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ORIGINAL RESEARCH

# Echocardiography-Guided Radiofrequency Ablation for Cardiac Tumors

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## ABSTRACT

**BACKGROUND** Patients with cardiac tumors may present challenges for surgical resection due to poor clinical condition. Echocardiography-guided transapical radiofrequency ablation for cardiac tumors (TARFACT) potentially offers a less invasive palliative therapy option.

**OBJECTIVES** This study aimed to evaluate the safety and efficacy of TARFACT.

**METHODS** Five patients with cardiac tumors (mucinous liposarcoma, myocardial hypertrophy with inflammatory cell infiltration mass, fibrous tissue tumor hyperplasia, myocardial clear cell sarcoma, and cardiac rhabdomyoma) were included. All patients underwent TARFACT and were assessed with electrocardiogram, echocardiographic imaging, biochemical analysis, and pathological confirmation.

**RESULTS** The median follow-up for all patients was 9 (range 4-12) months. Three surviving patients were alive at their last follow-up (9, 12, and 12 months, respectively), whereas 2 patients with late-stage tumors survived 6 months and 13 months after TARFACT, respectively. After TARFACT, all patients showed significant reductions in tumor size: the mean length decreased from 6.7 ± 2.0 cm to 4.7 ± 1.8 cm ($P = 0.007$); and the mean width decreased from 5.0 ± 2.1 cm to 2.5 ± 0.7 cm ($P = 0.041$). NYHA functional class also improved: median (IQR) decreased from 3.0 (1.5) to 2.0 (1.0) ($P = 0.038$), Peak E-wave on echocardiography showed a mean increase from 64.4 ± 15.7 cm/s to 76.6 ± 18.6 cm/s ($P = 0.008$), and NT-pro BNP levels had a median (IQR) reduction from 115.7 (252.1) pg/mL to 55.0 (121.6) pg/mL ($P = 0.043$).

**CONCLUSIONS** TARFACT is a novel palliative treatment option for cardiac tumors, reducing accessible tumors and improving clinical symptoms in a preliminary group of patients. (Cardiac Tumors Interventional [Radio Frequency/Laser Ablation] Therapy [CTIH]; NCT02815553) (JACC CardioOncol 2024;6:560-571) © 2024 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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Cardiac tumors, although rare, pose a serious threat to patients' lives.[1] Autopsy series show that primary cardiac tumors occur at a rate of 0.002% to 0.3%, with approximately 90% being benign. Secondary cardiac tumors, arising from distant metastasis, hematogenous dissemination, or lymphatic spread, are estimated to be more than 20 times more prevalent than primary tumors.[2,3] Clinical symptoms of cardiac tumors vary depending on factors such as size, location, nature of the tumor, and invasion of cardiac structures, often presenting as palpitations, dyspnea, heart failure, syncope, and in severe cases, sudden death.[4] Treatment strategies target removing or debulking cardiac tumors to improve patient outcomes, with surgical resection, chemotherapy, and/or radiotherapy being the most common and effective treatments. However, patients with malignant cardiac tumors may face challenges, such as high-dose chemotherapy leading to cardiotoxicity, left ventricular dysfunction, or heart failure.[5] Research has shown the significance of margin-negative resection (R0) in cardiac tumor management, correlating with prognosis and median overall survival.[6,7] Nevertheless, complete tumor removal while preserving cardiac structure and function, especially near critical areas such as the atrioventricular node and myocardium, remains a clinical challenge.

Radiofrequency ablation has emerged as a widely used therapeutic modality for various types of tumors, including liver, kidney, lung, breast, and adrenal tumors, due to its minimally invasive nature and high efficacy.[8] In line with this, we have developed a novel treatment for debulking cardiac tumors termed echocardiography-guided transapical radiofrequency ablation for cardiac tumors (TARFACT). This procedure provides a new potential approach for patients with cardiac tumors who are deemed unsuitable or unable to tolerate surgical resection, chemotherapy, or definitive/palliative radiation therapy, as determined by multidisciplinary team evaluation. Our previous report detailed the initial experience of TARFACT in a patient with cardiac myxoma, with a follow-up period of 9 months.[9] The aim of this study is to evaluate the safety and efficacy of TARFACT in debulking cardiac tumors.

## METHODS

**PATIENTS.** We enrolled patients diagnosed with cardiac tumors at Xijing Hospital Ultrasound Interventional Treatment Center for Cancer in Xi'an, China, spanning from March 2017 to January 2021. Our study had the following inclusion criteria: 1) cardiac tumors deemed unsuitable for or intolerant of surgical resection, chemotherapy, or definitive/palliative radiation therapy based on evaluation by a multidisciplinary team; and 2) patients exhibiting significant clinical symptoms or obstruction. Exclusion criteria included symptoms of heart failure and left ventricular ejection fraction (LVEF) <40%. All patients participated in the shared decision-making process with the heart team. Cardiac biopsy in 1 patient showed seminoma, warranting referral for radiation therapy.

In this preliminary study, primary outcomes were safety and tumor debulking efficacy. Each patient was registered at clinicaltrials.gov (Cardiac Tumors Interventional [Radio Frequency/Laser Ablation] Therapy [CTIH]; NCT02815553) and provided informed consent after a discussion with the heart team. The Institutional Ethics Committee (KY20162034-1) of Xijing Hospital approved the procedure, ensuring adherence to the ethical standards outlined in the Declaration of Helsinki.

**ECHOCARDIOGRAPHY.** All transthoracic echocardiography (TTE) studies were performed using a 1.0 to 5.0 MHz transducer. Before TARFACT, tumor location, dimensions (including length and width), septal thickness, left atrial diameter, left ventricular diameter, left ventricular end-diastolic volume, left ventricular end-systolic volume, and LVEF were assessed following the guidelines recommended by the American Society of Echocardiography.[10] Myocardial contrast echocardiography (MCE) involved the administration of 2 mL of sulfur hexafluoride microbubbles (SonoVue, Bracco) as the contrast agent.

**ELECTROCARDIOGRAM AND RHYTHM MONITORING.** Standard 12-lead electrocardiogram (ECG-1250P, Nihon Kohden) and 24-hour Holter (DMS300-4A, DM Software) were conducted for all patients.

