrial appendage isthmus (the shortest distance between the margin of the orifice of the left atrial appendage and the margin of the mitral annulus, perpendicular to the mitral annulus),
- the intercommissural and aorto-mural diameters of the mitral annulus.

Finally, we also did a transverse cut of the ridge at the level of the left superior and inferior pulmonary vein ostia to measure the thickness of the myocardium and the maximum total wall thickness
FIGURE 1 Photographs of cadaveric heart specimens showing studied region of the left atrium with marked measurement sites. A, The left atrial ridge (LAR) is absent. B, The prominent LAR is marked in heart with classical pattern of left-sided pulmonary venous drainage. C, The heart with left common pulmonary vein—the significant LAR is visible. IW, inferior width; L, ridge length; LAA, left atrial appendage; LCPV, left common pulmonary vein; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; MA, mitral valve annulus; SW, inferior width
of the atrium (endocardium, myocardium, epicardium together with adipose tissue) (Figure 2).

2.3 | Statistical analysis

Our categorical results are presented as numbers and percentages. We performed the Shapiro-Wilk test to determine if the quantitative data had a normal distribution. The results were reported as means with their respective standard deviation (SD) and range (minimum and maximum). We performed group comparisons using either the t-test or the Mann-Whitney test. Correlation coefficients were calculated to assess whether there was statistical dependence between the measured parameters. To detect a simple correlation (r = .25), with 80% power and a 5% significance level (two-tailed; α = .05; β = .2), the required minimal sample size was set at approximately 123 cases. Statistical analyses were conducted using STATISTICA v13.3 (StatSoft Inc, Tulsa, OK) software. Results were considered statistically significant when the P-value was lower than .05.

3 | RESULTS

The left atrial ridge was present in 59.5% of cases and absent in the remaining 40.5% of hearts (Figure 1). Its occurrence did not correlate with the sex of the donor (P = .17). Table 1 reports the morphometric characteristics of the ridge. Our results showed that the width of the ridge was wider in the inferior sector when compared to the superior sector (9.1 ± 5.0 vs 7.9 ± 3.2 mm, P = .028). In 15.1% of hearts (18/119), the width of the superior aspect of the ridge was less than 5 mm. Conversely, only 12.6% (15/119) of specimens had an inferior width less than 5 mm. The mean length of the ridge was 22.4 ± 5.1 mm and it correlated with cardiac weight (r = .29, P = .021) and the length of the mitral (r = .31, P = .001) and left atrial appendage isthmuses (r = .28, P = .001). The whole wall of the left atrial ridge was significantly thicker at the level of the left inferior than at the left superior pulmonary vein ostium (6.2 ± 3.5 vs 4.3 ± 1.8 mm, P < .001). Interestingly, the opposite trend was observed for myocardial thickness, which was significantly larger at the level of superior ostium (3.1 ± 1.4 vs 1.9 ± 0.9 mm, P < .001) (Figure 2). The sex of the donor had no influence on any measured parameter (P > .05). No other significant correlations were found.

