Journal of the American Heart Association

ORIGINAL RESEARCH

Impact of the Aortomitral Positional Anatomy on Atrioventricular Conduction Disorder Following Mitral Valve Surgery

Kazuma Handa, MD; Masashi Kawamura, MD, PhD; Daisuke Yoshioka, MD, PhD; Shunsuke Saito, MD, PhD; Takuji Kawamura, MD, PhD; Ai Kawamura, MD, PhD; Yusuke Misumi, MD, PhD; Masaki Taira, MD; Kazuo Shimamura, MD, PhD; Sho Komukai, PhD; Tetsuhisa Kitamura, MD, MSc, DrPH; Shigeru Miyagawa, MD, PhD

BACKGROUND: Variations in the aortomitral positional anatomy, including aortic root rotation appear to be related to variations in the location of the conduction system, including the bundle of His. However, little is known about their clinical significance.

METHODS AND RESULTS: This study included 147 patients with normal ECGs who underwent mitral valve surgery. The aortomitral anatomy was classified using preoperative 3-dimensional transesophageal echocardiography, and postoperative conduction disorders, including atrioventricular block and bundle branch block, were analyzed. Variations classified as aortomitral appearance were designated as having a center appearance (85.7%, n=126/147) or lateral appearance (14.3%, n=21/147) on the basis of whether the aortic root was located at the center or was shifted to the left fibrous trigone side. Subsequently, those with a center appearance, aortic root rotation was classified as having a center rotation (83.3% [n=105/126]), in which the commissure of the left and noncoronary aortic leaflet was located at the center, lateral rotation (14.3% [n=18/126]), rotated to the left trigone side, or medial rotation (2.4% [n=3/126]), rotated to the right. The incidence of 3-month persistent new-onset conduction disorder was higher in the lateral appearance than the center appearance group (21.1% versus 5.0%; *P*=0.031) and higher in the lateral rotation than in the center or medial rotation groups (29.4% versus 1.0% versus 0.0%, respectively; *P*<0.001).

CONCLUSIONS: Aortomitral variations can be classified using 3-dimensional transesophageal echocardiography. Lateral appearance and lateral rotation are risk factors for conduction disorders in mitral valve surgery.

Key Words: aortic root rotation position ■ atrioventricular conduction disorder ■ mitral valve surgery ■ 3-dimensional transesophageal echocardiography

Recent epidemiological research has demonstrated that valvular heart diseases pose a considerable public health burden globally.[1,2] Compared with other major valvular diseases, the prevalence of those associated with the mitral valve increases with age.[3] Despite the emergence of transcatheter mitral valve treatment, mitral valve repair and replacement surgery plays an important role in treating patients with mitral valve disease. These surgical interventions offer excellent short- and long-term outcomes for mitral valve disease.[4–7] However, the associated sutures can damage the bundle of His near the mitral annulus and right fibrous trigone, leading to postoperative atrioventricular conduction disorder.[8]

Cardiac imaging technologies have advanced significantly. In particular, computed tomography (CT), magnetic resonance imaging, and transesophageal echocardiography (TEE) can provide beautiful 2-dimensional images of the heart with high resolution as well as 3-dimensional volume renderings that

Correspondence to: Masashi Kawamura, MD, PhD, Department of Cardiovascular Surgery, Osaka University Graduate School of Medicine, 2-2 Yamada-oka, Suita 565-0853, Japan. Email: masashi.kmura@gmail.com

This manuscript was sent to John S. Ikonomidis, MD, PhD, Guest Editor, for review by expert referees, editorial decision, and final disposition.

For Sources of Funding and Disclosures, see page 12.

JAHA is available at: www.ahajournals.org/journal/jaha

CLINICAL PERSPECTIVE

What Is New?

- Variation in the aortomitral positional anatomy was effectively classified using preoperative 3-dimensional transesophageal echocardiography, facilitating the classification of the aortomitral positional anatomy into "aortomitral appearance," which was identified as a novel variation, and "aortic root rotation" categories.
- The aortomitral appearance was classified as center or lateral appearance (the aortic root was located at the center of the anterior mitral leaflet or shifted to the left fibrous trigone side), and within the center appearance group, the aortic root rotation was classified as center rotation, lateral rotation, or medial rotation (the commissure of the left and noncoronary aortic leaflet was located at the center of the anterior mitral leaflet, rotated to the left fibrous trigone side, or to the right, respectively).
- The lateral appearance and lateral rotation exhibited a significantly higher frequency of postoperative atrioventricular conduction disorders, which could lead to an increased incidence of paroxysmal atrial fibrillation, following mitral valve surgery.

What Are the Clinical Implications?

- Three-dimensional transesophageal echocardiography is particularly useful in mitral valve surgery, and the diagnosis of aortomitral positional variation was easily available for each case during the mitral valve assessment.
- For patients exhibiting the lateral appearance and lateral rotation, vigilant postoperative monitoring is essential to detect atrioventricular conduction disorders, and long-term outpatient follow-up is necessary to prevent cardiac events, such as arrhythmias and heart failure, leading to improved prognoses through timely intervention.

Nonstandard Abbreviations and Acronyms

AVB	atrioventricular block
PAF	paroxysmal atrial fibrillation
PPI	permanent pacemaker implantation
TEE	transesophageal echocardiography

provide information regarding the precise and detailed anatomy of the heart. An accurate understanding of the local anatomy is critical to surgical planning and prevention of surgery-related complications.

Variations in aortic root rotation in the normal heart are a notable phenomenon recently revealed using cardiac CT or magnetic resonance imaging.[9–19] The variation in aortic root rotation is related to the distance between the right trigone and membranous septum, where the atrioventricular conduction system is located.[14,15,17] Thus, variations in aortic root rotation are reflected by differences in the atrioventricular conduction system location; however, the associated clinical significance has not been fully characterized.

The primary aims of the current study are to classify the anatomic variations of the aortomitral positional anatomy, including aortic root rotation, using preoperative 3-dimensional TEE and analyze their clinical influence on atrioventricular conduction disorders associated with mitral valve surgery.

METHODS

Data Availability

The authors declare that all data in this article are available within the article.

Study Population

Patient data were retrospectively collected from the medical records. A total of 217 patients with sinus rhythm and normal preoperative ECGs underwent their first mitral valve plasty via a right-sided left atrial approach at Osaka University Hospital between January 2012 and August 2023. All patients had no history of any arrhythmia, including paroxysmal atrial fibrillation (PAF). Of these, preoperative 3-dimensional TEE and postoperative ECG data were available for 147 patients (Figure 1). Patients undergoing redo mitral valve procedures, concomitant aortic or tricuspid valve surgeries, the maze procedure (including pulmonary vein isolation), coronary artery bypass grafting, mitral valve replacement, or mitral valve surgery via the transseptal approach were excluded. All included patients (n=147) had no comorbid cardiac diseases other than mitral valve disease and no history of cardiac disease treatment.

ECG follow-ups were conducted 1 week (n=147) and 3 months (n = 139) postoperatively to assess the occurrence of atrioventricular conduction disorders. Among the 8 patients without ECG records 3 months after surgery, 6 were followed up at our institution but had no ECG records, and 2 transitioned to follow-up at other facilities (Figure 1).

