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Research Article

Novel Echocardiographic Metrics Predict Tricuspid Insufficiency in Pediatric Ebstein Anomaly

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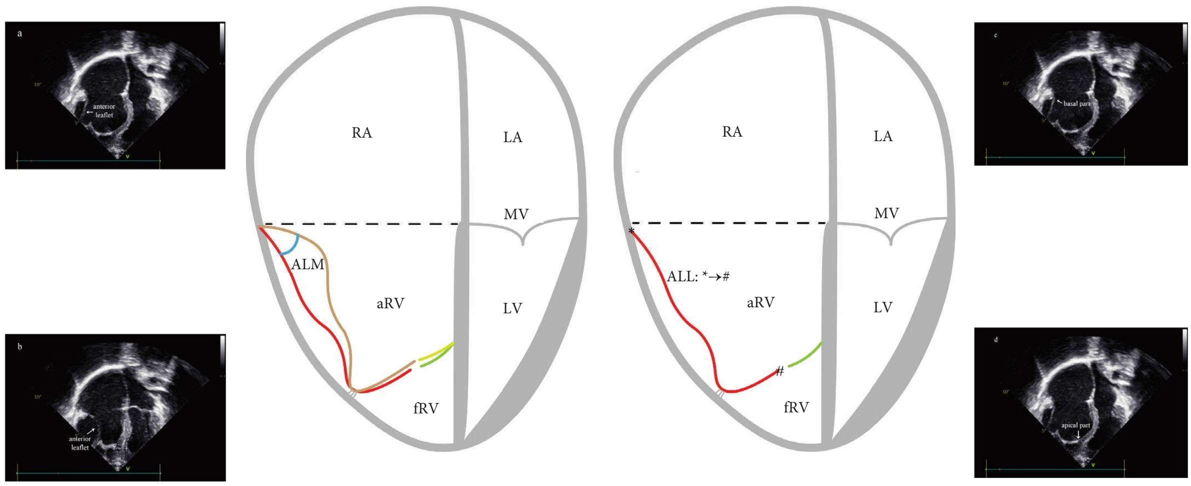
Objectives. The tricuspid anterior leaflet is considered important in most repair techniques for Ebstein anomaly (EA). We aim to assess the anterior leaflet morphology using novel metrics and investigate the association of the morphology with recurrent moderately severe or greater tricuspid regurgitation (TR). *Methods*. Seventy-four paediatric patients with EA undergoing cone reconstruction (CR) between 2010 and 2021 were included. Anterior leaflet mobility (ALM) and anterior leaflet length (ALL) were remeasured on preoperative 2D echocardiography. The prediction accuracies of ALM and ALL-I (ALL indexed to body surface area) for recurrent TR were evaluated using receiver operating characteristic (ROC) curve analyses. *Results*. The median age of patients was 3.3 years (interquartile range, 1.9–7.1 years). Both ALM and ALL-I correlated with the Carpentier type and GOSH score. Nine patients (12.2%) developed recurrent TR during the one-year follow-up. By univariable logistic regression analyses, ALM (odds ratio [OR], 0.89; 95% CI [confidence interval], 0.82–0.96; $p = 0.003$) and ALL-I (OR, 1.39; 95% CI, 1.08–1.78; $p = 0.011$) were risk factors for recurrent TR. ROC curve analyses showed that ALM (AUC = 0.81) and ALL-I (AUC = 0.77) had better predictive performance for recurrent TR compared with the GOSH score (AUC = 0.68), the Carpentier type (AUC = 0.67), and preoperative TR severity (AUC = 0.58), and the combinations of ALM and ALL-I (AUC = 0.87) improved the predictive performance compared with ALM or ALL-I alone. *Conclusions*. ALM and ALL-I can help optimize evaluation in the anterior leaflet morphology and predict recurrent TR after CR in pediatric EA.

