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Original Article

Elongated ascending aorta predicts a short distance between his-bundle potential recording site and coronary sinus ostium ☆

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STRUCTURED ABSTRACT

Background: When performing catheter ablation of atrioventricular nodal reentrant tachycardia (AVNRT), it can be difficult to maintain a safe distance from the His recording site to avoid AV block in patients with a short distance between this recording site to the coronary sinus (CS) ostium (small triangle of Koch [TOK]). In this study, we sought to identify parameters predicting small TOK and test these parameters in patients undergoing AVNRT catheter ablation.

Methods: Twenty-eight patients who underwent catheter ablation of atrial fibrillation using a three-dimensional (3D) electroanatomical mapping system (EAM) with computed tomography (CT) merge (23 males; mean age, 65.8 ± 12.1 years) were included. The shortest distance between the CS ostium and His recording sites (His-CSd) was measured on the EAM. Aortic (Ao) unfolding in chest X-ray scan, Ao angle to the LV, Ao length, Ao to the right ventricular distance, size of the Valsalva in the CT scan, and parameters of echocardiogram were evaluated. The identified parameters were subsequently tested as predictors for small TOK in patients undergoing AVNRT ablation.

Results: The size of TOK was associated with Ao length ($r = -0.70$, $p < 0.01$), left ventricular end-systolic dimension (LVDs) ($r = -0.51$, $p < 0.01$), and Ao unfolding. In patients with AVNRT, only Ao unfolding predicted a smaller TOK.

Conclusions: Small TOK was associated with longer Ao, larger LVDs, and Ao unfolding. Of these, Ao unfolding was associated with smaller TOK in patients with AVNRT.

1. Introduction

Catheter ablation of atrioventricular nodal reentrant tachycardia (AVNRT) is a highly successful treatment based on targeting the slow pathway [1,2]. To reduce the risk of AV block, radiofrequency applications are usually made below the level of the coronary sinus (CS) roof. The AV node is located at the base of the right atrial septum, at the apex of Koch's triangle (TOK). TOK is bordered anteriorly by the insertion of the septal leaflet of the tricuspid valve and posteriorly by the fibrous tendon of Todaro. In the pediatric population, TOK dimensions are best predicted by body surface area [3,4] or age [5], but these parameters are not useful in adults [6]. A short distance from the His recording site to the ostium of CS (His-CSd) is often encountered in elderly patients. Therefore, we sought to identify variables associated with small TOK using echocardiogram, chest X-ray scanning, and chest computed tomography (CT), and subsequently validate these variables in patients undergoing catheter ablation of AVNRT.

2. Materials and methods

2.1. Step 1: Identification of parameters

Consecutive patients who underwent catheter ablation of atrial fibrillation or structural heart-related ventricular tachycardia using a three-dimensional (3D) electroanatomical mapping system (EAM) with a pre-procedure cardiac CT for image integration and transthoracic echocardiography from December 2013 to April 2014

