Research Article

Evaluation of Surgical Effect of Atrial Septal Defect with Tricuspid Regurgitation by Transesophageal 3D Echocardiography Based on MC Image Reconstruction Algorithm

Xuliang Chen ¹, Sichao Tai ¹, Pengxiang Zhou ¹, and Xiao Chen ²

¹Department of Cardiology, The Second Affiliated Hospital of Wenzhou Medical University, Wenzhou 325027, China

²Department of Cardiology, The First Affiliated Hospital of Wenzhou Medical University, Wenzhou 325000, China

Correspondence should be addressed to Xiao Chen; chenxiao@wzhospital.cn

Xuliang Chen and Sichao Tai contributed equally to this work.

Received 31 March 2021; Revised 7 May 2021; Accepted 23 May 2021; Published 4 June 2021

Academic Editor: Gustavo Ramirez; dr.gustavophd@gmail.com

Copyright © 2021 Xuliang Chen et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

This study was to explore the application and effect of three-dimensional (3D) images of the esophagus in the treatment of atrial septal defect (ASD) combined with tricuspid regurgitation (TR) surgery under the processing of marching cubes (MC) image reconstruction algorithm. The MC image reconstruction algorithm was improved as the optimized MC image reconstruction algorithm. 100 patients who had successfully undergone the ASD combined with TR surgery in the hospital from January 2017 to December 2019 were selected as the research objects and grouped based on size of the defect. The preoperative and postoperative conditions of the patients were analyzed with the MC image reconstruction algorithm. Compared with the traditional MC image algorithm, the optimized MC was advanced with less running time and fewer fixed points ($P < 0.05$). There were significant differences in TR of all ASD patients after the surgery ($P < 0.05$), and the TR of all patients showed obvious declines from the 1st day to 30th day after surgery and gradually stabilized from the 3rd month to the 6th month after surgery. Compared with patients with normal pulmonary artery pressure, the amount of TR in patients with elevated pulmonary artery pressure increased significantly, and the difference was statistically significant ($P < 0.05$). In addition, the improvement of TR after occlusion was correlated with the preoperative ASD of the patient. The optimized MC algorithm had been improved greatly in the number of fixed points and running time. The analysis using the optimized MC algorithm showed that ASD patients generally suffered different degrees of TR, TR increased with the increase of the defect, and good effect could be achieved in surgery of all kinds of ASD patients.

1. Introduction

About 10%–15% of patients with congenital heart disease suffer from ASD. As one of the most common congenital heart diseases, ASD accounts for about 1:2 in males and females. In adult congenital heart disease, the incidence of ASD accounts for about 35% to 40% [1]. TR blood enters the right atrium from the right ventricle via the insufficient TR. TR is usually secondary to the right ventricular dilatation and single dilatation or single high pressure due to severe pulmonary hypertension or right ventricular outflow tract obstruction [2]. At this stage, the clinical assessment of ASD mainly relies on coronary angiography, intravascular ultrasound, and optical coherence tomography [3, 4]. Surgery

for ASD is usually realized under the guidance of ultrasound images at this stage. For young doctors, it is difficult to complete the entire surgical process only with ultrasound images. On this basis, three-dimensional reconstruction is introduced. Most of the three-dimensional reconstruction is only for the human brain, bones, liver, and other organs. The three-dimensional vascular reconstruction is just starting, and three-dimensional reconstruction based on intravascular ultrasound is both the focus and the difficulty. The research on intravascular ultrasound images can be roughly divided into the following aspects: coronary artery image vessel segmentation and skeleton extraction, ultrasound image plaque segmentation, intravascular ultrasound (IVUS), and coronary arteriography (CAG) image data

fusion [5–7]. At this stage, certain results have been achieved in these fields, but there is still not much research on the construction of the three-dimensional model of the heart. The MC is a three-dimensional reconstruction algorithm, which is widely used in vascular reconstruction. However, the vascular model reconstructed by the MC algorithm is composed of a large amount of triangular mesh data, which is low in computational efficiency. Thus, the MC algorithm has to be optimized. At present, ASD occlusion and surgical repair are the main treatment methods for the treatment of ASD. Since the first case of secondary ASD was closed successfully by King et al. with interventional therapy in 1976, occlusion surgery has been become the first choice for the treatment of ASD [8]. Relevant studies have confirmed that some patients with ASD will have different degrees of TR at the same time. In the treatment of ASD, whether it is necessary to further actively intervene in TR is a question that clinicians need to consider. This is directly related to the choice of surgical repair or interventional occlusion for ASD treatment [9, 10].

