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Original Article

Transseptal puncture using the Carto-Merge technique: a fluoroscopy-free and echocardiography-free method for real-time observation of needle position in the left atrium

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Abstract: Background: Transseptal puncture (TSP) is a necessary procedure for radiofrequency ablation of atrial fibrillation. At present, many scholars are exploring safe and radiation-free transseptal puncture methods such as transseptal puncture guided by intracardiac echocardiography (ICE) or transesophageal echocardiography (TEE), transseptal puncture guided by a three-dimensional (3D) mapping system, and transseptal puncture guided by intracardiac ultrasound combined with a 3-Dimensional mapping system. Our center tried to use Carto-Merge to guide transseptal puncture and explore a safe and effective transseptal puncture method that does not need ultrasound and X-ray and can observe the position of the puncture needle in the left atrium in real-time. Methods: We conducted a prospective observational study of patients undergoing left atrial septal puncture requiring atrial fibrillation ablation. We fused cardiac computed tomography (CT) images with 3D electroanatomical images of the heart. Two fusion methods were used in each patient: a multi-site fusion of the right atrium and a single-site fusion of the left main. A multi-point fusion of the right atrium was performed first, followed by a single-point fusion of the left main. According to the CT fusion effect, one of the images was selected to guide the transseptal puncture. Results: 52 patients underwent transseptal puncture under Carto-Merge guidance. The first puncture was successful in 50 cases (96%), the second and third puncture was successful in 1 case each (2%), and the incidence of cardiac tamponade was 0. Comparison of the impedance of ablation catheter in left sinus and left main: the impedance of the left sinus was 138.6±18.3 Ω and the impedance of the left main was 212.7±19.4 Ω. The impedance of the ablation catheter in the left main was significantly higher than that in the left sinus ($P<0.001$). Right atrial multi-point fusion had only 70% of points within 2 mm. In 91.2% of patients, the error between three-dimensional electroanatomic and CT anatomy was less than 2 mm with the left main single-point fusion method. Conclusions: Transseptal puncture guided by Carto-Merge is a safe, effective, and radiation-free procedure. The left main single-point fusion can accurately fuse the cardiac CT anatomical structure with the three-dimensional electroanatomic of the heart. Under the guidance of this technology, the atrial septal puncture can observe the position of the puncture needle in the left atrium in real-time, avoiding serious complications such as pericardial tamponade caused by mispunctuation.

Keywords: Transseptal puncture, Carto-Merge, three dimensional electroanatomic mapping, atrial fibrillation, cardiac radiofrequency ablation

Introduction

Transseptal puncture is a very important procedure in radiofrequency ablation of atrial fibrillation. Traditional X-ray-assisted transseptal puncture has been widely used in clinical practice, but safe and radiation-free transseptal puncture is the puncture method that many scholars have been exploring [1]. At present, the commonly used radiation-free transseptal puncture methods are transseptal puncture guided by intracardiac echocardiography [2] or transesophageal echocardiography [3], transseptal puncture guided by a three-dimensional

(3D) mapping system [4] and transseptal puncture guided by intracardiac echocardiography combined with 3-Dimensional [5]. The medical cost of transseptal puncture guided by intracardiac ultrasound is high, so it is not suitable for universal popularization, especially in developing countries. Transseptal puncture under the guidance of transesophageal ultrasound often requires intubation anesthesia, which is easy to cause esophageal injury and increases the risk of esophageal leakage in the left atrium [6]. 3-Dimensional Transseptal Puncture is also the early commonly used transseptal puncture method in this center. However, for patients with a small left atrium, 3-Dimensional Transseptal Puncture has certain risks, which may penetrate the posterior wall of the left atrium. Because it is impossible to accurately determine the position of the left atrial edge and aortic sinus.

Carto-Merge is a software that fuses cardiac computed tomography (CT) images with 3-Dimensional images of the heart. It was early used to guide radiofrequency ablation treatment of atrial fibrillation, which is helpful to judge whether there is an anatomical abnormality in pulmonary vein vessels [7, 8]. Some scholars also used CT fusion technology to guide ablation catheters to pass through the patent foramen ovale for pulmonary vein ablation in patients with atrial fibrillation. This study attempted to investigate the use of cardiac CT images fused with 3-Dimensional images to guide transseptal puncture without the need for fluoroscopy and intracardiac or esophageal echocardiography.

Research methods

Study population

Inclusion criteria: 52 patients underwent radiofrequency ablation for atrial fibrillation for the first time, all of whom were symptomatic and did not respond well to more than one antiarrhythmic drug.

Exclusion criteria: Patients with stenosis of the left main coronary artery, proximal anterior descending coronary artery, and proximal circumflex coronary artery; Patients with severe stenosis, occlusion, or thrombosis from inferior vena cava to bilateral femoral veins; Severe stenosis, occlusion or dissection of the ascending aorta to the femoral artery; Severe cardiac, hepatic and renal insufficiency.

