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Research Article

Minimally Invasive Approach versus Sternotomy for Bentall Procedure: A Single-Center Experience

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Background. The need for minimally invasive Bentall surgery for the treatment of aortic lesions with aortic insufficiency is increasing; however, comparative studies on the safety of the minimally invasive Bentall procedure and sternotomy Bentall procedure are lacking. *Methods.* Clinical data of 56 patients who underwent the Bentall procedure performed by the same surgical team at our center between December 2018 and December 2021 were retrospectively analyzed and followed up for 6 months after discharge. After dividing the patients into a right anterior chest minimally invasive Bentall surgery (RAT-Bentall) group ($n = 13$) and a conventional sternotomy Bentall surgery (C-Bentall) group ($n = 43$), intraoperative and early postoperative clinical data and echocardiography at 6 months after discharge were compared. *Results.* Compared with the C-Bentall group, the RAT-Bentall group had a lower postoperative visual analogue scale (VAS) pain score [(3.00 ± 2.08) VS (5.77 ± 1.84), $P < 0.001$] and a shorter CSICU hospital stay [(1.90 ± 0.52) VS (2.51 ± 1.58) d, $P < 0.001$] and postoperative hospital stay [(7.62 ± 1.81) VS (10.42 ± 2.45) d, $P = 0.035$]. The incidence of postoperative complications and echocardiographic at 6-month follow-up after discharge was not statistically different between the two groups. *Conclusion.* The RAT-Bentall procedure is safe and effective. Compared with the sternotomy Bentall procedure, it can reduce postoperative pain as well as patients' CSICU and postoperative hospital stay. Therefore, this technology is worth promoting and applying.

1. Introduction

The trend toward minimally invasive surgery is becoming increasingly evident in various surgical fields. Cardiac surgeons have also been exploring minimally invasive procedures in patients with heart disease. Currently, the use of minimally invasive cardiac surgery is growing [1], and various minimally invasive surgical procedures have emerged in an endless stream, including minimally invasive aortic valve surgery, mitral valve surgery, and congenital heart disease surgery [2–5]. The Bentall procedure is a classic procedure for treating ascending aorta/aortic root aneurysms complicated by aortic valve disease [6], and the need for minimally invasive procedures continues to increase.

At present, a small number of centers have reported the minimally invasive Bentall procedure, which uses a small incision in the upper sternum as the surgical approach [7–9]. This differs from the approach used for the minimally invasive Bentall procedure at our center. Based on our experience with our minimally invasive aortic valve replacement procedure, we chose a small incision on the right anterior chest as the preferred approach [2]. This minimally invasive Bentall procedure has shown advantages in some patients [10]. Nonetheless, the safety and efficacy of minimally invasive Bentall procedures remain controversial due to the lack of evidence from controlled studies on sternotomy Bentall procedures. Therefore, we retrospectively analyzed the clinical data of 56 patients who underwent minimally invasive Bentall procedures and sternotomies performed by the same surgical team at our center. The safety and feasibility of minimally invasive Bentall surgery were explored by comparing intraoperative and postoperative clinical data with postoperative follow-up data.

2. Methods

2.1. Study Participants. A total of 56 patients who underwent the Bentall procedure done by the same surgical team in our center between December 2018 and December 2021 were selected as the research subjects. Inclusion criteria were (1) ascending aortic dilatation >5 cm with aortic valve disease, (2) Marfan syndrome, and (3) Debakey type II aortic dissection combined with aortic valve insufficiency that cannot be repaired. Exclusion criteria included (1) femoral artery plaques, (2) pulmonary insufficiency, (3) patients with aortic dissection within 3 days of onset, and (4) emergency surgery. Based on the surgical approach, the patients were divided into a right anterior chest minimally invasive Bentall procedure group (RAT-Bentall group) and a conventional median thoracotomy Bentall procedure group (C-Bentall group). There were 10 males and 3 females in the RAT-Bentall group, ranging in age from 24 to 67 years old, with an average of 55.31 ± 11.42 years old. There were 33 males and 10 females in the C-Bentall group, ranging in age from 26 to 76 years old, with an average of 55.35 ± 12.74 years old. There were no significant differences in the general data between the two groups ($P > 0.05$). The preoperative data of the patients in the two groups are shown in Table 1.