Ethical Statement

This study was conducted in accordance with the principles of the Declaration of Helsinki. The Osaka University Hospital Clinical Research Ethics Committee

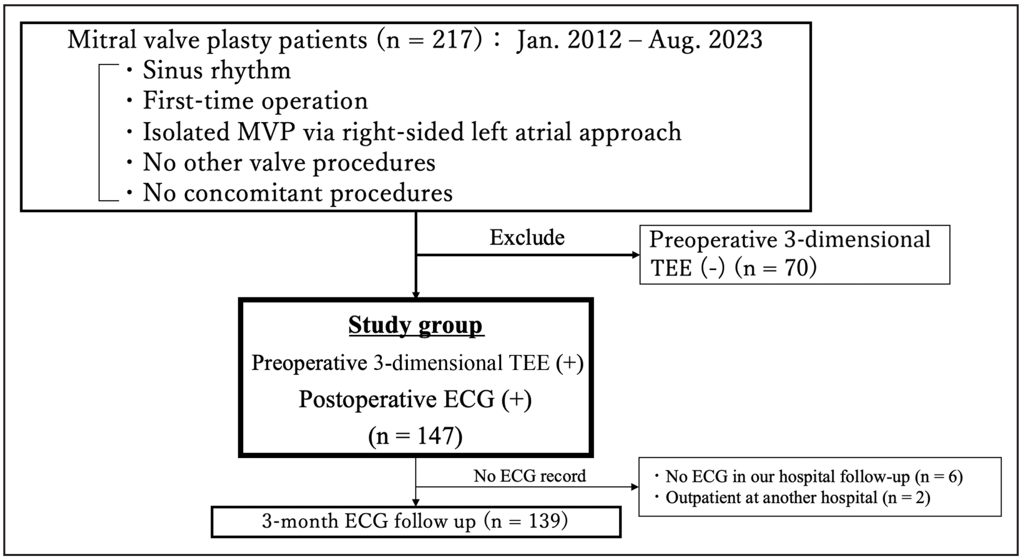

Figure 1. Study design.
MVP indicates mitral valve plasty; and TEE indicates transesophageal echocardiography.

approved this study and publishing its data (approval number: 16105; approval date: November 2, 2016). Written informed consent was obtained from all patients.

Surgical Details

Cardiopulmonary bypass was established for aortobicaval cannulation under mild hypothermia for full sternotomy, and peripheral artery and vein cannulation under mild hypothermia during the right minithoracotomy. Intraoperative myocardial protection was ensured through antegrade administration of cold blood cardioplegia at 15 °C, with subsequent doses administered antegrade or retrograde at 20-minute intervals. Annuloplasty using a full ring or partial ring was performed in all patients who underwent mitral valve repair. All patients were evaluated for residual mitral regurgitation by intraoperative TEE.

Defining Aortomitral Positional Anatomy Variation Using Preoperative 3-Dimensional TEE

Preoperative 3-dimensional TEE was performed using an EPIQ ultrasound machine (Philips Medical Systems, Andover, MA) and an X8-2t probe (Philips Medical Systems). QLAB software packages (Philips, Best, Netherlands) were used for real-time 3-dimensional TEE analysis.

Determination of aortomitral anatomic variations using 3-dimensional TEE involved assessing the aortic root positional variation based on the surgeon's view of the mitral valve. Two independent cardiovascular surgeons blinded to the patient and outcome data evaluated the images separately. In cases of discrepancies, the opinion of a cardiovascular echocardiologist was sought.

The criteria for classifying aortomitral anatomic variations are presented in Figure 2. First, anatomic variation was classified as having an aortomitral appearance, in which the aortic root was located at the center of the anterior mitral leaflet (center appearance) or shifted to the left fibrous trigone side (lateral appearance). Meanwhile, medial appearance (ie, the aortic root shifted to the right fibrous trigone side) was not observed in this population. Second, in the center appearance, we classified the aortic root rotation for which the commissure of the left and noncoronary aortic leaflet was located at the center of the anterior mitral leaflet (center rotation), rotated to the left fibrous trigone side (lateral rotation), or rotated to the right fibrous trigone side (medial rotation).

Notably, previous literature has used expressions such as "clockwise, counterclockwise," and "left/rightward" deviation of the commissure of the left and noncoronary aortic leaflet to describe the aortic root rotational position.[9–19] However, these expressions are typically used to assess the aortic valve from an apical perspective, often in the context of CT scans or similar methods. In contrast, we opted to use the terms *lateral* and *medial* in our classification on the basis of 3-dimensional TEE images as they correspond to the perspectives of viewing the aortic and mitral valves from the aortic and left atrial sides, respectively, as in the surgical context.

The preoperative diameter of the ascending aorta was measured using CT scans in all cases, and

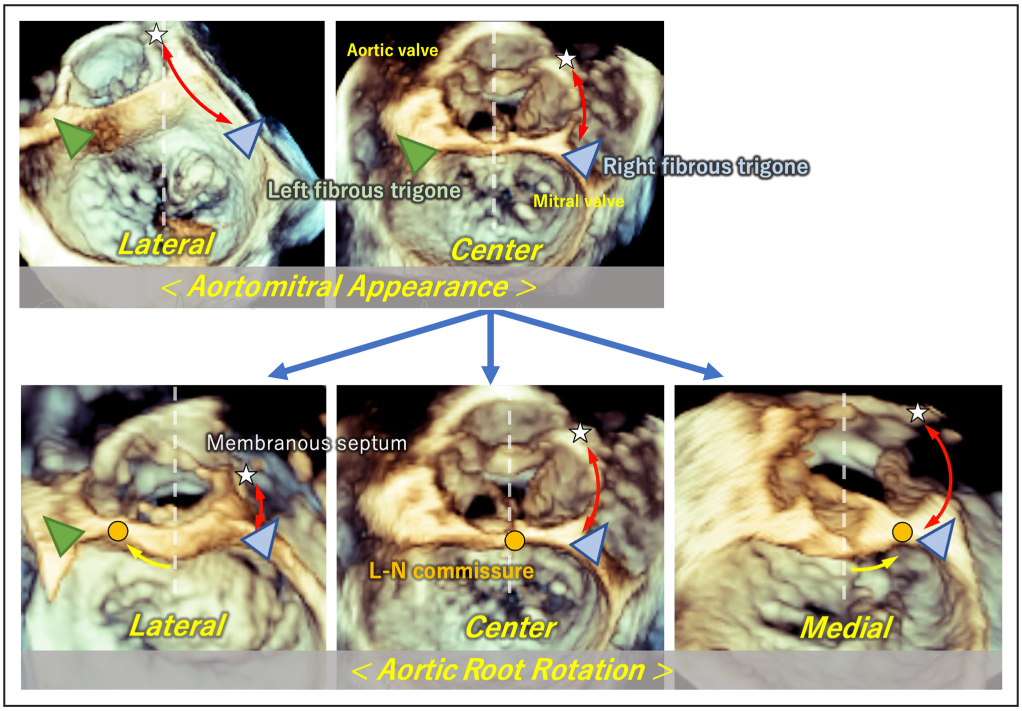

Figure 2. Definitions of aortomitral positional anatomy diagnosed by 3-dimensional transesophageal echocardiography.
Preoperative 3-dimensional transesophageal echocardiography reveals the aortic root located at the center of the anterior mitral leaflet (center appearance) or shifted to the left fibrous trigone side (lateral appearance). The center appearance is further classified as center, lateral, or medial rotation according to the left and noncoronary commissures (orange circles). This variation affects the distance and positional relationship (red double arrow) between the membranous septum (star) and the right fibrous trigone (blue triangle), which might be synonymous with variations in the conduction system location. L-N commissure indicates commissure of the left and noncoronary aortic leaflet.

its relationship with aortomitral anatomic variations (center/lateral appearance and center/lateral/medial rotation) diagnosed using 3-dimensional TEE was investigated.

Postoperative Follow-Up and Detection of Atrioventricular Conduction Disorder by ECG

Standard 12-lead ECGs were recorded at a paper speed of 25 mm/s, 1 mV/10 mm gain, and 0.05- to 150-Hz filter for each patient's baseline assessment. The heart rate, PR interval, and QRS duration were measured for leads II and V6. A PR interval >200 ms was considered abnormal. Right bundle-branch block (BBB), left BBB, left anterior fascicular block, and left posterior fascicular block were defined according to the current guidelines.[20] All ECG measurements, including the PR interval, were performed by 2 experienced cardiovascular surgeons blinded to the patients, clinical presentations, and outcomes. In case of disagreement, a third cardiologist was consulted. Preoperative ECG was performed immediately before mitral valve surgery. Subsequent ECGs were obtained 1 week and 3 months postoperatively to assess the occurrence of new atrioventricular conduction disorders and determine their persistence at 3 months after surgery.

