Background—The proximity to vascular structures is a limiting factor during radiofrequency ablation. However, little or no attention has been given to the atrial arterial circulation during the development of atrial fibrillation (AF) catheter ablation techniques.

Methods and Results—We examined the atrial arterial circulation in areas involved in AF ablation in 24 heart specimens by colored resin injection and careful dissection. The sinus node artery (SNA) arose from the circumflex artery in 42% of case; proximal to the LA appendage in 29%, crossing the left atrium (LA) anterior wall; and after the LA appendage in the remaining 13%, crossing the mitral isthmus and passing close to the left pulmonary veins (PVs), the LA roof, and the right superior PV. In 58%, the SNA arose from the right coronary artery. Major arteries (≥1 mm in external diameter) were found in the mitral isthmus in 54%, at the LA roof in 54%, and at the LA anterior wall in 29%. Around the left PV ostia, there were areas with major arteries in up to 37% (at the roof and inferior segments) and around the right PV ostia in up to 29% (at the roof segment).

Conclusions—Major atrial coronary arteries, including the SNA, were commonly found in the areas involved in AF ablation and could cause difficulties in obtaining transmural lesions and electric isolation or even lead to ischemic sinus node or atrial dysfunction. (Circ Arrhythm Electrophysiol. 2010;3:600-605.)

Key Words: arteries ■ atrium ■ catheter ablation ■ anatomy ■ atrial fibrillation

Atrial fibrillation (AF) is the most common arrhythmia in clinical practice, with an estimated prevalence of 0.4% to 1% in the general population1-2 and rising with age to 8% in patients >80 years.3 Its pharmacological treatment has yielded suboptimal results, leading to a search for nonpharmacological options for therapy.4

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During the development of the surgical approaches for AF ablation, knowledge of the atrial coronary anatomy was essential, leading to important technical modifications and better results. Recognition of the importance of the sinus node artery (SNA) and its relationship to the areas of atrial surgical incisions contributed to refinement in surgical technique with the maze III procedure,5 reducing sinus node and atrial dysfunction commonly found after the initial maze I surgery. Later studies with the atrial coronary anatomy in dogs led to the proposal of the radial incisions technique,6 reducing even further the mechanic dysfunction observed during the follow-up of patients submitted to the initial techniques.7

The earliest techniques of radiofrequency (RF) catheter ablation simulated the surgical maze procedure8 or attempted to eliminate ectopic foci inside the pulmonary veins (PVs).9 In more recent modifications, endocardial RF pulses are delivered circumferentially around the PV antrum to obtain electric isolation10,11 associated with linear ablations in the left atrium (LA) and mitral isthmus in selected patients.12 Despite the atrial coronary arteries being described as early as the 17th century13 and being essential in the development of open heart operation techniques,14 little or no attention has been given to their role during the development of the current AF RF catheter ablation techniques. The mechanism of RF ablation is due to direct resistive heating, passive thermal conduction, and microvascular injury.15 Nevertheless, blood flow across even small vessels in the vicinity of an RF lesion can reduce lesion size and prevent transmural lesion formation by convective heat loss to the blood, leaving a preserved cuff of tissue around the vessel and preserving conduction through linear RF lesions.16 On the other hand, experimental models17,18 and human case reports19-21 showed that if RF energy delivered and heat generated overcome the cooling capability of the blood vessel, arterial wall injury and occlusion can occur, with subsequent infarct of the irrigated territory. Therefore, the knowledge of the atrial coronary arteries anatomy and characteristics may play an important role in enhancing both efficacy and safety of AF ablation.
Methods

Specimens Characteristics
The specimens used for this investigation were fresh adult human hearts obtained from 24 cadavers with cause of death unrelated to cardiorespiratory diseases in accordance with local guidelines for retention of organs for medical research. Age at death ranged from 23 to 82 years (mean, 47.2 years), with 71% men and 63% white. The study protocol was approved by the institution ethics committee.

Preparation and Dissection Technique
After gross inspection in search for anatomic defects, coronary artery lesions, or thoracic wounds, both coronary ostia were dissected, cannulated, and injected with black-colored vinlyc resin. The left main and right coronary arteries were then ligated close to the aortic wall. The hearts were fixed in formaldehyde solution, immersed in hydrogen peroxide solution for bleaching, and dissected with careful epicardectomy of the atrial territory to expose the atrial coronary arteries.