The reported values of nearby cardiac structures were not affected by the presence of the left atrial ridge. The only exception to this finding was the diameter of the orifice of the left atrial appendage, which was slightly larger in hearts with a ridge (12.9 ± 4.6 vs 11.6 ± 4.4 mm, P = .032) (Table 2). Most hearts (92%) had classical pattern of left-sided pulmonary venous drainage (ie, with one inferior and one superior pulmonary vein ostium), while the remaining 8.0% had a single common left pulmonary vein ostium. Hearts with classical venous drainage were more likely to have a left atrial ridge present than those with a single ostium (62.0% vs 31.3%, P = .019) (Figure 1C). However, we did not record any differences in the dimensions of the ridge between these two groups (P > .05).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean (mm)</th>
<th>SD (mm)</th>
<th>Min (mm)</th>
<th>Max (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of the ridge at the level of left superior pulmonary vein ostium</td>
<td>7.9</td>
<td>3.2</td>
<td>3.6</td>
<td>17.8</td>
</tr>
<tr>
<td>Width of the ridge at the level of left inferior pulmonary vein ostium</td>
<td>9.1</td>
<td>5.0</td>
<td>2.8</td>
<td>29.0</td>
</tr>
<tr>
<td>Length of the ridge</td>
<td>22.4</td>
<td>5.1</td>
<td>11.2</td>
<td>42.7</td>
</tr>
<tr>
<td>Whole wall thickness of the ridge at the level of left superior pulmonary vein ostium</td>
<td>4.3</td>
<td>1.8</td>
<td>0.8</td>
<td>9.6</td>
</tr>
<tr>
<td>Whole wall thickness of the ridge at the level of left inferior pulmonary vein ostium</td>
<td>6.2</td>
<td>3.5</td>
<td>0.9</td>
<td>13.7</td>
</tr>
<tr>
<td>Myocardial thickness of the ridge at the level of left superior pulmonary vein ostium</td>
<td>3.1</td>
<td>1.4</td>
<td>0.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Myocardial thickness of the ridge at the level of left inferior pulmonary vein ostium</td>
<td>1.9</td>
<td>0.9</td>
<td>0.3</td>
<td>4.1</td>
</tr>
</tbody>
</table>
TABLE 2  Morphometric characteristics of the measured surrounding structures with the division into groups with present and absent left atrial ridge (mm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present ridge (n = 119)</th>
<th>Absent ridge (n = 81)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse diameter of the left superior pulmonary vein ostiuma</td>
<td>14.4 ± 3.3</td>
<td>13.5 ± 3.2</td>
<td>.334</td>
</tr>
<tr>
<td>Transverse diameter of the left inferior pulmonary vein ostiuma</td>
<td>13.4 ± 3.6</td>
<td>12.7 ± 3.1</td>
<td>.371</td>
</tr>
<tr>
<td>Transverse diameter of left atrial appendage orifice</td>
<td>12.9 ± 4.6</td>
<td>11.6 ± 4.4</td>
<td>.032</td>
</tr>
<tr>
<td>Length of the mitral isthmus</td>
<td>29.6 ± 7.3</td>
<td>28.4 ± 6.7</td>
<td>.473</td>
</tr>
<tr>
<td>Length of the left atrial appendage isthmus</td>
<td>14.2 ± 4.8</td>
<td>13.9 ± 5.0</td>
<td>.670</td>
</tr>
<tr>
<td>Intercommissural diameter of the mitral annulus</td>
<td>23.0 ± 7.1</td>
<td>21.6 ± 6.5</td>
<td>.137</td>
</tr>
<tr>
<td>Aorto-mural diameter of the mitral annulus</td>
<td>22.3 ± 5.6</td>
<td>21.9 ± 5.7</td>
<td>.421</td>
</tr>
</tbody>
</table>

aValues for hearts with classical pattern of left-sided pulmonary veins drainage.

4 | DISCUSSION

Up until now, the morphology of the left atrial ridge was not well explored. Contrary to previous findings,9,10,12,13 our study demonstrated that the left lateral ridge was not present in all hearts, and occurred with a prevalence of 59.5%. The other most in-depth anatomical study of the left atrial ridge was performed by Cabrera et al. Authors have examined 40 formalin-fixed hearts collected from patients who died of noncardiac-related causes.10 They reported that the myocardial width of the ridge was not uniform with a narrower end at the superior level than at the inferior level (5.6 ± 0.4 vs 10.2 ± 0.5 mm, P < .001). This same trend was observed in our study, although the difference between sectors was smaller (superior 7.9 ± 3.2 mm vs inferior 9.1 ± 5.0 mm; P = .028). Cabrera et al reported that the ridge had a mean length of 25.3 ± 5.5 mm, a number significantly higher than that found in our study (P = .003). Moreover, the myocardial thickness was measured, which was thicker in the superior than inferior sector of the ridge (2.8 ± 1.1 versus 1.7 ± 0.8 mm, P < .001), the same was observed in the current study (3.1 ± 1.4 versus 1.9 ± 0.9 mm, P < .001).

In a recent study published by Gupta et al, which examined 30 human formalin-fixed hearts, the thickness of the ridge measured at the level of the left superior pulmonary vein ostium was considerably larger than in the Cabrera et al study (8.3 ± 2.3 versus 5.6 ± 0.4 mm, P < .001). Their results were similar to our findings (8.3 ± 2.3 versus 7.9 ± 3.2 mm, P = .521), although they did not include any additional morphometric parameters of the ridge.12 Another study by DeSimone et al conducted a partial investigation of the ridge and reported its length (19.0 ± 7.0 mm), width (3.9 ± 1.5 mm), and thickness (4.1 ± 1.4 mm). Although the researchers examined 620 formalin-fixed hearts, the measurements of the width and of the thickness of the ridge were performed in one undefined place. In light of the knowledge about the unevenness of the ridge’s borders, these results are less representative of the structure’s true dimensions.9

Furthermore, a magnetic resonance angiography imaging study conducted by Mansour et al13 was the first to report the basic morphometric characteristics of the left atrial ridge using in vivo imaging techniques. They also found that the ridge had a narrow waist which widened in the superior and inferior direction. They measured the ridge in two different groups: those with (n = 50) and without (n = 30) an accessory right middle pulmonary vein. In the group with a right middle pulmonary vein, the superior width of the ridge was 3.8 ± 1.1 mm, whereas the inferior width was 5.8 ± 2.0 mm. In patients without an additional right pulmonary vein, the superior width was 4.0 ± 0.7 mm and the inferior width was 5.5 ± 0.5 mm. In both groups evaluated by Mansour et al, the width was larger in the superior aspect, a finding which contrasted with the results from our study (superior < inferior). Also, they only measured the length of the ridge in the group with the right middle pulmonary vein with an average of 16.6 ± 6.4 mm, a value which is significantly smaller than the results from both this study (P < .001) and the study by Cabrera et al (P < .001).10