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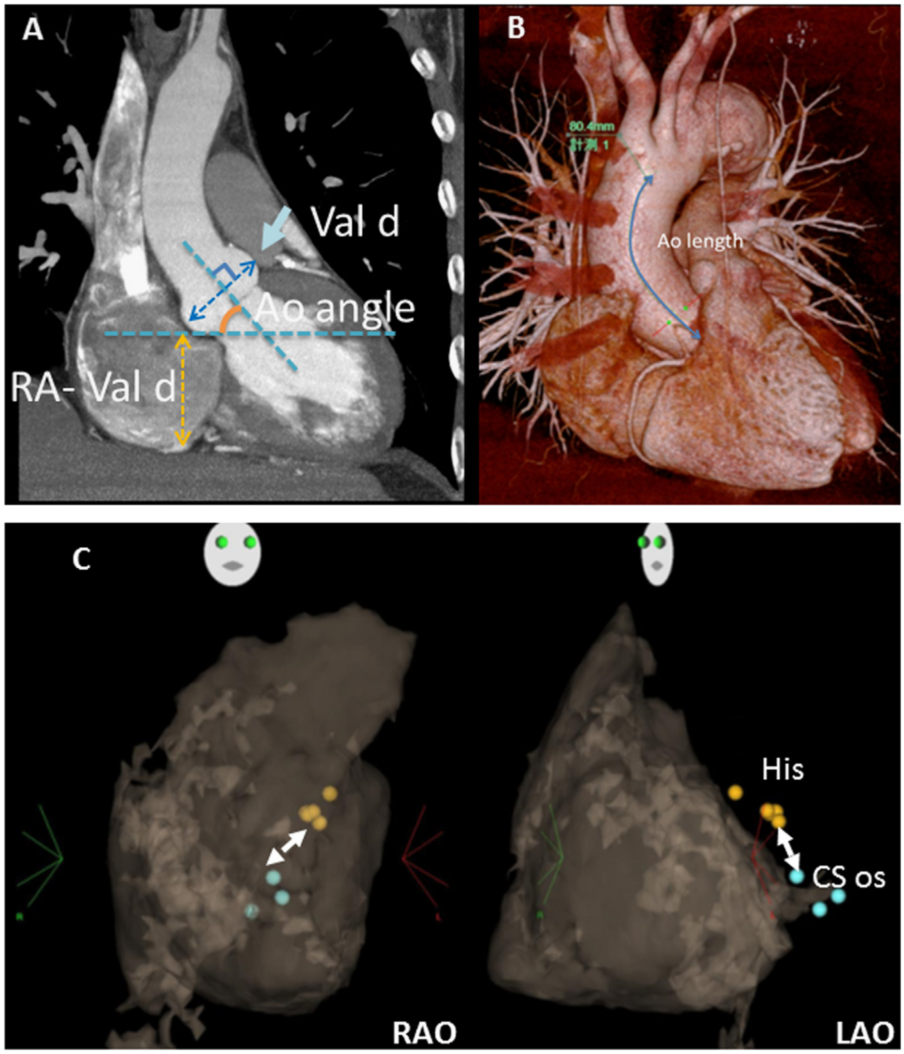

Fig. 1. Computed tomography measurements and measurements on the electroanatomical mapping system. (A) The Ao angle is the ascending aorta angle to the horizontal line. RA-Val d is the distance of the lowest point of the sinus of Valsalva to the floor of the right atrium. (B) The Ao length is defined as the length of the ascending aorta from the sinotubular junction to the right carotid artery. (C) The distance between the His recording site (yellow tags) and coronary sinus ostium (blue tags) was measured.

were included in this study. All patients had a chest X-ray scans performed on admission, as is routine in our clinical practice.

2.1.1. Echocardiography

On M-mode echocardiogram, the left ventricular dimension at end-diastole (LVDd), end-systole (LVDs), and maximal left atrial diameter (LAD) were measured. LV end-diastolic (EDV) and end-systolic volumes (ESV) were calculated from the apical two- and four-chamber views using a modified Simpson's method, and the LV ejection fraction was calculated as follows: $(EDV-ESV)/EDV \times 100$. The mitral inflow patterns were evaluated by peak early diastolic velocity (E), peak atrial systolic velocity (A), E/A ratio, and deceleration time (DcT). In addition, the mitral annular velocities on tissue Doppler (E/e′) were evaluated.

2.1.2. CT measurements

We measured the tilt angle of the aorta to the horizontal line (Ao angle), the distance between the bottom of the right atrium and sinus of Valsalva (RA-Val d), and the diameter of the sinus of Valsalva (Val d) (Fig. 1, panel A). The length of the ascending Ao from the sinotubular junction to the right carotid artery as measured at the center of the ascending Ao was defined as the Ao length (Fig. 1, panel B).

2.1.3. Chest X-ray scanning

With advancing age, the thoracic aorta loses its elasticity and expands both in cross-sectional area and in length. Therefore, the ascending aorta dilates and displaces from the central position towards a more lateral position, and the curvature of the aortic arch decreases. In this study, obtained chest X-ray images were read by two physicians and judged if these findings were present.

