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Original Article

An Off-Pump Repair Technique for Postinfarction Apical Left Ventricular Aneurysm

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Purpose: The conventional surgical treatment for postinfarction left ventricular aneurysm (LVA) is open-heart repair with cardiopulmonary bypass. However, the risk of the open-heart surgery under cardiopulmonary bypass may result in an unacceptable risk for many patients with multiple comorbidities. Here, we reported a new off-pump repair technique for postinfarction apical LVA.

Methods: A new off-pump repair technique, circular banding and occlusion technique, was applied to repair the postinfarction apical LVA in 12 patients. Clinical data of all those 12 patients were retrospectively reviewed. Patients were followed up prospectively by direct interviews and echocardiographic examination.

Results: The new repair technique was successfully performed in all these 12 patients. Acute reduction of the LVA mouth diameter, the left ventricular (LV) end-diastolic volume and end-systolic volume, and an increase in the LV ejection fraction (EF) were immediately obtained after the repair. Patients had an uneventful postoperative course. They were in New York Heart Association class 1–2, and the LV volume and EF detected by echocardiography remained unchanged during an average 28.4 ± 9.9 months (range 13 to 45 months) follow-up.

Conclusions: Circular banding and occlusion is a simple, safe, and effective off-pump repair technique for postinfarction apical LVA. It can allow effective LV remodeling and improve heart function.

Keywords: left ventricular aneurysm, heart failure, device therapy

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Abbreviations and Acronyms

LVA = left ventricular aneurysm
LV = left ventricular
EF = ejection fraction
NYHA = New York Heart Association
LAD = left anterior descending coronary artery
TEE = transesophageal echocardiography

Introduction

Left ventricular aneurysm (LVA) is a serious complication of acute myocardial infarction, especially when revascularization cannot be provided at an early stage.[1,2)]

Development of a large LVA can usually lead to chronic heart failure, ventricular arrhythmia, and emboli resulting from a clot inside the aneurysm, which result in lower life expectancy and poorer quality of life.[3,4] Due to the limited long-term effect of the pharmacological therapy, a large LVA has been routinely treated with surgery.[5–8] Activation of the systemic inflammatory response due to cardiopulmonary bypass and related deleterious effects on the hemostatic system have been well described in the literature.[9,10] So we believe that the risk of the cardiopulmonary bypass may result in an unacceptable risk for many patients with multiple comorbidities. Therefore, for this subgroup of high-risk surgical patients, a less invasive repair strategy without cardiopulmonary bypass will be very attractive.[11,12] Because approximately 90% of LVA occurs due to the occlusion of the left anterior descending coronary artery (LAD), apical aneurysm is the most common LVA.[13,14] Herein, we introduce a new off-pump repair technique for large postinfarction apical LVA involving extended portions of the interventricular septum: circular banding and occlusion technique.

Materials and Methods

The institutional review board and the ethics committee of our hospital approved this study protocol. All participants and their legal representatives were informed of this study in detail and provided signed preoperative informed consent.

Patients

From February 2019 to April 2022, 12 patients with large postinfarction apical LVA involving extended portions of the interventricular septum underwent circular banding and occlusion repair technique in our center. These patients were selected for this repair technique because they had repair indications for the postinfarction apical LVA and were high-risk candidates for traditional repair under cardiopulmonary bypass. Demographics and preoperative variables of these patients are summarized in **Table 1**.

All patients were affected by exertion dyspnea and two by effort angina at the time of hospital admission. The preoperative diagnosis was based on the history of acute myocardial infarction, the damage of heart function, and echocardiography. In all these 12 patients, the LVA was the evolution of an acute anterior myocardial infarction caused by occlusion of LAD. The average interval between the infarction and the operation was

