The Anatomic Basis of Connections Between the Coronary Sinus Musculature and the Left Atrium in Humans

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Background—This study determined the histological features of the atrial myocardium connecting the coronary sinus and the left atrium in humans.

Methods and Results—Ten necropsied hearts were studied by performing serial longitudinal sections parallel to the long axis of the coronary sinus that extended its full length using a large microtome. In all specimens, the venous wall of the coronary sinus was surrounded by a cuff of striated muscle extending 40±8 mm from the ostium. Striated myocardial connections of varying number and morphology left this coronary muscle cuff and connected to the left atrium; they ranged from 1 to 2 fascicles to a widely intermingled continuum (thickness, 2.79±2 mm; width, 2.91±3.5 mm). These connections originated 8.8±5.7 mm from the coronary sinus ostium and inserted 18±11 mm distally into the left atrium. The insulating compartment in which the connections traversed between the left atrium and the coronary sinus was mostly formed of adipose tissue. The valve of Vieussens was found in 6 hearts at a mean distance of 3.4±3.2 mm from the distal extremity of the coronary sinus muscle cuff.

Conclusions—In the human heart, a consistent but morphologically variable left atrial coronary sinus myocardial connection was found. This emphasizes the need for surgical dissection or catheter ablation in or around the coronary sinus to eliminate these connections. (Circulation. 2000;101:647-652.)

Key Words: atrium ▪ histology ▪ pathology

In 1916, Bachmann1 proposed that the anterior interatrial band was the primary connection between the right and left atria. Many studies have since evaluated the histological and electrophysiological characteristics of this band and its branches or the nature of putative pathways between the sinus and atrioventricular nodes; however, little anatomic and histological information is available on other interatrial connections.2–6 Although Thorel3 found no relationship between histological information and other interatrial connections, he suggested the possibility of interatrial connections through the atrioventricular triangle, the Eustachian ridge, the tricuspid valve insertion, and the posterior internodal pathway (in or near the crista terminalis) and the left atrial myocardium, James7 suggested the presence of these connections and described a coronary sinus ostium, including Koch’s triangle, the Eustachian ridge, the tricuspid valve insertion, and the distal extremity of the coronary sinus muscle cuff.

Experiments that involved incising or crushing Bachmann’s bundle consistently showed persistent interatrial conduction, with surface ECG morphology indicating a caudocephalad activation of the left atrium and, thus, an inferior right-to-left atrial anatomic connection.12,13 In epicardial mapping studies, Boineau et al14 confirmed such a breakthrough in the region of the coronary sinus. Scherlag et al15 described a left atrial tract within the ligament of Marshall that originated from the coronary sinus ostium, and a study by Ludinghausen et al16 reported the anatomic features of the myocardial cover of the coronary sinus. The precise features of this interatrial link through the coronary sinus have not been defined. The present anatomical and histological study determined and described the connections of the muscular architecture of the coronary sinus to the left atrial myocardium.

Methods

Ten necropsied hearts were studied; all were from patients who died of noncardiac disease (Table 1). The hearts were removed, together with the proximal portions of the great vessels, and rinsed in Tyrode’s solution.

We defined the coronary sinus as the portion of the cardiac venous system that begins (in the direction of blood flow) at the insertion of the oblique vein of Marshall and ends with its ostium in the right atrium. The ostium was characterized by an abrupt change in the orientation of the right atrial endocardium, which usually coincided with the Thebesian valve. The valve of Vieussens, when present, was located at the junction of the great cardiac vein and the origin of the coronary sinus.17

The full coronary sinus and 2 cm of surrounding tissue, including the immediately adjacent regions of the left atrium, the mitral valve, and the left ventricle, were dissected out en bloc. The tissue block, therefore, extended along the left atrioventricular sulcus for 10 cm. Tissue surrounding the coronary sinus ostium, including Koch’s triangle, the Eustachian ridge, the tricuspid valve insertion, and
TABLE 1. Coronary Sinus Muscle Cuff

