The positional relationship between the coronary sinus musculature and the atrioventricular septal junction

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Aims

The atrioventricular (AV) septal junction includes the coronary sinus (CS) and the compact part of the AV node and its posterior extensions. It has been recognized as the target site for ablation therapy of the AV nodal reentrant tachycardia and its variant forms. Despite the clinical significance of this region, the arrangement of the musculature in the AV septal junction, including the CS, has not fully been elucidated. We tried to explore the histological muscular diversity within the AV septal junction.

Methods and results

Sixteen autopsied human hearts (seven women), mean age 59.8 years, without structural anomalies, were studied. We removed the whole AV septum, including the CS opening after the macroscopic measurements, and prepared serial sections parallel to mitral and tricuspid annuli (short-axis style) to elucidate the positional relationships between the compact AV node and the CS musculature. Out of 16 hearts, the CS musculature extended deeply into the AV septal junction in eight hearts. In the other eight hearts, the CS musculature was located above the AV septal junction. In the former group, we found that the offset of both annuli was wide (mean 3.8 ± 1.4 vs. 2.4 ± 1.1 mm), the distance between CS opening and membranous septum was long (mean 14.8 ± 1.6 vs. 12.3 ± 2.2 mm), and the CS opening level was lower and closer to the His bundle level (mean 2.8 ± 1.9 vs. 5.8 ± 2.9 mm) (P < 0.05).

Conclusion

The deep extension of CS musculature into the AV septal junction seems to increase the tissue non-uniformity in this area.

Keywords

Atrioventricular node • Coronary sinus • Histology • Atrioventricular nodal reentrant tachycardia • Atrioventricular septal junction

Introduction

The Koch’s triangle is known as a landmark of the atrioventricular (AV) nodal tissue.1 It is observed from the macroscopic endocardial view of the right atrium, and is delineated by the following three elements: the tendon of Todaro, the tricuspid valve annulus, and the coronary sinus (CS) opening. In a study, it was shown that the dimensions of the Koch’s triangle show considerable diversity.2 In addition to this diversity, the myocardial orientation beneath the endocardium has not fully been elucidated. However, the recent advances of clinical electrophysiology revealed that most of the critical regions of the AV nodal reentrant tachycardia (AVNRT) prevail around the anterior CS opening,3 though the histological prospects of the pathway of AVNRT are still obscure.4 Therefore, we propose a modified histological method that can provide a reference for the relation between the dimensions of Koch’s triangle and the arrangement of CS musculature within the AV septal junction.

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Methods

Subjects
The present study included randomly selected 16 autopsied human hearts (9 men, 7 women) without structural anomalies or a history of significant conspicuous supraventricular arrhythmia. The mean age was 57.9 ± 18.2 years ranging between 20 and 80 years. Ten of the human subjects died of malignant diseases, the others died of a liver disease, sepsis, pneumonia, brain haemorrhage, aortic aneurysm, or gastrointestinal bleeding. None of them died of structural heart disease.

Macroscopic measurement
After fixation in 10% formalin, the posterior AV septal junction, including the opening of the CS, tricuspid valve, and mitral valve, was removed en bloc. We defined the CS as the portion that begins at the confluence of the great cardiac vein and the oblique vein (bundle) of Marshall and ends with its ostium in the right atrium (CS opening).

We measured each dimension in this area as follows: (a) the width of the mitral valve-tricuspid valve offset, (b) the longitudinal distance between the CS opening and membranous septum (CS-MS offset), (c) the diameter and the surface area of the CS opening, (d) the distance between the CS opening and tricuspid valve annulus (septal isthmus), and (e) the distance between CS opening and membranous septum (Figure 1).

Microscopic observation
Removed blocks of the hearts were conventionally processed to paraffin inclusions, and then serial sections of 7-μm thickness were made parallel to both the tricuspid and mitral valve annuli, i.e. the short-axis plane of the both ventricles. From the level of the tricuspid valve to the posterior margin of CS opening, every 10th section was stained with Masson’s trichrome. We observed the distribution of the CS musculature in this area, and compared it with the dimensions of the Koch’s triangle. The CS musculature was defined as the myocardial coverage of the CS.