Arrhythmias following cardiac surgery typically occur during the initial postoperative week and often exhibit substantial improvement within 6 to 8 weeks postoperatively.[21] To address these potential issues, permanent pacemaker implantation (PPI) is deemed necessary, particularly in patients with severe sick sinus syndrome or atrioventricular block (AVB). When the AVB and BBB were detected 1 week after surgery and persisted at the 3-month follow-up assessment, a diagnosis of permanent conduction disorder was made.

End Points

Preoperative 3-dimensional TEE was used to classify aortomitral positional variations. To assess the influence of these variations on the development of postoperative atrioventricular conduction disorders, we initially examined the incidence of new AVB and BBB during the first postoperative week and analyzed the differences among the anatomic variations. Subsequently, we monitored whether these new AVB and BBB persisted at the 3-month postoperative evaluation and analyzed the impact of aortomitral positional variations on their persistence. Additionally, we investigated the PR interval (ms), and each anatomic variation.

Additionally, the frequency of persistent atrioventricular conduction disorders in patients with ECG follow-up for >1 year was analyzed. The association between the persistence of postoperative conduction disorders and the incidence of PPI, cardiac death, and atrial fibrillation was also analyzed at both the ≥3-month and the ≥1-year postoperative follow-up.

Statistical Analysis

Categorical variables were presented as percentages, whereas continuous variables were expressed as median with interquartile range. To compare the 2 groups, Fisher's exact test was used for categorical variables, and the Wilcoxon rank-sum test was used for continuous variables. The PR intervals observed repeatedly at baseline, 1 week after surgery, and 3 months after surgery were analyzed using a mixed-effect model for repeated measures, including explanatory variables for group, time, and interaction between group and time, and in this analysis, continuous outcomes were expressed as mean and SEM. Univariate analyses by logistic regression model were performed to identify the risk factor for new-onset and persistent postoperative conduction disorder at 1 week and 3 months after the surgery. Statistical significance was set at $P<0.05$. All statistical analyses were performed using JMP Pro version 17.1.0 (SAS Institute Inc., Cary, NC).

RESULTS

Patients' Baseline Characteristics

Patient background information is presented in Table 1. The median age was 61.0 years, and 70.1% (n=103) were men. Preoperative antiarrhythmic medication was not administered to 78.2% (n=115) of the patients, and β blockers were administered to 19.7% (n=29). Moderate or greater mitral valve regurgitation was observed in 98.6% (n=145) of the patients, 93.9% (n=138) had degenerative mitral valve regurgitation, while 1.4% (n=2) had active infective endocarditis, and none had annular abscesses.

Operative Data and Postoperative Medications

Table 2 provides an overview of the surgical and postoperative medical data. The median approach was used in 34.7% of cases (n=51), while the minimally invasive cardiac surgery approach was applied for the remaining cases. Myocardial protection strategies varied, with 44.4% of the patients (n=63) receiving only antegrade cardioplegia, without the use of retrograde cardioplegia. In the other cases, a combination of antegrade and retrograde cardioplegia was administered. A full prosthetic ring was used for mitral annuloplasty in 80.3% (n=118) of cases, while a partial ring was used in the remaining 19.7% (n=29) of cases. All rings, both full and partial, were semirigid; no flexible rings or bands were used. In the postoperative phase, no antiarrhythmic medication was prescribed to 50.3% of the patients (n=74), whereas β blockers

Table 1. Patient Baseline Characteristics

Variable	All patients (N=147)
Baseline characteristics	
Age, y	61.0 (49.5–69.9)
Male sex	103 (70.1)
Body mass index (kg/m^2)	22.1 (20.0–24.5)
Diabetes	15 (10.2)
Dialysis	2 (1.4)
Liver dysfunction	1 (0.7)
Hypertension	59 (40.1)
Chronic lung disease (moderate or greater)	1 (0.7)
Peripheral artery disease	1 (0.7)
Cerebrovascular attack	9 (6.1)
NYHA class ≥III	21 (14.3)
Elective	146 (99.3)
Antiarrhythmic medication	
None	115 (78.2)
β blocker	29 (19.7)
Amiodarone	1 (0.7)
Digitalis	1 (0.7)
Verapamil	1 (0.7)
Preoperative transthoracic echocardiography	
LVDd (mm)	57 (53–61)
LVDs (mm)	34 (30–38)
LVEF (%)	68 (64–74)
Left atrial diameter, mm	46 (42–51)
Moderate or greater mitral valve regurgitation	145 (98.6)
Carpentier 1	1 (0.7)
Carpentier 2	138 (93.9)
Carpentier 3a	1 (0.7)
Carpentier 3b	7 (4.7)
Mitral stenosis	0 (0.0)
Active infective endocarditis	2 (1.4)
Moderate or greater TR	1 (0.7)
TRPG, mm Hg	24 [18–34]

Data are presented as n (%) or median (interquartile range).

LVDd indicates left ventricular end-diastolic diameter; LVDs, left ventricular end-systolic diameter; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; TR, tricuspid regurgitation; and TRPG, tricuspid regurgitation pressure gradient.

Table 2. Operative Data and Postoperative Medication

Variable	All patients (N=147)
Intraoperative myocardial protection	
CPB time, min	174.0 (139.0–220.0)
Cross-clamp time, min	120.0 (96.0–151.0)
Antegrade cardioplegia only	63 (44.4)
Operative procedures	
Median approach	51 (34.7)
Mitral valve plasty	147 (100.0)
Full prosthetic ring	118 (80.3)
Prosthetic ring size, mm	30 (30–32)
Antiarrhythmic medication	
None	74 (50.3)
β blocker	72 (48.9)
Amiodarone	0 (0.0)
Digitalis	1 (0.7)

Data are presented as n (%) or median (interquartile range).
CPB indicates cardiopulmonary bypass.

were the most frequently administered, accounting for 48.9% (n=72).

Aortomitral Positional Anatomy Analysis by 3-Dimensional TEE

The aortomitral anatomic variations observed on preoperative 3-dimensional TEE are described in Table 3. Regarding the aortomitral appearance cases, 85.7% (n=126/147) were classified as center appearance, and 14.3% (n=21/147) as lateral appearance. In the center appearance group (n=126), aortic root rotation was further classified as center rotation (83.3% [n=105/126]), lateral rotation (14.3% [n=23/126]), and medial rotation (2.4% [n=3/126]).

There were no cases of dilation or aneurysm in the ascending aorta and aortic arch. Furthermore, no association was found between ascending aortic diameter and the appearance or rotation diagnosis (Figure 3).

