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Anatomy of the right atrial appendage and its importance in clinical practice

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Abstract

The right atrial appendage is an important anatomical marker of the right heart. With the developments in cardiology, more attention has been paid to the right atrial appendage. This article summarizes the progress in research regarding the right atrial appendage anatomy and its clinical value, to collate and augment the relevant data. The shape of the right atrial appendage differs from the left atrial appendage: its outer surface is relatively flat and its internal structure comprises a terminal crest and musculi pectinati. In clinical interventional therapy, the right atrial appendage is often used as the electrode implantation site. The thickness of the musculi pectinati and the wall thickness of the right atrial appendage are closely related to the outcomes in atrial lead implantation. In terms of atrial fibrillation, wherein thrombi formation is frequent, the right atrial appendage is one of the predilection sites of thrombosis. However, the incidence of thrombosis in the right atrial appendage is lower than that in the left atrial appendage.

Familiarity with the anatomy of the right atrial appendage is of prime importance in atrial lead implantation, and the role of the right atrial appendage in atrial fibrillation requires further investigation.

Key words: thrombosis, progress, atrial lead, atrial fibrillation

Introduction

The general RAA morphology is described in some anatomy-related textbooks, and most of them report that the RAA morphology is relatively simple: that it is roughly triangular in shape. However, the RAA has not been studied in detail. In fact, the morphology of the RAA is more than triangular: it can be subdivided into several shapes.

The current literature finds the right atrial appendage to be a predilection site of thrombosis owing to its special internal structure, which comprises the terminal crest (TC) and complicated musculi pectinati (MP). Right atrial appendage thrombi can be effectively detected using transesophageal echocardiography (TEE). In clinical interventional therapy, such as cardiac pacemaker implantation, the RAA is often used as the implantation site of atrial leads, because it is easy to reach the RAA, and because it is firmly fixed compared with other parts. In order to avoid repeated implantation and operative complications, familiarity with the morphology and location of the RAA is of great importance. This study aims to collate and augment data regarding the morphology and anatomy of the right atrial appendage (RAA), its Clinical value and elucidate the relationship of the RAA with thrombus formation in atrial fibrillation, which has been overlooked in the current literature.

Morphology of the RAA

The left and right atrial appendages originate from the atrium during embryonic development. Right atrial appendage is morphologically limited by the pericardium. In addition, it is influenced by the adjacent structures, including the ascending aorta,

superior vena cava, right ventricle, and right atrium (Figure 1, Figure 2). Some scholars have found that the shape of the RAA is approximately triangular with an irregular border, and its average area is approximately three square centimeters[1]. However, Renato Rissi et al. [2] studied the hearts of 172 adults and 61 children and found roughly five different types of RAA: quadrilateral (similar to a horse head), four-faced (similar to a parrot beak), trapezoidal (anvil-shaped), triangular (sailboat-shaped), and a fifth shape, with some lobes and randomly arranged notches, which is not yet clearly defined. The second shape, i.e., the four-faced RAA, is commonly observed, and the description of this shape was supported by that in the study by Manolis et al. [3]. Li C.Y. et al. divided the morphology of RAA into five types and nine subtypes, including the first type of triangular shape (Ia and Ib), the second type of M shape (IIa and IIb), the third type of L shape (IIIa and IIIb), the fourth type of reverse L shape (IVa and IVb), and the firth type of the balanced shape [4]. Their findings could lead to improvements in pacemaker placement in the RAA and help prevent complications. Thus, the RAA could be considered mainly polymorphic. Concurrently, Renato Rissi et al. demonstrated for the first time that the RAA is mainly lobed in 84.3% of adult hearts and 91.8% of children hearts [2]. They also reported that the shape and lobation of the RAA was unlikely to change with cardiac development or changes in height and weight. However, individual differences in RAA morphology still exist.