Therefore, the conventional MC algorithm was improved as the optimized MC to construct a three-dimensional ultrasound heart model, so as to further study the therapeutic effect of occlusion on patients with ASD combined with TR.

2. Materials and Methods

2.1. Image Reconstruction Based on the Marching Cubes Algorithm. A voxel was the basic unit in a three-dimensional data field. The $f(a, b, k)$ in the voxel was set to represent the coordinates of each pixel in the data field, where a and b represented the position of the pixel in the layer, and k referred to the number of layers. It was supposed that the distance between different sampling points is $\Delta x, \Delta y, \Delta z$; then the corresponding conversion relationship could be written as $a = x/\Delta x$, $b = y/\Delta y$, and $k = z/\Delta z$. The gray value of any point $A(x, y, z)$ in the coordinates could be calculated with the following equation:

$$f(x, y, z) = n_0 + n_1x + n_2y + n_3z + n_4xy + n_5xz + n_6yz + n_7xyz, \quad (1)$$

where n_i ($i = 0, 1, \dots, 7$) depended on the gray value of the eight vertices of the voxel. The gray value of any point in the voxel could be calculated with this equation.

The most important step in the MC algorithm was to extract the contour surface, which mainly included the following three steps: determining the positional relationship between the contour surface and the voxel focus and determining the division method of the voxel contour surface; determining the focal coordinates of the edge and the contour surface; and calculating the normal vector of the contour surface. When the focal coordinates of the edge and the contour surface was determined, the three-dimensional data field was assumed to be continuous, and the linear interpolation between the two points was adopted to calculate the coordinates of the intersection point of the edge and the contour surface. The coordinates of the two vertices

were set to be $D_1(x_1, y_1, z_1)$ and $D_2(x_2, y_2, z_2)$, and the coordinates of the intersection points were calculated as follows:

$$\begin{aligned} x &= x_1 + \frac{R - f(D_1)}{f(D_2) - f(D_1)}(x_2 - x_1), \\ y &= y_1 + \frac{R - f(D_1)}{f(D_2) - f(D_1)}(y_2 - y_1), \\ z &= z_1 + \frac{R - f(D_1)}{f(D_2) - f(D_1)}(z_2 - z_1), \end{aligned} \quad (2)$$

where R represented the threshold of contour surface and $f(D_1)$ and $f(D_2)$ were the pixels of the two vertices.

In the vector calculation by the contour surface method, the gradient value of each vertex on the voxel was calculated by the gray difference method, then the normal direction of the intersection could be obtained by linear interpolation of the gradient between the two vertices, which referred to the normal vector of the contour surface. It was assumed that the gray value of a vertex was $f(a, b, k)$; then the gradient vector of this point could be obtained by the gray difference method as follows:

$$\begin{aligned} s_x(a, b, k) &= \frac{f(x+1, y, z) - f(x-1, y, z)}{2\Delta x}, \\ s_y(a, b, k) &= \frac{f(x, y+1, z) - f(x, y-1, z)}{2\Delta y}, \\ s_z(a, b, k) &= \frac{f(x, y, z+1) - f(x, y, z-1)}{2\Delta z}, \end{aligned} \quad (3)$$

where s represented the gradient vector, $\Delta x, \Delta y, \Delta z$ referred to the distance between the two vertices, and the normal vector of the vertex unit could be obtained after normalization, as follows:

$$\vec{m} = \left(\frac{s_x(a, b, k)}{|s|}, \frac{s_y(a, b, k)}{|s|}, \frac{s_z(a, b, k)}{|s|} \right). \quad (4)$$

The normal vector of contour surface $\vec{m}$ could be written as

$$\vec{m} = \vec{m}_1 + \frac{R - f(D_1)}{f(D_2) - f(D_1)}(\vec{m}_2 - \vec{m}_1), \quad (5)$$

where $\vec{m}_1$ and $\vec{m}_2$ were the normal vectors of the vertex. Finally, the connection ambiguity in MC algorithm was solved by moving tetrahedron method and asymptotic method.