2.1.4. Measurements on the electroanatomical mapping system

The locations of the His recording site were tagged using the EAM (Carto system, Johnson & Johnson, Diamond Bar, USA), and merged with a pre-acquired CT image. The CS ostium was identified on the CT image, and the shortest distance between the His recording site to the CS ostium (His-CSd) was measured (Fig. 1, panel C).

2.2. Step 2: Validation of identified parameters in patients with AVNRT

In a subsequent group of patients, we evaluated the parameters associated with small TOK size in consecutive patients who underwent AVNRT ablation from January 2014 to December 2015.

Table 1
Patient characteristics for Step 1 analysis (n=28).

	Mean ± SD
Age, years (mean ± SD)	65.8 ± 12.1
Men, n (%)	23 (82)
BSA, m^2 (mean ± SD)	1.74 ± 0.2
Diabetes mellitus, n (%)	5 (18)
Dyslipidemia, n (%)	5 (18)
Hypertension, n (%)	14 (50)
Congestive heart failure, n (%)	5 (18)
Systolic blood pressure, mmHg (mean ± SD)	129 ± 18
Diastolic blood pressure, mmHg (mean ± SD)	78 ± 12

BSA: body surface area, SD: standard deviation.

2.3. Statistical analysis

Data is expressed as mean ± standard deviation (SD). Parametric correlation coefficients were used, as variables were normally distributed by the Kolmogorov-Smirnov test. Pearson correlations were performed to determine the association between the His-CSd and variables. Partial correlations were used to assess the relationship while controlling for sex, age, and history of hypertension. All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R 2.13.0 (R Foundation for Statistical Computing, Vienna, Austria). More precisely, EZR is a modified version of R Commander (version 1.6 to 3) that is designed to add statistical functions frequently used in biostatistics [7].

3. Results

3.1. Step 1: Identification of parameters by CT, chest X-ray scanning, and echocardiogram

Twenty-eight patients were included in the Step 1 analysis (23 males, mean age: 65.8 ± 12.1 years old). Table 1 summarizes patients' clinical characteristics. In these patients, His-CSd inversely correlated with the LVDs and Ao length, and correlated with the CS diameter (LVDs: $r = -0.51$, $p < 0.01$; Ao length: $r = -0.70$, $p < 0.01$; CS diameter: $r = 0.52$, $p < 0.01$); the other parameters did not show any significant correlation (Table 2). Fig. 2 (panel A–C) shows two patients, one with a short and the other with a standard His-CSd. The patient with the short His-CSd showed aortic elongation on chest X-ray scanning, and a shift in the His recording site to the lower right atrium was observed. Fig. 2 (panels D, E) shows the relationship between the His-CSd and Ao length (panel D) and LVDs (panel E). To identify the indices associated with the His-CSd, a partial correlation analysis was conducted, which showed that the His-CSd was associated with the LVDs, Ao length and CS diameter (LVDs: $r = -0.60$, $p < 0.05$; Ao length: $r = -0.77$, $p < 0.01$; CS diameter: $r = 0.56$, $p < 0.05$). A partial correlation analysis was conducted in order to control for the effects of sex, age, and history of hypertension.

Six patients were positive for Ao unfolding, and His-CSd was found to be smaller in these patients than in those without Ao unfolding (14.7 ± 3.9 vs. 22.2 ± 6.7 mm, $p < 0.05$). There were no significant correlations between the His-CSd and other parameters.

3.2. Step 2: Testing the parameters in patients with AVNRT

Twenty-five consecutive patients who underwent catheter ablation of AVNRT from January 2014 to December 2015 (10 males, mean age: 50.3 ± 18.4 years old) were included to test the identified parameters for their association with small TOK (Tables 3, 4).

Table 2
Pearson correlation analysis between His-CSd and demographic data (Step 1).