2.2. Surgical Procedures

2.2.1. RAT-Bentall. The patient was placed in a supine position under general anesthesia with a single-lumen endotracheal tube. The defibrillation electrodes were placed behind the right scapula and in the fifth intercostal space on the front line of the left axilla. After disinfection, the surgical area was covered with sterile surgical towel. In the groin area (usually on the right side), the skin and subcutaneous tissue were incised to expose the femoral artery and vein. Heparinized femoral artery and vein cannulas were used to establish peripheral CPB access. Right anterior parasternal incision was selected (select the second or third intercostal space according to the preoperative CT), and the skin, subcutaneous tissue, and muscle layer were incised. Initiation of CPB was done, and patient temperatures were lowered. The pericardium was incised longitudinally, 2-3 stitches were sutured on the left and right sides to suspend the pericardium, and an incision protection sleeve (Figure 1(a)) was placed to expose the aortic root and heart (Figures 1(b) and 1(c)). The ascending aorta was blocked using Chiwood-blocking forceps (Figure 1(d)). The aorta was incised, and myocardial protection solution was perfused through the left and right coronary arteries. One suture was placed at the valve commissure for suspension (three sutures in total; Figure 1(e)), and the diseased aortic valve was resected (Figure 1(f)). The aortic valve and vascular graft (or series aortic valve graft) were implanted, and the proximal ends of the valve and vascular graft were anastomosed. It should be noted that when performing distal anastomosis, the vascular graft should first be cut to the appropriate length. The recommended order of anastomosis is to first anastomose the posterior wall of the blood vessel and then the anterior wall of the blood vessel, starting from the proximal end to ending at the distal end. The proximal anastomosis sequence was first from 4 o'clock to 7 o'clock (suturing in a clockwise direction), then from 7 o'clock to 10 o'clock (suturing in a clockwise direction), and finally from 4 o'clock to 10 o'clock (suturing in a counterclockwise direction). Anastomotic bleeding can be reinforced by continuous and intermittent sensations. A 5-0 Prolene™ line was used to transplant the left and right coronary arteries to the corresponding vascular graft, and direct intraluminal anastomosis was performed. A 4-0 Prolene™ wire was used to anastomose the graft to the distal end of the ascending aorta (Figure 1(g)). The aortic root was wrapped with an autologous aortic wall, and a right atrial shunt was created (Figure 1(h)). The heart was then allowed to expel gas, and the blocking forceps were opened to facilitate circulation. The heart was returned to its normal rhythm, and the body temperature was then allowed to recover. Each cannula was removed after waiting for the circulation to stabilize. Protamine was used to neutralize heparin. The pericardial cavity was checked for active bleeding, and a chest drain was placed. The chest was then sutured layer-by-layer after checking the instruments and gauze.

2.2.2. C-Bentall. The conventional median thoracotomy-Bentall procedure adopts the standard median thoracotomy approach. A median longitudinal split of the sternum was selected followed by the Bentall procedure. For postoperative pain management, the patients in both groups used intravenous opioid pumps provided by the anesthesiology department.

2.3. Data Collection. Intraoperative variables included the duration of cardiopulmonary bypass (CPB), duration of aortic occlusion, duration of surgery, and occurrence of sternotomy conversion. Postoperative variables included ventilator assistance time, days of hospital stay in the intensive care unit (CSICU), postoperative 24 hour drainage volume, postoperative 24 hour blood transfusion rate, reoperation rate for hemostasis, days of postoperative hospital stay, visual analog scale (VAS) pain score (VAS pain score was assessed 24 h after the patient walked up), and the probability of complications. The postoperative complications included atrial fibrillation, stroke, pleural effusion, renal insufficiency, poor wound healing, and in-hospital mortality. Six months after the patient was discharged from hospital, outpatient reviews and telephone interviews were conducted. Follow-ups included echocardiography and all-cause mortality.

2.4. Statistical Analysis. Statistical analyses were performed using SPSS 23.0. Independent sample *t*-test analysis was used to compare enumeration data such as operation time, CPB time, aortic cross-clamp time, CSICU stay time, ventilator-assisted time, drainage during the first 24 hours, VAS pain score, days of postoperative hospital stay, and echocardiographic data at the 6-month follow-up. Chi-square tests were used to analyze quantitative data such as the blood transfusion rate in the first 24 h, reoperation rate

TABLE 1: Preoperative characteristics.