2.2. Optimization of Marching Cubes Algorithm. The traditional MC algorithm was to extract and draw the three-dimensional model based on the contour surface. The model was fitted by multiple triangular faces, and these three intersection points were obtained by linear interpolation among the vertices of the voxels. This type of approach required a long time, which affected the efficiency of model construction. In addition, analysis of previous studies

revealed that the ambiguity of contour surface connection also affected the effect of model generation. Based on this, the optimized MC algorithm was constructed in this study.

Firstly, the linear interpolation was optimized by replacing the linear interpolation point with the median point, and the equations could be written as follows:

$$\begin{aligned} M &= \frac{M_1 + M_2}{2}, \\ \vec{m} &= \frac{\vec{m}_1 + \vec{m}_2}{2}, \end{aligned} \quad (6)$$

where M was the coordinate of the midpoint, M_1 and M_2 were the coordinates of the two vertices, the normal direction at the midpoint, and $\vec{m}_1$ and $\vec{m}_2$ referred to the normal vectors of the vertex. The midpoint method could improve the efficiency of the computer but was prone to errors. The results were refined further through multiple equalizations. Firstly, the intersection point of the voxel and the edge was determined by the equal division, and then it was refined for equalization further till the final location was determined. The specific calculation formula could be expressed as follows:

$$x = \begin{cases} a_1 + 0.25\Delta x, R < (f(a) + f(b))/2 \\ a_1 + 0.75\Delta x, R > (f(a) + f(b))/2 \end{cases}, y = \begin{cases} b_1 + 0.25\Delta y, R < (f(a) + f(b))/2 \\ b_1 + 0.75\Delta y, R > (f(a) + f(b))/2 \end{cases}, z = \begin{cases} k_1 + 0.25\Delta z, R < (f(a) + f(b))/2 \\ k_1 + 0.75\Delta z, R > (f(a) + f(b))/2 \end{cases} \quad (7)$$

If the pixel at point a was $f(a)$, the pixel at point c was $f(c)$, b was the midpoint of a and c , the threshold of the contour surface was R , and $f(a) < R < f(b)$, then the coordinate of point a was (a_1, b_1, k_1) , and the coordinate of point c was (a_2, b_2, k_2) , and $\Delta x, \Delta y, \Delta z$ were the distance between the two points.

2.3. Research Objects and Grouping. A total of 100 adult patients with ASD combined with TR admitted to hospital from January 2017 to December 2019 were selected, and they all met the following criteria: patients who were clinically confirmed as ASD combined with TR; patients aging over 18 years old and under 60 years old; patients with normal liver function and kidney function; and patients conforming to the indications for occlusion. Patients with the following conditions were excluded: patients with other types of heart diseases; patients suffering from mental diseases; patients suffering from hypertension or diabetes; patients suffering from Eisenmenger syndrome; patients who received other treatments including traditional Chinese medicine (TCM); and patients with poor compliance. All patients participating in the experiment had signed the informed consent forms, and this study was reviewed and approved by the Ethics Committee of the hospital.

In this experiment, ASD patients were grouped based on the size of the ASD into group A with large ASD (group A), group B with medium ASD for no smaller than 30 mm (group B), and group C with small ASD of no smaller than 10 mm and no larger than 30 mm (group C).