The study protocol was approved by the Ethics Committee of the Affiliated Hospital of Guangdong Medical University and each patient's consent was obtained.

Fusion methods

(1) Right atrial multi-point fusion; (2) Left main single point fusion. A multi-point fusion of the right atrium was performed followed by a single-point fusion of the left main. According to the CT fusion effect, one of the images was selected to guide the transseptal puncture.

CT examination of the left atrium

The CT instrument was Siemens dual-source CT (SOMATOM Force). The patient was in the supine position, with both hands flat, and held breath at the end of expiration. Scanning range: from the upper edge of the aortic arch to the lower edge of the diaphragm. Scan conditions: 100 kv/Sn140 kv, iodine concentration 350-400 mg/ml, start-up delay time 20-25 ms.

Fusion of CT image and 3-Dimensional electroanatomic images

Import the CT image in Digital Imaging and Communication of Medicine (DICOM 3.0) format into the Three-dimensional electrophysiological mapping instrument (CARTO 3) host, use Carto-Merge software to cut the CT image, and finally extract the left atrium and right atrium; Left and right ventricles; pulmonary artery, ascending aorta (including left main) and descending aorta; Superior vena cava; pulmonary veins; coronary veins; and surface marker steel balls on the sternal surface.

Local anesthesia was used, and then a 6F sheath was placed through the left axillary vein puncture, an 8F sheath was placed through the right femoral artery puncture, and an 8.5F SL1 sheath was placed through the femoral vein puncture. Send the PENTRAY mapping catheter to the ascending aorta, adjust the modeling resolution to 20, and perform rapid modeling on the ascending aorta and aortic sinus. Send the PENTRAY mapping catheter to the right atrium to perform modeling on the right atrium and superior and inferior vena cava.

Figure 1. The aorta and left trunk were constructed, and the marking points were taken in the left trunk, and the corresponding marking points were taken in the left trunk of CT angiography (CTA).

Send the ablation catheter to the aortic root and adjust the ablation catheter to the left main trunk. Observe the potential, impedance, and pressure of the ablation catheter. The potential at the tip of the ablation catheter has A wave and V wave, and the impedance suddenly increases by more than 50 Ω, indicating that the tip of the ablation catheter has entered the left main trunk. Collect the electroanatomical marker point here. During the operation, the pressure at the tip of the ablation catheter shall be controlled within 10 g as far as possible.

Put the ablation catheter into the superior vena cava, and take an electroanatomical marker point at the middle and lower part of the right atrial side of the atrial septum. During the operation, the pressure at the tip of the ablation catheter shall be controlled within 10 g as far as possible.

Left main single-point fusion: Determine the position of the left main mar point of the three-dimensional CT image according to the depth and vector direction of the tip when the ablation catheter at the left main collects the electroanatomical marking point, and fuse the left main marking point of the three-dimensional CT image with the left main mar point of the electroanatomical marking point; Multi-point fusion of right atrium: According to the position of three electroanatomical marker points on the three-dimensional electroanatomic of the right atrium, the corresponding points are marked on the three-dimensional CT image by visual inspection method, and then multi-point fusion is performed.

The marking of the fossa ovalis and the needle visualization during transseptal puncture was performed regarding our previous method [6] and the method reported by Yu [9]. At the time of the transseptal puncture, the left window was used with the left anterior oblique 45° to display CT fusion images of the right atrium and left atrium; The right view is at 135° left front oblique (LAO) and shows a CT fusion of the right atrium, left atrium, and aorta. The puncture needle and puncture sheath can be seen to "jump" during the process of pulling down from the superior vena cava along the interatrial septum, and the puncture needle can be seen to enter the lower edge of the pre-marked oval fossa area. At this time, the puncture needle is slowly pushed to the left atrium. In the process of pushing, the direction of the puncture needle shall be appropriately adjusted according to the distance between the puncture needle and the aorta and posterior wall of the left atrium, to avoid accidentally puncturing the aorta and posterior wall of the left atrium. After the puncture needle and inner sheath enter the left atrium, withdraw the puncture needle and feed the guide wire. The guide wire is displayed in the same way. After the guide wire is fused into the left superior pulmonary vein, the whole guide wire is fed into the puncture sheath and enters the left atrium.