Table 1 Preoperative characteristics data

Case	1	2	3	4	5	6	7	8	9	10	11	12	Mean ± SD
Preoperative characteristics													
Age (y)	66	59	47	64	58	56	61	66	61	59	53	55	58.6 ± 5.6
Gender	Male	Male	Male	Male	Male	Male	Male	Female	Male	Male	Female		
NYHA	III	III	III	III	III	III	III	III	III	III	III		
LV EF (%)	31.1	22.5	26.3	38.1	27.5	29.3	40.3	30.8	33.2	34.5	29.7	30.2	31.1 ± 4.9
MI	–	Mild	Mild	–	Mild	–	Mild	–	–	Mild	–		
Thrombus in LVA	–	–	–	–	–	–	yes	–	–	–	–		
Arrhythmia	–	AF	PVC	–	–	–	–	–	–	–	–		
Inertia between the infarction and the operation (m)	16	21	29	13	17	22	11	14	18	17	19	21	18.2 ± 4.8
CAD	3-vessel	1-vessel	1-vessel	3-vessel	1-vessel	1-vessel	1-vessel	3-vessel	3-vessel	1-vessel	1-vessel		
EuroScore	10	11	9	8	10	11	9	9	10	8	9	9	9.4 ± 1.0

SD: standard deviation; NYHA: New York Heart Association; LV: left ventricular; EF: ejection fraction; MI: mitral insufficiency; LVA: left ventricular aneurysm; AF: atrial fibrillation; PVC: premature ventricular contraction; CAD: coronary artery disease

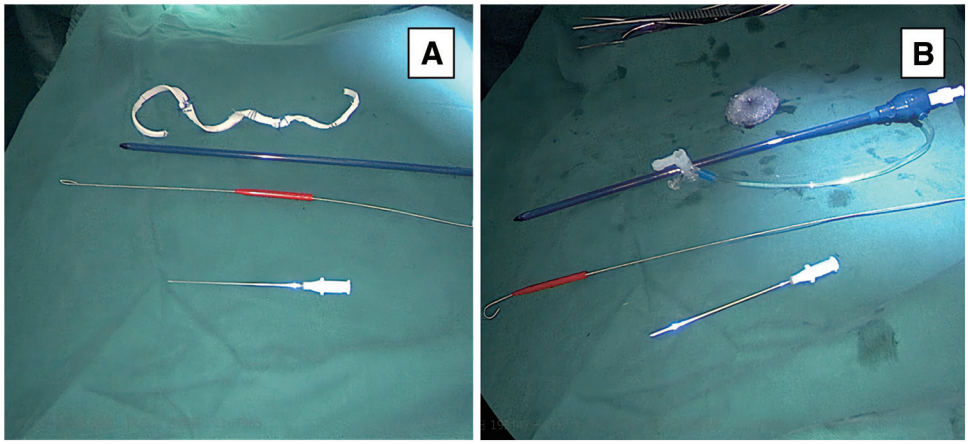

Fig. 1 (**A**) The circular banding device is composed of a circular banding strip, a puncture needle, a guidewire, and a selected delivery sheath containing a dilator. (**B**) The transthoracic device closure system for the atrial defect was applied for the LVA mouth device closure. The system consists of an occluder, a metal delivery sheath, and a pushing rod. LVA: left ventricular aneurysm

18.2 ± 4.8 months (range 11 to 29 months). During this interval, these patients had at least one past history of heart failure hospitalization and persistently accepted optimal medical management (including angiotensin-converting enzyme inhibitors, angiotensin receptor blocker, b-blockers, and aldosterone antagonists). The LAD lesion was successfully treated with insertion of a drug-eluting stent in 2 patients. Mild mitral regurgitation was present in 5 patients and a thrombus inside the LVA in 1 patient. The mean preoperative ejection fraction (EF) was 31.1% ± 4.9% (range 22.5% to 40.3%). A single LAD disease existed in 8 patients and a three-vessel disease displayed in other 4 patients.

This study was approved by the ethics committee of Union Hospital, Fujian Medical University (No. 2018012), and conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from the patients' family members.

Surgical procedure

Our repair technique was finished through a standard median sternotomy under general anesthesia. After the pericardium was opened, adhesion over the left ventricle and the LVA was totally freed. A lap pad was then placed behind the heart, which would elevate the apex out of the pericardium. Then the LVA and its junction between the left ventricle and the LVA were identified by visual confirm, slight palpation of the left ventricular (LV) muscle during its contraction, and transesophageal echocardiography (TEE). The new LVA repair technique consisted of circular banding and occlusion of the LVA mouth.