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Age, y/Sex of the Patients</th>
<th>Length of the Muscle Cuff</th>
<th>Thickness at CS Ostium</th>
<th>Thickness at CS Beginning</th>
<th>Distance Between the CS Ostium and the Valve of Vieussens</th>
<th>Distance Between the CS Cuff Lateral Extremity and the Valve of Vieussens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64/M</td>
<td>25</td>
<td>1.5</td>
<td>0.5</td>
<td>27</td>
<td>–2</td>
</tr>
<tr>
<td>2</td>
<td>71/M</td>
<td>35</td>
<td>1.5</td>
<td>0.3</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>57/M</td>
<td>48</td>
<td>2.5</td>
<td>1</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>4</td>
<td>74/M</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>5</td>
<td>48/F</td>
<td>40</td>
<td>0.3</td>
<td>0.5</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>69/M</td>
<td>38</td>
<td>1.5</td>
<td>1</td>
<td>35.5</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>77/M</td>
<td>31</td>
<td>1</td>
<td>0.5</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>27/M</td>
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<td>2</td>
<td>0.5</td>
<td>…</td>
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</tr>
<tr>
<td>9</td>
<td>70/F</td>
<td>45</td>
<td>0.5</td>
<td>1</td>
<td>38</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>55/F</td>
<td>51</td>
<td>0.7</td>
<td>0.5</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>Mean±SD</td>
<td></td>
<td>61.2±15.1</td>
<td>40.2±8</td>
<td>1.35±0.71</td>
<td>0.68±0.28</td>
<td>32.25±5.54</td>
</tr>
</tbody>
</table>

CS indicates coronary sinus. Unless otherwise indicated, data are in millimeters.

contiguous parts of the interventricular and interatrial septa, was retained (Figure 1).

To avoid fixation artifacts in such a large preparation, the specimen was straightened by inserting a rigid wire into the coronary sinus before it was fixed in 10% formalin. The tissue blocks were dehydrated in alcohol and embedded in paraffin for sectioning. The blocks were sectioned with a large microtome (Polycut), which allowed sections of up to $125/85 \text{ mm}$; each section encompassed the full length of the coronary sinus along its long axis and was perpendicular to the epicardium in the plane of the annulus. Sectioning ($4$-$mm$ thickness) began at the left ventricle margin of the block and continued until the left atrial margin. Sections performed at intervals of $700 \text{ mm}$ allowed the identification of regions of interest. Thereafter, intervening sections at intervals of $100 \text{ mm}$ allowed a detailed analysis of the architecture of the musculature encircling the coronary sinus and its connections with the left atrial myocardium. When necessary, supplementary sections at intervals of $20 \text{ mm}$ were examined to analyze specific features. Selected sections were stained with hematoxylin and eosin or Masson’s trichrome.

The following data were evaluated: total length of muscle surrounding the coronary sinus, thickness at the proximal and distal ends, fiber orientation, and the connections between the coronary sinus muscle and left atrial myocardium and their characteristics. The measurements are presented as mean±SD and range.

**Results**

**Musculature Surrounding the Coronary Sinus**

In all specimens, the venous wall of the coronary sinus was surrounded by a continuous cuff of striated muscle (Table 1; Figure 2). This cuff was continuous with the ostial right atrial myocardium and extended variably away from the ostium for $25 \text{ to } 51 \text{ mm}$ (mean, $40±8 \text{ mm}$). The cuff terminated close to the valve of Vieussens at a mean distance of $3.4±3.2 \text{ mm}$ in all $6$ hearts with this structure (range, $2 \text{ to } 7 \text{ mm}$). It was not continuous along its long axis with the left atrial myocardium. The thickness of this muscular cuff varied between hearts (range, $0.3 \text{ to } 2.5 \text{ mm}$), and in $8$ of the $10$ hearts, it was greater at the level of the ostium than at the other end ($1.35±0.7 \text{ and } 0.68±0.2 \text{ mm}$, respectively). No correlation existed between the thickness and the length of the cuff. In some sections, muscular bundles coiled in helical fashion around the coronary sinus.

**Connections Between the Coronary Sinus and the Left Atrial Myocardium**

The left atrial myocardium and the coronary sinus muscle cuff were separated by adipose tissue; this compartment tapered away from the ostium ($0.86±0.5 \text{ mm}$ to $1.47±1.2 \text{ mm}$) and was traversed by striated muscle fibers (Table 2). All hearts had connections between the coronary sinus musculature and the left atrial myocardium. The thickness of this muscular cuff varied between hearts (range, $0.3 \text{ to } 2.5 \text{ mm}$), and in $8$ of the $10$ hearts, it was greater at the level of the ostium than at the other end ($1.35±0.7 \text{ and } 0.68±0.2 \text{ mm}$, respectively). No correlation existed between the thickness and the length of the cuff. In some sections, muscular bundles coiled in helical fashion around the coronary sinus.

**Figure 1.** Gross appearance of tissue block, shown from right side of heart. Arrow enters coronary sinus through coronary ostium (CO) and below the interatrial septum separating the right atrium (RA) from the left atrium (LA). FO indicates fossa ovalis; TV, tricuspid valve; MV, mitral valve; IVS, interventricular septum; and LV, left ventricle. Orientation of sections is indicated by horizontal plane. Arrow indicates coronary sinus course.
human. No connections existed between the coronary sinus musculature and the left ventricular myocardium.