1. Introduction

The success of most tricuspid valve (TV) repair techniques for Ebstein anomaly (EA) rely on a mobile and large anterior leaflet, especially for pediatric patients who have more fragile valves. For instance, Danielson's technique [1] uses the anterior leaflet to construct a monocusp valve; Carpentier's technique [2] and cone reconstruction (CR) [3] detach the anterior leaflet to achieve extensive mobilization of the leaflet tissue. However, the conventional classification system, the Carpentier type, assesses the anterior leaflet morphology qualitatively and relies too much on the evaluator's experience. Limited studies have quantitatively analyzed the anterior leaflet morphology of EA and investigated the association between morphology and surgical outcomes. Although Hughes et al. [4] introduced the Ebstein valve rotation angle on cardiovascular magnetic resonance (CMR) to guide the feasibility of CR, they did not analyze the anterior leaflet morphology separately. In addition, the potential need for general anesthesia in young children makes it challenging to perform CMR routinely in pediatric patients with EA [5]. Therefore, in this study, we sought to assess the anterior leaflet morphology using novel 2D echocardiographic metrics quantitatively and examine the association of the novel metrics with surgical outcomes in pediatric patients with EA.



(a) (b)

Figure 1: Schematic illustration of the anterior leaflet mobility (ALM) and anterior leaflet length (ALL) measurement. (a) The angle α between the basal part of the anterior leaflet and the tricuspid annulus plane (dash line) was measured on each frame during the cardiac cycle. The red line indicates the anterior leaflet on the frame with the maximum value of α, and the brown line indicates the anterior leaflet on the frame with the minimum value of α, corresponding to echocardiographic image a and b, respectively. ALM was defined as the maximum value minus minimum value of α (indicated by a blue arc). (b) ALL was measured on the frame with the maximum value of α, and it was defined as the distance from the basal part (*) to the apical part (#) of the anterior leaflet, corresponding to echocardiographic image c and d, respectively. aRV, atrialized right ventricle; fRV, functional right ventricle; LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium.

2. Materials and Methods

2.1. Study Design and Patient Selection. The study was approved by the Institutional Review Board of Shanghai Children's Medical Center on June 9, 2022 (SCMCIRBK-2022076-1), with a waiver of informed consent due to the retrospective nature. Demographic and perioperative data were collected from the electronic databases, and cardiac imaging and clinical examination details were collected from the outpatient medical records. Consecutive pediatric patients with EA undergoing CR at our center between January 2010 and December 2021 were reviewed for inclusion. Patients whose preoperative and postoperative transthoracic echocardiographic images were unavailable for remeasurement and patients who underwent palliative procedures, non-CR repair techniques, or previous TV surgery at other institutions were excluded from this study. CR should generally be avoided during the early neonatal period [6]. Therefore, patients in this cohort were relatively older. Indications for operation were conventional and included one or more of the following: symptoms of cyanosis, exercise intolerance, atrial tachyarrhythmia, heart failure, or asymptomatic patients with progressive right ventricle (RV) dilation or dysfunction.

2.2. Surgical Technique. CR was performed according to the previous description [3]. The first step was to detach the anterior and posterior tricuspid leaflets from their anomalous attachments in the RV. Then, the anterior leaflet was carefully mobilized by freeing its connections to the interventricular septum. Finally, the free edge of the posterior leaflet was rotated clockwise and sutured to the recruited septal leaflet edge, forming a new TV resembling a cone. Atrialized RV was reduced by longitudinal plication at the junction of the anterior and posterior leaflets. In this cohort, bidirectional cavopulmonary shunt (BCPS) was performed intraoperatively due to hemodynamic instability after separation from cardiopulmonary bypass, and specific indications for BCPS in our center have been previously described [7, 8].

2.3. Echocardiographic Measurements. 2D echocardiographic examination was performed using the Philips iE33 ultrasound machine (Philips, Andover, MA, USA) equipped with an X5-1 matrix-array transducer. All preoperative 2D transthoracic echocardiographic images were reviewed by two cardiologists (Lijun Chen and Yuqi Zhang). In order to avoid the bias caused by the subjective factors, the cardiologists were blinded to the results of postoperative recurrent TR. The anterior leaflet morphology was analyzed in the apical four-chamber view of preoperative echocardiographic images. The angle α between the basal part of the anterior leaflet and the tricuspid annulus plane was measured on each frame during the cardiac cycle. The anterior leaflet mobility (ALM) was defined as the maximum value minus minimum value of α (Figure 1(a)). The anterior leaflet length (ALL) was measured on the frame with the maximum value of α, and it was defined as the distance from the basal part to the apical part of the anterior leaflet (Figure 1(b)). ALL was indexed to body surface area and referred to as ALL-I. Conventional echocardiographic parameters including the Carpentier type, GOSH score, right ventricle fractional area change (RV FAC), left ventricle ejection fraction, the grade of tricuspid regurgitation (TR), and the size of the TV annulus were also measured. The severity of TR was assessed according to vena contracta width (VCW) [9]. TR was graded as mild (VCW < 0.3), mild-moderate (VCW = 0.3), moderate ($0.3 < VCW \leq 0.69$), moderate-severe (VCW = 0.7), and severe (VCW > 0.7) in our center [8].