New-Onset Atrioventricular Conduction Disorder After Surgery

Table 3 provides a detailed overview of the new postoperative atrioventricular conduction disorders within the cohort. One week postoperatively, newly identified atrioventricular conduction disorder was observed in 12.9% (n=19/147) of patients, with 12.2% (n=18/147) exhibiting first-degree AVB and 1.4% presenting with BBB, specifically new-onset right BBB (n=2/147); one patient had first-degree AVB and right BBB. No second-degree or higher AVB or left bundle-branch block were detected. Among those with newly identified atrioventricular conduction disorder 1 week postoperatively, 7.2% (n=10/139) continued to present with

Table 3. Aortomitral Positional Anatomy Classification Based on 3-Dimensional TEE and New-Onset Postoperative Conduction Disorder

Anatomy/Classification	One-week follow-up (N=147)
Aortomitral positional anatomy classified by 3-dimensional TEE	
Lateral appearance*	21 (14.3)
Center appearance*	126 (85.7)
Center rotation†	105 (83.3)
Lateral rotation†	18 (14.3)
Medial rotation†	3 (2.4)
Postoperative atrioventricular conduction disorder	
New AVB or BBB	19 (12.9)
New AVB	
First-degree	18 (12.2)
Second-degree	0 (0)
Third-degree	0 (0)
New BBB (including LBBB/RBBB)	2 (1.4)
LBBB	0 (0)
RBBB	2 (1.4)
ΔPR, ms	+4 (−11 to +20)
	3-month follow-up (n=139)
Persistence of AVB or BBB	10 (7.2)
AVB	
First-degree	10 (7.2)
Second-degree	0 (0)
Third-degree	0 (0)
BBB (including LBBB/RBBB)	1 (0.7)
LBBB	0 (0)
RBBB	1 (0.7)
ΔPR, ms	+6 (−4 to +20)

Data are presented as n (%) or median (interquartile range).
AVB indicates atrioventricular block; BBB, bundle-branch block; LBBB, left bundle-branch block; RBBB, right bundle-branch block; ΔPR, prolongation between pre- and postoperative PR intervals; and TEE, transesophageal echocardiography.
*Aortomitral appearance, n=147.
†Aortic root rotation, n=126.

these disturbances at the 3-month follow-up. The median ΔPR interval, representative of differences in the PR interval between the preoperative period and 1 week or 3 months postoperatively, was +4 ms for the 1-week and +6 ms for the 3-month follow-up.

New-Onset Atrioventricular Conduction Disorder After Surgery in Patients With Aortomitral Appearance and Aortic Root Rotation

Figure 4A depicts the frequency of atrioventricular conduction disorder with an aortomitral appearance. One week postoperatively, the incidence of conduction disorder was significantly higher in the lateral appearance group (28.6% [n=6/21]) than in the center

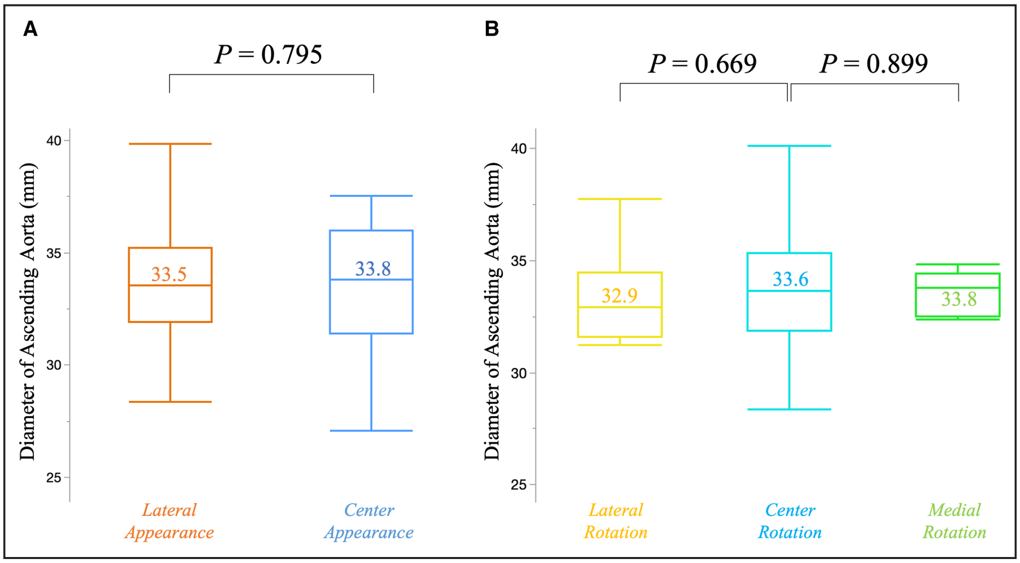

Figure 3. Relationship between ascending aortic diameter and anatomic variations.
Comparison of the ascending aortic diameter between the lateral and center appearance groups (**A**) and among the lateral, center, and medial rotation groups (**B**).

appearance group (10.3% [n=13/126]; *P*=0.033). Three months postoperatively, the persistence of the new-onset conduction disorder was significantly higher in the lateral appearance than the center appearance (21.1% [n=4/19] versus 5.0% [n=6/120]; *P*=0.031).

Figure 4B illustrates postoperative conduction disorder in relation to aortic root rotation. The frequency of conduction disorders during the first postoperative week was significantly higher in the lateral rotation (38.9% [n=7/18]; *P*<0.001) than in the center rotation (4.8% [n=5/105]) group, whereas the prevalence in the medial rotation group was not significant (33.3% [n=1/3]; *P*=0.159). This effect persisted at 3 months postoperatively in the lateral rotation (29.4% [n=5/17]; *P*<0.001) group compared with the center rotation group (1.0% [n=1/100]), whereas the prevalence in the medial rotation group was not significant (0.0% [n=0/3]; *P*=1.0).

Transition of the PR Interval in Patients With Aortomitral Appearance and Aortic Root Rotation

Serial PR interval in the aortomitral appearance (lateral and center appearance groups) at the time point

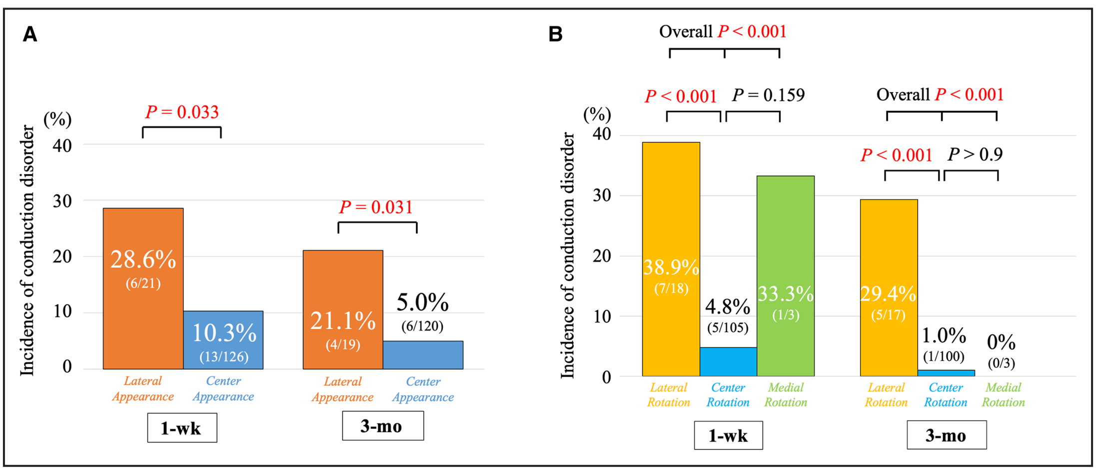

Figure 4. New-onset atrioventricular conduction disorder after surgery in patients with aortomitral appearance and aortomitral rotation.
Comparison of the incidence of postoperative conduction disorders newly recorded on the ECG at 1 week postoperatively and their persistence at 3 months between the lateral and center appearance groups (**A**) and among the lateral, center, and medial rotation groups (**B**).

of the preoperation, 1-week after the surgery, and 3-month follow-up were analyzed using a mixed-effect model. In the center rotation group, the postoperative PR interval remained almost unchanged, whereas in the lateral rotation group, there was a significant prolongation of the postoperative PR interval (time effect, P=0.016; group effect, P=0.002; interaction effect, P=0.025; Figure 5A). Figure 5B showed comparison of PR interval in each time point between 2 groups. One week postoperatively, the PR interval in the lateral appearance group was significantly longer than in the center appearance group (200 ms versus 170 ms; P=0.032). However, at 3 months postoperatively, although the median value in the lateral appearance group was larger than in the center appearance group, the difference was not significant (190 ms versus 170 ms; P=0.113).