**ABBREVIATIONS AND ACRONYMS**

**18F-FDG** = $^{18}$F-fluorodeoxyglucose

**CT** = computed tomography

**LVEF** = left ventricular ejection fraction

**MCE** = myocardial contrast echocardiography

**PET** = positron emission tomography

**TARFACT** = transapical radiofrequency ablation for cardiac tumors

**TTE** = transthoracic echocardiography

**VT** = ventricular tachycardia

The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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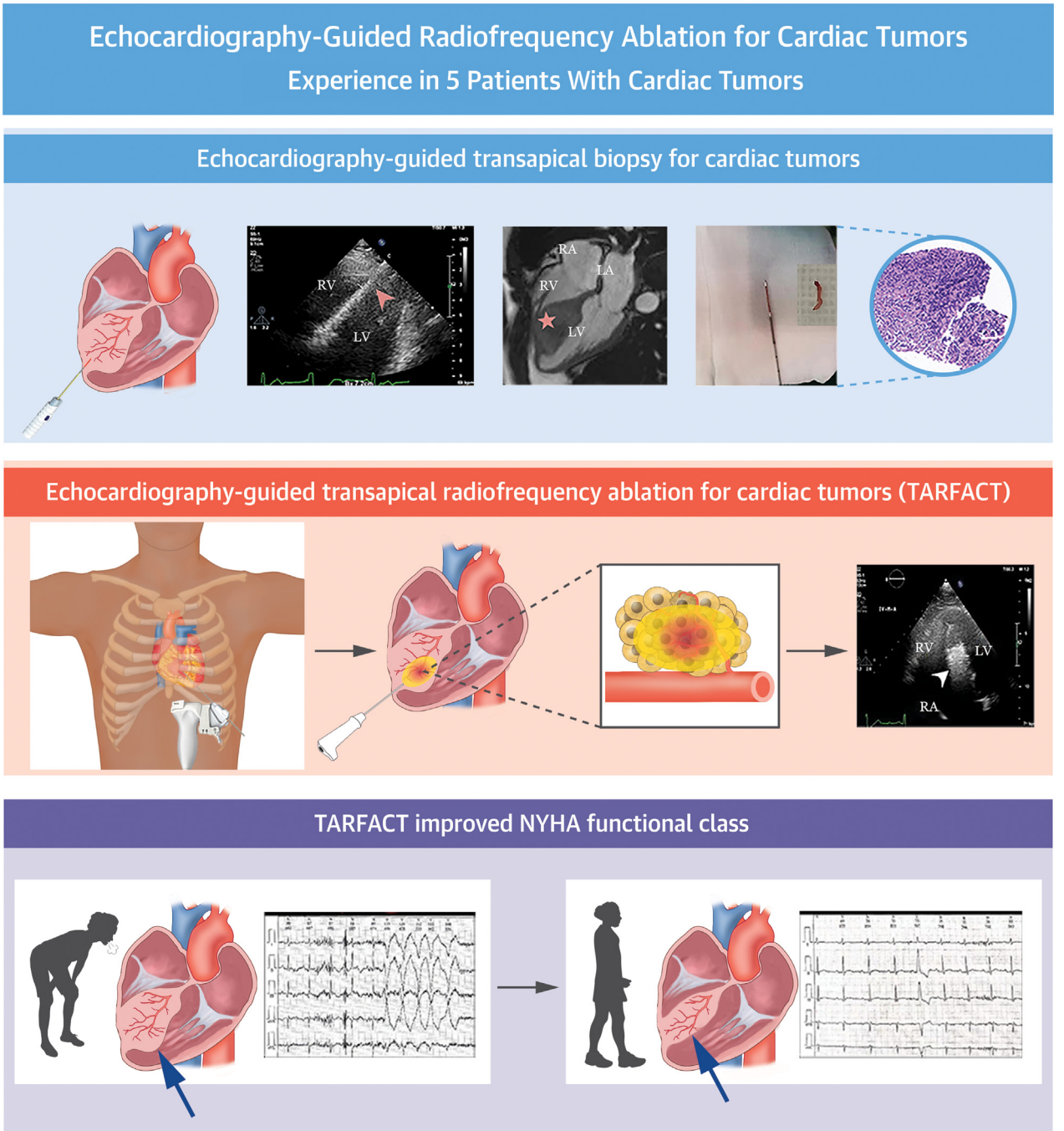
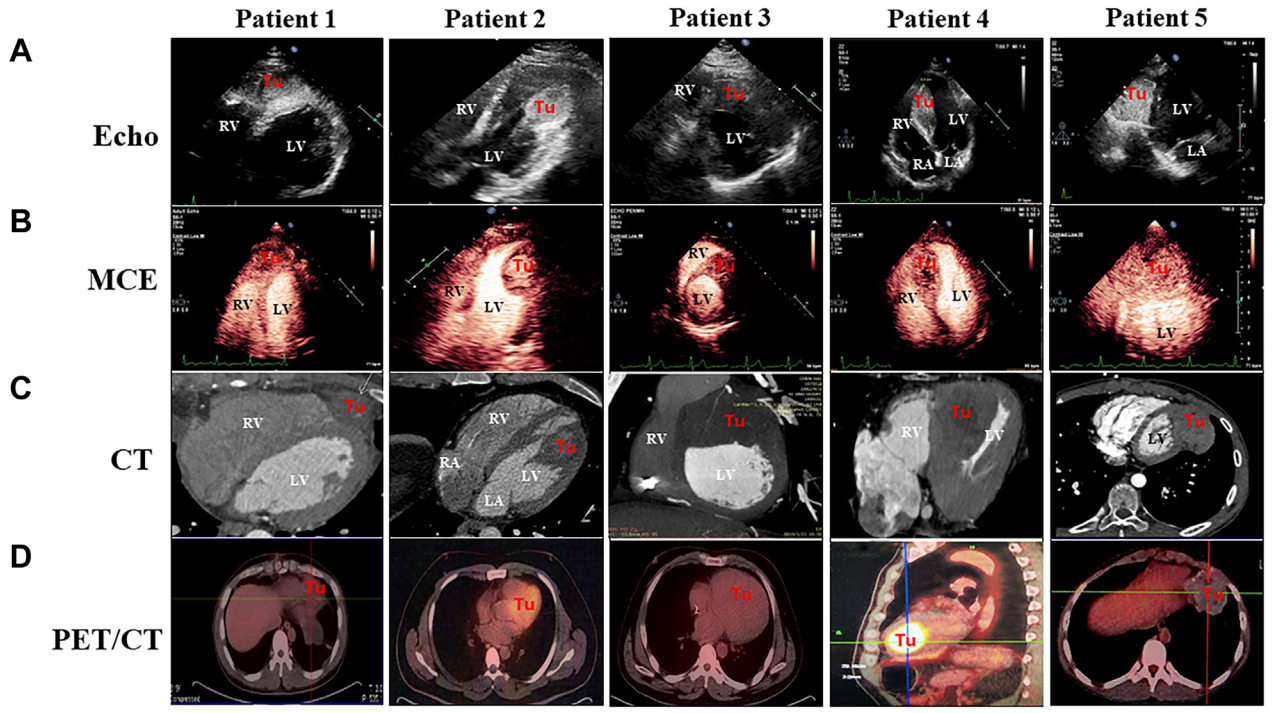
**CENTRAL ILLUSTRATION** **Echocardiography-Guided Transapical Biopsy and Radiofrequency Ablation for Cardiac Tumors**




