Clinical study of transcatheter occlusion in treating ventricular septal defect combined with right coronary cusp bulge

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Abstract

Background: Perimembranous ventricular septal defect combined with right coronary cusp bulge generally should be treated with surgical thoracotomy, owing to the potential aortic regurgitation. However, the minimally invasive method of transcatheter closure has always attracted the attention of cardiologists and patients. The present study aimed to apply transcatheter occlusion in treating ventricular septal defect with right coronary cusp bulge and further evaluate the clinical effect through follow-up.

Materials and methods: A total of 40 children diagnosed as having a ventricular septal defect with right coronary cusp bulge, examined using transthoracic echocardiography and cardiovascular angiography, were enrolled in this study. The ventricular septal defects were closed by placing occluders through transcatheter occlusion treatment. During the operation process, the children underwent angiography and transthoracic echocardiography examinations to check the position of the occlude and the extent of aortic regurgitation. The influence of occlusion on the conduction system was evaluated using a surface electrocardiogram. The children were followed up after their procedures.

Results: All 40 patients were immediately and successfully occluded. Three patients with filament residual shunts were observed during the operations. No major surgical complications occurred during the perioperative period. During the follow-up period, the positions of all the occluders were good, the residual shunts in the three patients disappeared, and no new or aggravated aortic regurgitation occurred. Electrocardiogram did not reveal any atrioventricular blocks. Only one patient suffered from an incomplete right bundle branch block.

Conclusions: Children diagnosed with ventricular septal defect combined with right coronary cusp bulge could be considered for transcatheter occlusion. With appropriate indications and methods, the effect may be favorable.

Keywords: aortic regurgitation; right coronary cusp bulge; transcatheter occlusion; ventricular septal defect
Informed consent: The relatives of patients were fully informed before the procedures of all potential complications.

Author contributions: WJ conducted the operation and completed the draft; ZZ conducted the transthoracic echocardiography during and after the operation; WZ analyzed data; JS analyzed the cardiovascular angiography results during the operation; LF analyzed the electrocardiogram results during and after the operation; LS collected the follow-up data; YC carried out the communications about the disease with the children’s parents; FL designed the study and provided financial support.

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INTRODUCTION

Transcatheter occlusion of perimembranous ventricular septal defect (VSD) has been widely used (1,2). At present, the transcatheter closure of perimembranous VSD (pmVSD) with aortic right coronary cusp bulge is still an unconventional operation in clinical practice. It has been suggested that implantation of the occluder likely leads to aortic regurgitation. For a long time, surgical thoracotomy and hybrid therapy have been the first-line treatments for this kind of VSD. However, as the demands for minimally invasive therapy increased, some patients with this kind of VSD may be helped by transcatheter occlusion therapy. This study introduced a group of patients with pmVSD combined with aortic right coronary cusp bulge from Shanghai Children’s Medical Center, who were treated with percutaneous catheter intervention occlusion, and followed them up.

SUBJECTS AND METHODS

Subjects

All the patients in this study were diagnosed with pmVSD with right coronary cusp bulge, and who underwent transcatheter occlusion therapy in the Shanghai Children’s Medical Center, affiliated to Shanghai Jiao Tong University School of Medicine, China, from August 2013 to March 2017. The inclusion criteria were that patients had to be the newly diagnosed children, children older than 2 years,
and had their pmVSD with right coronary cusp bulge of hemodynamic significance identified by transthoracic echocardiography (TTE). The exclusion criteria were as follows: comorbidity of infective endocarditis, ventricular horizontal right-to-left shunt, systemic sepsis, complicated heart deformities requiring surgery, and clinical conditions that conflicted with postoperative antiplatelet therapy. TTE (Figure 1A and 1B) and cardiovascular angiography (Figure 2A and 2B) confirmed VSD with right coronary cusp bulge. In 30 patients, the right coronary cusp was embedded in the VSD. No patient with mild or more severe aortic regurgitation was present before therapy. The study was approved by the Shanghai Children's Medical Center for Biomedical Research Ethics Committee. The relatives of patients were fully informed before the procedures of all potential complications.