Right atrium and coronary sinus modeling to verify CT fusion effect Under the guidance of the CT image, send the decapolar coronary sinus electrode from the left axillary vein to the great cardiac vein, send the ablation catheter from the femoral vein to the great cardiac vein of the coronary sinus, adjust the red surface of the ablation catheter tip to point to the left atri-

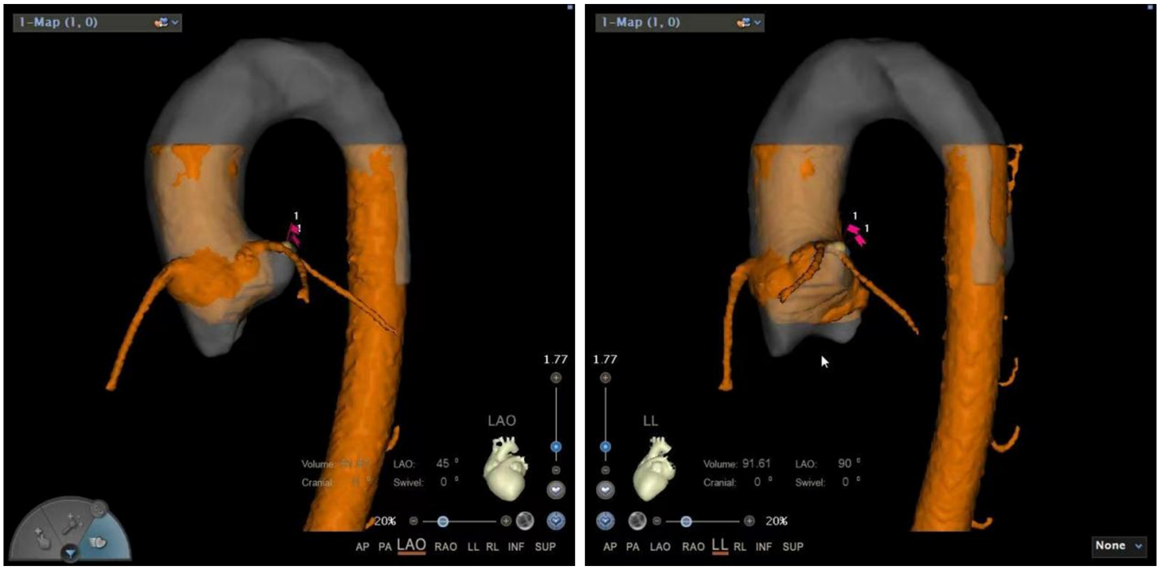

Figure 2. Effect after single point fusion of the left trunk, showing high fusion of the ascending and descending aorta.

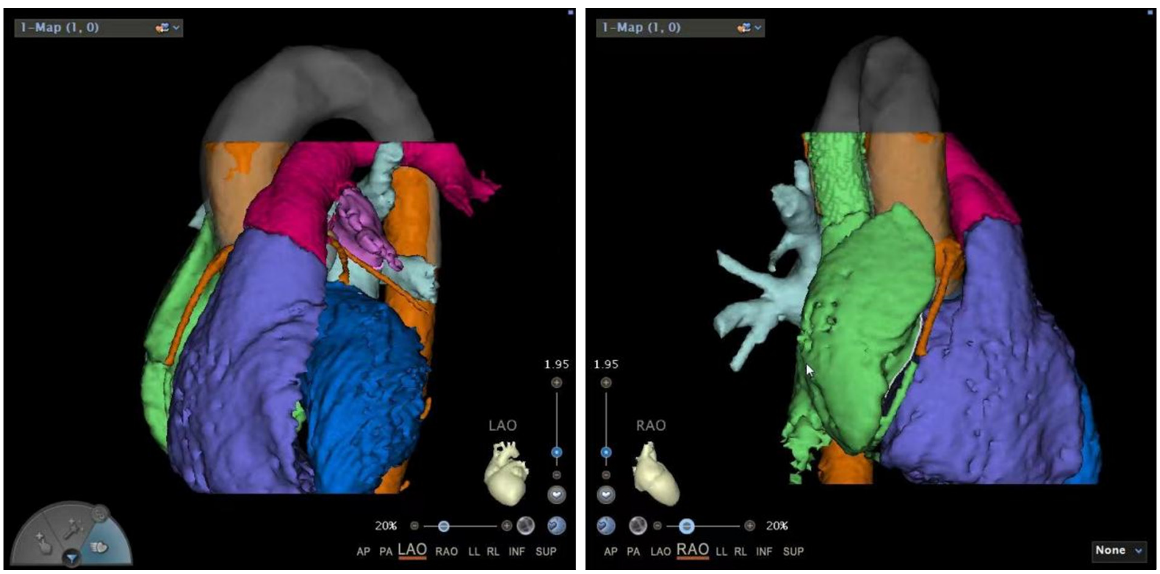

Figure 3. Map of other chambers of the heart imported after single point fusion of the left trunk.

um, and the tip pressure is within 10 g. Take 4 electroanatomical markers from the distal end to the proximal end of the coronary sinus and 6 electroanatomical markers around the tricuspid annulus. Good fusion was defined as the position of the electroanatomical markers in the coronary sinus and tricuspid annulus within 2 mm of the CT anatomical position of the left atrium and tricuspid annulus. 2-4 mm is moderate fusion; greater than 4 mm is poor fusion.