Measurement	Mean ± SD	Correlation coefficient	Partial correlation coefficient
His-CS distance, mm	20.75 ± 6.9		
Age, years	65.8 ± 12.1	0.028	
BSA, m^2	1.74 ± 0.20	−0.12	
CTR	0.51 ± 0.045	0.040	
CT data			
Ao angle, degree	44.4 ± 9.9	0.14	
Ao length, mm	82.8 ± 9.52	−0.70†	−0.77†
RA-Val d, mm	37.4 ± 11.6	0.17	
Valsalva diameter, mm	38.3 ± 4.3	−0.31	
CS diameter, mm	12.7 ± 4.4	0.52†	0.56‡
Echocardiographic data			
LVDd, mm	46.0 ± 4.8	−0.24	
LVDs, mm	28.1 ± 4.5	−0.51†	−0.60‡
LAD, mm	36.5 ± 5.12	0.025	
LVEF, %	63.8 ± 5.89	0.24	
Ao diameter, mm	33.4 ± 4.27	0.0081	
DcT, msec	195.8 ± 54.7	−0.066	
E/A	1.07 ± 0.4	0.17	
E/e′	11.02 ± 2.79	−0.11	

BSA: body surface area, CTR: cardio-thoracic ratio, CT: computed tomography, Ao: aorta, RV: right ventricle, LVDd: end-diastolic left ventricular dimension, LVDs: end-systolic left ventricular dimension, LAD: left atrial diameter, LVEF: left ventricular ejection fraction, RA-Val d: distance of the lowest point of the sinus of Valsalva to the floor of the right atrium, DcT: deceleration time, E: peak early diastolic velocity, A: peak atrial systolic velocity, e′: peak early diastolic motion velocity.

† p value < 0.01.
‡ p value < 0.05.

These patients did not undergo CT scan; therefore, Ao length was not evaluated. Patients with Ao unfolding had smaller TOK than did patients without Ao unfolding (16.4 ± 2.5 vs. 21.9 ± 3.9 mm, $p < 0.01$). LVDs did not show any correlation with the size of TOK.

In the patients who underwent ablation of AVNRT, those 50 years of age or older had smaller His-CSd (17.9 ± 3.5 vs. 22.2 ± 4.2 mm, $p < 0.05$), larger Ao diameter (31.5 ± 5.8 vs. 25.7 ± 2.2 mm, $p < 0.01$), and decreased E/A (0.90 ± 0.2 vs. 1.7 ± 0.6 $p < 0.01$), as compared with patients younger than 50 years of age. In addition, seven patients were found to have Ao unfolding in the older group, but none were observed to have such unfolding in the younger group (Table 5).

Furthermore, patients were also divided in larger His-CSd vs. smaller His-CSd groups. Cutoff was set at 19 mm, based on the previous study of Irie [8]. Patients with smaller TOK were typically older (62.0 ± 14.6 vs. 43.3 ± 17.9 years old, $p < 0.05$), had larger Ao diameters (31.0 ± 4.0 vs. 26.8 ± 3.1 mm, $p < 0.05$), and reduced E/A values (1.0 ± 0.3 vs. 1.5 ± 0.7, $p < 0.01$) (Table 6).

4. Discussion

This study showed that a small TOK correlated with an elongated ascending aorta, larger LVDs, and aortic unfolding. Of these parameters, the validation study showed that aortic unfolding, which could easily be diagnosed on chest X-ray scanning, in particular predicted small TOK. Clinical electrophysiologists have in the past reported that the size of TOK is smaller in elderly patients, but no previous study has determined either an explanation or demonstrated predictive factors for small TOK. One study showed that the size of TOK correlated poorly with body length, body weight, and body surface area in adults [6]. Thus, our current findings will be of benefit in predicting TOK size and in identifying