The connections varied greatly in size and location (Table 3). In 2 hearts, the connections were discrete (Figure 3), limited to 1 or 2 fascicles, and visible in their entirety, either in 1 or 2 adjoining sections. In 8 hearts, the connections were multiple and wide (Figure 4); in 1 of these 8 hearts, the coronary sinus musculature and left atrial myocardium were completely intermingled so that it was not possible to differentiate the 2 groups of fibers (Figure 5). The connections originated 4 to 20 mm from the ostium of the coronary sinus; their implantation extended for 5 to 40 mm (Figures 3 through 5).

Discussion

This study describes the anatomic and histological features of connections linking the inferior right atrium to the left atrial myocardium via a cuff of striated muscle around the coronary sinus in humans. The presence of these connections in all hearts examined indicates a consistent pathway for interatrial propagation.

Interatrial Connection Through the Coronary Sinus

The existence of interatrial, and particularly internodal, conduction pathways has been the subject of lively debate over many decades. It is presently generally accepted that although specialized internodal pathways do not exist, routes of preferentially rapid conduction, as defined by the muscular architecture of the right atrium, do exist. The interatrial septum is also traversed by muscular fibers connecting the 2 atria. Anatomic investigations of interatrial connections followed the initial electrophysiological studies of Bachmann in 1916.1 The anterior interatrial band named Bachmann’s bundle extends from the right of the superior caval vein transversally to the anterior wall of the left atrium until the left appendage. It was considered the principal connection and studied histologically. Some authors ascribed its preferential conduction properties to specialized myocytes; others attributed them to the geometry of nonspecialized myocardial fibers.18 Further anatomic studies on interatrial conduction were focused on the interatrial septum, notably the triangle of Koch. Rossi9 and Sanchez-Quintana et al10 demonstrated right-left interlaced myocardial strands throughout the interatrial septum, and Inoue and Becker11 described leftward posterior extensions of the atrioventricular node. Nevertheless, in experiments that crushed or incised Bachmann’s bundle and in surgical procedures, left atrial isolation required additional lesions outside the septum, in the mitral annulus area, and on the coronary sinus.19–23

The present study demonstrated histological continuity between the right atrium and the left atrium through the coronary sinus myocardium using longitudinal plane sections along the long axis of the coronary sinus distinct from the preferentially conducting intraatrial pathways described above. The connections are made of striated muscle fibers arranged in 2 distinct parts: a muscular cuff surrounds the
coronary sinus wall along 25 to 51 mm of its length, and other fibers emerge from this cuff to join the left atrial myocardium; these fibers have anatomic characteristics varying from a few discrete fascicles to a widely interconnecting plexus. A previous detailed anatomic study documented the presence of a myocardial cover of the coronary sinus in 240 human hearts. In all specimens, the myocardial coat also covered the adjacent 2 to 11 mm of the great cardiac vein and was sometimes thickened in a sphincter-like fashion. The valve of Vieussens was found in 87% of cases, whereas the ostium of the oblique vein was a more constant marker for determining the beginning of the coronary sinus. However, this anatomic study revealed connections with the posterior wall of the left atrium in only 9% of cases; all hearts in the present histological study, which is based on serial sectioning, demonstrated connections. A study by Scherlag et al performed in dogs described anatomic and electrophysiological characteristics of a left atrial tract within the ligament of Marshall that began in the coronary sinus and ran through the left posterior atrium to the left superior pulmonary vein, without reinsertion into the atrial muscle; the coronary sinus musculature was not studied. In a recent experimental study, the existence of coronary sinus–left atrial connections was histologically confirmed in dogs by Antz et al. They demonstrated centrifugal activation of the left atrium from discrete inputs originating from the coronary sinus musculature. Incisions isolating the ostium of the coronary sinus from the right atrium disconnected the coronary sinus and left atrial musculature, which substantiated the electrophysiological role of these connections in maintaining left atrial activation. In our study, we did not investigate the relationship of the coronary sinus musculature with the ligament of Marshall or with the interatrial septum.