2.4. Follow-Up and Outcomes. All patients were required to undergo follow-up examinations including echocardiography and cardiogram every 3 months postoperatively. If a scheduled visit was missed, we would interview the patients by telephone for confirmation of their condition. Follow-up in local hospitals was advised for patients living far from our center, and echocardiographic reports were sent to us through a mobile phone app (WeChat). If moderate or greater TR was suspected, patients were required to come to our center for further evaluation. The primary endpoint of the study was the presence of significant recurrent TR, defined as TR of moderate-severe or greater grade within one year after CR.

2.5. Statistical Analysis. Categoric data were presented as counts and percentages, and continuous data were presented as means ± standard deviations or medians and interquartile ranges (IQR) as appropriate. Correlation coefficients are derived using the Pearson method for continuous variables and Spearman rank-order correlation for ordinal variables. Univariable logistic regression analyses were performed to determine the risk factors for recurrent TR. Multivariable analysis was not performed given the limited sample size. To analyze the predictive power of the two novel echocardiographic metrics for recurrent TR, receiver operating characteristic (ROC) curves were performed and the area under the curve (AUC) together with a 95% confidence interval (CI) was calculated. The calculation formula of the combined ALM and ALL-I values was shown as follows: $-0.035 - 0.103 \times \text{ALM} + 0.268 \times \text{ALL-I}$. The coefficients and constant term were derived from multivariable logistic regression analysis which incorporated both ALM and ALL-I. The optimal cutoff values of ALM, ALL-I, and ALM + ALL-I to predict recurrent TR were evaluated using the maximum value of the Youden index. Time-to-event analysis was studied using Kaplan–Meier estimates, and comparisons were performed using the log-rank test. All statistical analyses were performed using R version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria), and a p value of <0.05 was considered to be significant.

3. Results

3.1. Patients' Characteristics. In total, 74 pediatric patients with EA were fit for inclusion. Baseline characteristics of the entire cohort are presented in Table 1. Median age at operation was 3.3 (IQR, 1.9–7.1) years, and 10 patients were aged less than 1 year. Most of the cohorts were classified as Carpentier type A (63.5%). GOSH scores < 1 were reported in 80% of the patients. The mean of ALM and ALL-I was 43.8 ± 12.4 and 6.4 ± 2.9 cm/m^2, respectively, and there was no statistical difference in ALM and ALL-I among patients with different grades of TR ($p = 0.40$ and 0.176, respectively). Correlations of ALM and ALL-I with conventional echocardiographic parameters are demonstrated in Table 2. Both ALM and ALL-I were significantly related to the Carpentier type and GOSH score but were not related to preoperative TR severity. In addition, ALM was also associated with RV FAC.

3.2. In-Hospital and Follow-Up Results. Operative and early postoperative data are summarized in Table 3. The median bypass time and aortic cross clamp time were 105 (IQR, 88–124) and 75.5 (IQR, 58–89) minutes, respectively. Adjunctive BCPS was required in 13 (17.6%) patients. In-hospital death and reoperation for recurrent severe TR occurred in 2 (2.7%) patients each. There were no late deaths. Follow-up was completed in all survivors discharged from the hospital. Five patients developed recurrent moderate-severe or greater TR during one-year follow-up in whom one underwent reoperation 2 years after the initial operation. Freedom from recurrent TR during one-year follow-up of the entire cohort is shown in Figure 2.

3.3. Risk Factors of Recurrent TR. By univariable logistic regression analyses, ALM (odds ratio [OR], 0.89; 95% CI, 0.82–0.96; $p = 0.003$) and ALL-I (OR, 1.39; 95% CI, 1.08–1.78; $p = 0.011$) were significantly associated with recurrent TR, whereas the Carpentier type (OR, 3.12; 95% CI, 0.85-11.41; $p = 0.085$), GOSH score (OR, 3.25; 95% CI, 0.60-17.61; $p = 0.172$), and preoperative TR severity (OR, 0.73; 95% CI, 0.40–1.31; $p = 0.293$) were not risk factors for recurrent TR (Table 4).