Our study was innovative because aside from reporting the myocardial thickness, we also measured total wall thickness, a parameter not reported elsewhere in the literature. In the superior section of the ridge, we observed a thicker myocardium but a thinner total left atrial wall, whereas the opposite trend was observed in the inferior section (thinner myocardium but thicker total left atrial wall). These observations are in agreement with previous studies that investigated the postero-lateral area of the left atrium. They noted a thin myocardium near the edge of the mitral valve annulus, with abundant epicardial adipose tissue.14,15

Looking at the architecture of the myocardial fibers within the ridge nonuniform structure may be observed with abrupt changes of myofibers orientation transmurally through the atrial wall.16 Moreover, the Bachmann’s bundle final branches (main interatrial conduction tract), after encircling the left atrial appendage, forms the subepicardial myocardial layer of the left atrial ridge. The ridge is also in close relationship with the vein of Marshall or its ligament, that is present in 71.0% and 29.0% of cases, respectively.10,16 These structures are located on the epicardial part of the ridge at a distance of 3 mm away from its superior level.12,17 Ganglia and fibers of the autonomic nervous system are also known to travel near the epicardial aspect of the ridge. These are most frequently observed in the superior section of the ridge, although other locations are possible.10 Due to the additional structures which can traverse the
The left atrial ridge can usually be differentiated from most cardiac abnormalities, due to its characteristic shape, size, echogenic properties, and mobilities.\textsuperscript{19} Still, caution should be maintained when distinguishing abnormal structures from the ridge.\textsuperscript{20} The most commonly observed pathological mass in the left atrium is a thrombus, usually originating from the left atrial appendage and associated with supraventricular arrhythmias.\textsuperscript{21} A thrombus located in the postero-lateral region of the left atrium is hard to differentiate from the left atrial ridge. Historically, this phenomenon has been associated with considerable abuse of anticoagulants in patients with an incidentally detected left atrial ridge.\textsuperscript{4} Nevertheless, the prominent ridge may coexist with a tightly adhering thrombus, thus multimodal imaging should be performed to exclude any emboli located in this region of the left atrium.\textsuperscript{7}

The left atrial ridge can also be easily mistaken for a myxoma of the left atrium, which is the most common benign cardiac tumor in adults. Since both are characterized by smooth surfaces and a homogeneous consistency, it is important to identify the exact location of the protuberance. Myxomas are usually found in the interatrial septum, whereas the left atrial ridge is located in a position near the left inferior pulmonary vein. Consequentially, a fetopathological diagnosis should be considered in the differential diagnosis.\textsuperscript{8,23} Fortunately, another way in which clinicians can distinguish the left atrial ridge from other structures is by observing the pattern of blood flow. Tumors and thrombi will often cause changes in blood flow, whereas the left atrial ridge will not cause any anomalous findings in intracardiac hemodynamics.\textsuperscript{5}

Lastly, a study by Singh et al showed that the presence of the left atrial ridge could have diagnostic value. Their study showed that the existence of the ridge implied that there was a normal opening in the left upper pulmonary vein. Consequently, a fetopathological echocardiography which showed a left atrial ridge could be used to rule out diagnosis of total anomalous pulmonary venous return.\textsuperscript{24}

The current study has several limitations. The main drawback is that all our measurements were taken from heart specimens after formaldehyde fixation, which could have potentially affected the size and shape of the tissue. Despite this, other studies have shown that the use of 10% paraformaldehyde in cardiac tissue preservation did not cause significant changes in atrial tissue dimensions.\textsuperscript{25,26} Another limitation of this study is that it only considered hearts with no known electrophysiological disturbances. A third limitation of this study was that measurements were performed postmortem and thus were not a representation of the physiology of tissues in vivo. Therefore, our findings cannot infer much about the natural dimensional changes within the studied area and within the cardiac cycle. Nevertheless, we believe that these limitations do not significantly impede our morphological analyses, especially those regarding the prevalence of the ridge, the relationships between the individual heart structures and their dimensions.

5 | CONCLUSIONS

The left atrial ridge is a variable structure, present in 59.5% of human beings. It is widest at the level of the left inferior pulmonary vein ostium, although the layer of the myocardium is most prominent in the superior sector of the ridge. The presence of the left atrial ridge does not seem to affect the size of surrounding cardiac structures. Clinicians should be aware of left atrial ridge existence, typical location, and morphological characteristics to avoid unnecessary interventions and decrease complications associated with invasive procedures.

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REFERENCES