Regarding the classification of the aortic root rotation, serial PR interval in the lateral, center, and medial rotation groups at the time point of the preoperation, 1 week after the surgery, and 3-month follow-up were analyzed using a mixed-effect model. In the center rotation group, the postoperative PR interval remained virtually unchanged, and in the medial rotation group, the prolongation of the postoperative PR interval was transient. In contrast, the lateral rotation group showed continuous prolongation of the postoperative PR interval. (time effect, P=0.119; group effect, P=0.044; interaction effect, P=0.375; Figure 5C). Figure 5D showed that comparisons of PR interval in each time point were made between the lateral rotation and medial rotation groups with reference to the center. At 1 week postoperatively, the PR interval in the lateral rotation group was significantly longer than in the center group (175 ms versus 168 ms; P=0.011); this difference persisted 3 months postoperatively (200 ms versus 168 ms; P=0.004). However, no significant differences were observed between the medial rotation and center rotation groups across time points.

Univariate Analysis of Risk Factors for New-Onset Atrioventricular Conduction Disorder

For new-onset postoperative atrioventricular conduction disorder, lateral appearance (odds ratio [OR], 3.48 [95% CI, 1.09–10.03]; P=0.036) and lateral rotation (OR, 12.73 [95% CI, 3.45–26.06]; P=0.001) were the

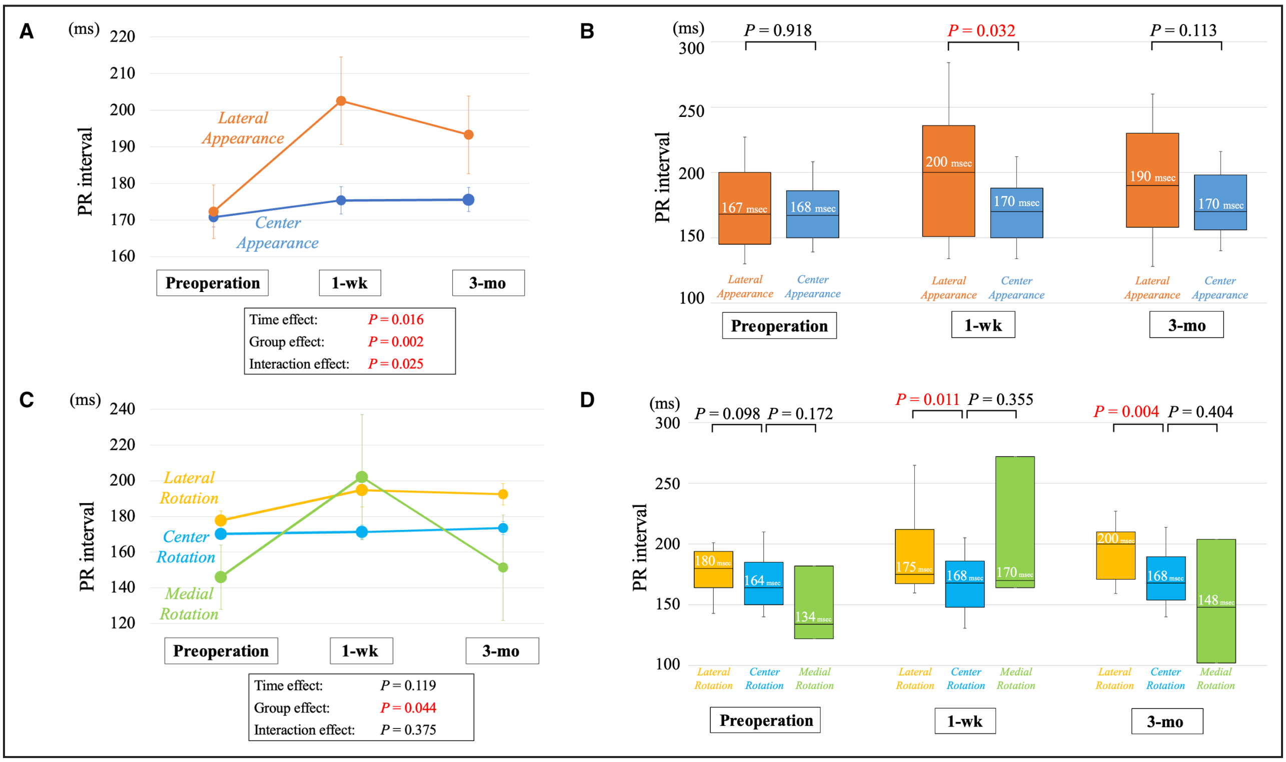

Figure 5. PR interval transition and differences between the pre- and postoperative periods in patients with aortomitral appearance and rotation.

Comparisons were made between the lateral and center appearance groups for the PR interval at preoperative, 1-week, and 3-month postoperative intervals using a mixed-effect model (**A**); detailed comparison between the lateral and center appearance groups for the PR interval at each time point (**B**). Comparisons across the lateral, center, and medial rotation groups for the preoperative, 1-week, and 3-month postoperative intervals using a mixed-effect model (**C**); detailed comparison between the center appearance group, and lateral or medial rotation groups for the PR interval at each time point (**D**).

only statistically significant risk factors. Similarly, lateral appearance (OR, 5.07 [95% CI, 1.28–20.04]; *P*=0.021) and lateral rotation (OR, 31.25 [95% CI, 2.44–383.26]; *P*=0.001) were the only statistically significant risk factors for persistent conduction disorder at 3 months postoperatively (Table 4). On the other hand, operative procedures such as cross-clamp time (OR, 1.00 [95% CI, 0.99–1.01]; *P*=0.993), the use of antegrade cardioplegia only (OR, 1.08 [95% CI, 0.29–3.43]; *P*=0.905), and the use of a full prosthetic ring (versus partial ring; OR, 1.69 [95% CI, 0.41–7.02]; *P*=0.465) were not significant factors for postoperative conduction disorders.

Relationship Between Patient Follow-Up Status and Cardiac Events

The follow-up status of the patients and the occurrence of postoperative cardiac events are shown in Figure 6. A total of 117 patients underwent ECG follow-up for >1 year. Of the 10 patients with new-onset postoperative atrioventricular conduction disorder persisting for >3 months, 7 patients had ECG follow-up for >1 year. All 7 patients had residual atrioventricular conduction disorder; none of them recovered to a normal ECG. No patients required PPI during follow-up, and no cardiac deaths occurred.

However, an analysis of the relationship between the frequency of PAF requiring oral anticoagulants and patients with persistent postoperative conduction disorder after 3 months postoperatively showed that PAF was significantly more frequent in patients with persistent conduction disorder than in those without conduction disorder (50.0% [n=5/10] versus 15.5% [n=20/129]; *P*=0.017), and this trend did not change even after 1 year (57.1% [n=4/7] versus 17.3% [n=19/110]; *P*=0.027; Figure 6).