Circular banding placement

The circular banding strip was placed around the junction between the left ventricle and the LVA in order to reduce the size of the LVA mouth. Two Dacron tube graft strips were used as banding strip (**Fig. 1A**): one strip was implanted at the right ventricular surface of interventricular septum via puncture of both anterior and posterior right ventricular walls guided by TEE, while the other was directly placed around the LV peripheral part of the junction.

The puncture site in the anterior wall of right ventricle was at the cross point between the horizontal line of the junction and the anterior–posterior tangent plane of the right ventricular convex surface of the interventricular septum (**Fig. 2A**). It was usually located 1.0 cm away from the LAD.

A purse string suture was placed in this site and a long puncture needle containing guidewire went vertically through the anterior right ventricular wall within the suture into the right ventricular cavity. Under continuous TEE guidance, the needle vertically and slowly advanced and finally punctured through the posterior right ventricular wall. Another purse string was placed in this puncture-out site. The needle was withdrawn, while the guidewire was kept in position. A selected delivery sheath containing a dilator was introduced through the guidewire. After the guidewire and the inner dilator were removed, the Dacron tube graft strip was drawn into the delivery sheath. Finally, withdraw of the delivery sheath resulted in the Dacron tube graft strip implanted at the right ventricular surface of the interventricular septum.

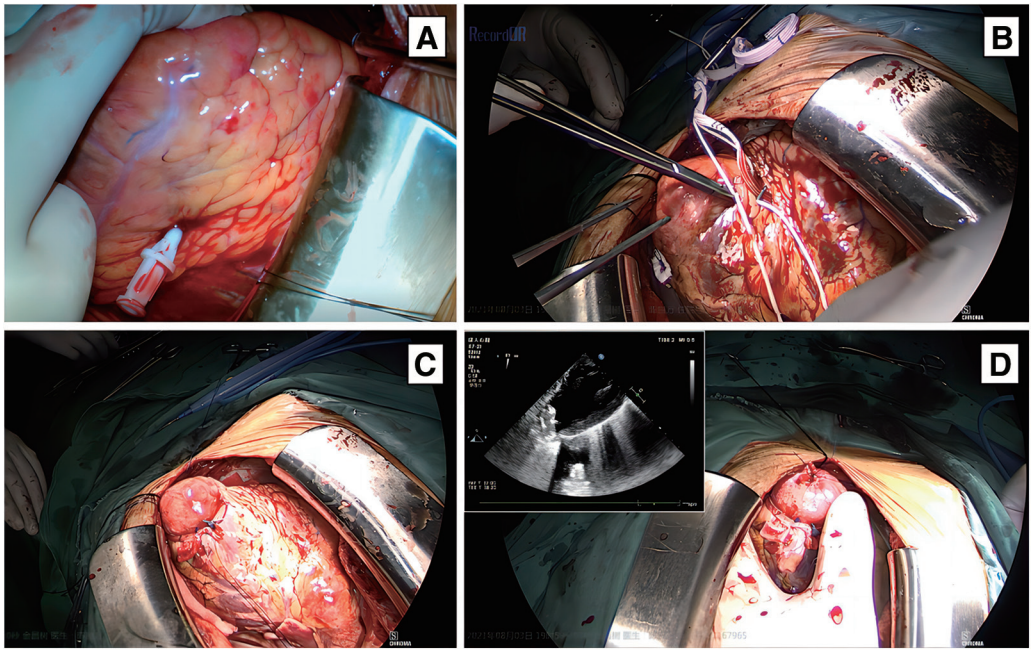

Fig. 2 (**A**) The puncture site in the anterior wall of right ventricle is at the cross point between the horizontal line of the junction and the anterior–posterior tangent plane of the right ventricular convex surface of the interventricular septum. (**B**) The coronary branches are totally free from the epicardium, and the Dacron tube graft strips go beneath the free coronary branches. (**C**) The two strips are tightened and connected together, and the aneurysmal mouth can be brought down to a size estimated to be close to that of the original infarcted area of left ventricle. (**D**) Under continuous TEE guidance, the occluder is deployed to occlusion of the LVA mouth. The sheath and the pushing rod are withdrawn with the suture ligation. TEE: transesophageal echocardiography; LVA: left ventricular aneurysm