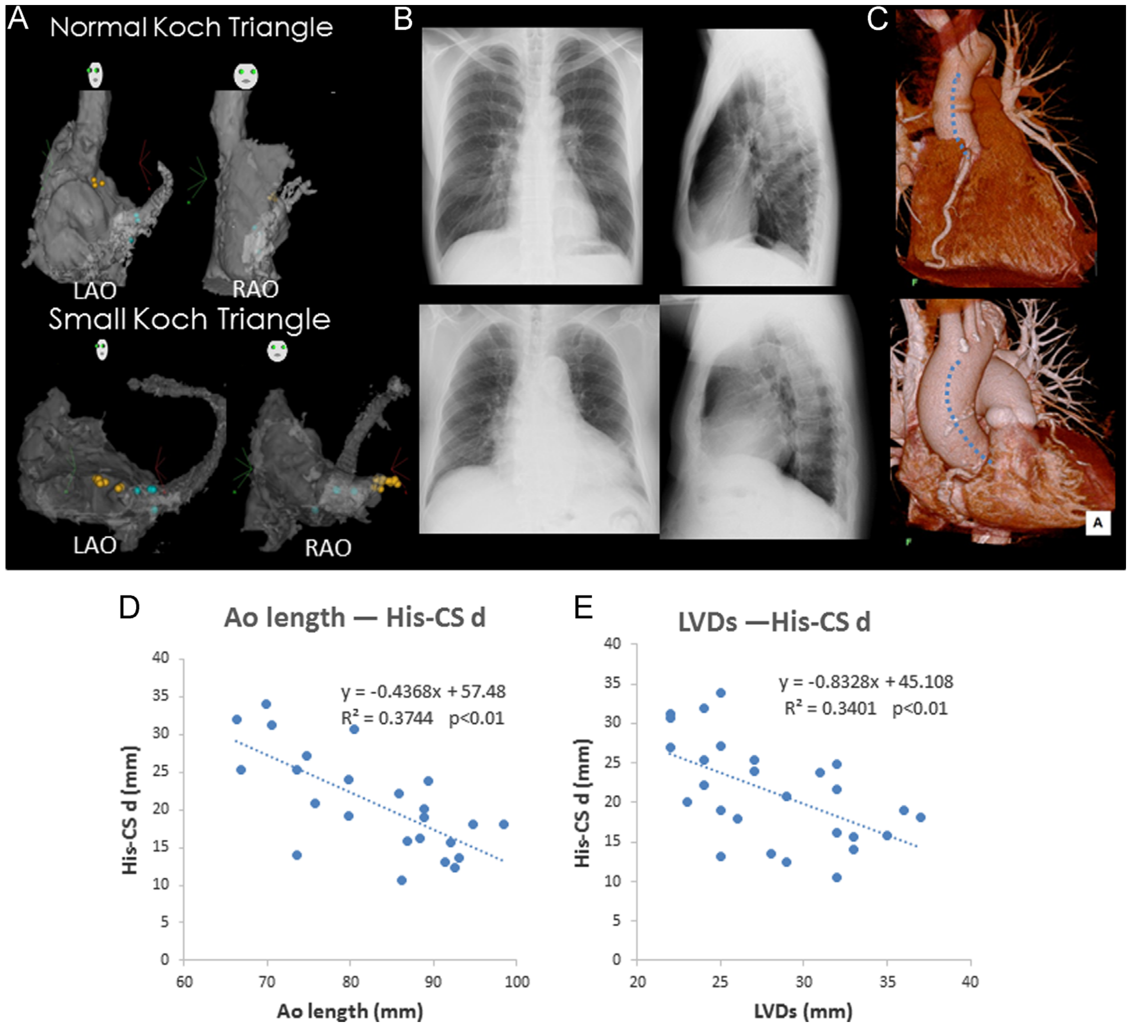

Fig. 2. A–C) Patients with a normal size (upper panels) and with a small size (lower panels) Koch's triangle. Panel A shows the electroanatomical mapping with yellow tags at the His recording sites and blue tags for the ostium of the coronary sinus. Panel B shows the chest X-ray scan (posterioranterior and lateral). The lower chest X-ray shows aortic unfolding. Panel C shows the 3D CT. An elongated aorta pushing against the His area can be appreciated. D, E). The relationship between the His-CSd and Ao length (panel D) and LVDs (panel E). The His-CSd is inversely related to the Ao length and LVDs.