Items	RAT-Bentall ($n = 13$)	C-Bentall ($n = 43$)	P value
Gender (male/female)	10/3	33/10	1.000
Age (years)	55.31 ± 11.42	55.35 ± 12.74	0.992
BMI (kg/m^2)	23.28 ± 3.44	24.20 ± 3.23	0.378
LVEF (%)	58.62 ± 9.95	58.40 ± 11.58	0.951
Aortic sinus (mm)	37.46 ± 10.00	41.65 ± 12.64	0.279
Ascending aortic diameter (mm)	53.62 ± 11.15	52.42 ± 10.00	0.733
LVEDD (mm)	53.08 ± 11.49	53.16 ± 12.55	0.983
LVESD (mm)	36.62 ± 10.54	36.95 ± 12.27	0.929
NYHA class II/III	4/9	18/25	0.473
Marfan's syndrome (n, %)	2 (15.4%)	4 (9.3%)	0.615
Bicuspid aortic valve malformation (n, %)	3 (23.1%)	5 (11.6%)	0.370
AF (n, %)	0 (0.0%)	2 (4.7%)	1.000
Stroke (n, %)	0 (0.0%)	1 (2.3%)	1.000
Diabetes (n, %)	3 (23.1%)	7 (16.2%)	0.682
Hypertension (n, %)	5 (38.5%)	12 (27.9%)	0.504

BMI, body mass index; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; LVEDS, left ventricular end-systolic diameter; AF, atrial fibrillation; RAT-Bentall, right anterior chest minimally invasive; Bentall, conventional sternotomy. Values were expressed as the mean ± SD, n (%), or n1/n2.
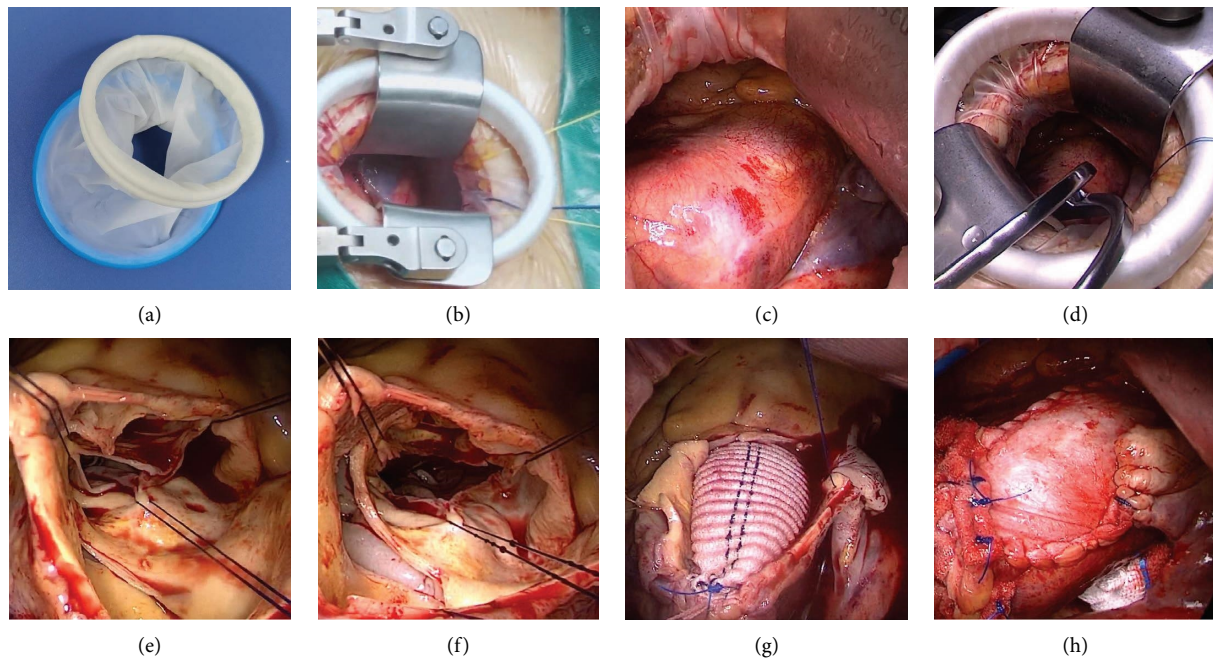

(a) (b) (c) (d)

(e) (f) (g) (h)

FIGURE 1: The RAT-Bentall procedure. (a) The incision protection sleeve we use in RAT-Bentall surgery. (b) and (c) The pericardium was incised longitudinally on the left side, 2-3 stitches were sutured on the left and right sides to suspend the pericardium, and then an incision protection sleeve was placed to expose the aortic root and the heart. (d) The ascending aorta was blocked using Chiwood blocking forceps. (e) One suture was sutured at the valve commissure for suspension, 3 sutures in total. (f) Resection of the diseased aortic valve. (g) Anastomose the graft of the ascending aorta. (h) The aortic root was wrapped with an autologous aortic wall, and right atrial shunt was performed.

for hemostasis, postoperative complication rates, and mortality. Differences were considered statistically significant at $P < 0.05$.