2.4. Treatment Methods. The right femoral artery and vein were punctured to the 6F and 7F arteriovenous sheaths, respectively; systemic heparinization was realized with the first dose of intravenous heparin 100 U/kg (if the operation exceeded 1 hour, half the initial heparin dose should be added). The right heart was catheterized firstly to measure the pressure of the right atrium, right ventricle, and pulmonary artery, and the blood oxygen saturation of each part

was detected. The form and size of the atrial septal defect and the distance from the upper edge of the defect to the right coronary valve of the aorta were measured further. If necessary, the ascending aortic angiography was performed to determine whether there was aortic valve prolapse and regurgitation. The angiography catheter was selected based on the form of ASD in left ventricle angiography, and the catheter was rotated counterclockwise from the femoral artery to the left ventricle so that the tip points to the ASD could be open. The catheter was moved slowly so that the tip could jump through the ventricular septal defect opening to the right ventricle, and then the catheter was fixed. The occluder was selected according to the defect diameter measured by angiography. Generally, the diameter of the occluder should be 1-2 mm larger than the angiographic diameter. A suitable occluder was sent to the left ventricular surface along the delivery sheath, and the left ventricular surface umbrella was released firstly. It was not necessary to adjust the direction for the symmetrical occluder, and the mark of the left ventricular side umbrella of the eccentric occluder should point to the apex so that left ventricular umbrella of the occlude could be close to the interventricular septum. The position of the occluder could be determined through hand feel, fluoroscopy, ultrasound, or even ventriculography. If the position was appropriate and there was no obvious residual shunt displayed by the ultrasound image, the wire was fixed and the long sheath was withdrawn. The right ventricular umbrella of the occlude was released. The left ventricular angiography and ascending aorta angiography were repeated. Contrast and transthoracic ultrasound were adopted to confirm that the occluder was fixed and there was no obvious residual shunt; then the occlude could be completely released. The sheath was removed, the puncture port was pressurized, and then the surgery was completed.

2.5. Related Observation Indicators. Before the examination, the patient was instructed to refrain from eating for 12

hours. If the patient was nervous on the day of the examination, 2.5 mg of diazepam could be taken orally. Before the formal examination, the patient was required to take lidocaine glue orally, so that the oral cavity, pharynx, and esophagus of the patient were anesthetized by the topical anesthetic, so as to reduce and even avoid the response during intubation. The patient was placed in a lateral position, and the examiner stood on the left side of the patient. Dentures (if any) had to be removed before intubation. The patient was required to bite the mouth pad, and the glue was applied on the surface of the transducer. The curved probe was inserted along the middle of the oral tongue base, and moved rapidly after entering the esophagus to reach the middle of the esophagus (about 34 cm). The horizontal and vertical axis of the patient should be examined, respectively.

2.6. Statistical Analysis. The SPSS 22.0 software was adopted for statistical analysis, and the counting results were expressed as the mean $\pm$ standard deviation. The t test was employed to compare the indicators of two groups. $P < 0.05$ was deemed as statistically significant.

3. Results

3.1. Comparison on MC Algorithm Data before and after Optimization. The collected transesophageal 3D ultrasound heart images were undertaken as the original dataset to test the traditional MC algorithm and the optimized MC algorithm under different sizes of dataset, and the calculation time of each algorithm and the number of fixed points of the constructed model were recorded and compared. The result is shown in Figure 1. In each dataset, the number of fixed points of the optimized MC algorithm to build a model is significantly less than that of the traditional MC algorithm with statistical difference ($P < 0.05$); the running time of the optimized MC algorithm was also greatly shorter than that of the traditional MC algorithm with statistical difference ($P < 0.05$).

3.2. Comparison of MC Algorithm Images before and after the Optimization. The MC ultrasound images before and after optimization are shown in Figures 2 and 3, respectively. Figures 2(b) and 3(b) show the three-dimensional heart models constructed by the traditional MC algorithm and the optimized MC algorithms, respectively. By comparison, it was found that the three-dimensional heart models constructed by the two ultrasound images were similar overall, and both could achieve better results. The optimized MC algorithm could achieve the same effect as the traditional MC algorithm through fewer fixed points and shorter running time.