Atrial Coronary Arteries Nomenclature
Throughout the present work, we use the geographic nomenclature of the atrial arteries as first proposed by Spalteholz, which classifies them as anterior, lateral, or posterior and either right or left relative to their origin at the tricuspid or mitral rings, respectively.14

Areas Potentially Involved in AF Catheter Ablation
For the purpose of this work, we defined areas potentially involved in AF catheter ablation as those located at an imaginary circumferential PV ablation line encircling either left or right ipsilateral PV ostia, an imaginary line at the mitral isthmus connecting the left inferior PV to the mitral annulus, a roof line superiorly connecting the left superior to the right superior PV, the anterior LA wall potentially aimed at when targeting fractionated potentials, and the LA appendage (LAA). For analysis and descriptive purposes, we empirically divided the imaginary circumferential line around the ipsilateral PV ostia equally into 6 segments: anterosuperior, roof, posteroinferior, inferior, and anteroinferior (Figure 1).

SNA
For each specimen, the origin and course of the SNA were recorded, and the external diameter was measured at the areas previously described as potentially involved in AF catheter ablation if the SNA crossed such areas. The final course of the SNA relative to the cavoatrial junction was classified either as precaval when it entered the terminal groove and the sinus node anteriorly to the superior vena cava, retrocaval when coursing posteriorly to the superior vena cava, or encircling when forming an arterial circle around the superior vena cava.

Major Left Coronary Arteries
Additionally, we analyzed the presence of major coronary arteries in the LA, which are defined empirically as arteries with an external diameter >1 mm, irrespective of their origin being from the right or left side, in areas potentially involved in AF catheter ablation.

Caliber Measurements
For caliber analysis, pictures were taken with a high-resolution digital camera with a ruler near the target artery, and the pictures were analyzed with the software Image Tool 3.0 (University of Texas Health Science Center at San Antonio; San Antonio, Tex) to calculate the external diameter in millimeters to the nearest 2 decimal places, using the ruler as a calibrating scale.

Results

SNA
The SNA arose from the circumflex artery in 10 (42%) of the 24 cases, thus having an LA course; in 9 cases, the sinus node irrigation was accomplished exclusively from the left system, and in 1 case, the sinus node irrigation had a mixed origin from the left and right system. In 7 (29%) of these cases, the SNA was a branch of the left anterior atrial artery, an LA artery that originates from the circumflex artery proximal to the LAA in an anterior position relative to the mitral annulus (Figure 2). In such cases, the SNA crossed the LA through the anterior wall, with a mean caliber of 1.31±0.34 mm, before reaching the right atrium and finally the terminal groove and the sinus node either precaval as seen in 3 (13%) cases, retrocaval as in 2 (8%), or encircling as in 2 (8%). In 1 (4%) of the previously described precaval cases, the sinus node irrigation also was accomplished from an SNA that originated from the right lateral atrial artery, being the only case with a mixed sinus node supply in the specimens we analyzed.

In the remaining 3 (13%) cases of left origin, the SNA was a branch of the left lateral atrial artery; an LA artery originated from the circumflex artery after the LAA in a lateral position in relation to the mitral annulus (Figure 3). In such cases, the left lateral atrial artery is prominent, running partly parallel to the circumflex artery after its origin in the left atrioventricular groove until it crosses the transition...
between the lateral and posterior aspects of the LA, reaching the mitral isthmus region with a mean caliber of 3.14 ± 0.60 mm. From there, it makes an acute curve, crossing again an imaginary mitral isthmus line and passing close to the left inferior PV antrum with a mean caliber of 2.58 ± 0.20 mm; enters the left lateral ridge (the muscular fold lying between the left PVs and the LAA); contours the left superior quadrant of the left superior PV with a mean diameter of 2.45 ± 0.28 mm; runs along the LA roof between the superior PVs with a mean diameter of 2.27 ± 0.26 mm; and diverges gently away from the right superior PV antrum with a mean caliber of 2.10 ± 0.60 mm from where it crosses to the right atrium, reaching the sinus node in a precaval manner as seen in 2 cases and a retrocaval manner as in 1 case (Figures 3 and 4). In either case, the SNA had an LA course in close relation to the transverse sinus toward the right atrium. Also of notice is the fact that whenever the SNA was a branch of the left system, the right atrial coronary arteries were poorly developed, especially when the SNA was a branch of the left lateral atrial artery. In such cases, no right lateral or right posterior atrial coronary artery were identified, with only the presence of small right anterior atrial arteries.