3.4. Predictive Performance for Recurrent TR of Different Echocardiographic Metrics. For predicting recurrent moderate-severe or greater TR within one year after CR, ROC curves analyses were conducted to evaluate the predictive performance of ALM, ALL-I, the Carpentier type, GOSH score, preoperative TR severity, and the combinations by including both ALM and ALL-I in the logistic model. ALM (AUC, 0.81; 95% CI, 0.67–0.94; $p = 0.003$) and ALL-I (AUC, 0.77; 95% CI, 0.65–0.90; $p = 0.008$) had better predictive performance compared with the GOSH score (AUC, 0.68; 95% CI, 0.48–0.89; $p = 0.078$), the Carpentier type (AUC, 0.67; 95% CI, 0.48–0.86; $p = 0.107$), and preoperative TR severity (AUC, 0.58; 95% CI, 0.35–0.61; $p = 0.497$), and the combinations of ALM and ALL-I (AUC, 0.87; 95% CI, 0.76–0.97; $p < 0.001$) improved the predictive performance compared with ALM or ALL-I alone (Figure 3).

ROC curve analyses demonstrated that the optimal cutoff values of ALM, ALL-I, and ALM + ALL-I for predicting recurrent TR were 39.5° (sensitivity, 69.2%; specificity, 77.8%), 5.6 cm/m^2 (sensitivity, 50.8%; specificity, 100%), and −2.16 (sensitivity, 75.2%; specificity, 88.9%), respectively. When an ALM of >39.5° was used as the cutoff value to define patients with a flexible anterior leaflet, there were 47 patients with an ALM of >39.5° (flexible group) and

Table 1: Baseline characteristics.

Variables	Values
Age (months), median (IQR)	39.9 (23.4–86.4)
Male, *n* (%)	27 (36.5)
Weight (kg), median (IQR)	14.85 (11–25)
Height (cm), median (IQR)	96 (85–122)
BSA (m^2), median (IQR)	0.59 (0.47–0.88)
ASD, *n* (%)	41 (55.4)
VSD, *n* (%)	8 (10.8)
Left ventricular ejection fraction (%), mean ± SD	70.8 ± 7.9
Z-score of the tricuspid annulus diameter, median (IQR)	7.3 (3.7–9.9)
RV FAC (%), median (IQR)	46.0 (40.1–50.8)
ALM (degrees), mean ± SD	43.8 ± 12.4
ALL-I (cm/m^2), median (IQR)	6.1 (4.1–8.1)
Carpentier type, *n* (%)	
A	47 (63.5)
B	26 (35.1)
C	1 (1.4)
D	0 (0)
GOSH score, *n* (%)	
<0.5	14 (18.9)
0.5–0.99	45 (60.8)
1–1.49	11 (14.9)
≥1.5	4 (5.4)
Preoperative TR severity, *n* (%)	
Mild	4 (5.4)
Mild-moderate	7 (9.5)
Moderate	25 (33.8)
Moderate-severe	16 (21.6)
Severe	22 (29.7)

Abbreviations: ALM, anterior leaflet mobility; ALL-I, anterior leaflet length indexed to body surface area; ASD, atrial septal defect; BSA, body surface area; RV FAC, right ventricle fractional area change; TR, tricuspid regurgitation; VSD, ventricular septal defect.

Table 2: Results of correlation analysis of conventional echocardiographic parameters with ALM and ALL-I.

Echocardiographic parameters	Correlations with ALM		Correlations with ALL-I	
	r	*p* value	*r*	*p* value
Carpentier type	−0.423	<0.001	0.324	0.005
GOSH score	−0.233	0.046	0.489	<0.001
RV FAC	0.229	0.0497	−0.157	0.180
Diameter of tricuspid annulus	−0.178	0.111	−0.029	0.806
Left ventricular ejection fraction	−0.116	0.329	0.043	0.720
Preoperative TR severity	−1.33	0.260	−0.144	0.220

Note. Values are correlation coefficients (*r*) and corresponding *p* values. ALM, anterior leaflet mobility; ALL-I, anterior leaflet length indexed to body surface area; RV FAC, right ventricle fractional area change; TR, tricuspid regurgitation.

Table 3: Operative and early postoperative data.