Methods

Occluders

The occluders with different sizes were named according to the diameter of their waist. Heart symmetric membranous VSD occlusion devices procured from Lifetech Scientific Corporation, Shenzhen, China, were used in 27 patients. Eccentric VSD occlusion devices from Huayi Shengjie, Beijing, China, were implanted in 11 patients. A symmetric membranous VSD occlusion device from Xingzhuang Jiyi, Shanghai, China, was used in one patient. The Amplatzer eccentric membranous VSD occlusion device from AGA Corporation, USA, was used in another patient.

Closure

The forward method was adopted to implant the occluder. The approximate operation procedure was to first puncture the right femoral vein and artery, and then perform cardiac catheterization to exclude obstructive pulmonary hypertension. Left ventricular
(Figure 2A) and ascending aortic (Figure 2B) angiography were performed at the left ventricular long-axis oblique position to calibrate the shunt diameter on the left ventricular side and to exclude the aortic regurgitation before the operation. The transseptal guide wire was grasped at the pulmonary artery to establish a track. The transport sheath and pigtail were delivered along the track on the femoral vein side and femoral artery side, respectively. Subsequently, the operator pressed the distal end of the transport sheath to the apex of the left ventricle when the sheath and pigtail converged, and withdrew the core, retaining the outer sheath. The occluder was then delivered into the long sheath after the air inside was fully discharged. After sending it to the end of the long sheath, the occluder was slowly delivered and opened the left ventricular disc first and then slightly withdrawn. The wire rope was fixed when the left ventricular disc was slightly bent with deformation. Subsequently, the long sheath was withdrawn. The waist and right ventricular side of the occluder were released. After occlusion, the left ventricle (Figure 2C), ascending aortic (Figure 2D) angiography, and TTE examination (Figure 1C and 1D) were performed for the second time to confirm the correct positioning of the occluder, with no significant residual shunt and no aortic regurgitation. Finally, the occluder was unscrewed.

Follow-up

Patients returned to the hospital after 1, 3, 6, and 12 months, and then once a year for follow-up studies. At present, the longest follow-up time was 27 months, with an average of over 7 months. Patients underwent TTE and electrocardiogram (EKG) examinations. TTE was used mainly to assess the position of the occluder, the residual shunt, the aortic regurgitation, size of the left ventricle, and left ventricular ejection fraction. The EKG examination was used mainly to evaluate whether or not an atrioventricular block or bundle branch block existed and to measure the PR and QRS interval.

Statistical analysis

Statistical analysis was performed using PASW Statistics 20 (IBM Corporation, NY, USA). The variables with a normal distribution were compared using Student’s t-test, and values were presented as mean ± standard deviation. Two-sided P values ≤0.05 were considered to be statistically significant.

RESULTS

Overview of the surgery

A total of 40 patients (22 males and 18 females) were included. The patients were aged 2–14 years with a mean age of 5.06 ± 3.17 years. Their body weight was 10–49.5 kg, and the average body weight of all participants was 20.56 ± 10.74 kg. The VSD base region ranged from 4.3 to 14 mm with a mean diameter of 8.11 ± 1.92 mm. The shunt diameter of defect ranged from 1.8 to 5.7 mm with an average diameter of 3.28 ± 0.92 mm. The mean waist diameter of the occluders was 6.97 ± 1.98 mm, with a range of 5–12 mm. The mean surgical time was 54.62 ± 15.19 min, with a range of 30–85 min (Table 1).

All 40 patients were immediately and successfully occluded. There were no occurrences of death, hemolysis, cardiac perforation, pericardial tamponade, complete atrioventricular block, infective endocarditis, or other major surgical complications during the perioperative period. Three patients with a filament residual shunt were observed during surgery (the shunt diameter was less than 1 mm). A follow-up TTE examination identified that the residual shunt had disappeared, and no displacement or fall of an occluder occurred.