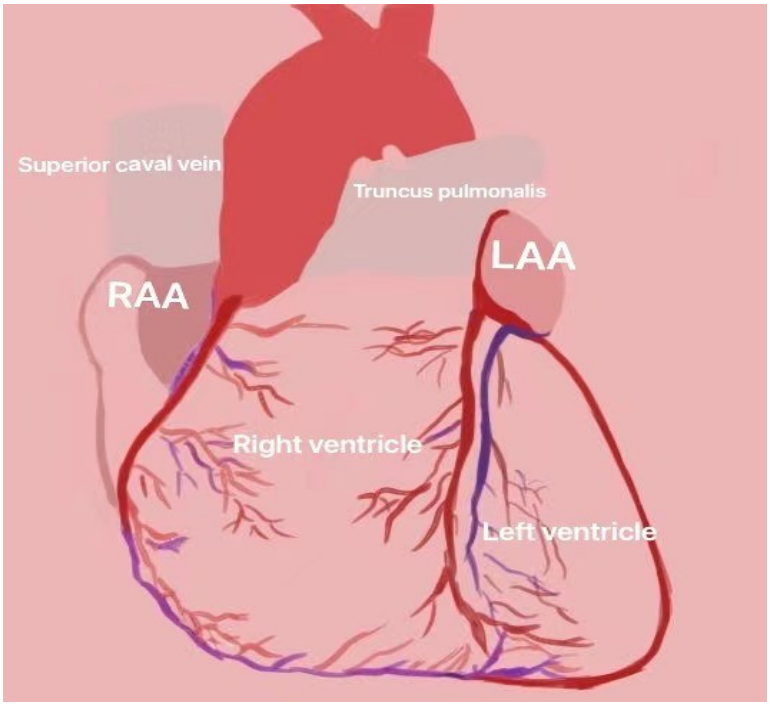

Figure 1. Schematic representation of the position of the right atrial appendage.

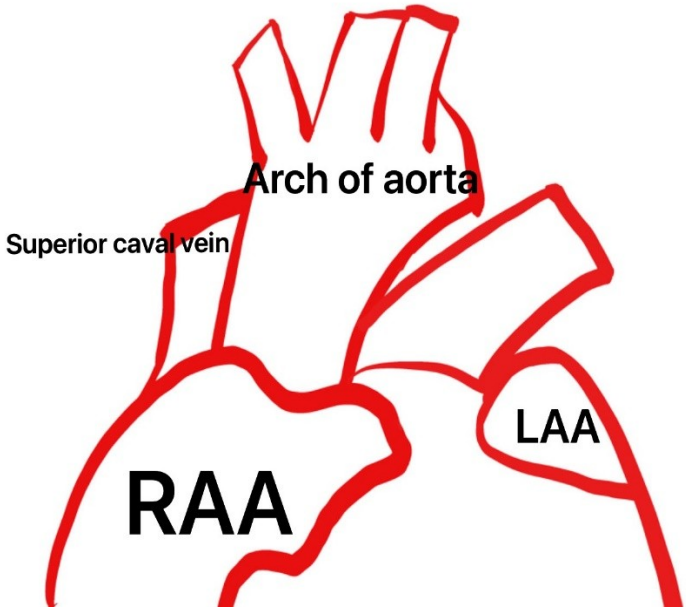

Figure 2. Schematic representation of the right atrial appendage and its adjacent structures.

The size of the basilar part of the RAA is correlated with its morphology. Manolis et al. found that the average aperture of the RAA (length of RAA basilar part) was 2.0 ± 1.0 cm [3]. They found that the aperture of the RAA was smaller in people aged over 70 years than in young people, and the depth of the RAA was decreased in people aged over 70 years than in those aged under 70 years.

By echocardiographic examination, De Divitiis found that the RAA area in patients with atrial fibrillation was larger than that in patients with sinus rhythm [5]. Reportedly, the RAA of patients with atrial fibrillation is enlarged due to significant enlargement of myocardial cells in the atrial septum and atrial appendage [6]. However, echocardiography cannot measure other parameters, such as the RAA volume, in detail. Based on 256-slice computed tomography, a study has [7] proposed a more accurate reference range of data for a healthy RAA, including parameters such as volume. They also found that the volume, height, and basal axis of the RAA were higher in males than in females.

Anatomy of RAA

Right atrial appendage is the anatomical marker of the right heart, located anterolaterally to the right atrium. It is a prominent and vestigial auricular structure during embryonic development [3]. In contrast to the traditional concept that the right atrial appendage is at the apex of the right atrium, Anderson et al. suggested that the anterior atrial wall is almost entirely composed of the atrial appendage, which extends around the vestibule of the tricuspid valve. In addition, the presence of musculi pectinati makes it easy to distinguish the right atrial appendage from the rest of the atrium. Musculi pectinati originates from the prominent terminal crest[8]. Terminal crest serves as a barrier to the heart conduction system during common atrial flutter [9,10,11] .

There are several crisscrossing bands of muscle (MP) in the RAA. Musculi pectinati of the RAA is the muscle ridge extending from the anterolateral side of TC to the auricle; a variety of MP shapes and sizes are observed. This MP originates from the TC. Musculi

pectinati with high trabecularization of muscle fibers is prone to arrhythmia. Right atrial appendage comprises a large and prominent muscle bundle, which originates from the TC and branches distally into a band of smaller muscle bundles, one of which returns to the RAA vestibule [12]. Zoppo et al. found that this large muscle bundle divided the RAA into two regions: the proximal superior lumen RAA, which faces the ascending aorta, and the distal cystic RAA, which is located close to the pulmonary artery [13].