The other Dacron tube graft strip was placed around the LV peripheral junction and fixed with 2–4 sutures, which were tied loosely so that the strip can be smoothly drawn inside the sutures. During the Dacron tube graft strip placement, coronary branches (including LAD, posterior descending coronary artery, and other coronary branches) were totally free from the epicardium if those branches were deemed to be usable, and the Dacron tube graft strips went beneath the free coronary branches (**Fig. 2B**). Then two strips were tightened and connected together so that the mouth could be brought down to a size estimated to be close to that of the original infarcted area of left ventricle (**Fig. 2C**).

Occlusion of the aneurysmal mouth

After the LVA mouth was circularly banded to a desire size, a transthoracic device closure system (Shan Dong Visee Medical Apparatus Co. Ltd. Tai an, Shan Dong, China) for the atrial septal defect was applied for the LVA mouth device closure. The system consists of an occluder, a metal delivery sheath, and a pushing rod. The occluder, made from an alloy of nickel and titanium, is self-expandable and double-disk (**Fig. 1B**). The selection of the occluder depended on the LVA mouth diameter after the circular banding placement as defined by TEE, and it was 2–3 mm larger than the mouth diameter.

A purse string suture approximately 10 mm in diameter was placed in the apex of the LVA. An incision was opened inside the purse string suture, and the delivery sheath containing the occluder was inserted. Under continuous TEE guidance, the sheath was advanced through the LVA mouth into the LV cavity. The pushing rod was introduced into the delivery sheath, the occluder was slowly advanced to the tip of the sheath, and the first disc was deployed. Then, the sheath was pulled back slowly until the first disc approximated the mouth, followed by the second disc deployed. The sheath and the pushing rod were withdrawn with the suture ligation (**Fig. 2D**).

The rest of the operation, including bleeding control, pericardial closure, and chest closure, was performed according to the usual standard.

Data collection and follow-up

Clinical data of all 12 patients were retrospectively reviewed. All survivors were contacted by direct interviews in our department after discharge. They were

followed up prospectively by means of general examination and echocardiography on the following schedule: before discharge, 3 months after the operation, and annually thereafter.

Statistical analysis

Baseline characteristics were described as mean ± standard deviation values for continuous variables and counts and percentages for categorical variables. A repeated measures analysis of variance was used to estimate the difference in LV end-diastolic volume, LV end-systolic volume, and LV EF between visits. The Holm–Bonferroni method was used for multiple comparison correction; only significant results for pairwise comparisons were presented in the Box/violin plot. All analyses were performed using SAS version 9.3 (SAS, Cary, NC, USA) or R 4.1.3.

Results

Our new technique was technically successful and could be completed within 30 to 60 minutes in all these 12 patients. Concomitant surgical revascularization was obtained in 4 patients (one by grafting the LAD using the internal thoracic artery and the other by grafting the LAD, diagonal and obtuse marginal branches using the internal thoracic artery and a saphenous vein). Hypotension during the apex lifted occurred in 2 patients, which was managed with temporary low-dose noradrenaline. In the process of the LVA repair, we did not encounter any uncontrollable bleeding and any malignant ventricular arrhythmia.

Intraoperative TEE

After circular banding placement, the diameter of the LVA mouth can be quickly decreased to our desirable extent (from 36.7 ± 6.0 mm to 24.6 ± 4.7 mm) (**Table 2**). All those decreased mouth were effectively closed by the occlusion devices resulting in isolation of the LVA.