In the remaining 14 (58%) of the 24 cases, the SNA arose exclusively from the right coronary artery. In 12 (50%) of the 24 cases, the SNA was a branch of the right anterior atrial artery (Figure 5), reaching the sinus node in a precaval manner in 8 (33%), retrocaval in 3 (13%), and encircling in 1 (4%). In the remaining 2 (8%) of the 24 cases, the SNA was a branch of the right lateral atrial artery and ended in a retrocaval way.

**Major Left Coronary Arteries**

When analyzing the presence of major coronary arteries in areas potentially involved in AF ablation catheter ablation in the LA (defined previously as arteries with an external diameter >1 mm regardless of their origin), a high proportion was found (Figure 1). Major atrial coronary arteries were found in 13 (54%) of the 24 cases at the imaginary mitral isthmus line, in 13 (54%) at the imaginary roof line, and in 7 (29%) at the LA anterior wall. Considering the presence at each of the 6 segments in which we empirically divided the imaginary circumferential PV ablation line around the left PV ostia, major coronary arteries were found in 8 (33%) at the anterosuperior segment, 9 (37%) at the roof segment, 2 (8%) at the anterosuperior segment, 1 (4%) at the anteroinferior segment, 5 (21%) at the inferior segment, and 9 (37%) at the anteroinferior segment. At the imaginary circumferential line around the right PV ostia, major arteries were found in 1 (4%) at the anterosuperior segment, 7 (29%) at the roof segment, 2 (8%) at the anterosuperior segment, 0 (0%) at the anteroinferior segment, 1 (4%) at the inferior segment, and 0 (0%) at the anteroinferior segment.

**LAA Irrigation**

LAA irrigation was accomplished in all studied specimens by small branches arising from the circumflex artery, entering
from the inferior aspect of its base, and running toward its apex.

**Discussion**

In the present work, atrial coronary arteries with significant caliber were frequently found in the LA epicardium within or adjacent to areas involved in AF RF catheter ablation. Of note is the high frequency of the SNA arising from the circumflex artery; although this agrees with earlier studies,\textsuperscript{13,14} it was not well recognized that the SNA takes an LA course across areas affected during RF ablation with such a remarkable high caliber. The most exuberant LA arteries were found when the SNA was a branch of the left lateral atrial artery. This variant of the coronary arteries extending to the region between the LAA and left superior PV in 35% of patients and 46% in the mitral isthmus region. Although generally in accordance with our results, Yano et al did not identify LA arteries originating from the right, near the right PVs, or at the roof. They did not recognize that possibly many of the arteries described as being present at the region between the LAA and left superior PV but not at the mitral isthmus region (which they called a previous study using either x-ray films or corrosion casting was identified postmortem in 24 (8%) of 300 human hearts in a previous study using either x-ray films or corrosion casting techniques.\textsuperscript{22} Our work demonstrated a slightly higher percentage (13%), probably because of our smaller sample, but evidenced that in such cases, the larger arteries were also the most closely related to target sites during AF ablation.

A recent study by Yano et al\textsuperscript{23} retrospectively analyzed coronary angiography in 262 patients referred for electrophysiological study of arrhythmias, excluding AF, and found arteries extending to the region between the LAA and left superior PV in 35% of patients and 46% in the mitral isthmus region. Although generally in accordance with our results, Yano et al did not identify LA arteries originating from the right, near the right PVs, or at the roof. They did not recognize that possibly many of the arteries described as being present at the region between the LAA and left superior PV but not at the mitral isthmus region (which they called the SNA as a branch of the right anterior atrial artery, occurring in 12 (50%) of 24 cases. Notice that in this specimen, despite the SNA having an origin at the right coronary artery, there is a significant branch crossing to the LA toward the LSPV through the anterior and roof walls. RAA indicates right atrial appendage. Other abbreviations as in Figures 1 and 2.

**Figure 4.** Different views of the SNA as a branch of the left lateral atrial artery. Pictures of the same specimen as in Figure 3A in left superolateral (A) and superior (B) view and a schematic drawing in left lateral view (C) showing the course of the SNA (arrows) around the LPVs and across the LA roof toward the right atrium and reaching the sinus node in a precaval manner. IVC indicates inferior vena cava; RAA, right atrial appendage. Other abbreviations as in Figures 1 and 2.