Table 1 Surgical data of the patients.

| Patients, N = 40 |  |
|-----------------|------------------|
| Male/Female     | 22/18            |
| Age (year)      | 5.06 ± 3.17 (2–14) |
| Body weight (kg)| 20.56 ± 10.74 (10–49.5) |
| VSD basal region (mm) | 8.11 ± 1.92 (4.3–14) |
| Defect of shunt diameter (mm) | 3.28 ± 0.92 (1.8–5.7) |
| Waist diameter of occluder (mm) | 6.97 ± 1.98 (5–12) |
| Surgical time (min) | 54.62 ± 15.19 (30–85) |

Examination of valves and atrioventricular conduction function before and after closure

TTE and EKG examinations were performed before surgery and in the postoperative follow-up period. At present, the mean follow-up time is more than 6 months. The TTE examination revealed that no newly occurring mild or more severe aortic regurgitation was observed after implantation of the occluder. Two patients exhibited mild-to-moderate tricuspid
regurgitation before surgery, but the tricuspid regurgitation disappeared after surgery (Table 2). The left ventricular end-diastolic and end-systolic diameters decreased, and the left ventricular ejection fraction slightly increased after closure compared with those before closure (Table 3).

**DISCUSSION**

VSD is the most common congenital heart disease (CHD), accounting for about 20% of all CHDs, of which the perimembranous defect accounts for about 70–80% (3). The transcatheter occlusion of pmVSD has been performed more frequently since the development of the asymmetric VSD packing device, which was made mainly of nickel–titanium alloy by Amplatzer in 2001. However, the application of the occluder was not widely developed due to the high incidence of the complete atrioventricular block during and after surgery (4,5). Various types of modified VSD occluders were developed and applied around 2002. The application of these new occluders has significantly reduced the incidence of atrioventricular block caused by transcatheter occlusion (6,7), which has become a relatively safe therapeutic procedure.

However, so far, transcatheter occlusion therapy has not been the first-line solution for pmVSD with right coronary cusp bulge. This lag could be because, generally, the position of the defect in such VSD was relatively high, and the shunt was close to the aortic valve. It was hypothesized that, after closure, the right coronary valve might be withstood by the disc inside the left ventricle, causing aortic regurgitation. Another possible reason is that surgeons tend to select the smaller occluder under equivalent conditions to avoid affecting the valve closure, so that the generation of residual shunt after the closure is easy. Finally, the right coronary cusp bulge shielded part of the shunt, leading to misjudging or underestimating the diameter of the defect, and therefore the selection of an inappropriate occluder. Invalid occlusion using an occluder of smaller size is an easy way to elicit displacement or fall of the occluder.

Traditionally, surgical thoracotomy or hybrid therapy was selected to treat this kind of VSD. However, the development of surgical scars after thoracotomy at an older age and the inherent need of people to avoid trauma encouraged researchers to explore the feasibility of transcatheter occlusion of pmVSD with right coronary cusp bulge. One recent study used transcatheter occlusion therapy in 65 children with VSD having aortic valve prolapse. In that study, only two patients’ occlusion was terminated due to the aggravation of device-related aortic regurgitation. After 1 year of follow-up, the aortic regurgitation alleviated compared with that before surgery in 39 patients (61.9%) (8), suggesting that VSD with right coronary cusp bulge is not a forbidden zone for interventional therapy. Early treatment was even expected to improve the function of impaired valves.

There are many reasons why transcatheter occlusion of such VSD would not influence the function of aortic valve closure. In the presence of a high-positioned defect, the right coronary cusp lacked support. The aortic valve shifted downward during the left ventricular diastole. The implantation of the

### Table 2 Comparison of valve regurgitation and atrioventricular conduction before and after occlusion.

| Parameters              | Before occlusion | After occlusion | P value |
|-------------------------|------------------|-----------------|---------|
| TTE                     |                  |                 |         |
| Mitral regurgitation    | 1                | 1               |         |
| Aortic regurgitation    | 0                | 0               |         |
| Tricuspid regurgitation | 2                | 0               |         |
| Pulmonary valve         | 0                | 0               |         |
| regurgitation           |                  |                 |         |
| EKG                     |                  |                 |         |
| I-degree atrioventricular block | 0            | 0               |         |
| II-degree atrioventricular block | 0         | 0               |         |
| III-degree atrioventricular block | 0          | 0               |         |
| Left bundle branch block | 0              | 0               |         |
| Right bundle branch block | 2              | 3               |         |