Variables	Values
BCPS, *n* (%)	13 (17.6)
Delayed sternal closure, *n* (%)	2 (2.7)
Bypass time (min), median (IQR)	105 (88–124)
Aortic cross clamp time (min), median (IQR)	75.5 (58–89)
Length of CICU stay (h), median (IQR)	48 (40.74–74.48)
Length of mechanical ventilation (h), median (IQR)	18.6 (7.0–24.17)
Arrhythmia, *n* (%)	7 (9.5)
Hydrothorax, *n* (%)	6 (8.1)
ECMO, *n* (%)	1 (1.4)
In-hospital reoperation, *n* (%)	2 (2.7)
In-hospital death, *n* (%)	2 (2.7)

Abbreviations: BCPS, bidirectional cavopulmonary shunt; CICU, cardiac intensive care unit; ECMO, extracorporeal membrane oxygenation.

27 patients without an ALM of >39.5° (inflexible group). Recurrent TR developed in 2 patients in the flexible group and in 7 patients in the inflexible group (log-rank $p = 0.006$, Figure 4(a)). When an ALL-I of >5.6 cm/m^2 was used as the cutoff value to define patients with a redundant anterior leaflet, there were 41 patients with an ALL-I of >5.6 cm/m^2 (redundant group) and 33 patients without an ALL-I of >5.6 cm/m^2 (nonredundant group). Recurrent TR developed in 9 patients in the redundant group and in no patients in the nonredundant group (log-rank $p = 0.005$, Figure 4(b)). When an ALM + ALL-I of > −2.16 was used as the cutoff value to define patients with a dysfunctional anterior leaflet, there were 24 patients with an ALM + ALL-I of > −2.16 (dysfunctional group) and 50 patients without an ALM + ALL-I of > −2.16 (functional group). Recurrent TR developed in 8 patients in the dysfunctional group and in 1 patient in the functional group (log-rank $p < 0.001$, Figure 4(c)).

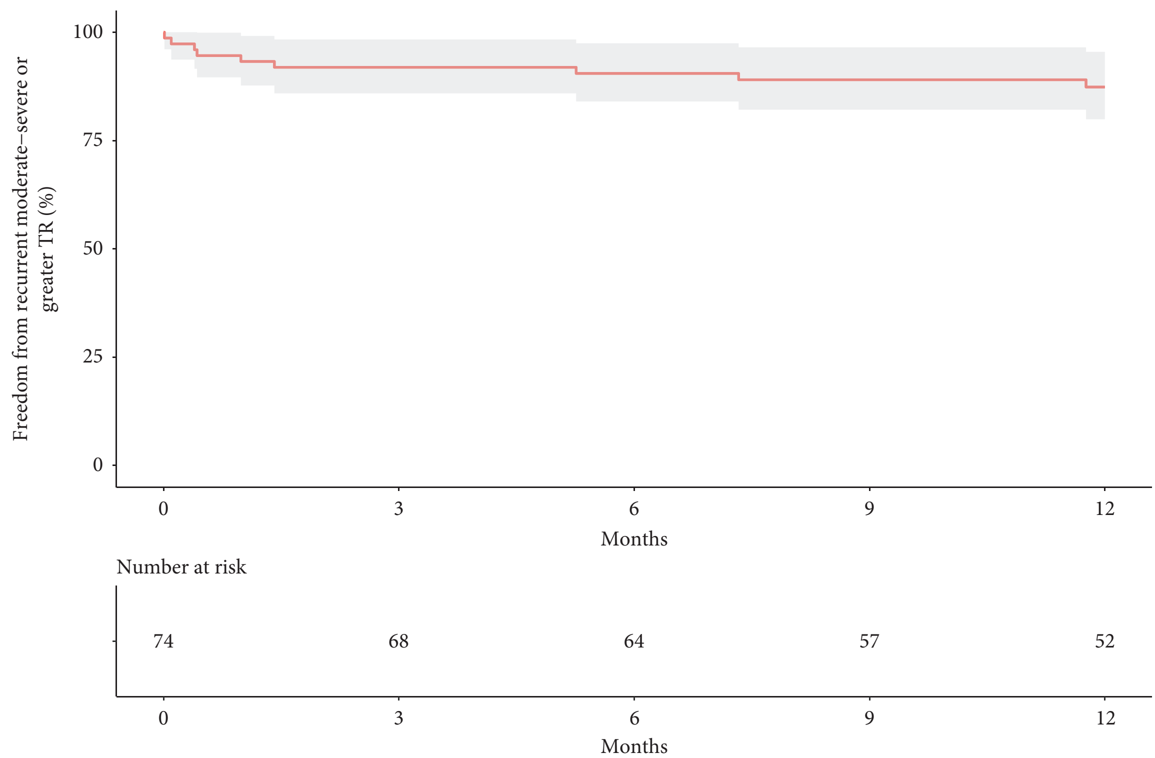


Figure 2: Freedom from recurrent moderate-severe or greater tricuspid regurgitation (TR) of the entire cohort. The 95% confidence interval is plotted as shades.