In the existing literature, RAA vestibule is generally regarded as an area between the orifice of the RAA and the right atrioventricular annulus. Jakub Hołda et al. found an RAA vestibule in each heart they examined; 84.7% of the specimens had a completely smooth vestibule surface, while the rest (15.3%) had obvious gaps, diverticuli, recesses, etc [14]. The wall of RAA vestibule is composed of endocardial, myocardial, and adipose tissue layers. Three isthmuses with varying thicknesses were observed in the vestibule: the inferior RAA, superior RAA, and middle RAA isthmus. The structural differences between the isthmuses are evident: the superior RAA isthmus is higher than the middle and inferior RAA isthmuses, with increased overall atrial and adipose tissue layer thickness [14]. In a previous study involving 200 hearts, the vast majority of RAA isthmuses were observed to contain the right coronary artery. In each heart, the right coronary artery was visible in 100% of the superior isthmuses, 98.0% of the middle isthmuses, and 93.5% of the inferior isthmuses, and the proximity of the right coronary artery, which passes through the vestibule of the RAA, to the endocardial surface differs based on this. The artery is closest to the endocardial surface when it is located in the inferior RAA isthmus. The study also reported relatively few vessels in the RAA vestibule, other than the coronary arteries [15]. Coronary vessels, such as the right coronary artery and the cardiac vein, in the wall of the RAA vestibule may be a source of interference in ablation procedures. These vessels are at risk of physical damage, compression, and thrombosis, among other risks, during this procedure[16].

Relationship between RAA and atrial lead implantation

Regardless of the type of pacemaker used, the RAA remains an important place for lead implantation. This is because the RAA is easy to reach during atrial lead implantation and the lead can be firmly fixed to the RAA, and also because the SA node is located adjacent to the RAA. In-depth understanding of the anatomical morphology of the RAA and its relationship with adjacent structures can help surgeons avoid unnecessary complications and reduce instances of repeated atrial lead implantation. The most common complication of pacemaker implantation is dislocation, which is caused by the inhibition of fibrous adhesions between the atrial tissue and pacemaker leads after prolonged use of immunosuppressants [17]. Additionally, other factors such as microperforation and pull can cause lead dislocation of leads [18]. A previous study showed that the electrode head should be placed at a depth of at least 5 mm in the RAA fossa, to ensure that it is firmly fixed on the RAA MP [19]. If this depth is not achieved, the lead may be placed on the right side of the right margin of the spine; lead placement in this area is prone to dislocation. When the lead is placed in the RAA, it swings from side to side, similar to the movement of a car wiper blade, due to the relatively free systolic and diastolic movement of the RAA, which is one of the best radiological marker of distal RAA lead anchorage. If the lead is fixed to the proximal RAA, the amplitude of its swing will be smaller [13].

Aliform passive and spiral active leads are generally used as atrial leads. The electrode tip of the aliform passive lead is j-shaped, and it is inserted into the RAA MP using the needle inside the lead. During traditional permanent pacemaker implantation, passive leads serve as the main pacemakers. Clinicians generally use this traditional approach due to its convenience, simplicity, and low cost. However, aliform passive leads have some disadvantages, such as a limited number of implantation locations, increased duration of postoperative bed rest and hospital stay, and higher rate of atrial lead dislocation and implantation failure. In addition, because the passive lead is difficult to

move after it is fixed in the MP, extraction of the passive lead is challenging [20].

The spiral active lead is fixed in the myocardium by means of its helical design, and the pacing position can be adjusted until a reliable pacing threshold is obtained. However, repeated insertion in the same part should be avoided to prevent myocardial perforation and injury. One study showed that active fixation leads were positively correlated with pericardial effusion and pericardiocentesis, leading to a greater likelihood of microperforation [21]. In addition, Sivakumaran et al. showed that if the atrial muscle was thin, the spiral lead would easily penetrate it, leading to an increased incidence of myocardial perforation [22]. Another study showed that the RAA wall between the adjacent MP is thin and transparent: histological examination revealed that cardiac myocytes are almost non-existent in this area. Zoppo et al. studied the cadaver right atrial appendage to roughly divide the right atrial appendage into two parts, the proximal superior lumen RAA and the distal cystic RAA [13]. Some researchers have studied the right atrial appendage in vivo, using 256-slice spiral CT to divide RAA into 5 types and 9 subtypes in detail, and 256-slice MDCT data can be used to reconstruct the three-dimensional shape of the right atrial appendage, which is more helpful for the safe implantation of pacemakers and the prevention of surgical complications [4]. CT can clearly visualize and measure the right atrial appendage, which is noninvasive and fast. This demonstrates that understanding the anatomy of the RAA is extremely important successful pacemaker atrial lead implantation. Traditional RAA pacing may, however, increase the incidence of atrial fibrillation by exacerbating bilateral dyssynchrony [23].