Statistical analysis
For all the study subjects, we compared heart weights, and each dimension within the Koch’s triangle. The values were shown as mean ± SD. One-factor ANOVA was used for statistical comparisons between the groups. A P-value of <0.05 was considered statistically significant.

Results

Measurements
The mean heart weight was 334.9 ± 75.8 g, ranging between 169 and 465 g. The macroscopic measurements as described in Figure 1 were as follows: (a) the mean width of the tricuspid valve–mitral valve offset was 3.1 ± 1.4 mm, (b) the mean longitudinal distance between the CS opening level and membranous septum level (CS–MS offset) was 4.3 ± 2.8 mm, (c) the mean surface area and diameter of the CS opening were 43.7 ± 17.3 mm² and 10.5 ± 2.8 mm, respectively, (d) the mean septal isthmus length was 9.9 ± 1.8 mm, (e) the mean distance between CS opening and membranous septum was 13.5 ± 2.3 mm. Detailed measurements and histological patterns of the each individual are shown in Table 1.

Relationship of the distribution of coronary sinus musculature and the atrioventricular septal junction
We divided the hearts into two groups according to the distribution patterns of CS musculature.

Group A: deep extension group (Figure 2)
At a level just above the tricuspid valve, the CS musculature around the CS opening deeply intrudes into the AV septum and merges with the myocardium of the septal isthmus. In the middle part of the CS cavity, the CS musculature was found to have sparse and loose connections with the left atrial myocardium just beneath the compact AV node. In this group, the myocardial connections between both atria were observed mainly at the superior border of the CS opening through the CS musculature.

Group B: superficial extension group (Figure 3)
Sections within the septal isthmus just above both mitral and tricuspid annuli showed that the compact node was located between left and right atrial myocardium, and this configuration
means that this level is above the AV septal junction and that the CS musculature does not deeply intrude into AV septum. Not only the CS musculature was found to have no connections with the left atrial myocardium in this level, but also myocardial connections between both atria were hardly observed.

In the middle part of the CS of this group, it was found that the musculature of the CS opening merges with the myocardium of the vestibule of the right atrium, in which it is defined as the flat endocardial sector just above the AV valve attachment (Figure 3C). At this level, the CS musculature was close to the left atrial myocardium. The myocardial connections between both atria were observed mainly in the antero-superior border of CS opening through the CS musculature.

Comparison between the dimensions of each group

The CS musculature showed a deep extension distribution into the AV septal junction in eight hearts (Group A, Figure 2). The musculature around the CS opening spread beneath the level of the mitral valve annulus as shown in Figure 2B. The remaining eight hearts (Group B, Figure 3) showed that the CS musculature was located above the AV septal junction and showed non-intruding distribution, i.e. superficial extension. In Group A, the offset of both annuli was significantly wider (mean 3.8 ± 1.4 vs. 2.4 ± 1.1 mm, P < 0.05), the length between the CS opening and the membranous septum was longer (mean 14.8 ± 1.6 vs. 12.3 ± 2.2 mm, P < 0.05), and the CS opening level was lower and closer to the membranous septum level (His bundle level) (mean 2.8 ± 1.9 vs. 5.8 ± 2.9 mm, P < 0.05; Table 2).

Figure 4 represents a schematic explanation for the distributions of the CS musculature in both groups. In Group A (deep extension, Figure 4A), one normal variant of the tricuspid valve anatomy shows the downward displacement of the tricuspid valve annulus into the right ventricle, which draws the CS opening more anteriorly with constant distance between the tricuspid valve annulus and the CS opening. In this group, the CS is facing the compact AV node by its superior margin. This orientation brings the CS musculature to a close relation beneath the compact AV node. In Group B (superficial extension, Figure 4B), another tricuspid valve anatomical pattern is shown in which the tricuspid valve is straight, pushing the CS opening more posteriorly. In this group, the CS opening is facing the compact AV node by its antero-superior margin, an orientation that brings the CS musculature away from the level of the compact AV node. There was no significant difference between both groups regarding age, sex, heart weight, CS diameter, and the septal isthmus length (Table 2).