3. Results

3.1. Intraoperative Data Comparison. All patients in both groups successfully completed the Bentall procedure, and none in the RAT-Bentall group underwent thoracotomy.

The operation time of the RAT-Bentall group was 268.31 ± 71.43 min, the CPB time was 136.69 ± 40.42 min, and the ascending aortic cross-clamp time was 97.69 ± 25.36 min. In the C-Bentall group, the operation time was 286.79 ± 103.84 min; the CPB time was 119.72 ± 45.03 min; and the ascending aortic cross-clamp time was 81.63 ± 29.01 min. In this study, the intraoperative data of the two groups were compared and found not to be statistically significant (Table 2).

Table 2: Intraoperative and postoperative data characteristics.

Items	RAT-Bentall ($n = 13$)	C-Bentall ($n = 43$)	P value
Operation time (min)	268.31 ± 71.43	286.79 ± 103.84	0.552
CPB time (min)	136.69 ± 40.42	119.72 ± 45.03	0.229
Aortic cross-clamp time (min)	97.69 ± 25.36	81.63 ± 29.01	0.078
CSICU stay time (d)	1.90 ± 0.52	2.51 ± 1.58	<0.001*
Ventilator assisted time (h)	20.23 ± 6.85	22.48 ± 7.96	0.362
Drainage of first 24 h (ml)	303.00 ± 431.42	354.41 ± 312.51	0.075
Blood transfusion rate of first 24 h (n, %)	8 (61.5%)	31 (72.1%)	0.504
VAS pain score	3.00 ± 2.08	5.77 ± 1.84	<0.001*
Days of postoperative hospital stay (d)	7.62 ± 1.81	10.42 ± 2.45	0.035*
Incidence of pleural effusion (n, %)	2 (15.4%)	4 (9.3%)	0.615
Incidence of atrial fibrillation (n, %)	2 (15.4%)	11 (25.6%)	0.710
Incidence of renal insufficiency (n, %)	1 (7.7%)	1 (2.3%)	0.414
Incidence of poor incision healing (n, %)	0 (0.0%)	1 (2.3%)	1.000
Reoperation rate for hemostasis (n, %)	0 (0.0%)	2 (4.7%)	1.000
Incidence of stroke (n, %)	0 (0.0%)	0 (0.0%)	—
Mortality rate (n, %)	0 (0.0%)	0 (0.0%)	—

CPB: cardiopulmonary bypass; VAS: visual analogue scale; RAT-Bentall: the right anterior chest minimally invasive Bentall; C-Bentall: conventional sternotomy Bentall. Values were expressed as the means ± SD or n (%). *$P < 0.05$.

3.2. Comparison of Postoperative Data. In the RAT-Bentall group, the CSICU stay time was 1.90 ± 0.52 d; the ventilator assisted time was 20.23 ± 6.85 h; the drainage of first 24 h was 303.00 ± 431.42 ml; 8 cases were transfused within the 24 hours, with a transfusion rate of 61.5%; VAS pain score was 3.00 ± 2.08 points; the days of postoperative hospital stay was 7.62 ± 1.81 days; 0 cases of reoperation for hemostasis, 2 cases of postoperative pleural effusion, 2 cases of new-onset atrial fibrillation, 1 case of renal insufficiency, no post-operative stroke, poor incision healing, and deaths. In the C-Bentall group, the CSICU stay time was 2.51 ± 1.58 d; the ventilator assisted time was 22.48 ± 7.96 h; the drainage of first 24 h was 354.41 ± 312.51 ml; 31 cases were transfused within the 24 hours, with a transfusion rate of 72.1%; VAS pain score was 5.77 ± 1.84 points; the days of postoperative hospital stay was 10.42 ± 2.45 days. There were 4 cases of pleural effusion, 11 of new-onset atrial fibrillation, 1 of renal insufficiency, 1 of poor incision healing, 2 of reoperation for hemostasis, and 0 of death. The results showed that compared with the C-Bentall group, the CSICU stay time, VAS pain score, and the days of postoperative hospital stay in the RAT-Bentall group were significantly decreased and the differences were statistically significant ($P < 0.05$) (Table 2).