### Table 3 Comparison of left heart function and EKG parameter before and after occlusion.

| Parameters              | Before occlusion | After occlusion | P value |
|-------------------------|------------------|-----------------|---------|
| TTE                     |                  |                 |         |
| Left ventricular        | 3.8±0.5          | 3.7±0.5         | 0.043   |
| end-diastolic diameter  |                  |                 |         |
| (mm)                    |                  |                 |         |
| Left ventricular        | 2.4±0.3          | 2.2±0.4         | 0.045   |
| end-systolic diameter   |                  |                 |         |
| (mm)                    |                  |                 |         |
| Left ventricular        | 67.8±4.7         | 68.1±4.6        | 0.657   |
| ejection fraction (%)   |                  |                 |         |
| EKG                     |                  |                 |         |
| PR interval (ms)        | 125.6±14.7       | 122.6±14.2      | 0.132   |
| QRS interval (ms)       | 75.4±10.4        | 79.8±11.4       | 0.028   |

An EKG examination revealed no abnormalities in PR interval after closure, with a slightly longer QRS duration but still within the normal range (Table 3). One patient had a right bundle branch block after surgery, but the block was incomplete. No other cases of atrioventricular block or left bundle branch block were observed (Table 2).
occluder supported the root of the right coronary cusp. In addition, before treatment, the blood flowed from the left ventricle, which was at high pressure, to the right ventricle during systole. According to the Venturi principle, high-speed blood had downward tractive effects to the right coronary cusp. The shunt was terminated after the closure of VSD, which relieved the tractive effects of blood flow (8). Finally, generally, the left ventricular disc of the occluder was tightly clamped, and the body of the right coronary valve could not be touched by the top of the disc inside the left ventricle. Moreover, the cells crawled along the inner surface of the occluder after 3–6 months of operation. Hyperplasia of tissues made the perimeter of the occluder smoother. Therefore, the wear and tear of the right coronary cusp by the occluder was limited at a later stage.

In the present clinical study, patients with mild or severe aortic regurgitation before surgery were excluded during screening because these patients may have comorbid conditions like organic valve disease or irreversible valve regurgitation. A surgical operation to close the defects should be selected as the first line of treatment for these patients. Simultaneously, the valve function should be evaluated, and the necessity of valve plastic surgery or replacement should be determined. In the selection of the occluder type, if the defect was located under the aortic valve and little tissue remained on the superior of the shunt, only an eccentric occluder could be selected. During the operation, the left ventricular side mark of the occluder should always be located at the lowest position. On the other hand, if a small part of tissue still exists on the superior end of the shunt, a symmetrical double-disk occluder should be selected. As for the selection of the occluder size, because the right coronary cusp bulge may shield part of the shunt, which would bias the estimation of shunt size, usually a relatively larger size occluder should be selected. An occluder with a waist diameter of about 2–3 mm larger than the diameter of the shunt was chosen in the present study. After release, the TTE and left ventricular angiography were performed again. If the residual shunt occurred or the large occluder affected the closure of the aortic valve, the occluder would not be released and was withdrawn. The operator would then replace the size of the occluder for a second closure.

The immediate success rate of closure in this study was 100%. The termination of surgery due to the aggravation of aortic regurgitation or newly occurred severe aortic regurgitation did not occur. The basal part of the defect, shunt, and the size of the occluder in the baseline data were within the normal range. The average duration of the procedure was around 55 min, suggesting that the difficulty for closure in such defects was moderate. The incidence of major surgical complications during the perioperative period was zero, and no obvious aortic regurgitation during the follow-up was found, indicating an overall safety of the occlusion procedures. As for the cardiac electrophysiological aspect, only one patient presented with right bundle branch block. No case of injury of other cardiac conduction system was noted, including a complete atrioventricular block, suggesting that these defects with high position had a safe distance with the essential conduction system, such as the His bundle. Therefore, the present study demonstrated that treating pmVSD with aortic right coronary cusp bulge using interventional therapy is feasible if the indications are appropriate. Large-sample follow-up studies are needed to evaluate its efficacy and safety.

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