Table 4: Univariable logistic regression analysis for recurrent TR within one year after cone reconstruction.

Variables	OR (95% CI)	p value
Age	0.999 (0.998–1.0)	0.187
Male	1.46 (0.36–5.98)	0.598
Weight	0.93 (0.84–1.03)	0.170
Height	0.98 (0.95–1.01)	0.167
ASD	7.76 (0.92–65.6)	0.060
VSD	2.81 (0.47–16.69)	0.256
Left ventricular ejection fraction	1.03 (0.94–1.12)	0.577
Diameter of tricuspid annulus	0.73 (0.40–1.31)	0.293
ALM	0.89 (0.82–0.96)	0.003
ALL-I	1.39 (1.08–1.78)	0.011
Carpentier type	3.12 (0.85–11.41)	0.085
GOSH score	3.25 (0.60–17.61)	0.172
Preoperative TR severity	0.73 (0.40–1.31)	0.293
BCPS	2.75 (0.59–12.8)	0.198
Bypass time	1.01 (0.999–1.02)	0.069
Aortic cross clamp time	1.01 (0.98–1.03)	0.663
Length of CICU stay	1.01 (1.0–1.02)	0.002
Length of mechanical ventilation	1.02 (1.00–1.04)	0.035
Arrhythmia	1.23 (0.14–11.57)	0.857
Hydrothorax	4.36 (0.67–28.24)	0.123

Abbreviations: ALM, anterior leaflet mobility; ALL-I, anterior leaflet length indexed to body surface area; ASD, atrial septal defect; BCPS, bidirectional cavopulmonary shunt; CICU, cardiac intensive care unit; CI, confidence interval; OR, odds ratio; TR, tricuspid regurgitation; VSD, ventricular septal defect.

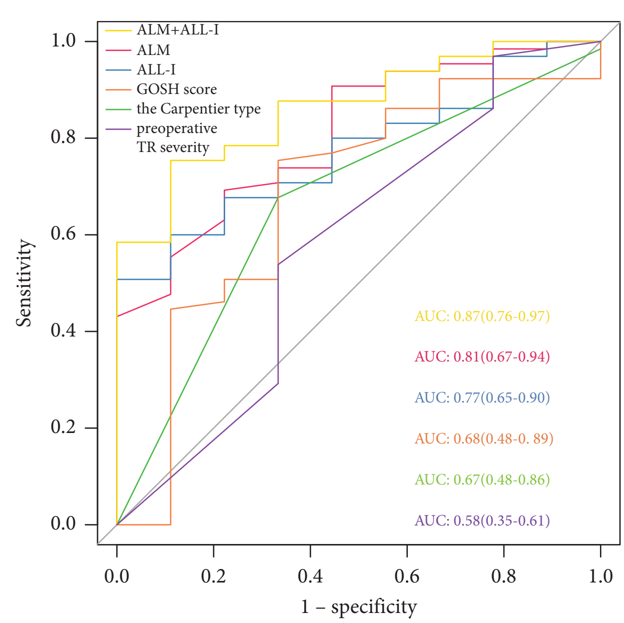
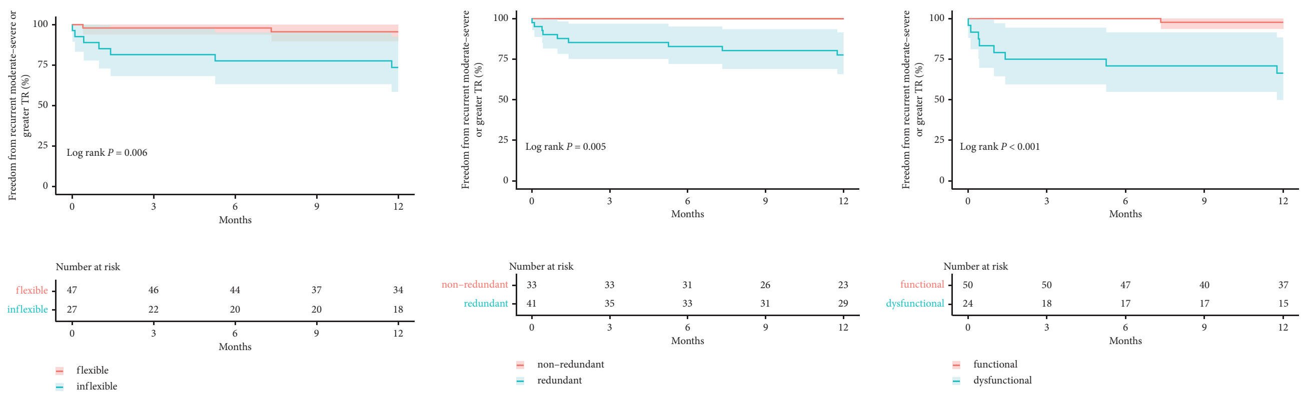