**Huang J, et al. JACC CardioOncol. 2024;6(4):560–571.**

Echocardiography-guided transapical biopsy and radiofrequency ablation of cardiac tumors. The arrowhead indicates the insertion of the biopsy needle into the cardiac tumor, and star indicates the tumor. Debulking of cardiac tumors by transapical radiofrequency ablation for cardiac tumors (TARFACT) can improve NYHA functional class. The arrow indicates the cardiac tumor. LV = left ventricle; RA = right atrium; RV = right ventricle.

**FIGURE 1** Imaging Evaluation of Cardiac Tumors for TARFACT



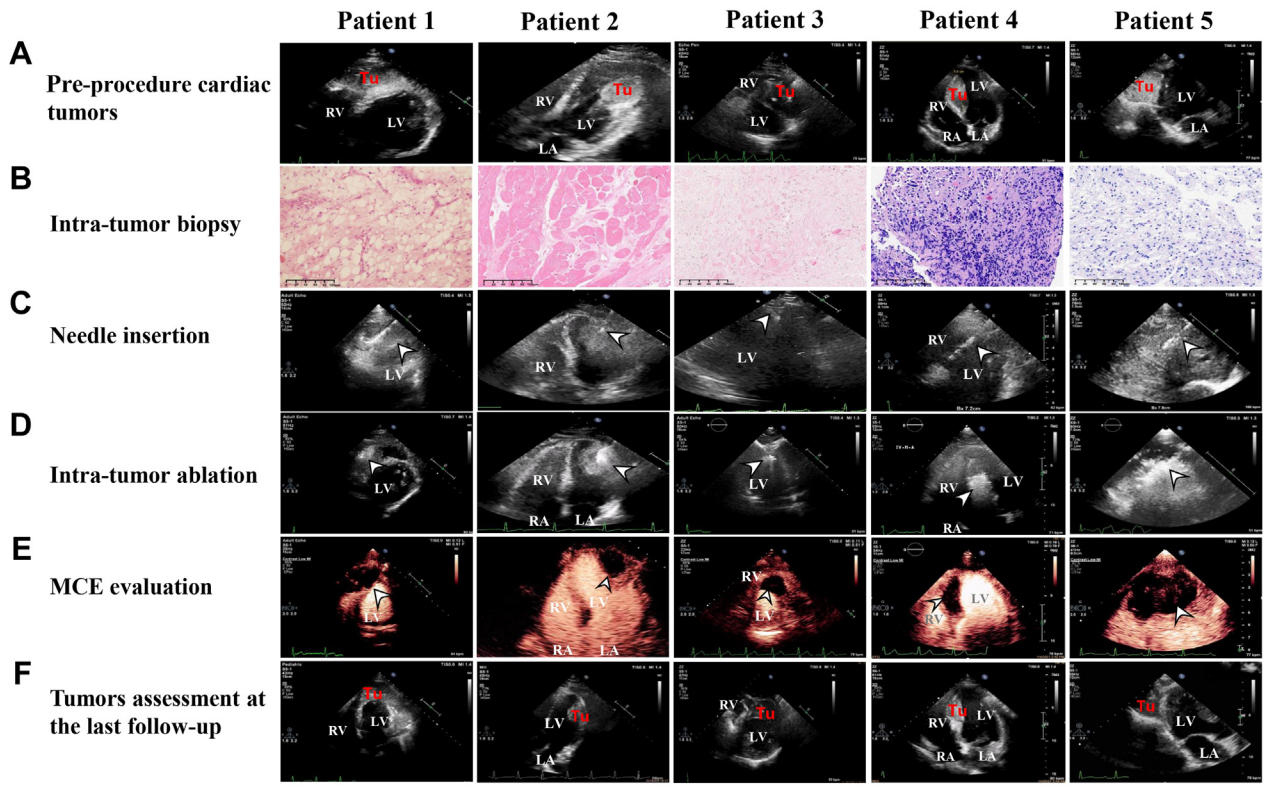

(A) Echocardiography showed the size and location of cardiac tumors. (B) Pre-procedure myocardial contrast echocardiography (MCE) was used to evaluate the vasculature of the tumors. (C) Cardiac computed tomography (CT) was performed to obtain comprehensive anatomic information of the heart. (D) Positron emission tomography (PET)/CT scans showed various levels of glucose metabolism in cardiac tumors. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle; TARFACT = echocardiography-guided transapical radiofrequency ablation for cardiac tumors; Tu = tumor.

**PREPROCEDURAL COMPUTED TOMOGRAPHY ANGIOGRAPHY.** Retrospective electrocardiogram-triggered spiral acquisition of cardiac computed tomographic (CT) angiography imaging was performed using a 128-slice dual-source CT (Somatom Definition Flash, Siemens Healthineers). All images were reconstructed with a slice thickness of 0.75 mm and an increment of 0.5 mm. Subsequently, all images were transferred to an external workstation (Syngo MMWP VE 36A, Siemens Healthineers) for analysis.