3.3. Comparison of Follow-Up Data 6 months after Discharge. Patients were followed up for 6 months after discharge through outpatient reviews and telephone interviews. A total of 53 of the 56 patients were followed up, including one patient who died in the RAT-Bentall group (the cause of death was sudden acute severe pancreatitis). The 3 patients who were lost to follow-up were all in the C-Bentall group. These 3 patients did not visit the outpatient clinic for reexamination and could not be contacted. Scarring in the patient who underwent the RAT-Bentall procedure was less visible 6 months after discharge (Figure 2). The 52 patients who were followed up were examined using echocardiography. No statistical significance was found in the ejection

fraction or other echocardiographic indicators between the two groups (Table 3).

4. Discussion

Alleviating patient pain and accelerating postoperative recovery are the goals of surgeons. We performed the RAT-Bentall procedure in the hope that patients would have fewer surgical complications and faster recovery. In the RAT-Bentall procedure performed at our center, all patients recovered and were discharged from the hospital. Compared to the C-Bentall procedure, there was no increased risk of complications, postoperative pain was reduced, and both CSICU and postoperative hospital stays were shorter.

Therefore, in which types of patients is RAT-Bentall appropriate? The experience at our center is that as long as there are no contraindications, the RAT-Bentall procedure can be selected. Contraindications to the RAT-Bentall procedure include the presence of a significant femoral plaque that hinders peripheral CPB techniques or severe thoracic deformity that holds back surgical manipulation from the intercostal space. In the real world, our strategy for deciding who gets the RAT-Bentall and who gets the C-Bentall is "Patient choice takes precedence over surgeon driven." The patient will be fully informed of both surgical options. When both methods are available, it is up to the patient to decide which surgical method to use. However, when some patients are unsuitable for RAT-Bentall, we recommend that they choose the C-Bentall instead of the RAT-Bentall.

Therefore, it is important to select the RAT-Bentall incision approach using preoperative CT scans. The incision selection for the RAT-Bentall is the same as that for the aortic valve we made previously, which is the right anterior thoracic intercostal incision [2]. The choice of incision requires the aorta to be located on the right and generally more than 1/2 of the sternum [11, 12]. The incision protection sleeve was placed in the pericardial position to

FIGURE 2: The scarring of the patient who underwent the RAT-Bentall procedure was less visible 6 months after discharge.

TABLE 3: Patient echocardiographic data 6 months after discharge.

Items	RAT-Bentall ($n = 12$)	C-Bentall ($n = 40$)	P value
Gender (male/female)	9/3	30/10	1.000
LVEF (%)	61.25 ± 7.66	56.85 ± 11.11	0.121
Aortic sinus (mm)	33.66 ± 3.60	33.38 ± 5.06	0.854
Ascending aortic diameter (mm)	27.41 ± 2.91	28.45 ± 3.43	0.350
LVEDD (mm)	43.17 ± 6.77	47.45 ± 9.27	0.145
LVESD (mm)	29.17 ± 6.56	34.40 ± 10.04	0.096

LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; LVEDS, left ventricular end-systolic diameter; RAT-Bentall, right anterior chest minimally invasive; C-Bentall, conventional sternotomy. Values were expressed as the means ± SD or n1/n2.

obtain a better surgical view (Figures 1(a) and 1(b)). The appropriate intercostal space was selected through three-dimensional reconstruction of the preoperative chest CT scan. Selection was based on the intercostal space that was more parallel to the right pulmonary artery. In most cases, the second intercostal space was selected and some were placed in the third intercostal space. Another important point is that when performing preoperative CT, the patient is required to follow the surgical position, not to raise his hands above his head but to place his hands naturally on his side. The CT results obtained in this manner were more consistent with the position at the time of surgery. To avoid damaging the right internal mammary artery, the skin was incised approximately 1.0 cm away from the right border of the sternum.

The main risks associated with the Bentall procedure are coronary ischemia and proximal anastomotic bleeding [13]. In our Bentall procedure, the experience with coronary ostium anastomosis is that coronary ostium release must be performed to achieve a tension-free anastomosis. When suturing the vascular graft, the recommended order of anastomosis is to first anastomose the posterior wall of the blood vessel and then the anterior wall of the blood vessel, starting from the proximal end and ending at the distal end. After the vascular graft opened the channel through a coronary opening, we adopt the method of directly anastomosing the opening of the coronary artery. Care must be taken when stitching and tying knots to not overstretch the thread. This is done to prevent the blood vessel wall from tearing and bleeding and to prevent the coronary arteries from twisting and stretching, causing ischemia. One strategy to prevent proximal anastomotic bleeding is to perform right atrial shunt. The right atrial shunt is an effective method of preventing bleeding with good results over the years [14, 15].