Statistical treatment

In this study, SPSS 19.0 was used for statistical analysis of sample data. One-sample t test was used for measurement data in two groups, and One-way ANOVA was used for measurement data in three groups. Qualitative data were calculated by Chi-square test. $P<0.05$ indicates statistical difference. The graphic software was Carto-Merge software.

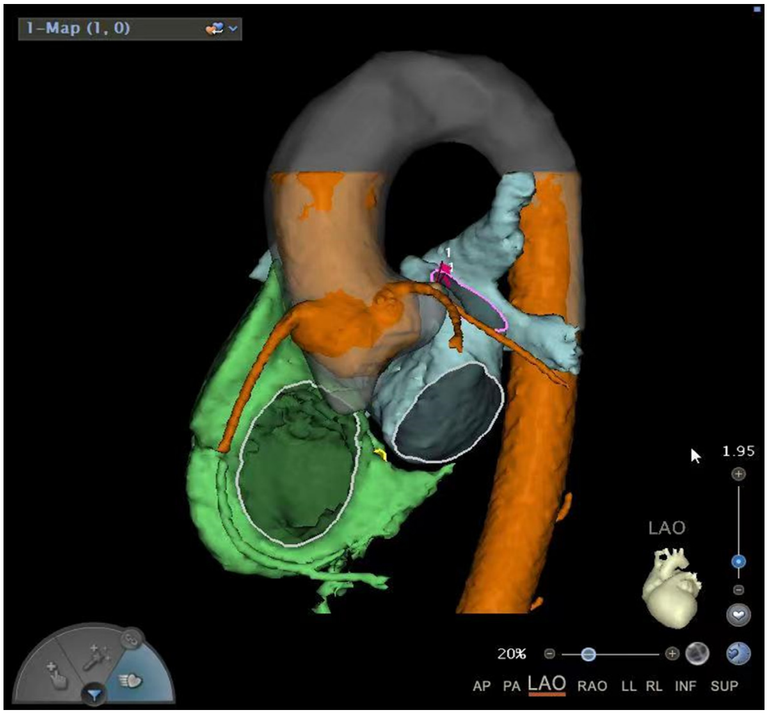

Figure 4. Left and right atrium diagram imported after single point fusion of the left trunk.

Results

Among the 52 patients, 36 were males, with an average age of 62.3±13.6 years. There were 16 females with an average age of 63.5±12.7 years. There were 40 cases of paroxysmal AF and 12 cases of persistent AF. All patients were randomly divided into two groups (26 patients per group), one using right atrial multi-point fusion and the other using left main single point fusion. Left main single dot fusion tags aortic enhancement CT and three-dimensional measurement corresponding position as shown in **Figure 1**. **Figure 2** shows the effect of single point fusion of the left trunk. In addition, a single point fusion of the left main trunk led to the left and right atria and other ventricles, as shown in **Figures 3**-**5**.

The 3D diagram of right atrial multi-point fusion construction is shown in **Figure 6**.

During the single point ablation of the left main artery, the endoaortic ablation catheter impedance was 164 Ω, as shown in **Figure 7**. However, when the ablation catheter entered the left spindle, the impedance increased sharply to 280 Ω (**Figure 8**). It can be seen from the fusion image that the puncture needle was successfully entered the atrial septum. Impedance measurement at this time showed that the impedance of left sinus was 138.6±18.3 Ω compared with that of left main trunk: the impedance of left sinus was 138.6±18.3 Ω, and the impedance of left main trunk was 212.7±19.4 Ω. The impedance of left internal trunk ablation catheter and left internal sinus ablation catheter was significantly increased (**Figure 9**). The three-dimensional reconstruction map of atrial septum under CT mode can be successfully constructed by impedance, which can realize the accurate navigation of atrial septal puncture (**Figure 10**). Compared with adverse effects of left atrial angiography or transesophageal echocardiography, the new method enables patients to have a better surgical experience.

Finally, we sort out the data, as shown in **Table 1**. On the basis of the total score of 520, the proportion of good fusion using the single point fusion method of left main trunk was as high as 91.2%, while the multi-point fusion method of right atrium was only 70%. In 91.2% of patients, the error between 3D electroanatomic and CT anatomy was less than 2 mm with the left main single-point fusion method. The left main single point fusion method did not show poor fusion, while the right atrial multi-point fusion method showed poor fusion of 9.4%, indicating that the left main single point fusion method had better advantages and accuracy than the traditional multi-point fusion method.