3.3. Comparison on Basic Information of Patients. 100 patients were included in the experiment, including 56 patients in group A (17 males and 39 females, with an average age of 35.17 ± 5.78 years old), 31 patients in group B (11 males and 20 females, with an average age of 36.45 ± 7.22 years old),

and 13 patients in group C (5 males and 8 females, with an average age of 36.14 ± 6.17 years old). Comparison of the above information showed that the difference between the two groups was not statistically meaningful ($P > 0.05$), as shown in Figure 4.

3.4. Relationship of the Defect Size to Right Atrium (RA), Right Ventricular (RV), and TR. The average RA, RV, and TR of patients with different sizes of defect were statistically analyzed, and the results are given in Figure 5. It revealed that the average RA, RV, and TR for patients in group A were 51.33 ± 4.55 mm, 39.13 ± 5.54 mm, and 10.54 ± 6.57 mm, respectively; those in group B were 45.97 ± 6.13 mm, 30.54 ± 4.78 mm, and 6.48 ± 2.98 mm, respectively; and those in group C were 36.11 ± 5.12 mm, 20.45 ± 3.44 mm, and 2.97 ± 1.43 mm, respectively. Thus, the RA, RV, and TR in the three groups were statistically different ($P < 0.05$).

Correlations of RA, RV, and TR of three groups of patients were analyzed further, and the results are illustrated in Figure 6.

3.5. Correlation between Pulmonary Artery Pressure and Tricuspid Regurgitation. Among all ASD patients, 13 patients had elevated pulmonary artery pressure (PAP), and 87 patients with ASD had normal PAP. The TRs of the patients with elevated PAP were compared with those of the patients with normal PAP, and the results are shown in Figure 7. In contrast to the patients with normal PAP, the amount of TR in patients with elevated PAP increased observably ($P < 0.05$).

3.6. Tricuspid Regurgitation of Patients before and after the Surgery. Surgery was performed only on patients in group A and group B, the changes in the amount of TR volume of patients before and one day after surgery were compared, and the results are illustrated in Figure 8 below. Compared with the amount before surgery, the amount of TR in groups A and B was increased greatly, and the differences were statistically meaningful ($P < 0.05$).

3.7. Tricuspid Regurgitation of Patients at Different Time Points after the Surgery. The amounts of TR of patients were detected at the 1st day, 7th day, 1st month, 3rd month, and 6th month after surgery. The results shown in Figure 9 revealed that the overall decline trend of patients in group A and group B was consistent with an obvious decline within 1 month after surgery and stability after 3 months. There was no statistically meaningful difference in the amount of TR between patients in group A and group B after the surgery ($P > 0.05$), but there was an opposing situation for both groups before and after surgery ($P < 0.05$).

4. Discussion

ASD is caused by hypoplasia of the septum between the left ventricle and the RV of the patient. The atrioventricular septum has a defect that leads to a congenital disease in

FIGURE 1: Comparison of the original MC algorithm and the optimized MC algorithm. (a) The number of fixed points of the model; (b) the running time of the model.

FIGURE 2: Ultrasound heart model based on traditional MC algorithm. (a) The ultrasound image; (b) the heart model.

FIGURE 3: Ultrasound heart model based on optimized MC algorithm. (a) The ultrasound image; (b) the heart model.

FIGURE 4: Comparison of basic information of patients in two groups. (a) Comparison results of gender; (b) comparison results of age.

FIGURE 5: Comparison of RA, RV, and TR of three groups of patients. (a) Comparison results of TR; (b) comparison results of RA and RV. (* indicated $P < 0.05$ in contrast to A; and # suggested $P < 0.05$ in contrast to B).

which the blood flow is connected [11]. Under normal circumstances, the pressure of the left atrium is greater than that of the right atrium. When a patient develops ASD, the blood in the atrioventricular septum will flow from the left to the right, causing the pulmonary blood volume to increase, and the long-term pulmonary blood volume increase will cause the pulmonary circulation blood volume to exceed the capacity of the pulmonary vascular bed, causing irreversible resistance pulmonary hypertension in the body. The further development of resistance pulmonary hypertension will cause bidirectional shunt at the atrial level, and even a right-to-left shunt, and eventually develop Eisenmenger syndrome

[12, 13]. Therefore, early detection and treatment are of great significance. In this experiment, images based on the optimized MC algorithm were adopted to evaluate the ultrasound images of the patients in this study. It was found that the ultrasonic heart three-dimensional model constructed by the traditional MC algorithm had high accuracy but long running time. On this basis, the optimized MC algorithm constructed in this experiment could achieve the same configuration model and shorten the model construction time. The optimized MC algorithm could increase the efficiency by about 20% overall. Compared with the two-dimensional digital image, the three-dimensional model could

FIGURE 6: Correlation analysis of RA, RV, and TR of patients in three groups.