Prolonged CPB can have potentially detrimental effects on patient outcomes [16]. In this study, the CPB and aortic cross-clamp times in the RAT-Bentall group were slightly longer than those in the C-Bentall group; however, the difference was not statistically significant. This is because the incision of the RAT-Bentall surgery is small; therefore, the

operation space is reduced, and the operation difficulty is increased. However, the operative time in the RAT-Bentall group in this study was very similar to that in the C-Bentall group. This is because, although the RAT-Bentall group prolongs the time for major surgical operations, it shortens the time required to close the chest for hemostasis, so the overall operation time is not much different from that of the C-Bentall group or even shorter.

Patients typically require a transfer to the CSICU for monitoring and treatment after cardiac surgery. Studies have shown that prolonged use of ventilators after surgery is associated with increased pulmonary complications, length of CSICU stay, and length of hospital stay [17]. In this study, the ventilator assistance times of the two groups were comparable, and the average ventilator assistance time of the RAT-Bentall group was shorter than that of the C-Bentall group; however, the difference was not statistically significant. It can be seen that the RAT-Bentall group does not prolong the duration of ventilator assistance. Appropriate postoperative analgesia is essential for fast recovery of patients [18]. Postoperative pain management in the two groups was the same at our center; we will provide patients with analgesia pumps after surgery and remove them when the VAS pain score decreases. The study found that the pain scores of patients in the RAT-Bentall group were significantly lower than those in the C-Bentall group. This indicates that the RAT-Bentall procedure can reduce postoperative pain. Minimally invasive cardiac surgery is as safe as traditional surgery and can reduce hospital costs due to shorter CSICU stay [19]. The durations of CSICU stay and postoperative stay in the RAT-Bentall group were shorter than those in the C-Bentall group. The RAT-Bentall procedure allowed the patients to recover more quickly. In this study, there was no statistically significant difference in the incidence of postoperative complications between the two groups, which may be related to the small sample size. However, the RAT-Bentall procedure does not result in many complications. Therefore, a comparison of complications requires multicenter studies with large sample sizes to determine the advantages.

This study had the inherent limitations of a retrospective study design, single-center design, and short follow-up period. The small number of patients who underwent the RAT-Bentall procedure indicates a potential weakness in the results.

5. Conclusion

The RAT-Bentall method is safe. Compared with the C-Bentall procedure, it can reduce postoperative pain and patients' CSICU and postoperative hospital stay. Based on our center's experience, certain conditions must be met to conduct a RAT-Bentall procedure. First, regardless of the surgical procedure, suitable surgical instruments are essential, and there must be suitable cardiac surgical instruments for the RAT-Bentall procedure. For example, we used long-shafted instruments to assist in suturing and knot pushers to assist in tying knots. Second, reasonable team cooperation is essential; therefore, a skilled minimally invasive cardiac surgery team is required. Finally, the chief surgeon must have proficient minimally invasive surgical skills (for example, have mastered minimally invasive aortic valve replacement first) and excellent vascular anastomosis techniques. With its benefits in safety and patient outcomes, the RAT-Bentall procedure is worthy of further promotion.

Data Availability

The datasets used in this study are available from the corresponding author upon request.

Ethical Approval

Ethical approval was obtained from the Institutional Review Board of the Second Affiliated Hospital of Nanchang University (No. 2018068). This study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Consent

Written informed consent was obtained from all participants after explaining the possible consequences of the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Yong-Bing Wu and Hong-Peng Zou designed the study. Hong-Peng Zou conducted the study with the assistance of Yong-Bing Wu and Feng Lu. Hong-Peng Zou and Feng Lu interpreted the results and drafted the paper. Xiang Long, Shu-Qiang Zhu, and Kun Lin interpreted the results. Hong-Peng Zou and Yong-Bing Wu revised the paper. Jian-Jun Xu and Yong-Bing Wu performed all operations with the assistance of Xin Yang, Bai-Quan Qiu, Xiang Long, and Shu-Qiang Zhu. All the authors have read and approved the final manuscript for publication.

Acknowledgments

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