Discussion

At present, most of the transseptal puncture techniques are guided by intracardiac ultrasound or potential mapping of fossa ovalis, and the CT fusion method has not been reported. The atrial septal puncture guided by either

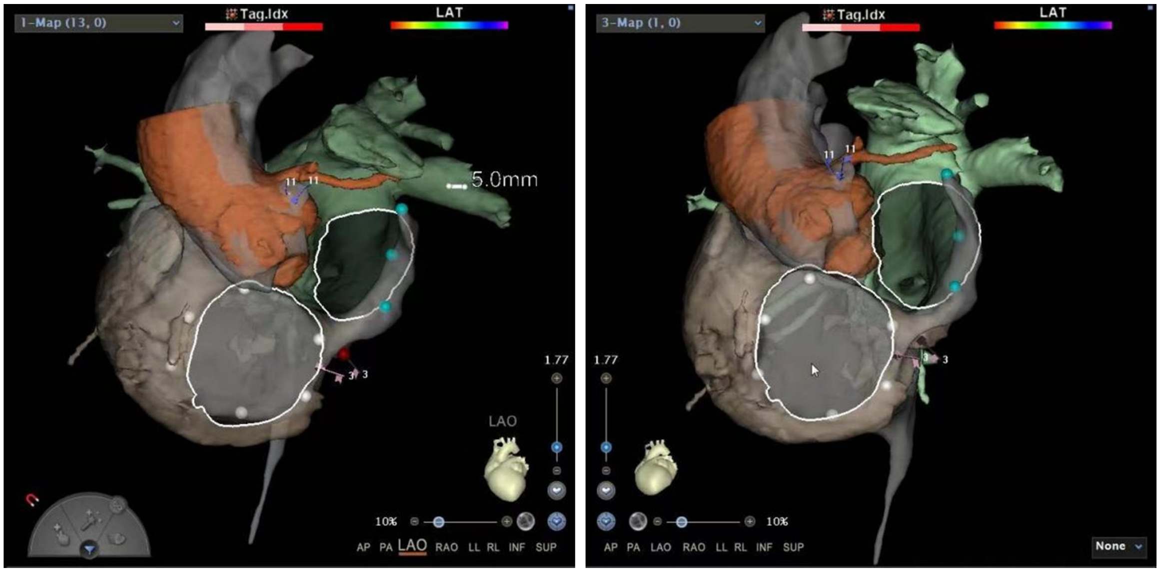

Figure 5. Single-point fusion of the left trunk.

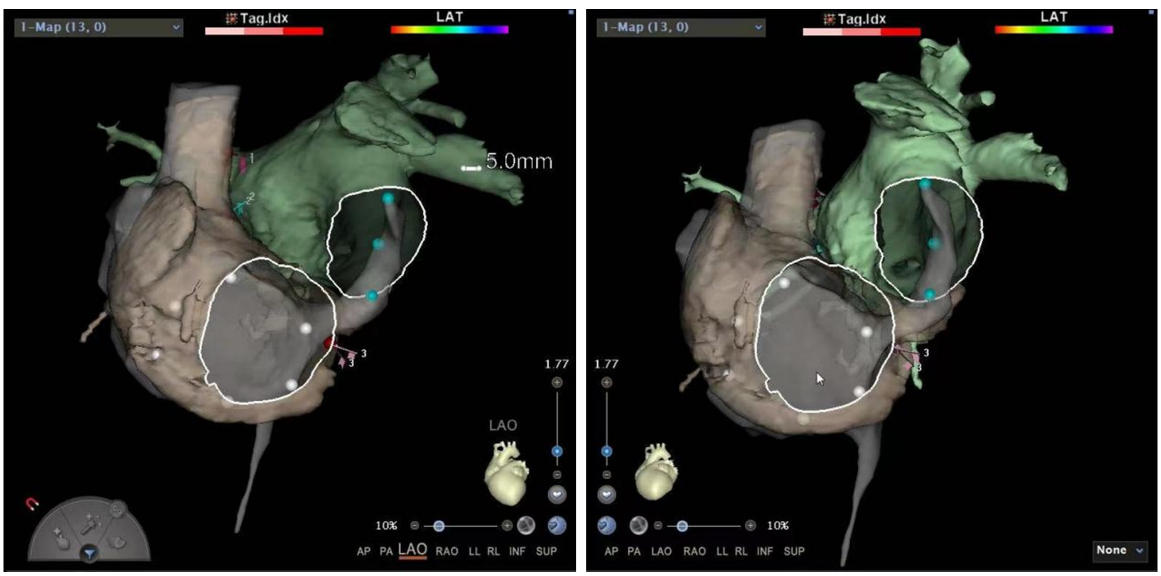

Figure 6. Multipoint fusion in the right atrium.

intracardiac ultrasound or the potential of the fossa ovalis has limitations. The intracardiac ultrasound is difficult to continuously observe the position of the puncture needle tip due to the scanning sector problem of the ultrasonic probe, and the position is often delayed; After the puncture needle reaches a certain position, the ultrasound is used for checking whether the tip of the puncture needle is in the safe area of the left atrium. The method of using the fossa ovalis potential mapping method to guide the atrial septal puncture can display the position of the puncture needle tip; however, because the model of the left atrium has not been established, leading to a large blind area, which makes it hard to judge whether the puncture needle passes through the area of the left atrium.