FIGURE 7: Correlation between the pulmonary artery pressure and tricuspid regurgitation.

FIGURE 8: Comparison of tricuspid regurgitation before and after the surgery.

more directly and comprehensively present the spatial information of the object, so the reconstructed three-dimensional model of the blood vessel was conducive to diagnosis of the disease better.

Manuel et al. (2017) showed in the study that most adult ASD patients had different degrees of TR, and patients with

FIGURE 9: Changes in the amount of tricuspid regurgitation of patients at different time points after the surgery.

moderate to severe TR accounted for about 20% of the total number [14]. In this experiment, there were 12 patients with the amount of TR above 25 mL before the surgery, and there were no patients with the amount of TR higher than 50 mL. On the one hand, this result was related to the small number of samples. On the other hand, Geggel (2017) found that people's awareness of congenital diseases such as ASD was gradually improving, so the disease could be controlled in the early stage through treatment in time [15]. At this stage, the mechanism of TR is not completely cleared. Hari et al. (2015) suggested in the literature that tricuspid annulus expansion may be the most important factor for TR [16]. Cua et al. (2017) further proposed that the geometric configuration changes of the RV, the RV remodeling caused by pulmonary hypertension, and tricuspid annulus expansion were the main causes of TR [17]. The results of this study indicated that the amount of TR in patients with ASD and TR after occlusion had been increased obviously ($P < 0.05$), and occlusion had an effect on patients with large and medium ASD. In addition, the amount of TR in patients with ASD had increased observably one day after the surgery; the improvement effect gradually stabilized at the 3rd month with the increase of time. The combined TR before surgery could be increased greatly and a stable state could be formed within 3 months, which was consistent with the report of Astarcioglu et al. (2015) that the remodeling of the heart could be stopped quickly with the occlusion of the defect [18]. A study by Henzel et al. (2018) showed that 50% of ventricular remodeling after ASD occlusion occurred within 24 hours after the surgery, and 90% could be completed 1 month later. TR could be decreased due to decline of the load for RV after the surgery [19].

5. Conclusion

The MC algorithm was explored and optimized to get the optimized MC algorithm, and a 3D heart model was successfully constructed. The efficacy of occlusion for patients with ASD and TR was further studied, and the results showed that the amount of TR in patients with large and medium ASD had been increased sharply after occlusion.

However, this study only focused on the cardiac ultrasound images for the study of algorithm. Whether the algorithm is useful for other ultrasound images has to be further explored in future. In addition, the explored samples were too less and the patients with small ASD who do not need occlusion were not studied, which had to be further studied in depth in future. In summary, the results of this study can provide reliable basis for clinical treatment for ASD combined with TR.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