DISCUSSION

This study makes several significant contributions to the field. First, the aortic and mitral valves could be simultaneously visualized using 3-dimensional TEE; consequently, the aortomitral positional anatomy was distinctly classified into "appearance" and "rotation" categories. The aortomitral appearance was further categorized into center appearance and lateral appearance. Within the center appearance group, the aortic root rotation was classified as center rotation, lateral rotation, or medial rotation. Second, compared with the center appearance and center rotation, the lateral appearance and lateral rotation exhibited a significantly

Table 4. Risk Factors for Postoperative New-Onset Atrioventricular Conduction Disorder

	1 week after the surgery No. events: 19/147 (12.7%) univariate analysis		3-month follow-up No. events: 10/139 (7.2%) univariate analysis	
Variable	Odds ratio (95% CI)	*P* value	Odds ratio (95% CI)	*P* value
Baseline characteristics and echocardiography				
Age, y	1.01 (0.98–1.05)	0.437	1.02 (0.97–1.07)	0.521
Male sex	0.91 (0.32–2.59)	0.867	1.03 (0.25–4.18)	0.971
Diabetes	1.04 (0.22–5.02)	0.961	2.43 (0.46–12.81)	0.328
Dialysis	Unconverged†		Unconverged†	
Hypertension	1.40 (0.53–3.69)	0.492	2.29 (0.62–8.53)	0.209
Peripheral artery disease	Unconverged†		Unconverged†	
LVEF (%)	1.00 (0.95–1.06)	0.871	0.96 (0.91–1.04)	0.201
Left atrial diameter, mm	1.02 (0.95–1.09)	0.584	1.03 (0.94–1.12)	0.537
Active infective endocarditis	Unconverged†		Unconverged†	
Aortomitral positional anatomy				
Lateral appearance (vs center appearance)*	3.48 (1.09–10.03)	**0.036**	5.07 (1.28–20.04)	**0.021**
Lateral rotation (vs center rotation)**	12.73 (3.45–26.06)	**0.001**	31.25 (2.44–383.26)	**0.001**
Operative procedures				
Cross-clamp time (min)	1.00 (0.99–1.01)	0.618	1.00 (0.99–1.01)	0.993
Antegrade cardioplegia only	0.70 (0.26–1.89)	0.479	1.08 (0.29–3.43)	0.905
Full prosthetic ring (vs partial ring)	2.11 (0.72–6.13)	0.171	1.69 (0.41–7.02)	0.465
Postoperative antiarhythmic medication				
β blocker	0.73 (0.27–1.93)	0.522	0.98 (0.27–3.57)	0.981

*This group including aortomitral appearance, n=147.
**This group including lateral rotation and center rotation, n=123.
†Calculation was not feasible, as there were no events.
LVEF indicates left ventricular ejection fraction. Values in bold indicate statistically significant.

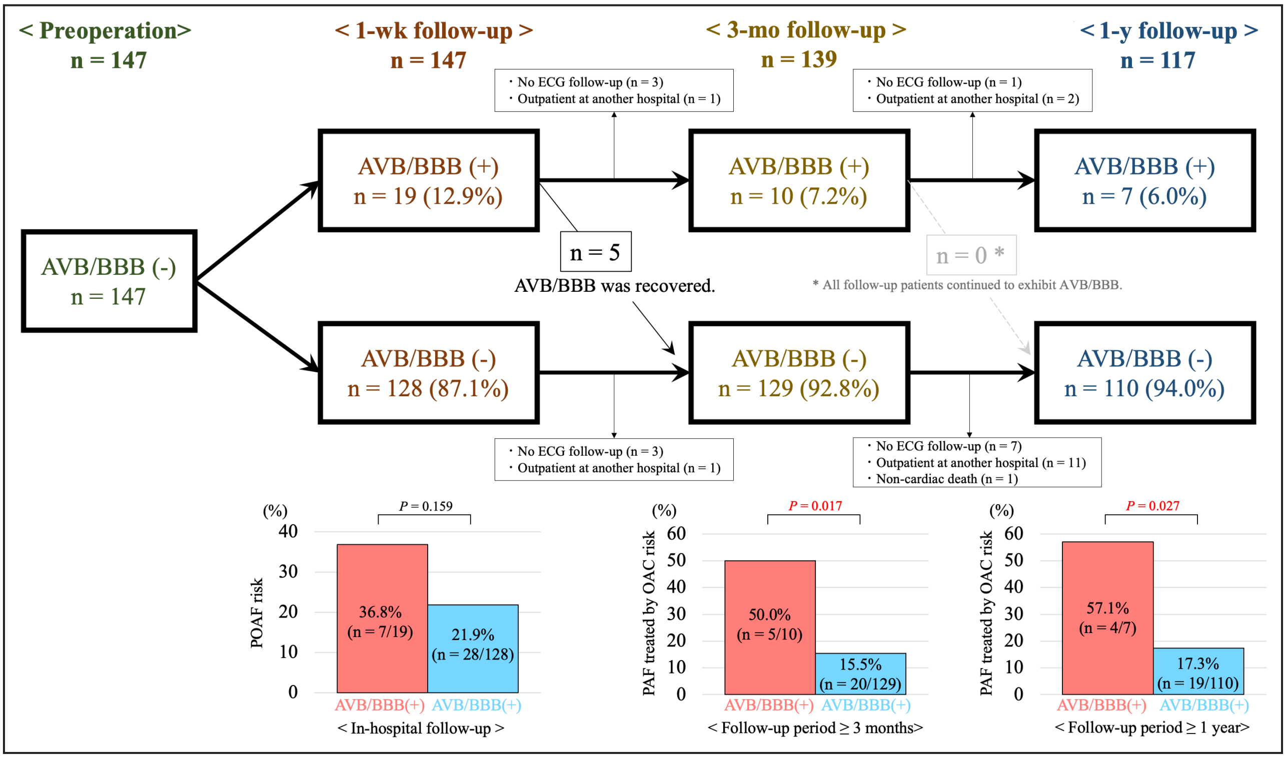

Figure 6. Patients' follow-up chart. Relationship between persistent conduction disorder and inpatient postoperative atrial fibrillation in patients with hospital and outpatient paroxysmal atrial fibrillation treated with oral anticoagulants.
AVB indicates atrioventricular block; BBB, bundle-branch block.

higher frequency of postoperative conduction disorders following mitral valve surgery, primarily comprising first-degree AVB. Third, the sustained occurrence of these disorders for up to 3 months postoperatively was significantly higher in the lateral appearance and lateral rotation groups, and these disorders persisted >1 year. The persistence of conduction disorders was suggested to be associated with an increased incidence of PAF. Fourth, in the analysis that included preoperative and perioperative factors, both lateral appearance and lateral rotation emerged as risk factors for postoperative atrioventricular conduction disorders following mitral valve plasty.

This study represents the first classification of aortomitral position variation using 3-dimensional TEE and is the first to indicate that such variation is a risk factor for atrioventricular conduction disorder following cardiac surgery. The most significant advantage of 3-dimensional TEE is its ability to simultaneously visualize the aortic and mitral valves. This facilitated the identification of a novel variation, namely, the lateral appearance, characterized by a lateral shift of the aortic root, which went unnoticed in previous imaging modalities such as CT or magnetic resonance imaging.[9–19] Furthermore, the identification of lateral appearance and lateral rotation as risk factors for new-onset conduction disorders following mitral valve surgery suggests a potential association between the aortomitral positional anatomy and the conduction system location. Intraoperative TEE is essential in cardiac surgery,[22] and 3-dimensional TEE is particularly useful in mitral valve repair.[23,24] Hence, the diagnosis of aortomitral positional variation was available for each case during the mitral valve assessment. Although there was no significant impact on postoperative atrioventricular conduction disorders based on mitral valve surgery techniques, such as replacement versus plasty/full ring versus partial ring, and at present, these findings do not suggest any modifications in surgical techniques, they may influence postoperative follow-up planning.

While severe AVB requiring PPI was not observed in the present study, first-degree AVB or BBB is a significant risk factor for PPI, atrial fibrillation, heart failure, and death.[25–27] In particular, the Framingham study revealed that first-degree AVB is associated with a 2-fold increase in the incidence of atrial fibrillation, a 3-fold increase in the rate of PPI, and a 1.5-fold increase in death.[25] Postoperative first-degree AVB following heart valve surgery has been suggested as a potential risk factor for PPI in long-term follow-up.[28,29] However, the implications related to specifically mitral valve surgery remain unclear. Therefore, further clinical research is warranted to investigate the long-term outcomes of new-onset first-degree AVB following mitral valve surgery. Nevertheless, even in those studies, the possibility of an increased risk of long-term event such as atrial fibrillation has been suggested in patients with first-degree AVB. In the current study, 21.1% of patients with lateral appearance and 29.4% of patients with lateral rotation had persistent conduction system disorder 3 months after mitral valve surgery, at which point the surgical influences were presumed to be negligible. Accordingly, these patients were considered to have permanent conduction system impairment.[21] Among the 10 patients who still had new-onset atrioventricular conduction disorders 3 months postoperatively, 7 patients were followed up with ECG for >1 year. All 7 patients continued to exhibit conduction disorders, and none of them returned to a normal ECG. This suggests that residual conduction disorders at 3 months postoperatively may indicate persistent changes. Patients with persistent conduction disorders also had a significantly higher incidence of PAF that required oral anticoagulants. This phenomenon may be clinically significant. Therefore, for patients diagnosed with these variations via 3-dimensional TEE, attention should be paid to the occurrence of postoperative conduction disorders, and long-term outpatient follow-up is necessary. Timely intervention can prevent cardiac events and lead to improved prognoses.