**CARDIAC MAGNETIC RESONANCE IMAGING.** Cardiac magnetic resonance studies were conducted using a 1.5-T magnetic resonance scanner (MAGNETOM Aera, Siemens). Late gadolinium-enhanced sequences were acquired 10 minutes after the intravenous administration of 0.2 mmol/kg of gadolinium-diethylenetriamine penta-acetic acid (Magnevist, Schering) using breath-holding 2-dimensional phase-sensitive inversion recovery.

**POSITRON EMISSION TOMOGRAPHY/COMPUTED TOMOGRAPHY.** All patients underwent $^{18}$F-fluorodeoxyglucose (18F-FDG) positron emission tomography/computed tomography (PET/CT) imaging using the Shanghai Lianying uMI780 system. Before imaging, patients fasted for 6 to 8 hours and maintained blood glucose levels below 11.1 mmol/L. Intravenous administration of 18F-FDG (3.7-5.5 MBq/kg or 0.13 mCi/kg of body weight) was performed, followed by image collection 60 minutes after injection. The scanning range extended from the cranial roof to the middle part of the femur, with scanning parameters set at a tube voltage of 120 kV, tube current of 200 mA/s, layer thickness of 1.5 mm, and pitch of 1.1875. The scanning duration was 2 min/bed for body scans and 3 min/bed for head scans. Subsequently, the computer system automatically reconstructed PET/CT images to produce fusion PET/CT projection images. The glucose metabolism value (SUV max) of cardiac tumors, as measured by PET-CT scan, served as an initial indicator for determining the tumor's nature as benign or malignant. Furthermore, PET-CT imaging allowed for the monitoring of treatment response and systemic screening for distant metastases.[11]

**FIGURE 2** Echocardiography-Guided TARFACT Procedure




(A) Cardiac tumors were reassessed by echocardiography before TARFACT. (B) Percutaneously cardiac intratumor biopsy was performed, and images are shown here are at 200× magnification after hematoxylin and eosin staining. (C) The radiofrequency needle was percutaneously inserted into the tumors, guided by color Doppler guidance to avoid vascular injury. The arrowhead indicates the needle in the cardiac tumor through the guide frame. (D) Ablation of the cardiac tumor was performed. The bright echo signal, indicated by the arrowhead, represents the ablation area. (E) After tumor ablation, contrast echocardiography was used to assess whether the ablation range was adequate. (F) At a median (IQR) of 9 (8) months after TARFACT, the cardiac tumor demonstrated a reduction in size. Abbreviations as in Figure 1.

**PATIENT AND PUBLIC INVOLVEMENT.** Written informed consent was obtained from all patients before the TARFACT procedure, following discussions regarding alternative and established therapies, including surgery, chemotherapy, and/or radiotherapy. The feasibility, benefits, and risks associated with radiofrequency ablation were deliberated with each patient. Moreover, active participation in the shared decision-making process was highly encouraged for all patients and/or referral physicians before proceeding with the ablation procedure.

**TARFACT PROCEDURE.** Patients were positioned in the left lateral position under general anesthesia with endotracheal intubation, ensuring continuous monitoring of electrocardiography, blood pressure, oxygen saturation, and central venous pressure during the procedure. The TARFACT procedure (**Central Illustration**) was performed as previously described.[9]

In brief, preprocedure multimodal imaging was used to assess cardiac tumor size, location, invasiveness, and the presence of feeding branches of blood vessels (**Figures 1 and 2A**). Under TTE guidance, we introduced an 18G automatic biopsy needle (BARD Magnum, C.R. Bard) through the puncture guide frame (S5-1) into the cardiac tumor via a percutaneous transthoracic approach, carefully avoiding blood vessels in the puncture path. Subsequently, we activated the biopsy needle switch to obtain the tumor tissue sample for pathology (**Figure 2B**). Subsequently, a 17-gauge radiofrequency electrode needle (17G, Cool-tip Radiofrequency Ablation System and Switching Controller, Medtronic) was inserted into the cardiac tumor (**Figure 2C**), and radiofrequency ablation was initiated upon reaching the target area of the tumor (**Figure 2D**). The ablation power was gradually increased from 20 W at the beginning of procedure, up to 130 W if needed.

**TABLE 1 Baseline Clinical Characteristics**

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 | Patient 5 |
|---|---|---|---|---|---|
| Clinical characteristic | | | | | |
| Sex | Male | Male | Male | Male | Male |
| Age, y | 36 | 28 | 38 | 57 | 13 |
| Height, cm | 178 | 176 | 170 | 165 | 155 |
| Weight, kg | 72 | 105 | 83 | 62 | 44.5 |
| BMI, kg/m$^2$ | 22.7 | 33.9 | 28.7 | 22.8 | 18.5 |
| Clinical symptoms | Chest tightness, dyspnea | Palpitation | Chest tightness | Palpitation, chest tightness | Palpitation, syncope |
| NYHA functional classification | II | II | IV | III | IV |
| Comorbidity | N | N | Tachycardia | N | NSVT |
| History of other procedure | Resection of liposarcoma on the leg and pericardial tumor | N | ICD implantation | Resection of gluteus maximus sarcoma | The LV tumor partly resected |
| Cardiac tumor marker | | | | | |
| CA242, U/mL | – | 12.8 | 0.1 | 8.5 | 11.1 |
| NSE, U/mL | – | 12.4 | 18.2 | 11.3 | 17.3 |
| hs-CRP, mg/L | 23.6 | 1.67 | <0.809 | 6.78 | < 0.809 |
| SF, μg/L | 56 | 336 | 113 | 180 | 11.7 |
| Cardiac tumor characteristics | | | | | |
| Tumor location | AW and apex of RV | Lateral-posterior wall of LV | AIVS and LVAW | IVS | Apex of LV |
| Pathology | Myxoid liposarcoma | Myocardial hypertrophy with inflammatory cell infiltration | Fibroma | Hyaline cell sarcoma of myocardium | Rhabdomyoma |
| Primary/metastatic | Metastatic | Primary | Primary | Metastatic | Primary |
| Clinical diagnosis | Highly differentiated mucinous liposarcoma | Benign tumor of cardiac origin with rich blood supply | Fibrous tissue tumor hyperplasia | Myocardial clear cell sarcoma | Cardiac rhabdomyoma |
| Tumor size | | | | | |
| Length, cm | 8.2 | 4.1 | 9.1 | 5.5 | 6.5 |
| Width, cm | 4.3 | 3.0 | 8.6 | 4.1 | 4.8 |

AIVS = anterior interventricular septum; AW = anterior wall; BMI = body mass index; ICD = implantable cardioverter defibrillator; IVS = interventricular septum; LV = left ventricular; LVAW = left ventricular anterior wall; N = none; NSE = neuron specific enolase; NSVT = non-sustained ventricular tachycardia; NYHA = New York Heart Association; RV = right ventricular; RVOT = right ventricular outflow tract; SF = serum ferritin.