Discussion

The AV conduction axis begins from the top of the Koch's triangle. It then penetrates the central fibrous body, and bifurcates into bundle branches beneath the membranous septum. The histological approach for the AV node has not been changed since Tawara’s monograph was established. In that method, the histological exploration of the AV conduction axis has mainly been
performed by vertically sliced sections of the AV annuli, and this method has been applied for many years. The CS opening is one of the elements composing the Koch’s triangle. However, these traditional vertically sliced sections of the Koch’s triangle had technical limitations with regard to observing the histological structure of the lower part of the Koch’s triangle, including CS opening due to its curvature and the divergence of both mitral and tricuspid annuli. Our histological method employed in this study, in which we made sections parallel to both annuli, provides the reference to the relation between the dimensions of Koch’s triangle and the arrangement of CS musculature. Furthermore, these specimens showed both atria in the famous clinical fluoroscopical left anterior oblique (LAO) view style and made it easy to observe myocardial connections between both atria. Chauvin et al. described the myocardial connections between the left atrial myocardium and the CS musculature using a similar method. Furthermore, Racker and Kadish highlighted the myocardial arrangement within the AV node using the three-plane histological sectioning in dog hearts. However, they have not explored the myocardial arrangement around the AV septal junction. Inoue and Becker described the distribution of the compact node and its extensions with reference to the substrate of the slow pathway in AVNRT in the AV septal junction. In their study, however, spatial distribution of the CS musculature around the AV nodal tissue was not mentioned. The present study with short-axis style sections unveiled the right and left atrial connection beneath the septal isthmus. This myocardial area that might participate in AVNRT was shown in a single autopsy case report.

Figure 2 Representative of hearts with the Group A (the coronary sinus musculature deeply extends into the atrioventricular septum). (A) The macroscopic endocardial view of the Koch’s triangle. Three lines (B–D) show the levels of histological sections. (B) Level B is within the septal isthmus, the coronary sinus musculature intrudes into the atrioventricular septal junction and merges with vestibule myocardium (black arrows). (C) Level C is through the middle part of the coronary sinus opening, the coronary sinus musculature shows loose connections with the left atrial myocardium (black star) just behind the atrioventricular node. The black arrow heads show the thin strand of transitional cells which are interposing between the atrioventricular node and the intermingled muscles of coronary sinus and vestibule. The white arrow shows the junction of the atrioventricular node and the penetrating bundle of His. (D) Level D is the posterior margin of the coronary sinus opening adjacent to the Eustachian ridge, the coronary sinus musculature scarcely has connections with left and right atrial myocardium. The connection between both atria through the coronary sinus musculature is observed mainly at the anterior border of the coronary sinus opening (No. 2, 26-year-old male). ANT, anterior; AVN, atrioventricular node; CS, coronary sinus; EV, Eustachian valve; FO, foramen ovale; INF, inferior; LA, left atrium; MCV, middle cardiac vein; MS, membranous septum; MV, mitral valve; POST, posterior; RA, right atrium; SUP, superior; TV, tricuspid valve; VS, ventricular septum. Bars = 5 mm.
The concern about the exploration of the CS morphology, dilatation of the CS opening, or increase of the CS volume was reported using CS angiography or intracardiac ultrasounds in AVNRT cases.13,14 Furthermore, DeLurgio et al.15 have also reported a good correlation between CS volume and the presence of dual AV nodal physiology in case of AVNRT. For this reason, it is supposed that small morphological variations of the CS may provide some substrates of AVNRT. We could not calculate the real volume of the AV septal junction in these specimens, though the CS opening-membranous septum dimension was longer in CS deep extension group (Group A) than in the superficial extension group (Group B). We have reached the conclusion that not

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**Table 2** Comparison between the two groups