- [1] X. Liang, J. A. Bradley, D. Zheng et al., "The impact of dose algorithms on tumor control probability in intensity-modulated proton therapy for breast cancer," *Physica Medica*, vol. 61, pp. 52–57, 2019.
- [2] S. Rana, K. Greco, E. J. J. Samuel, and J. Bennouna, "Radiobiological and dosimetric impact of raystation pencil beam and monte carlo algorithms on intensity-modulated proton therapy breast cancer plans," *Journal of Applied Clinical Medical Physics*, vol. 20, no. 8, pp. 36–46, 2019.
- [3] F. Hatib, Z. Jian, S. Buddi et al., "Machine-learning algorithm to predict hypotension based on high-fidelity arterial pressure waveform analysis," *Anesthesiology*, vol. 129, no. 4, pp. 663–674, 2018.
- [4] X. Liang, Z. Li, D. Zheng, J. A. Bradley, M. Rutenberg, and N. Mendenhall, "A comprehensive dosimetric study of monte carlo and pencil-beam algorithms on intensity-modulated proton therapy for breast cancer," *Journal of Applied Clinical Medical Physics*, vol. 20, no. 1, pp. 128–136, 2019.
- [5] C. Q. M. Reis, P. Nicolucci, S. S. Fortes, and L. P. Silva, "Effects of heterogeneities in dose distributions under nonreference conditions: monte carlo simulation vs dose calculation algorithms," *Medical Dosimetry*, vol. 44, no. 1, pp. 74–82, 2019.
- [6] K. D. Boudoulas, K. Marmagkiolis, and H. Boudoulas, "Atrial septal defect sizing and transcatheter closure," *Cardiology*, vol. 142, no. 2, pp. 105–108, 2019.
- [7] R. V. Parikh, J. Boyd, D. P. Lee, and R. Witteles, "Atrial septal defect as unexpected cause of pulmonary artery hypertension," *Texas Heart Institute Journal*, vol. 45, no. 1, pp. 42–44, 2018.
- [8] T. Akagi, "Current concept of transcatheter closure of atrial septal defect in adults," *Journal of Cardiology*, vol. 65, no. 1, pp. 17–25, 2015.
- [9] J. F. Goldberg, "Long-term follow-up of "simple" lesions-atrial septal defect, ventricular septal defect, and coarctation of the aorta," *Congenital Heart Disease*, vol. 10, no. 5, pp. 466–474, 2015.
- [10] M. Nakata, Y. Miwa, J. K. Chambers, T. Saito, and K. Uchida, "Ostium secundum type of atrial septal defect in a rabbit," *Journal of Veterinary Medical Science*, vol. 80, no. 8, pp. 1325–1328, 2018.
- [11] H. Wang, Y. Liu, Y. Li et al., "Analysis of NKX2-5 in 439 Chinese patients with sporadic atrial septal defect," *Medical Science Monitor*, vol. 25, pp. 2756–2763, 2019.
- [12] S. Supomo, A. Z. Arjana, and H. Darmawan, "Predictive model for secundum atrial septal defect closure with pulmonary artery hypertension in adult: when to close," *Heart Surgery Forum*, vol. 21, no. 2, pp. E108–E111, 2018.
- [13] Y. Yang, X. Li, M. Chen, and Y. Feng, "Transcatheter closure of a huge iatrogenic atrial septal defect: a case report," *Medicine (Baltimore)*, vol. 96, no. 50, Article ID e9216, 2017.
- [14] D. A. Manuel, G. C. Ghosh, and A. G. Alex, "Atrial septal defect with right-to-left shunt in the absence of pulmonary hypertension," *Cardiology in the Young*, vol. 27, no. 3, pp. 575–576, 2017.
- [15] R. L. Geggel, "Clinical detection of hemodynamically significant isolated secundum atrial septal defect," *The Journal of Pediatrics*, vol. 190, pp. 261–264, 2017.
- [16] P. Hari, R. G. Pai, and P. Varadarajan, "Echocardiographic evaluation of patent foramen ovale and atrial septal defect," *Echocardiography*, vol. 32, no. Suppl 2, pp. S110–S124, 2015.
- [17] C. L. Cua, A. L. Cooper, M. Dutro, and D. P. Berman, "Transgastric: a forgotten view for atrial septal defect device closure procedures?" *Echocardiography*, vol. 34, no. 12, pp. 1967–1968, 2017.
- [18] M. A. Astarcioglu, M. Kalcik, T. Sen et al., "Ceraflex versus amplatzer occluder for secundum atrial septal defect closure," *Herz*, vol. 40, no. S2, pp. 146–150, 2015.
- [19] J. Henzel, M. Konka, A. Wójcik et al., "Focus on the perimeter and skip the balloon," *JACC: Cardiovascular Imaging*, vol. 11, no. 11, pp. 1731–1732, 2018.