Different from the approach, ablation range, and biophysics of radiofrequency catheter ablation for arrhythmias, TARFACT involves the insertion of a radiofrequency needle into the cardiac tumor followed by application of high-frequency alternating current to energize ions within the tumor cells and generate heat. The local tissue temperatures recorded by the system could exceed 80°C. Dehydration of the tissue surrounding the needle led to necrosis of the tumor tissue and regional blood vessels, resulting in reduced blood supply.

A closed-circuit water-cooling system connected to the radiofrequency needle was employed to maintain optimal temperatures during the procedure. Once the tissue impedance reached 150% of baseline value, automatic shutdown and hibernation mode activation occurred for 15 seconds on the radiofrequency machine. To achieve complete necrosis of tumor cells, typically 3 rounds of "hibernation" or 12 minutes ablation were used as a single ablation stop indication.

After each ablation, the needle position was adjusted based on preprocedure multimodal imaging combined with real-time imaging. A 12-lead electrocardiogram and TTE were used to monitor the occurrence of arrhythmia and pericardial effusion during the procedure. Radiofrequency ablation was applied a mean of 6 ± 3 times per each lesion. Total ablation time ranged from 48.0 to 126.3 minutes, with a mean duration of 76.6 minutes and mean ablation power of 60.9 ± 11.5 W.

MCE detected perfusion defects in the ablation area and elimination of blood vessel branches supplying blood to the tumor (Figure 2E). The mean ablation length for cardiac tumors was 5.0 (3.8-6.0) cm, and the ablation width was 3.4 (2.3-4.6) cm. After the procedure, the ablation needle was removed and pressure was applied to the puncture site for a duration of 3 to 5 minutes.

**FOLLOW-UP.** After hospital discharge, patients were monitored 1 week and 1, 3, 6, and 12 months later, with

**TABLE 2 Antitumor Treatments Before and After TARFACT**

| Patient | Antitumor Treatments | |
|---|---|---|
| | Preprocedure | Postprocedure |
| 1 | Surgical thoracotomy | Patient intolerant to postoperative chemotherapy |
| 2 | — | Improved clinical symptoms have improved; standard follow-up recommended |
| 3 | Implantation of ICD for tachycardia | Surgical resection performed 30 months after TARFACT due to reduced tumor size and absence of VT |
| 4 | Resection of gluteus maximus sarcoma, with chemotherapy and radiotherapy | Chemotherapy |
| 5 | Surgical thoracotomy | — |

ICD = implantable cardioverter-defibrillator; TARFACT = echocardiography-guided transapical radiofrequency ablation for cardiac tumors; VT = ventricular tachycardia.

subsequent follow-up visits scheduled every 6 months. During these follow-up assessments, we surveyed for possible complications, including in-hospital and 30-day deaths, pericardial effusion, procedure-related stroke, and malignant arrhythmias.

**STATISTICAL ANALYSIS.** Individual patient data at baseline, in-hospital, and during follow-up for those undergoing TARFACT are presented. Clinical outcomes at baseline and last follow-up, including echocardiographic, 24-hour Holter, and biochemistry results, were summarized as mean ± SD or median (IQR) or full range based on data distribution. Comparison between pre- and postprocedure was performed using a paired *t*-test or Wilcoxon signed rank test, as appropriate. Normal distribution was assessed using a normal Q-Q plot and Kolmogorov-Smirnov test. Statistical analysis was performed using SPSS Statistics 22.0 (IBM), and a 2-sided *P* value of $<0.05$ was considered statistically significant.

## RESULTS

**BASELINE CHARACTERISTICS.** We enrolled 5 patients with cardiac tumors who were not candidates for surgical resection. Among them, 2 patients (patients 1 and 5) experienced cardiac tumor recurrence at 4 months and 28 months after surgical resection, respectively, rendering them unsuitable candidates for re-do surgery. For the remaining 3 patients, unclear tumor boundaries posed a significant risk of injury to the surrounding vital tissues with surgical resection. Consequently, after extensive heart team discussions, surgical intervention was deemed unfeasible for these patients.

A summary of their baseline characteristics is presented in Table 1. Clinical diagnoses included mucinous liposarcoma, myocardial hypertrophy with inflammatory cell infiltration mass, fibrous tumor, myocardial clear cell sarcoma, and cardiac rhabdomyoma. The mean age at treatment was 34 (range: 13-57) years, with all patients being male. None of the patients had undergone prior radiation therapy. Persistent symptoms of NYHA functional class II or higher were reported by all patients. Details of additional antitumor treatments administered to these patients before the procedure are summarized in Table 2.

Patient 1 experienced recurrence after surgical resection, while patient 3 underwent implantation of an implantable cardioverter defibrillator for ventricular tachycardia (VT). Patient 4 underwent resection of gluteus maximus sarcoma followed by chemotherapy and radiation therapy, yet still experienced metastasis to the heart. Patient 5 presented with VT, which was a longer-term event. Initially, he was admitted to a local hospital due to syncope and subsequently diagnosed with paroxysmal VT. After this diagnosis, the patient underwent cardiac tumor resection; however, the procedure had to be terminated due to bleeding from tumor vessels and the need for resuscitation due to VT. Despite receiving radiofrequency catheter ablation treatment post-surgery, the patient continued to experience palpitations and intermittent VT. Six months later, recurrent VT necessitated resuscitation once again, and the tumor was found to be slightly enlarged, prompting TARFACT intervention at our center.