Patients had an uneventful postoperative course. No patients required additional surgical treatment to correct excessive postprocedural bleeding. The postoperative mechanical ventilation support period was 8.8 ± 3.9 hours (range 4 to 18 hours) and the duration of an intensive care unit stay was 20.7 ± 6.5 hours (range 14 to 36 hours). Postoperative arrhythmia, embolization, and infection did not occur in those patients. A lower chest wound dehiscence existed in one patient, which needed surgical reclosure (**Table 2**).

Table 2 Intraoperative TEE data and postoperative data

Case	1	2	3	4	5	6	7	8	9	10	11	12	Mean ± SD
Intraoperative TEE data													
Pre-repair LVA mouth (mm)	40.5	42.7	33.5	32.8	26.2	46.7	29.1	33.8	39.7	42.6	37.9	35.4	36.7 ± 6.0
Post-repair LVA mouth (mm)	31.2	30.1	25.9	24.4	20.9	31.6	16	21.8	23.8	26.6	22.9	20.2	24.6 ± 4.7
Postoperative data													
Ventilation time (h)	4	7	12	5	11	10	11	6	18	8	8	5	8.8 ± 3.9
Mediastinal drainage (mL)	210	170	320	110	250	180	240	180	240	120	200	180	200 ± 57.8
ICU stay time (h)	14	26	24	19	26	21	20	18	36	16	13	15	20.7 ± 6.5
Hospital time (d)	8	11	10	8	31	12	11	9	15	10	8	7	11.7 ± 6.5
Complications	–	–	–	–	Lower chest wound dehiscence	–	–	–	–	–	–	–	

TEE: transesophageal echocardiography; SD: standard deviation; LVA: left ventricular aneurysm; ICU: intensive care unit

Follow-up

All survivors were followed up to the end of this study (April, 2023). The follow-up was 100% complete. The average duration of follow-up was 28.4 ± 9.9 months (range 13 to 45 months). There were no deaths and no need for heart failure hospitalization. No embolization, device migration, and infection were observed in those survivors. They were in New York Heart Association class I–II and free from angina.

The postoperative echocardiographic examinations showed that all the occlusion devices were in place and there was no thrombus inside the rebuilt LV cavity. The LV end-diastolic volume and end-systolic volume were 167.03 mL and 117.46 mL preoperatively, 96.66 mL and 46.54 mL before discharge, 99.13 mL and 48.99 mL at 3 months postoperatively, and 95.21 mL and 44.97 mL at 1 year postoperatively, respectively. Statistical analysis demonstrated both LV end-diastolic volume and end-systolic volume with no further decrease overtime. The LV EF was 30.73% preoperatively, 52.36% before discharge, 51.16% at 3 months postoperatively, and 53.34% at 1 year postoperatively. There was not any significant difference over those 3 postoperative time points.

Discussion

In our present study, a new off-pump repair technique, circular banding and occlusion technique, was introduced for postinfarction apical LVA. Results of the preliminary application in 12 patients demonstrated that this technique could quickly isolate the LVA, reduce the LV volume, and increase the LV EF.

In the surgical repair of LVA, the basic principle is the elimination or the exclusion of the LVA in order to decrease paradoxical or akinetic motion of the LV wall.[6,7,15] This elimination or exclusion will also decrease the LV end-diastolic volume and consequently result in optimization of the law of Laplace, which simply states that tension on the ventricular wall increases as the radius of the ventricle increases. Therefore, this volume may decrease myocardial work and wall stress to receive a hemodynamic benefit.[12,15] Results of our present study showed that our new repair technique could immediately isolate the LVA, reduce the LV volume, and increase the LV EF. Thus, it would benefit heart functional recovery and consequently improve patient's life quality and expectancy.

Since the first successful surgical LVA repair in 1958, two major repair techniques have been described: linear repair and circular patch repair.[15] The linear repair technique involves a longitudinal resection and linear closure of LVA. However, the functional LV cavity size will decrease when the ventricle is directly closed after resection of the LVA.[15] Furthermore, for an apical LVA, this linear repair does not imbricate septal scar and consequently cannot restore the natural LV geometry.[15] Circular patch repair arose from the idea that all apical scarring will be completely excluded from the ventricle, resulting in retained ventricular geometry and better postoperative LV function.[15] Therefore, more and more surgeons prefer the circular repair for large apical LVA. Our technique was originally based on the concept of circular patch repair, in which the mouth was first decreased and then closed with the occlusion device. It could not only provide recreation of the LV geometry but also reduce the size of the akinetic zone in the newly formed ventricular cavity.