The most important thing about atrial septal puncture is to avoid accidentally puncturing the aorta, posterior wall of the left atrium, and top of the left atrium. In the past, in order to improve the success rate of atrial septal puncture, inva-

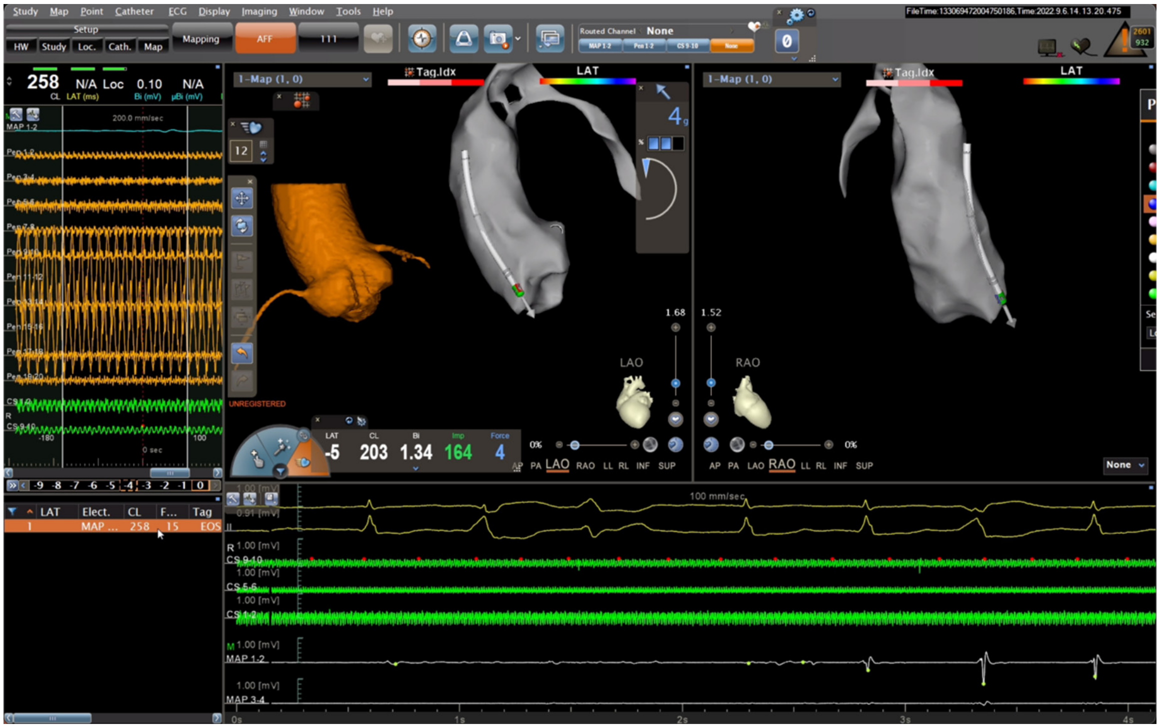

Figure 7. The impedance of the intraaortic ablation catheter was 164 Ω.