All patients presented with prominent symptoms such as palpitation, chest tightness, dyspnea, or syncope. Most patients (60.0%) had NYHA functional class III or IV dyspnea. Preprocedural imaging, including TTE, CT, and PET/CT, was performed for evaluation of cardiac tumor location and size (Figure 1). The mean length of tumor was 6.7 ± 2.0 cm and the mean width was 5.0 ± 2.1 cm. Cardiac tumors occurred in the left ventricle, interventricular septum, and pericardium. PET/CT 18F-FDG images showed hypermetabolic glucose metabolism in patients 1, 2, and 4, respectively.

**PROCEDURE-RELATED EVENTS.** The median (range) follow-up for all patients was 9 (4-12) months. Factors associated with outcomes, including ablation parameters and clinical events, are summarized in Table 3. None of the patients died in hospital or within 30 days after procedure. Additionally, no patient developed pericardial effusion requiring surgery or pericardiocentesis. The incision size for the TARFACT procedure was <2.0 mm. Mean intraprocedure blood loss was 7.0 ± 2.7 mL, with a mean total postoperative hospital stay of 6 ± 2.0 days.

**TABLE 3** Procedural, In-Hospital Parameters, and Clinical Events

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 | Patient 5 |
|---|---|---|---|---|---|
| Procedural ablation parameters | | | | | |
| Exposure length of RF needle, cm | 2.0 | 2.0 | 3.0 | 2.0 | 2.0 |
| Ablation times, n | 10.0 | 4.0 | 4.0 | 4.0 | 7.0 |
| Total energy, kJ | 334.8 | 167.0 | 324.0 | 473.6 | 131.7 |
| Maximum power, W | 80 | 100.0 | 130.0 | 95.0 | 70.0 |
| Total ablation time, min | 90 | 48.0 | 70.0 | 126.3 | 48.8 |
| Mean power, W | 62.0 | 58.0 | 77.1 | 62.5 | 45.0 |
| Ablation range, cm | | | | | |
| Length | 6.0 | 3.8 | 5.1 | 4.6 | 5.5 |
| Width | 3.5 | 2.3 | 4.6 | 2.3 | 4.2 |
| Clinical events | | | | | |
| In-hospital and 30-d mortality | No | No | No | No | No |
| Pericardial effusion | | | | | |
| Requiring surgery | No | No | No | No | No |
| Requiring pericardiocentesis | No | No | No | No | No |
| Procedure-related stroke | No | No | No | No | No |
| Permanent pacemaker after the procedure | No | No | No | No | No |
| Premature ventricular contraction | No | No | No | Yes | No |
| Accelerated idioventricular rhythm | No | No | Yes | No | No |
| Ventricular tachycardia requiring brief resuscitation | No | No | No | No | Yes |
| Intra-procedure blood loss, mL | 10.0 | 5.0 | 10.0 | 5.0 | 5.0 |
| Hospitalization days, d | 5 | 5 | 4 | 7 | 9 |
| Last follow-up time, mo | 5 | 9 | 12 | 4 | 12 |
| Survival time, mo | 6 | Alive | Alive | 13 | Alive |
| Reason for death | Tumor recurrence, end-stage organic changes | — | — | Multiple organ metastases | |

RF = radiofrequency.

During intraoperative electrocardiogram monitoring, accelerated idioventricular rhythm was observed in patient 3. Furthermore, patient 5 experienced VT necessitating electrical cardioversion.

Histopathology results showed myxoid liposarcoma, myocardial hypertrophy with inflammatory cell infiltration, fibroma, hyaline cell sarcoma of myocardium, and rhabdomyoma. Among the patients treated by TARFACT, 3 survivors underwent the procedure over 2 years ago and were still alive at the last follow-up. Additionally, 2 patients with malignant cardiac tumors survived for 6 months and 13 months after the procedure, respectively.

**CLINICAL AND TUMOR BENEFITS AFTER THE PROCEDURE.** Results over a median follow-up of 9 (range: 4.0-12.0) months are shown in Table 4. At last follow-up, all patients had significant improvement in symptoms, with the NYHA functional class decreasing from 3.0 (1.5) to 2.0 (1.0) ($P = 0.038$). Echocardiography confirmed continued shrinkage of the ablation-induced tumor lesions at the last follow-up (Figures 2F and 3). Notably, a favorable reduction effect on tumor was observed, as both the mean length and width of the tumors decreased from 6.7 ± 2.0 cm to 4.7 ± 1.8 cm ($P = 0.007$) and from 5.0 ± 2.1 cm to 2.5 ± 0.7 cm ($P = 0.041$), respectively. Moreover, there were improvements in the mean peak E-wave on echocardiography, increasing from 64.4 ± 15.7 cm/s to 76.6 ± 18.6 cm/s ($P = 0.008$), and NT-pro BNP levels decreased from a median (IQR) of 115.7 (252.1) pg/mL to 55.0 (121.6) pg/mL ($P = 0.043$).

## DISCUSSION

This preliminary small series study was designed to evaluate the safety and medium-term efficacy of the TARFACT procedure for patients with cardiac tumors who were not candidates for surgical therapy. The results of this study suggest several key findings: 1) the TARFACT procedure may be an effective palliative treatment for cardiac tumors, effectively reducing tumor size and improving clinical symptoms; 2) ventricular arrhythmia and pericardial effusion are potential adverse effects of this procedure, although no patients experienced pericardial tamponade; and 3) transapical biopsy may also be a novel technique for diagnosis of cardiac tumors, enabling the collection of samples from multiple locations.