Table 3
Characteristics of patients with AVNRT in Step 2 (n=24).

	Mean ± SD
Age, years (mean ± SD)	50.3 ± 18.4
Men, n (%)	10 (42)
BSA, m^2 (mean ± SD)	1.56 ± 0.16
Diabetes mellitus, n (%)	0 (0)
Dyslipidemia, n (%)	1(4)
Hypertension, n (%)	3 (13)
Congestive heart failure, n (%)	0 (0)
Systolic blood pressure, mmHg (mean ± SD)	113.5 ± 27.4
Diastolic blood pressure, mmHg (mean ± SD)	67.9 ± 16.4

AVNRT: atrioventricular nodal reentrant tachycardia, BSA: body surface area, SD: standard deviation.

patients at increased risk for developing AV block with AVNRT ablation.

4.1. Aorta and triangle of Koch

This study showed that the length of the ascending aorta correlated with TOK size. The ascending aorta enlarges with advancing age [9]. As the proximal ascending aorta is located within a relatively free mediastinal space without fixed branches [10], it is subject to constant pulsatile stress, which causes fragmentation and breakdown of the elastic components of the aortic media, with replacement by fibrosis [11]. These histological processes stiffen the aortic wall and increase blood pressure, resulting in transverse dilatation and elongation of the aorta [12]. Elongation of the ascending aorta results in its anterior tilting [13], which could shift the His recording site downward and decrease the size of TOK. These changes typically result in aortic unfolding on chest X-ray scanning.

Although it was assumed that both the length and angle of the aorta correlated with the size of TOK, ultimately, only the length of the aorta showed an inverse relationship. This might be due to the fact that the measurement of the angle on the coronal view does not necessarily represent the steepest angle of the aorta.

Comparison of patients with smaller vs. larger TOK showed that smaller TOK patients were older, had larger Ao diameters and reduced E/A values. In addition, older patients had smaller His-CSd, larger Ao diameters and reduced E/A values. These findings suggest that the enlargement of aorta associated with age might have significant relationship with the size of TOK. Our results are

Table 4
Pearson correlation analysis between His-CSd in Step 2 ($n=24$).

	Mean ± SD	Correlation coefficient	Partial correlation coefficient
His-CS distance, mm	20.2 ± 4.4		
Age, years	50.3 ± 18.4	0.0083	
BSA, m^2	1.56 ± 0.16	0.02	
LVDd, mm	43.1 ± 5.4	0.047	
LVDs, mm	28.3 ± 2.8	0.17	
LAD, mm	30.2 ± 5.0	−0.30	
LVEF, %	63.8 ± 3.9	−0.12	
Ao diameter, mm	28.4 ± 3.9	−0.52†	0.06
DcT, ms	192 ± 39	−0.182	
E/A	1.34 ± 0.60	0.71†	0.48
E/e′	10.0 ± 3.6	−0.18	

BSA: body surface area, LVDd: end-diastolic left ventricular dimension, LVDs: end-systolic left ventricular dimension, LAD: left atrial diameter, LVEF: left ventricular ejection fraction, Ao: aorta, DcT: deceleration time, E: peak early diastolic velocity, A: peak atrial systolic velocity, e′: peak early diastolic motion velocity, SD: standard deviation.

† p value < 0.01.

Table 5
Comparison of parameters between patients under 50 vs. 50 y/o or older in Step 2 ($n=24$).

Measurement	< 50 ($n=13$)	≥ 50 ($n=11$)	p value
His-CS distance, mm	22.2 ± 4.2	17.9 ± 3.5	< 0.05
Ao unfolding, n	0	7	
BSA, m^2	1.56 ± 0.16	1.54 ± 0.15	NS
LVDd, mm	42.2 ± 5.1	44.2 ± 5.6	NS
LVDs, mm	28.8 ± 2.5	27.7 ± 3.0	NS
LAD, mm	28.2 ± 2.9	32.5 ± 5.8	NS
LVEF, %	64.5 ± 4.4	62.9 ± 3.0	NS
Ao diameter, mm	25.7 ± 2.2	31.5 ± 5.8	< 0.01
DcT, msec	181.8 ± 28.8	205.9 ± 45.7	NS
E/A	1.7 ± 0.6	0.90 ± 0.2	< 0.01
E/e′	9.2 ± 2.1	11.0 ± 4.6	NS