Figure 3: Receiver operating characteristic curve for prediction of recurrent moderate-severe or greater tricuspid regurgitation (TR) within one year after cone reconstruction by the anterior leaflet mobility (ALM), the anterior leaflet length (ALL-I), the Carpentier type, GOSH score, preoperative TR severity, and ALM + ALL-I.



(a) (b) (c)

Figure 4: Freedom from recurrent moderate-severe or greater tricuspid regurgitation (TR) after cone reconstruction (CR) between the flexible group and the inflexible group (a), between the redundant group and the nonredundant group (b), and between the functional group and the dysfunctional group (c). The 95% confidence interval is plotted as shades.

4. Discussion

To the best of our knowledge, this is the first study that investigated the anterior leaflet morphology on 2D echocardiography in pediatric Ebstein anomaly (pEA). The main findings of our study were as follows: (1) ALM and ALL-I were well associated with the Carpentier type and GOSH score, and ALM was also correlated to RV FAC; (2) ALM and ALL-I were risk factors for recurrent moderate-severe or greater TR after CR in pEA and were more reliable metrics to predict recurrent TR compared with the Carpentier type, GOSH score, and preoperative TR severity.

In most TV repair techniques involving EA, the anterior leaflet is the fundamental tissue for the reconstruction of a competent TV. Patients with restricted or insufficient anterior leaflets may need modified techniques, such as valve enlargement [10] and the Spinnaker repair [11]. In addition, the anterior leaflet morphology is an important criterion for grading the severity of EA according to the Carpentier type. Therefore, the anterior leaflet morphology may theoretically have an impact on surgical strategy and outcomes. Hughes et al. [4] found that 3 of the 4 patients with surgical dehiscence in their cohort exhibited thickened, rolled edges of the anterior leaflet and were noted to have numerous leaflet attachments to the RV anterior wall and poor leaflet mobility. None of the 16 patients without dehiscence exhibited thickened, rolled anterior leaflet margins. Similar circumstances have been found in mitral valve disease. Brescia et al. [12] assessed mitral anterior leaflet mobility and calcification to determine mitral repair or replacement in patients with rheumatic heart disease; Gupta et al. [13] found that mitral anterior leaflet length was a strong predictor of mitral valve repairability, and a value of 26 mm or more was associated with successful repair. Under this context, we remeasured the tricuspid anterior leaflet mobility and length on 2D echocardiography in a pediatric cohort with EA, and our result showed that measuring ALM and ALL might help identify Ebstein valves that were at risk of recurrent TR after CR in pEA.