Relationship between RAA, atrial fibrillation, and thrombosis

Atrial fibrillation a common type of arrhythmia. Compared with those in patients with sinus rhythm, the right atrium, right ventricle, and RAA are larger, and the RAA is less functional in patients with atrial fibrillation [5]. Atrial fibrillation may occur in either the left and right atria; blood in the atrial appendage is in stasis, resulting in thrombosis

during atrial fibrillation. Although the ejection velocity decreases by a similar amount in atrial fibrillation on both sides, thrombi occur more frequently in the left atrial appendage than in the RAA. This may be related to the fact that the RAA has a wider and shallower orifice than the left atrial appendage. Furthermore, the left atrial appendage is lower than the RAA and mainly hook-shaped. It has a narrow connection to the left atrium, and for patients with atrial fibrillation who have not received anticoagulant therapy for a long time, the blood can easily stagnate, promoting thrombosis [24]. Thus, compared with those of the RAA, the structures comprising the LAA promote blood flow stagnation. In terms of thrombus formation, a number of studies [25,26,27] have proven that the number of left atrial appendage lobes and its morphological diversity are closely related to the formation of left atrial appendage thrombi. The existence of many lobes in the RAA was also proposed [2], with the number of left atrial appendage lobes being similar to that of RAA; contrastingly, RAA has a more complex morphology, which may also affect the formation of thrombi in the RAA. However, no detailed studies have fully demonstrated this. Right atrial thrombi may attach to the RAA, causing pulmonary embolism, but this cause is often underestimated [28]. In addition to the usual causes, severe inflammation caused by COVID-19 may also lead to acute thrombosis [29].

Transesophageal echocardiography is usually used to evaluate the RAA in patients with atrial fibrillation. It is highly discernible and unaffected by the chest wall and the lungs; it can also detect newly formed thrombi that are difficult to spot. Therefore, TEE has important clinical value in detecting left and RAA thrombosis. Because of the complex structure of the RAA, with trabeculae, it is often difficult to image the thrombi with TTE. Moreover, it is difficult to evaluated the complete RAA structure using standard 2D-TTE in most cases. A previous study showed that the non-standard right parasternal approach can be used to evaluate the size of superior vena cava and the RAA. However, this technology is rarely mentioned [30].

With the continuous progress and developments in cardiology, some studies have

found that RAA thrombosis is also very dangerous [5]. In persistent atrial fibrillation, the cardiomyocytes of atrial free wall, atrial septum, and atrial appendages are observed to have hibernation-like changes [6], including significant expansion of the cells, resulting in impaired myocardial function. Changes in intracellular components mainly include the loss of muscle fibers and changes in the morphology and size of the mitochondria. There are few studies on RAA in patients with atrial fibrillation; therefore, the structural and functional changes of RAA in atrial fibrillation require further investigation.

Conclusions

Combined with several studies, the morphology of the right atrial appendage is diverse, and it is mainly lobulated. Right atrial appendage has a complex internal structure and is accompanied by trabeculae. It is mainly composed of TC and MP. The area between the RAA orifice and the right atrioventricular annulus is referred to as the RAA vestibule. Three isthmus of different thickness can be seen in the vestibule: inferior RAA, superior RAA, and middle RAA isthmus.

Familiarity with the anatomy of the right atrial appendage is essential for atrial lead implantation. It is also an important site for lead implantation because of easy access to RAA, firm fixation, and the presence of sinus node near RAA. Aliform passive and spiral active leads are generally used as atrial leads. Passive leads are mainly used in conventional permanent pacemaker implantation. However, passive leads have some limitations and they are difficult to remove. Active leads can adjust the pacing position repeatedly, but they may easily lead to myocardial perforation, which is influenced by the thickness of the atrial muscles and the RAA wall.

The structure and morphology of the left and right atrial appendage may lead to blood stasis and thus form thrombosis, but the incidence of thrombosis in the right atrial appendage is lower than that in the left atrial appendage. Because of the complex structure of the RAA, with trabeculae, TEE is usually used to evaluate the RAA in

patients with atrial fibrillation, which can easily identify RAA and is not affected by the chest wall and lung. It can also detect some newly formed thrombi that are difficult to detect. Although TEE technique is commonly used in clinical examination of the right atrial appendage, TEE technique is invasive and may cause some pain to the patients. With the rapid development of CT technology, it can also be used to detect the right atrial appendage, and CT has the characteristics of non-invasive and efficient, but there are few relevant studies.

In conclusion, this study collates the morphological and anatomical data and the clinical value of the RAA. However, there is a lack of imaging studies on the right atrial appendage, and further studies are needed.

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