Ao: aorta, BSA: body surface area, LVDd: end-diastolic left ventricular dimension, LVDs: end-systolic left ventricular dimension, LAD: left atrial diameter, LVEF: left ventricular ejection fraction, DcT: deceleration time, E: peak early diastolic velocity, A: peak atrial systolic velocity, e′: peak early diastolic motion velocity.

Table 6
Comparison of parameters of patients with His-CS distance under 19 mm vs. 19 mm or over in Step 2.

Measurement	< 19 mm($n=9$)	≥ 19 mm ($n=15$)	p value
Age, years	62.0 ± 14.6	43.3 ± 17.9	< 0.05
Ao unfolding	6	1	
BSA, m^2	1.53 ± 0.17	1.57 ± 0.16	NS
LVDd, mm	43.9 ± 6.3	42.6 ± 5.3	NS
LVDs, mm	28.4 ± 2.1	28.3 ± 3.3	NS
LAD, mm	32 ± 5.8	29.1 ± 5.8	NS
LVEF, %	65.2 ± 4.2	62.9 ± 3.7	NS
Ao diameter, mm	31.0 ± 4.0	26.8 ± 3.1	< 0.05
DcT, msec	191.6 ± 35.2	193.6 ± 44.2	NS
E/A	1.0 ± 0.3	1.5 ± 0.7	< 0.01
E/e′	11.1 ± 5.1	9.3 ± 2.4	NS

Ao: aorta, BSA: body surface area, LVDd: end-diastolic left ventricular dimension, LVDs: end-systolic left ventricular dimension, LAD: left atrial diameter, LVEF: left ventricular ejection fraction, DcT: deceleration time, E: peak early diastolic velocity, A: peak atrial systolic velocity, e′: peak early diastolic motion velocity.

in concert with a study that demonstrated that the distance between the proximal His bundle and coronary sinus ostium decreased progressively with age in AVNRT patients [14].

4.2. Left ventricular end-systolic dimension and triangle of Koch

His-CSd and LVDs exhibited an inverse relationship. The bundle of His is the only conductive tissue that penetrates the central fibrous body, formed by the connective tissue of the aortic, mitral and tricuspid valves, and the membranous interventricular septum. As LVDs becomes larger, the His penetrating bundle could be shifted towards the coronary sinus ostium, with the His-CSd becoming smaller. However, LVDs did not show any correlation with the size of TOK in patients with AVNRT ablation. The age difference between Steps 1 and 2 might well explain this difference.

4.3. Clinical implications

Catheter ablation of AVNRT is typically performed at the level of the coronary sinus ostium, usually away from the His recording site in order to minimize the risk of AV block. The identification of aortic unfolding correlated with a small TOK, and preoperative chest X-ray scanning, might be useful for risk stratification associated with AVNRT ablation. Although the patients undergoing AVNRT ablation in Step 2 were younger than those in the Step 1 analysis (50.3 ± 18.4 vs. 65.8 ± 12.1 years, $p < 0.01$), aortic unfolding was still found to correlate with TOK size.

4.4. Limitations

There are several limitations of this study. First, it included a relatively small number of patients, and the measurement of the aortic angle was performed in the coronal view on CT, which does not necessarily represent the steepest angle. In addition, CT was not conducted in patients with AVNRT.

Additionally, the patients in Steps 1 and 2 were not matched with age, due to the nature of the underlying arrhythmia. Aortic unfolding was more frequently observed in patients with smaller TOK and older patients, but the diagnosis of aortic unfolding is rather subjective, as no definite cutoff exists for its diagnosis.

5. Conclusions

Our findings indicated that a small TOK is associated with aortic unfolding.

Conflicts of interest

All authors declare no conflict of interest related to this study.

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