Indeed, the locational variation of the atrioventricular bundle has been demonstrated in a normal heart via gross anatomic and histological investigations.[30] Meanwhile, mitral valve surgery carries the risk of injuring the bundle of His by suturing the mitral annulus near the right fibrous trigone.[8] In the present study, both lateral appearance and lateral rotation were associated with a higher risk of developing conduction disorders after mitral valve surgery. These positional variations could predict or might be associated with the locational variation of the atrioventricular bundle. However, this was not confirmed in the current study as we did not perform an electrophysiological study to determine the precise location of the cardiac conduction system. Nevertheless, a recent study revealed that intraoperative conduction optical mapping using fiberoptic confocal microscopy and electrophysiological mapping can prevent heart block during congenital heart surgery.[31,32] Hence, the application of intraoperative mapping with preoperative evaluation of the aortomitral positional anatomy would provide a more in-depth understanding of normal or abnormal anatomy and variations in the cardiac conduction system.

To validate our study results, it is crucial to objectively evaluate and classify anatomic variations using CT measurements. This is a significant goal for future studies. Previous reports on rotation have relied on CT measurements but did not classify the aortomitral appearance, including any misalignment of the aortic root and the mitral valve. Consequently, there may be cases in which the rotational axis of the aortic root is misaligned, leading to inaccurate measurements. We are currently investigating how to measure the positional relationship between the aortic root and the mitral valve (appearance) using CT, which remains a challenging issue. Advances in 3-dimensional CT imaging technology now allow for 3-dimensional rendering of the traced mitral and aortic valve annulus,[33] which is very promising.

Importantly, even for patients with anatomic variations that increase the risk of postoperative atrioventricular conduction disorders, achieving optimal mitral valve surgical outcomes remains the highest priority. Building on this premise, our study provides the following insights: It is noteworthy that modifying surgical techniques for patients with anatomic variations that pose a high risk of lateral appearance or lateral rotation is an intriguing consideration. However, our findings did not reveal any significant impact of mitral valve surgery techniques, and we do not currently recommend any modifications in surgical techniques. Nevertheless, anatomic variations may predispose patients to postoperative atrioventricular conduction disorders, which are thought to be permanent and can lead to an increased incidence of PAF requiring oral anticoagulant treatment >3 months postoperatively, as suggested by our study. Despite the limited number of events and lack of long-term follow-up data, this is the first report highlighting the potential clinical significance of a new concept in the local anatomy of the heart.

This study has several limitations. First, this was a single-center retrospective study with a small number of patients. Second, improvements in the diagnostic capabilities of 3-dimensional TEE are a recent development, and long-term follow-up data are not yet available. Third, data regarding the occurrence of long-term events in patients who developed first-degree AVB are lacking. Therefore, further clinical research is warranted to investigate the long-term outcomes of new-onset first-degree AVB following mitral valve surgery. Nonetheless, this study is informative, as it is one of the few to classify the aortomitral positional anatomy using 3-dimensional TEE with high-quality imaging, and our study results offer novel insights and contribute to a better understanding of local anatomy in cardiac surgery.

Variations in the aortomitral positional anatomy was effectively classified using preoperative 3-dimensional TEE, introducing a novel category termed *lateral appearance*. In the context of mitral valve surgery, lateral appearance and lateral rotation may pose a risk of postoperative atrioventricular conduction disorders, particularly first-degree AVB. For patients exhibiting these variations, vigilant postoperative monitoring is essential to detect atrioventricular conduction disorders and assess the occurrence of cardiac events such as long-term arrhythmias and heart failure events.

ARTICLE INFORMATION

Received March 31, 2024; accepted July 26, 2024.

Affiliations

Department of Cardiovascular Surgery, Osaka University Graduate School of Medicine, Osaka, Japan (K.H., M.K., D.Y., S.S., T.K., A.K., Y.M., M.T., K.S., S.M.); Department of Integrated Medicine, Institute of Biomedical Statistics, Osaka University Graduate School of Medicine, Osaka, Japan (S.K.); and Department of Social and Environmental Medicine, Osaka University Graduate School of Medicine, Osaka, Japan (T.K.).

Acknowledgments

The authors thank Editage (www.editage.jp) for English language editing.

Author contributions: Drs Handa and M. Kawamura drafted and revised the manuscript. Drs Kitamura (epidemiologist) and Komukai (biostatistician) checked and supervised all statistical analyses. Drs Yoshioka, T. Kawamura, A. Kawamura, Misumi, Taira, Shimamura, and Miyagawa supervised the manuscript.

Sources of Funding

None.

Disclosures

None.