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**TABLE 4 Clinical Outcomes of TARFACT at Last Follow-Up**

| | Baseline | Last Follow-Up[a] | Difference[b] | *P* Value |
|---|---|---|---|---|
| Clinical results | | | | |
| NYHA functional classification | 3.0 (1.5) | 2.0 [1.0] | 1.6 (0.5) | 0.038 |
| Echocardiographic results | | | | |
| Tumor size | | | | |
| Length, cm | 6.7 ± 2.0 | 4.7 ± 1.8 | 2.0 ± 0.9 | 0.007 |
| Width, cm | 5.0 ± 2.1 | 2.5 ± 0.7 | 2.5 ± 1.9 | 0.041 |
| Septal thickness, mm | 12.8 ± 8.0 | 11.4 ± 5.0 | 1.4 ± 3.3 | 0.40 |
| Left atrial diameter, cm | 35.6 ± 4.8 | 33.8 ± 3.2 | 1.8 ± 4.1 | 0.39 |
| E, cm/s | 64.4 ± 15.7 | 76.6 ± 18.6 | -12.2 ± 5.6 | 0.008 |
| A, cm/s | 61.0 ± 10.8 | 50.8 ± 12.5 | 10.2 ± 17.7 | 0.27 |
| Left ventricular diameter, cm | 47.2 ± 4.0 | 47.8 ± 3.6 | -0.6 ± 2.3 | 0.59 |
| LVEDV, mL | 88.6 ± 19.0 | 99.0 ± 15.2 | -10.4 ± 26.1 | 0.42 |
| LVESV, mL | 38.0 ± 11.1 | 37.6 ± 8.7 | 0.4 ± 6.7 | 0.90 |
| SV, mL | 50.8 ± 9.6 | 61.0 ± 13.1 | -10.2 ± 20.9 | 0.34 |
| LVEF, % | 57.6 ± 4.8 | 61.4 ± 6.8 | -0.04 ± 0.06 | 0.22 |
| ECG, including 24-h Holter results | | | | |
| QRS, ms | 92.0 (18.0) | 95.0 (13.5) | −5.0 (7.4) | 0.30 |
| PR, ms | 158.0 (37.0) | 154.0 (77.5) | 2.0 (15.6) | 1.00 |
| RBBB | 0 (0) | 0 (0) | – | – |
| LBBB | 0 (0) | 0 (0) | – | – |
| Atrioventricular block, | 1 (20) | 1 (20) | – | 1.00 |
| Number of PACs | 1.5 (2.5) | 0.0 (0.75) | 1.3 (1.7) | 0.20 |
| Number of PVCs | 92.0 (779.8) | 10.5 (695.3) | 76.5 (56.6) | 0.068 |
| Number of VTs | 0.0 (6.8) | 0.0 (0.0) | 2.3 (4.5) | 0.32 |
| Biochemistry | | | | |
| NT-ProBNP, pg/mL | 115.7 (252.1) | 55.0 (121.6) | 83.1 (69.0) | 0.043 |
| Trop I, ng/mL | 0.007 (0.018) | 0.004 (0.026) | 0.01 (0.02) | 0.72 |
| CK-MB mass, ng/mL | 0.8 (1.0) | 1.6 (2.6) | −0.8 (0.8) | 0.11 |
| Mb, ng/mL | 20.2 (15.2) | 22.1 (15.9) | −7.3 (7.0) | 0.29 |

Values are median (IQR), mean ± SD, and n (%). [a]Median (range) follow-up of 9.0 (4.0-12.0) months. [b]Differences were calculated as baseline minus last follow-up.

CK-MB = creatine kinase-MB; LBBB = left bundle branch block; LVEDV = left ventricular end diastolic volume; LVEF = left ventricular ejection fraction; LVESV = left ventricular end systolic volume; Mb = myohemoglobin; PAC = premature atrial complex; PVC = premature ventricular complex; RBBB = right bundle branch block; other abbreviations as in Tables 1 and 2.

Tumors within the cardiac cavity can lead to hemodynamic disorders or arrhythmias. Outflow tract obstruction, heart failure, and detachment of tumor cells may lead to systemic embolism, which could cause serious clinical events such as stroke, syncope, and sudden death.[12] In 1954, Crafoord achieved the first successful removal of a cardiac tumor through surgery.[13] With the rapid advancement of cardiac surgery, the approach to cardiac tumor resection has evolved from traditional thoracotomy to right anterolateral small incision, and even full endoscopic robotic surgery.[14] The recurrence rate and overall survival time of cardiac tumors are closely related to the adequacy of surgical resection. Preprocedure neoadjuvant chemotherapy may improve R0 resection rates and improve survival.[15] For patients ineligible for surgical resection and chemotherapy, there is an urgent need for new palliative therapies. Our center has pioneered the use of percutaneous radiofrequency ablation treatment for a giant right ventricular outflow tract cardiac tumor,[9] and this patient remains alive 6 years after the procedure.

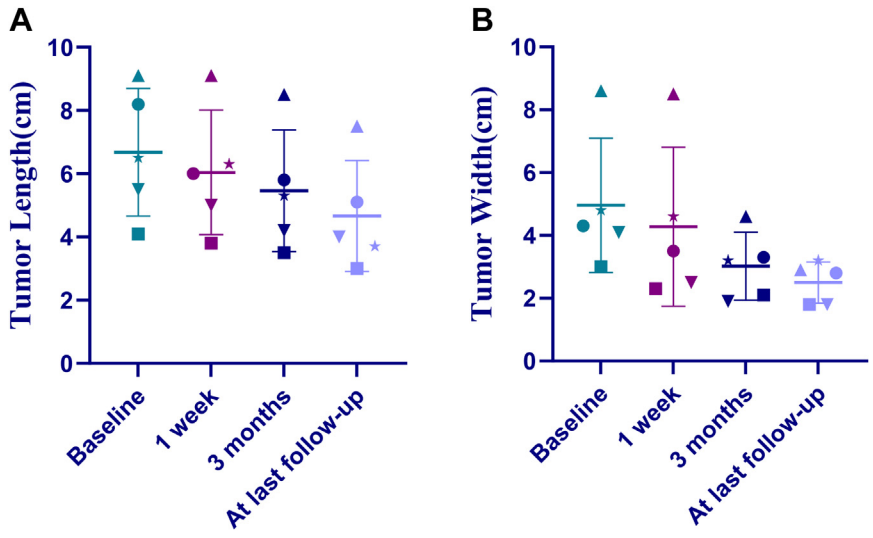
The TARFACT procedure offers several benefits, including the reduction of cardiac tumor size, avoidance of sternotomy, and minimization of injury to the conduction system underneath the endocardium. This procedure induces protein coagulation necrosis of tumor cells through high temperature thermal ablation, effectively blocking the tumor blood supply and depriving tumor cells of nutrient supply. The gradual absorption of necrotic tumor cells leads to a significant reduction in the volume of cardiac tumors. Tumor cells exhibit a higher sensitivity to temperature than normal cells, and their low heat dissipation ability results in rapid necrosis during ablation. The heat deposition effect of arterial blood vessels and blood pool in the cardiac chamber[16] effectively prevents excessive damage to the myocardium caused by the rapid rise in temperature.