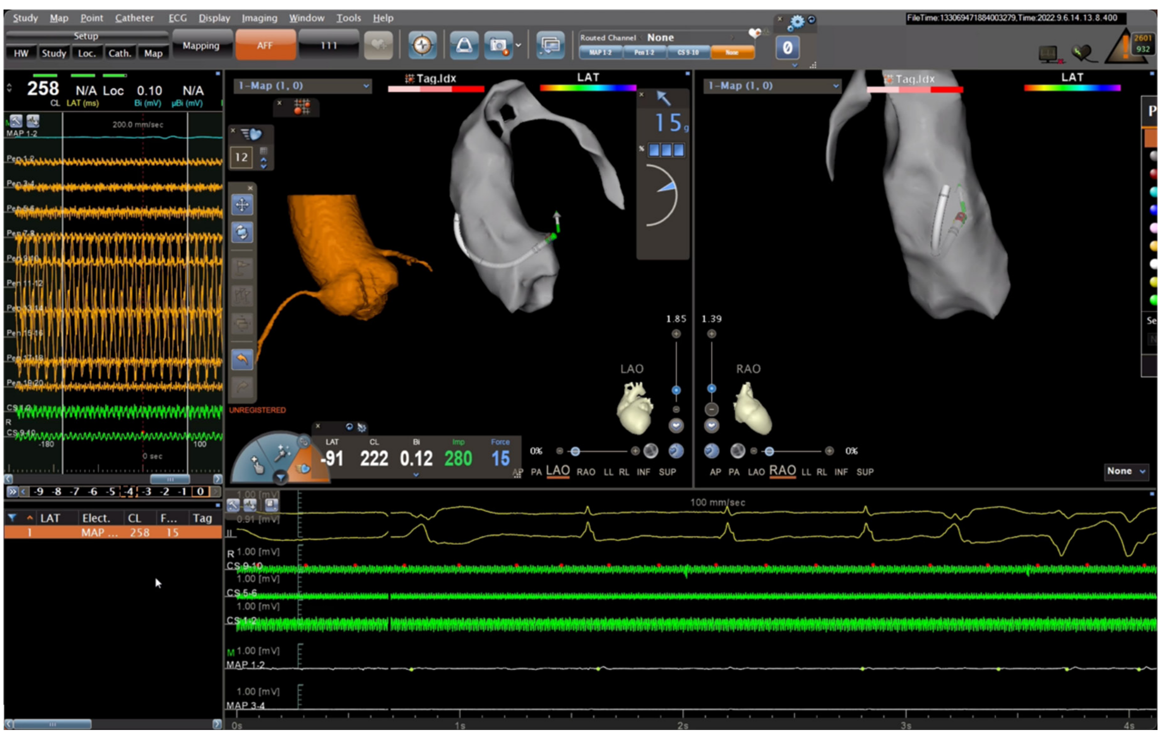

Figure 8. The impedance was suddenly increased to 280 Ω after the ablation catheter entered the left main shaft.

sive examination methods were used, such as Defense Shipping Authority (DSA) left atrial angiography and transesophageal echocardiography evaluation. During the evaluation

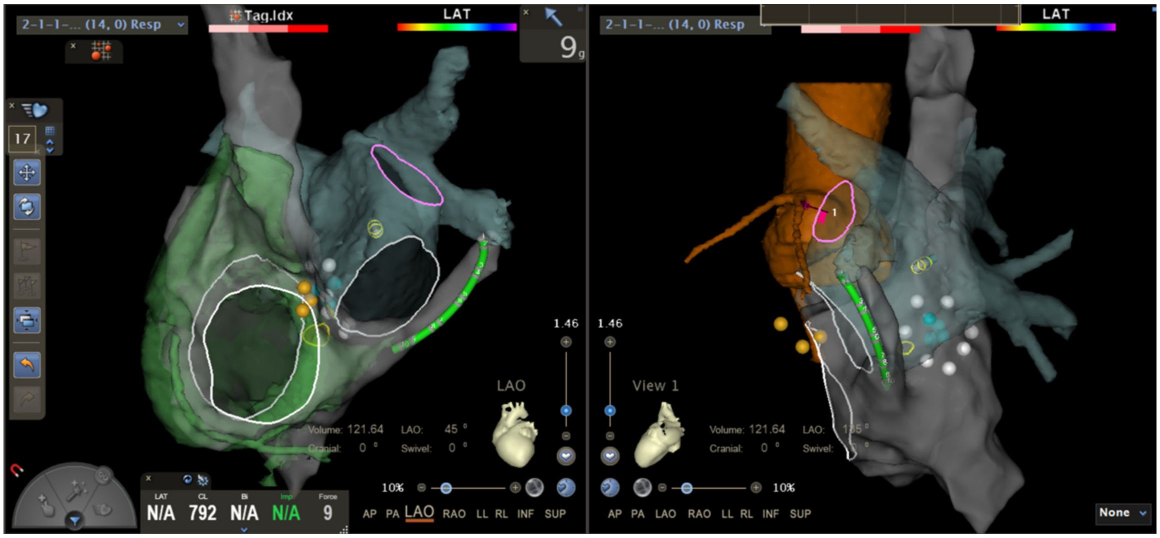

Figure 9. From the fusion image, the bright needle tip moving from the superior vena cava along the atrial septum to the fossa ovalis, with the direction pointing to 4 o'clock. A "jump" phenomenon often indicates the needle has entered the fossa ovalis. By slowly advancing the needle and sheath, a "loss" of resistance can be felt. When aspirating with a syringe, the presence of bright red blood confirms that the needle has traversed the septum. At a left anterior oblique (LAO) angle of 45°, the distance between the needle tip and both the roof and posterior wall of the left atrium can be clearly seen. At a LAO angle of 135°, the distance from the needle tip to the anterior wall of the left atrium is visible.