These observations regarding interatrial connections traversing the septum and connecting the coronary sinus with the left atrial musculature probably reflect the embryological development of this part of the heart. From the third week after the development of the primitive heart tube, the primitive atria are separated from the sinus venosus (which forms the caudal extremity of the heart tube) by a segmentation

### TABLE 3. Connections Between the Coronary Sinus Muscle Cuff and the Left Atrium

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Distance from the CS Ostium to the First Fascicle</th>
<th>Number of Fascicles</th>
<th>Total Length of the Connections</th>
<th>Aggregate Width (at the CS Insertion)</th>
<th>Aggregate Thickness</th>
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<tbody>
<tr>
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<td>Multiple</td>
<td>11</td>
<td>5</td>
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</tr>
<tr>
<td>2</td>
<td>5</td>
<td>Multiple</td>
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<td>5</td>
<td>Multiple</td>
<td>27</td>
<td>12</td>
<td>7.5</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>Multiple</td>
<td>5</td>
<td>3.5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>1</td>
<td>8</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>2</td>
<td>14</td>
<td>0.5 and 1.5</td>
<td>2</td>
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<tr>
<td>7</td>
<td>4</td>
<td>Multiple</td>
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<td>2</td>
<td>1.5</td>
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<tr>
<td>8</td>
<td>5</td>
<td>Multiple</td>
<td>25</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>5</td>
<td>40</td>
<td>0.5 to 5</td>
<td>2</td>
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<tr>
<td>10</td>
<td>12</td>
<td>Multiple</td>
<td>22</td>
<td>0.2 to 0.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Mean±SD</td>
<td>8.8±5.7</td>
<td></td>
<td>18±11.1</td>
<td>2.91±3.5</td>
<td>2.79±2.9</td>
</tr>
</tbody>
</table>

CS indicates coronary sinus. Data are in millimeters.

Figure 3. Thin and discrete muscular connections between pericoronary sinus muscle and left atrium myocardium. Coronary ostium and great cardiac vein are on left and right sides of figure, respectively, but are not shown. Arrows indicate coronary sinus (CS; 1) and left atrium (LA; 2) ends of connection, which is formed of a few thin fibers of myocardium, is 10 mm long, and traverses intervening adipose tissue between left atrium and coronary sinus. Masson’s trichrome stain.
termed the sinoatrial ring. The sinus venosus has 2 horns: the right horn gives rise to all the intercaval regions of the right atrium extending until the ostium of the coronary sinus and the precaval bundle and includes the crista terminalis, the eustachian ridge, and the valve of Thebesius; the left gives rise to the coronary sinus. The definitive left atrium is formed from 2 sources: the majority of it is from the pulmonary veins, but a narrow band around the mitral annulus is formed from the primitive atrium. During this process of embryological development, it is possible that the coronary sinus and the immediately adjacent region of the left atrium bordering the mitral annulus conserve their muscular interconnections in a fashion similar to that of the right horn of the sinus venosus and the primitive atrium.

**Implications for Nonpharmacological Treatment of Atrial Fibrillation**

The inferior interatrial connections through the coronary sinus may explain the need for additional ablation in and on the coronary sinus to complete left atrial ablation lines extending down to the mitral annulus in this area for curing atrial fibrillation. The varying anatomy, with some wide and multiple connections, is probably the basis for the inconsistent results reported for left atrial isolation, Cox’s maze,19 or Guiraudon’s corridor20 operations for atrial fibrillation. An inability to achieve left atrial isolation at or near the coronary sinus ostium was considered directly responsible for the failure of antiarrhythmic surgery in 7 of 37 patients (19%) in one study, despite extensive and circumferential local cryoapplications.23 After linear radiofrequency catheter ablation in the left atrium, the pericoronary sinus fibers were a critical substrate of left atrial flutters in 75% of patients in another study, as validated by detailed mapping.27 Of the 18 patients in the previous study, only 2 had their connections ablated by discrete energy delivery; wide and deep energy applications were required in 16, and 5 of these procedures were unsuccessful. The present histological data indicate that a laterally displaced ablation line or atriotomy would allow greater efficacy, without the need for ablation within the coronary sinus. This may be guided by radiographic or echographic imaging of the termination of the great cardiac vein or direct localization using pacing techniques.

Figure 4. Example of thicker and wider connection between muscular fibers around coronary sinus and left atrial myocardium (AM). Multiple and parallel myocardial fibers constitute a bridge ~3.5 mm wide that extends from coronary sinus (CS) below to left atrial (LA) myocardium above. PCM indicates pericoronary myocardium. Masson’s trichrome stain.

Figure 5. Transverse section in another heart 1 cm from ostium of coronary sinus (left of micrograph) to junction between coronary sinus wall (CS) and left atrium (LA). Tissue is 5 mm thick at this level and is composed almost entirely of myocardial fibers. Myocardial tissue surrounding coronary sinus (PCM) and left atrium (AM) merges indistinguishably. Masson’s trichrome stain.
In conclusion, the present study demonstrates that all human hearts exhibit a muscular connection between the coronary sinus and the left atrial myocardium of varying morphology.

References
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