<table>
<thead>
<tr>
<th>Distribution pattern of CS musculature into AV septum</th>
<th>Group A (n = 8)</th>
<th>Group B (n = 8)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>51.3 ± 20.4</td>
<td>64.6 ± 13.9</td>
<td>n.s. (P = 0.15)</td>
</tr>
<tr>
<td>Heart weight (g)</td>
<td>309.3 ± 85.9</td>
<td>360.6 ± 58.3</td>
<td>n.s. (P = 0.18)</td>
</tr>
<tr>
<td>a TV-MV offset (mm)</td>
<td>3.8 ± 1.4</td>
<td>2.4 ± 1.1</td>
<td>P = 0.04</td>
</tr>
<tr>
<td>b CS-MS offset (mm)</td>
<td>2.8 ± 1.9</td>
<td>5.8 ± 2.9</td>
<td>P = 0.03</td>
</tr>
<tr>
<td>c CS opening size (mm²)</td>
<td>48.3 ± 23.0</td>
<td>39.1 ± 7.8</td>
<td>n.s. (P = 0.30)</td>
</tr>
<tr>
<td>CS-diameter (mm)</td>
<td>11.0 ± 2.9</td>
<td>10.0 ± 2.8</td>
<td>n.s. (P = 0.49)</td>
</tr>
<tr>
<td>d CS-TV dimension (mm)</td>
<td>9.5 ± 1.8</td>
<td>10.3 ± 1.8</td>
<td>n.s. (P = 0.42)</td>
</tr>
<tr>
<td>e CS-MS dimension (mm)</td>
<td>14.8 ± 1.6</td>
<td>12.3 ± 2.2</td>
<td>P = 0.02</td>
</tr>
</tbody>
</table>

AV, atrioventricular; CS, coronary sinus; MS, membranous septum; MV, mitral valve; TV, tricuspid valve; a-e, see Figure 1.

The concern about the exploration of the CS morphology, dilatation of the CS opening, or increase of the CS volume was reported using CS angiography or intracardiac ultrasounds in AVNRT cases.13,14 Furthermore, DeLurgio et al.15 have also reported a good correlation between CS volume and the presence of dual AV nodal physiology in case of AVNRT. For this reason, it is supposed that small morphological variations of the CS may provide some substrates of AVNRT. We could not calculate the real volume of the AV septal junction in these specimens, though the CS opening-membranous septum dimension was longer in CS deep extension group (Group A) than in the superficial extension group (Group B).
only AV nodal anatomy, but also the spatial distributions of the CS musculature, may have a role in the pathology of AVNRT, and both of them should be investigated in AVNRT cases. Furthermore, the characteristics provided by CS morphology may be of more significance in the left variant AVNRT cases, because in these cases, the ablation therapy is sometimes performed within the CS.16

Ho et al.4 mentioned the myocardial arrangement around the compact AV node in patients with electrophysiologically proven dual AV nodal pathway using the conventional vertical histological sections. They focused on the distribution of transitional fibres approaching the AV node and found three patterns (superficial, deep, and posterior), but they concluded that the substrate of multiple pathways was ubiquitous. In our study, using the histological LAO view, both of the left and right atrial vestibules had connections with the CS musculature. In addition, the myocardial arrangements, including the CS musculature within the AV septal junction, showed non-uniformity and this phenomenon seems to be related to some of the electrical characteristics in this area.

Limitations

Because of the uncertainty in the cell-to-cell coupling under the optical microscope using the conventional staining of our study, quantification of the myocardial connections between CS musculature and the proximal AV conduction axis or the left and right atrial myocardium was not possible. We consider that using immunohistochemical staining methods, such as gap junction protein, might add information in this concern.

Although short-axis sections facilitate the histological observation of myocardial arrangements within the AV septal junction, myocardial arrangements do not always coincide with the electrophysiological phenomena. Recent experimental simulation showed that the transitional cells around the AV node and nodal extensions are associated with the formations of reentrant circuits.17 Concerning about the participation of the CS musculature in AVNRT cases, accumulation of autopsy findings after successful ablation procedure should be required.

Conclusion

The CS location provides the variations of the muscular arrangements within the AV septal junction. Especially, the deep extension of the CS musculature into the AV septal junction seems to increase the tissue non-uniformity around the AV node.

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Conflict of interest: none declared.

References