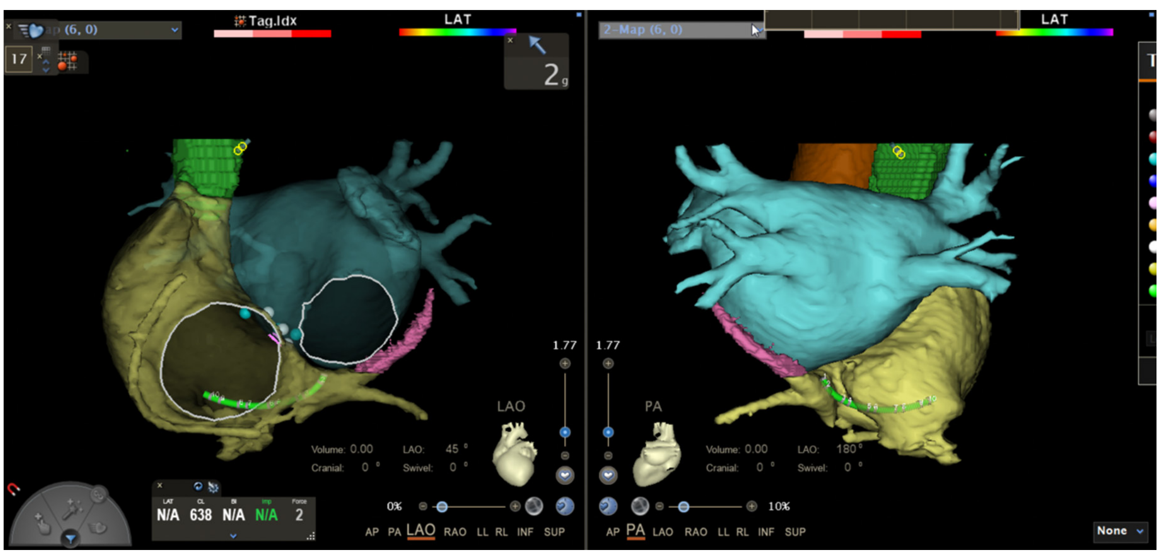

Figure 10. The guide wire was advanced to the left upper pulmonary vein through the atrial septal puncture inner sheath, followed by the advancement of the entire atrial septal puncture inner sheath to the left upper pulmonary vein. After a single-point fusion of the left trunk, atrial septal puncture can be performed directly using the CT mode.

process, patients were prone to hiccough and other adverse reactions, with poor surgical experience [10, 11]. In this study, CT fusion 3D image assisted atrial septal puncture was performed. The distance between the position of the atrial septal puncture needle and the aorta, the posterior wall of the left atrium, and the top of the left atrium can be seen on the CT fusion 3D image, to ensure the safety of the atrial septal puncture. In our study, the success rate of the initial puncture was 96% and the final puncture success rate was 100% without complication of pericardial tamponade, suggesting that the use of the CT fusion method to

Table 1. Comparison of the degree of fusion between right atrial multipoint fusion and left trunk single point fusion method

	Left main trunk single-point fusion group	Right atrial multipoint fusion group	P
Total number of points (s)	520	520	
Good fusion (point/%)	469 (91.2%)	364 (70%)	<0.01
Fusion Medium (point/%)	51 (9.8%)	107 (20.6%)	<0.01
Poor fusion (point/%)	0	49 (9.4%)	<0.01

guide transseptal puncture is safe and effective, and the position of the transseptal puncture needle can be tracked intuitively to avoid serious complications.

The most important thing about this method is to ensure the accuracy of CT fusion. There are two methods of CT fusion: multi-point fusion and single-point fusion [12]. The multi-point fusion method involves selecting more than three marked points at corresponding positions in both 3D electroanatomic and CT anatomical images, and then fusing them. This approach helps address potential inaccuracies caused by the presence of a false lumen during 3D modeling. Since the marked points in both 3D electroanatomic and CT anatomical images are identified by visual inspection, errors can easily occur, leading to an inaccurate representation of the left atrial position [13]. Previous studies have found that 70% of the points in the multi-point fusion through the right atrium have errors within 2 mm [14, 15]. The single-point fusion method is to fuse one point at the corresponding position of 3D electroanatomic and CT anatomy respectively. This method requires a relatively fixed and specific anatomical structure. Therefore, in this study, the left main trunk was used as the marker point, and the advantages of the left main trunk as the marker point are as follows: The left main trunk is small in space, and the 3D electroanatomical false lumen is also small. The impedance might be significantly increased when entering the left main. Most of the impedance suddenly increases by more than 50 Ω from the left coronary sinus to the left main. Together, these results suggest that with the left main single-point fusion method, the error between the cardiac 3D electroanatomic and CT anatomical position was less than 2 mm in 91.2% of patients, so the left main single-point fusion method could achieve accurate fusion.

Conclusion

Single-point fusion of the left main trunk can accurately fuse the cardiac CT anatomical structure with the 3D electroanatomic of the heart. Transseptal puncture under the guidance of this technology can observe the position of the puncture needle in the left atrium in real-time, avoiding serious complications such as pericardial tamponade caused by mispunctuation.

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Disclosure of conflict of interest

None.

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