Compared with the Carpentier type and GOSH score, ALM and ALL-I had better performance for predicting recurrent TR within one year after CR and the combinations of ALM and ALL-I increased the predictive performance compared with ALM or ALL-I alone. The possible explanations for this could include the following: (1) varying degrees of failed delamination of TV leaflets are the underlying pathology in EA. Specific to the anterior leaflet, it manifests a wide spectrum of morphologic variability, ranging from normal formation to sail-like redundance, to muscularization [14]; the failure of delamination also results in adherence of the anterior leaflet to the underlying myocardium, and the leaflet free edge shows varying degrees of limited mobility [15]. Therefore, in our cohort, where almost all patients' conditions are Carpentier types A or B, a sail-like redundant and less mobile anterior leaflet may suggest less delamination of the anterior leaflet and severer attachment of the leaflet body to RV walls, so the length and mobility of the anterior leaflet in EA may help assess the disease severity. This hypothesis was based on our results that ALM and ALL-I correlated well with the two conventional classification systems: the Carpentier type and GOSH score, and ALM also correlated with RV FAV; (2) the Carpentier type stratifies EA qualitatively according to severity of TV and RV, thus relying too much on the evaluator's experience. The GOSH score [16] is more frequently used for neonatal patients with EA and do not involve the function of TV. Both of them have limitations and cannot accurately evaluate EA patients who manifest a wide variety in clinical presentation and anatomic severity. In contrast, ALM and ALL-I stratify the vast variability in the anterior leaflet morphology quantitatively and can help discriminate the morphological difference among patients with the same Carpentier type or grade of the GOSH score.

With Geerdink et al., conflicting results have been reported about whether severe TR is associated with the prognosis in pediatric patients [17] and it was found that severe TR was a predictor of mortality in a multicenter cohort of 168 pediatric patients, whereas Prota et al. [18] concluded from a cohort of 50 pediatric patients that severe TR had no prognostic value in cardiac adverse events. Our study showed that preoperative TR severity was not a risk factor for recurrent TR. Some may question whether these negative results were due to the small number of enrolled patients; however, we should notice that quantitative parameters including RV FAC and right atrium peak atrial longitudinal strain were included in Prota's study [18]. In this study, ALM and ALL-I were associated with prognosis significantly, and our correlation analysis showed that ALM and ALL-I were not associated with preoperative TR severity. This may reflect the better competency of ALM and ALL-I as novel echocardiographic metrics to optimize evaluation in pEA and predict surgical outcomes.

Although prospective testing is needed, our findings can help surgeons better comprehend the morphological heterogeneity of the anterior leaflet in pEA and assist in surgical decision-making. First, surgeons can assess the anterior leaflet morphology on the basis of ALM and ALL-I preoperatively. Second, repair modifications such as leaflet augmentation may be considered if preoperative ALM and ALL-I suggest a high risk of recurrent TR after CR.

This study has several limitations. First, this cohort was a small number of pediatric patients with EA, and almost all of the patients' conditions were Carpentier types A or B. Further investigation of a larger patient population including various age subgroups and a wider spectrum of anterior leaflet morphology is needed to definitively confirm our results. Second, this is a retrospective, single-center study. Further multicenter or registry study with a cohort of normal patients as a comparison is undoubtedly necessary and useful. Third, the application of ALM and ALL-I in surgical decision-making is only a reasonable speculation because we did not analyze the association of the two metrics with repair modifications. Further prospective study with an appropriate design may help provide more scientific conclusions. Finally, the goal of CR is to create a cone-shaped TV from all available leaflet tissue including the posterior and septal tissue. However, the posterior and septal leaflets are hypoplastic and displaced downward in EA, which make it difficult to introduce appropriate metrics from 2D echocardiography to assess the morphology. A future cohort with 3D echocardiography may be helpful to provide more precise assessment of all leaflets.

5. Conclusions

Easily-acquired ALM and ALL-I from 2D echocardiography can help optimize evaluation of the anterior leaflet morphology and predict recurrent TR after CR in pEA.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Ethical Approval

The study was approved by the Institutional Review Board of Shanghai Children's Medical Center on June 9, 2022 (SCMCIRBK-2022076-1), with a waiver of informed consent due to the retrospective nature.

Disclosure

Wei Liu and Chen Wen shared co-first authorship.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Wei Liu was responsible for data analysis/interpretation, drafting the article, critical revision of the article, and approval of the article. Chen Wen was responsible for drafting the article, critical revision of the article, approval of the article, and data collection. Jin Shentu was responsible for data analysis/interpretation, critical revision of the article, and approval of the article. Yuqi Zhang was responsible for data analysis/interpretation, critical revision of the article, approval of the article, and statistics. Zhongqun Zhu was responsible for critical revision of the article, approval of the article, and statistics. Lijun Chen was responsible for concept/design, drafting the article, critical revision of the article, approval of the article, and funding security. Huiwen Chen was responsible for concept/design, drafting the article, critical revision of the article, approval of the article, and funding security. Wei Liu and Chen Wen contributed equally to this work and shared co-first authorship.

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