**Figure 5.** SNA as a branch of the right anterior atrial artery. Picture (A) and schematic drawing (B) showing the SNA as a branch of the right anterior atrial artery, occurring in 12 (50%) of 24 cases. Notice that in this specimen, despite the SNA having an origin at the right coronary artery, there is a significant branch crossing to the LA toward the LSPV through the anterior and roof walls. RAA indicates right atrial appendage. Other abbreviations as in Figures 1 and 2.

The effects of RF delivery in the vicinity of ventricular coronary arteries is well established in the literature.\textsuperscript{16–21} Additionally, the role of venous structures, such as the coronary sinus and the Marshall bundle and vein, during AF RF ablation has been studied extensively.\textsuperscript{25–28} The present work was not designed to evaluate the effects of RF near atrial arteries and limits itself to describing their presence at AF ablation sites. Nonetheless, on the basis of the existing data, it is plausible to suppose that interactions likely occur between the RF application on the endocardial surface and the subjacent artery on the subepicardial surface because of the relatively small thickness of the atrial wall. Such interactions could be expressed as a protective effect to the atrial myocardium because of convective heat loss to the blood flowing through the vessels, creating difficulties in obtaining transmural lesions and electric isolation and leading to gaps in the isolation lines or possibly to late reconnection or, as an ischemic effect, leading to atrial infarction that may produce arrhythmogenic substrate, unintended postablation atrial contractile dysfunction, or sinus node dysfunction.

It is interesting to acknowledge that in a study evaluating acute and chronic PV reconnection after AF ablation, Rajappan et al\textsuperscript{29} identified that besides the intervenous ridge (between ipsilateral PVs), the preferential site of acute reconnection is the PV-LAA ridge, and the preferential sites of chronic reconnections were at the PV-LAA ridge, the roof of the right superior PV, and the floor of the right inferior PV. Even though atrial arteries were not commonly found in our work at the inferior segment of the right inferior PV, atrial arteries were prevalent at the other areas described as sites of frequent reconnection. Besides other characteristics such as transmural myocardial thickness and catheter stability, the
presence of atrial arteries also may be hypothesized as a component in determining preferential sites of reconnections.

Although sinus node dysfunction cases after AF RF ablation have not, to our knowledge, been published, there are anecdotal cases where sinus node dysfunction is observed following AF ablation, even necessitating a temporary pacemaker, despite no RF applied near the sinus node.

Recently described hybrid techniques consisting of both endocardial and percutaneous epicardial catheter ablation are now under evaluation for AF management, and the potential effects of the presence of a major atrial artery close to the ablation lines may be even greater. The results of the present study suggest that special attention should be addressed when applying RF on the epicardial surface of the LA, especially at the mitral isthmus, adjacent to the left PVs and inside the transverse sinus, eventually demanding previous atrial coronary anatomy imaging whenever such approach is planned.

Although the present study was not designed to evaluate the physiological and clinical effects of such RF pulses delivered next to the LA coronary arteries, we believe that the hypothesis generated agrees with the literature and that the physiological and clinical aspects and possible implications should be addressed in future works. Another limitation is the fact that only structurally normal hearts were evaluated, which may differ from real-life patients with AF. Additionally, the number of specimens analyzed was limited because of the difficulty of the technique used, but nonetheless, the specimens did provide anatomic details of the LA coronary circulation that, in our understanding, may prove valuable to the improvement of AF RF ablation techniques.

Conclusions
Major atrial coronary arteries, including the SNA, were commonly found in or crossing the areas involved in AF ablation with a significant caliber. Their presence could cause difficulties in obtaining transmural lesions and electric isolation, be related to late reconnection, or lead to ischemic sinus node or atrial dysfunction. Further work is needed to evaluate the effects of their presence during AF RF ablation and to develop strategies to avoid the possible unwanted effects during RF delivery.

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Disclosures
None.

References
Clinical Perspective

The proximity to vascular structures is recognized as a limiting factor during radiofrequency ablation. However, no attention has been given to the atrial arterial circulation during the development of the atrial fibrillation catheter ablation techniques. Therefore, we examined the human atrial arterial circulation by colored resin injection and careful dissection and were able to identify that major atrial coronary arteries, including the sinus node artery, were commonly found in the areas involved in atrial fibrillation catheter ablation. As a result, this fact may eventually be the cause of difficulties in obtaining transmural lesions and electric isolation or even lead to ischemic sinus node or atrial dysfunction.
Atrial Coronary Arteries in Areas Involved in Atrial Fibrillation Catheter Ablation
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