Traditional LVA repair with either the linear technique or the patch technique is completed under cardiopulmonary bypass.[7] However, the risk of cardiopulmonary bypass may result in an unacceptable risk for many patients with multiple comorbidities.[5,6] Although long-term benefits of off-pump versus on-pump coronary artery bypass surgery are controversial, the short-term benefits of off-pump strategy to reduce reoperation, for postoperative bleeding, blood-product transfusion, acute kidney injury, and respiratory complications, have been documented in a large randomized study.[16] Therefore, for this subgroup of high-risk surgical candidates, a less invasive repair strategy without cardiopulmonary bypass will be very attractive. Two major mini-invasive techniques without cardiopulmonary bypass have been recently introduced for LVA repair: the linear plication with the Bioventrix Revivent anchoring system and occlusion with a septal occluder or a parachute ventricular partitioning device.[11,12] The Revivent technique is a hybrid percutaneous-surgical off-pump procedure that can successfully exclude the LVA by direct linear plication.[11] Compared with the traditional linear repair for an apical LVA, this linear plication imbricated septal scar. However, a major disadvantage of this plication is that the lateral and septal walls of the left ventricle are plicated together at a point where they would naturally lie several centimeters apart, which would significantly decrease the functional LV cavity size and distort the natural LV geometry. The parachute device technique is a percutaneous procedure to implant an umbrella-like device isolating the LVA.[12] It can recreate the LV geometry, but the endoventricular device is an akinetic zone in the newly formed

LV cavity. For a large apical LVA, an oversized endoventricular device can lead to larger akinetic segments and increased wall stress. In our technique, the LVA mouth was first decreased by circular banding placement and then closed with an occlusion device. Therefore, our technique might be a better choice for those surgical high-risk patients with a large apical LVA.

Two major technical concerns have emerged from our experiences with the application of this circular banding and occlusion technique for apical LVA repair. During the placement of the banding Dacron tube graft strip, it is very important to protect the LAD and other coronary branches from compression of the strip when those coronary branches are deem to be preserved. In our experience, we totally freed the coronary branches long enough from the epicardium and the strips passed loosely beneath the coronary branches. The second worry was the size of the occlusion device. The occlusion device is the akinetic part of the newly reconstructed LV cavity. Therefore, the device size is crucial in our new repair technique: a small device will allow for small LV volume, whereas an oversized device can lead to larger akinetic segments and increased wall stress. Actually, the occlusion device size was decided by the diameter of the LVA mouth. In our procedure, the mouth was controlled by the circular banding placement to a size close to that of the original infarcted area of left ventricle.

Study limitations

This study has limitations. Lack of comparison group is the major limitation of this study; randomized controlled study is necessary to confirm the efficacy of the procedure in the future. Only 12 cases were enrolled in this series; thus, selection bias cannot be avoided, resulting in restriction of generalization. Besides, continued follow-up is needed to assess long-term outcomes.

Conclusion

Circular banding and occlusion is a simple, safe, and effective off-pump repair technique for large postinfarction apical LVA. It can allow effective LV remodeling and improve heart function.

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee of Union Hospital, Fujian Medical University, and conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from the patients' family members.

Data availability statement

All data generated or analyzed during this study are included in this published article.

Authors' contributions

Liangwan Chen designed the study and submitted the manuscript. Zhihuang Qiu, Yunnan Hu, and Yue Shen prepared the first draft of the manuscript and made the literature review. Guanhua Fang and Heng Lu made substantial changes in the manuscript together. Qingsong Wu collected and analyzed data together. All authors read and approved the final manuscript.

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Disclosure Statement

The authors declare that they have no conflict of interest.

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