REFERENCES

1. Nkomo VT, Gardin JM, Skelton TN, Gottdiener JS, Scott CG, Enriquez-Sarano M. Burden of valvular heart diseases: a population-based study. *Lancet*. 2006;368:1005–1011. doi: 10.1016/S0140-6736(06)69208-8
2. Iung B, Delgado V, Rosenhek R, Price S, Prendergast B, Wendler O, De Bonis M, Tribouilloy C, Evangelista A, Bogachev-Prokophiev A, et al. Contemporary presentation and Management of Valvular Heart Disease: the EURObservational research Programme valvular heart disease II survey. *Circulation*. 2019;140:1156–1169. doi: 10.1161/CIRCULATIONAHA.119.041080
3. Dziadzko V, Clavel MA, Dziadzko M, Medina-Inojosa JR, Michelena H, Maalouf J, Nkomo V, Thapa P, Enriquez-Sarano M. Outcome and undertreatment of mitral regurgitation: a community cohort study. *Lancet*. 2018;391:960–969. doi: 10.1016/S0140-6736(18)30473-2
4. Silaschi M, Chaubey S, Aldalati O, Khan H, Uzzaman MM, Singh M, Baghai M, Deshpande R, Wendler O. Is mitral valve repair superior to mitral valve replacement in elderly patients? Comparison of short- and long-term outcomes in a propensity-matched cohort. *J Am Heart Assoc*. 2016;5:e003605. doi: 10.1161/JAHA.116.003605
5. Mick SL, Keshavamurthy S, Gillinov AM. Mitral valve repair versus replacement. *Ann Cardio Surg*. 2015;4:230–237.
6. Lazam S, Vanoverschelde JL, Tribouilloy C, Grigioni F, Suri RM, Avierinos JF, de Meester C, Barbieri A, Rusinaru D, Russo A, et al. Twenty-year outcome after mitral repair versus replacement for severe degenerative mitral regurgitation: analysis of a large, prospective, multicenter, international registry. *Circulation*. 2017;135:410–422. doi: 10.1161/CIRCULATIONAHA.116.023340
7. Uchino G, Murakami H, Mukohara N, Tanaka H, Nomura Y, Miyahara S, Kawashima M, Fujisue J, Tonoki S. Modes of the bioprosthetic valve failure of the porcine and pericardial valves in the mitral position. *Eur J Cardiothorac Surg*. 2022;62:ezab506. doi: 10.1093/ejcts/ezab506
8. Carpentier AF, Adams DH, Filsoufi F. Reconstructive valve surgery made simple. *Carpentier's Reconstructive Valve Surgery: from Valve Analysis to Valve Reconstruction*. Philadelphia, PA: Saunders Elsevier; 2010.
9. Tseng SY, Tretter JT, Gao Z, Ollberding NJ, Lang SM. Aortic root rotational position associates with aortic valvar incompetence and aortic dilation after arterial switch operation for transposition of the great arteries. *Int J Card Imaging*. 2023;39:1013–1021. doi: 10.1007/s10554-023-02794-1
10. Oishi K, Arai H, Oi K, Nagaoka E, Yashima M, Fujiwara T, Takeshita M, Mizuno T. The rotational position of the aortic valve: implications for valve-sparing aortic root replacement. *Eur J Cardiothorac Surg*. 2022;62:ezac179. doi: 10.1093/ejcts/ezac179
11. Tretter JT, Izawa Y, Spicer DE, Okada K, Anderson RH, Quintessenza JA, Mori S. Understanding the aortic root using computed tomographic assessment: a potential pathway to improved customized surgical repair. *Circ Cardiovasc Imaging*. 2021;14:e013134. doi: 10.1161/CIRCIMAGING.121.013134
12. Romeih S, Kaoud A, Hashem M, Abdelfattah M, Gibreel M, Elzoghby M, Shaaban M, Mozy WE. A quantitative assessment of aorta root rotation in patients with tetralogy of Fallot evaluated by MSCT. *Sci Rep*. 2021;11:14336. doi: 10.1038/s41598-021-93814-4
13. Moradi M, Mirfasihi RS. Is there any association between aortic root rotation angle and aortic dissection? *Ind J Thoracic Cardiovasc Surg*. 2020;36:181–185. doi: 10.1007/s12055-019-00859-2
14. Tretter JT, Mori S, Anderson RH, Taylor MD, Ollberding N, Truong V, Choo J, Kereiakes D, Mazur W. Anatomical predictors of conduction damage after transcatheter implantation of the aortic valve. *Open Heart*. 2019;6:e000972. doi: 10.1136/openhrt-2018-000972
15. Amofa D, Mori S, Toh H, Ta HT, Du Plessis M, Davis N, Izawa Y, Spicer DE, Anderson RH, Tretter JT. The rotational position of the aortic root related to its underlying ventricular support. *Clin Anat*. 2019;32:1107–1117. doi: 10.1002/ca.23462
16. Mori S, Anderson RH, Takaya T, Toba T, Ito T, Fujiwara S, Watanabe Y, Nishii T, Kono AK, Hirata KI. The association between wedging of the aorta and cardiac structural anatomy as revealed using multidetector-row computed tomography. *J Anat*. 2017;231:110–120. doi: 10.1111/joa.12611
17. Tretter JT, Mori S, Saremi F, Chikkabyrappa S, Thomas K, Bu F, Loomba RS, Alsaied T, Spicer DE, Anderson RH. Variations in rotation of the aortic root and membranous septum with implications for transcatheter valve implantation. *Heart*. 2018;104:999–1005. doi: 10.1136/heartjnl-2017-312390
18. Saremi F, Cen S, Tayari N, Alizadeh H, Emami A, Lin L, Fleischman F. A correlative study of aortic valve rotation angle and thoracic aortic sizes using ECG gated CT angiography. *Eur J Radiol*. 2017;89:60–66. doi: 10.1016/j.ejrad.2017.01.009
19. Isaaz K, Cloez JL, Marçon F, Worms AM, Pernot C. Is the aorta truly dextroposed in tetralogy of Fallot? A two-dimensional echocardiographic answer. *Circulation*. 1986;73:892–899. doi: 10.1161/01.CIR.73.5.892
20. Surawicz B, Childers R, Deal BJ, Gettes LS, Bailey JJ, Gorgels A, Hancock EW, Josephson M, Kligfield P, Kors JA, et al. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part III: intraventricular conduction disturbances: a scientific statement from the American Heart Association electrocardiography and arrhythmias committee, council on clinical cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society. Endorsed by the International Society for Computerized Electrocardiology. *Circulation*. 2009;119:e235–e240. doi: 10.1161/CIRCULATIONAHA.108.191095
21. Peretto G, Durante A, Limite LR, Cianflone D. Postoperative arrhythmias after cardiac surgery: incidence, risk factors, and therapeutic management. *Cardiol Res Pract*. 2014;2014:615987. doi: 10.1155/2014/615987
22. MacKay EJ, Zhang B, Augoustides JG, Groeneveld PW, Desai ND. Association of intraoperative transesophageal echocardiography and clinical outcomes after Open Cardiac Valve or proximal aortic surgery. *JAMA Netw Open*. 2022;5:e2147820. doi: 10.1001/jamanetworkopen.2021.47820
23. Tsang W, Lang RM. Three-dimensional echocardiography is essential for intraoperative assessment of mitral regurgitation. *Circulation*. 2013;128:643–652. doi: 10.1161/CIRCULATIONAHA.112.120501
24. Ender J, Sgouropoulou S. Value of transesophageal echocardiography (TEE) guidance in minimally invasive mitral valve surgery. *Ann Cardio Surg*. 2013;2:796–802. doi: 10.3978/j.issn.2225-319X.2013.10.09
25. Cheng S, Keyes MJ, Larson MG, McCabe EL, Newton-Cheh C, Levy D, Benjamin EJ, Vasan RS, Wang TJ. Long-term outcomes in individuals with prolonged PR interval or first-degree atrioventricular block. *JAMA*. 2009;301:2571–2577. doi: 10.1001/jama.2009.888
26. Tan NY, Witt CM, Oh JK, Cha YM. Left bundle branch block: current and future perspectives. *Circ Arrhythm Electrophysiol*. 2020;13:e008239. doi: 10.1161/CIRCEP.119.008239

27. Bussink BE, Holst AG, Jespersen L, Deckers JW, Jensen GB, Prescott E. Right bundle branch block: prevalence, risk factors, and outcome in the general population: results from the Copenhagen City heart study. *Eur Heart J*. 2013;34:138–146. doi: 10.1093/eurheartj/ehs291
28. Koplan BA, Stevenson WG, Epstein LM, Aranki SF, Maisel WH. Development and validation of a simple risk score to predict the need for permanent pacing after cardiac valve surgery. *J Am Coll Cardiol*. 2003;41:795–801. doi: 10.1016/S0735-1097(02)02926-1
29. Farina J, Biffi M, Folesani G, Di Marco L, Martin S, Zenesini C, Savini C, Ziacchi M, Diemberger I, Martignani C, et al. Long-term atrioventricular block following valve surgery: electrocardiographic and surgical predictors. *J Clin Med*. 2024;13:538. doi: 10.3390/jcm13020538
30. Kawashima T, Sasaki H. A macroscopic anatomical investigation of atrioventricular bundle locational variation relative to the membranous part of the ventricular septum in elderly human hearts. *Surg Radiol Anat*. 2005;27:206–213. doi: 10.1007/s00276-004-0302-7
31. Feins EN, O'Leary ET, Davee J, Gauvreau K, Hoganson DM, Schulz N, Eickoff E, Triedman JK, Baird CW, Del Nido PJ, et al. Conduction mapping during complex congenital heart surgery: creating a predictive model of conduction anatomy. *J Thorac Cardiovasc Surg*. 2023;165:1618–1628. doi: 10.1016/j.jtcvs.2022.11.033
32. Feins EN, Del Nido PJ. Conduction in congenital heart surgery. *J Thorac Cardiovasc Surg*. 2023;166:1182–1188. doi: 10.1016/j.jtcvs.2023.03.012
33. Reyaldeen R, Kaur S, Krishnaswamy A, Ramchand J, Layoun H, Schoenhagen P, Miyasaka R, Unai S, Kapadia SR, Harb SC. Role of cardiac computed tomography in planning transcatheter mitral valve replacement (TMVR). *Curr Cardiol Rep*. 2022;24:1917–1932. doi: 10.1007/s11886-022-01794-2