Myocardial enzyme tests showed a significant decrease in NT-pro BNP median (IQR) from 115.7 (252.1) pg/mL to 55.0 (121.6) pg/mL ($P = 0.043$) after the procedure. However, the levels of troponin I, myoglobin, and creatine kinase-MB mass showed no significant changes.

Arrhythmias could occur due to compression or stimulation of the sinus node or atrioventricular bundle by cardiac tumors.[17] Before the procedure, the 24-hour Holter monitor revealed atrioventricular block in 1 patient, premature atrial complexes in 3 patients, premature ventricular complexes in 4 patients, and VT in 1 patient. Patient 5, who experienced frequent salvos of VT, received intravenous lidocaine magnesium sulfate and esmolol, but ultimately required electrical cardioversion at 150 W twice to restore sinus rhythm. This event might be attributed to increased electrical excitability of the myocardium by the cardiac tumor or radiofrequency ablation. However, the remaining patients did not develop serious arrhythmias. Notably, potential heat transfer might have occurred from the tumor to myocardial tissue during ablation, particularly in cases of ventricular arrhythmia during ablation (ie, patient 3).

To protect the cardiac conduction system, we chose the percutaneous intra-tumoral route, which helps avoid damaging the subendocardial conduction network. We recommend maintaining a safe distance of at least 3 mm between the boundary of the ablation zone and the endocardium of the left or right ventricle. During the TARFARCT procedure, the needle remained within the tumor, emitting radiating

**FIGURE 3** Changes in Length and Width of Tumor Size in Individual Patients




(A) The tumor length continuously decreased in all patients after the procedure. (B) The tumor width continuously decreased in all patients during follow-up.

heat energy, which appeared hyperechogenic on real-time echocardiography. We maintained a high level of vigilance by continuously monitoring electrocardiogram and echocardiography to minimize conduction system injury. Throughout the procedure, we diligently monitored 12-lead electrocardiograms and promptly paused ablation whenever arrhythmias manifested (such as accelerated idioventricular rhythm). Upon achieving rhythm restoration, we considered either energy reduction or altering the ablation site for continued ablation.

Although tissue biopsy is the gold standard for determining the nature of cardiac tumors, it is difficult to sample myocardial tissue. Percutaneous cardiac tumor biopsy offers advantages such as short path, sufficient sampling volume, and accurate sampling.[18] When combined with a coaxial biopsy needle, multiple biopsy samples can be obtained (**Central Illustration**).

Two patients diagnosed with myxoid liposarcoma and hyaline cell sarcoma survived 6 months and 13 months, respectively. Patient 1, diagnosed with myxoid liposarcoma, exhibited a “black hole” effect on MCE in the radiofrequency ablation area, indicating a lack of blood flow. Unfortunately, multiple new lesions were found in the pericardium 5 months after the TARFACT procedure, leading to tumor recurrence and end-stage organ failure. Patient 4 succumbed to multiple organ metastases to the lung and bones.

Incomplete ablation of malignant tumors can result from inadequate measurement of the ablation range, influenced by the hyper-echogenicity of heat evaporation microbubbles generated during the procedure[19] and the location of tumors in critical cardiac regions.

The median survival time for untreated patients with primary cardiac sarcoma is four months, whereas patients undergoing surgical resection have a median survival time of seven months, with minimal improvement over the past decade.[20] Multidisciplinary cardio-oncology teams in centers of excellence for sarcoma surgery developed optimal surgical and systemic treatment plans, resulting in longer survival.[21] However, some patients were unable to undergo this treatment due to physical and geographic factors. For these individuals, the TARFACT procedure provides a minimally invasive alternative for tumor reduction, biopsy, and treatment.

Our follow-up showed a significant reduction in cardiac tumor size. In patient 3, right ventricular outflow tract obstruction was significantly improved after the procedure, with the gradient decreasing from 12 mm Hg to 5 mm Hg during the 12-month follow-up. Patient 5 presented with a tumor at the left ventricular apex accompanied by pre-excitation syndrome. Despite surgical resection, his tumor recurred 28 months later, necessitating the TARFACT procedure. A comparison of the 24-hour Holter

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monitor readings before and 1 year after the procedure showed a decrease in PVCs, from 1,476 beats to 12 beats, and the absence of nonsustained VT occurrences, from 9 to 0 occurrences. Left ventricular systolic function was not impaired by the TARFACT procedure, with a mean LVEF increasing from 57.6% ± 4.8% to 61.4% ± 6.8%. No instances of severe bleeding or pericardial effusion requiring drainage occurred during the procedure. However, to ensure the safety of debulking cardiac tumors via radiofrequency ablation, we suggest that a heart team with experience in pericardial drainage and/or mini-incision myocardial repair be on standby in the operating room.

TARFACT is a novel treatment option for patients for whom surgical resection or chemotherapy is either unsuitable or intolerable. Our preliminary study has shown that this procedure effectively reduces the volume of cardiac tumors, improves hemodynamics, and alleviates clinical symptoms. TARFACT holds promise as a potential palliative option for cancer and/or cardiac treatment. In 1 of our patients, after tumor debulking ablation and cessation of VT, surgical resection was performed 30 months after TARFACT. Some investigators have suggested the possibility of a systemic antitumor immune response induced by focal radiofrequency thermal ablation.[8] Adjuvant radiotherapy has been shown to significantly improve the survival of patients undergoing tumor reduction surgery. However, for patients who are not suitable for adjuvant radiotherapy, radiofrequency ablation is a potential palliative option. Given the unique advantages of TARFACT, further investigation into its safety and efficacy in combination with radiotherapy and/or systemic therapy in the neoadjuvant setting is warranted in future studies.

**STUDY LIMITATIONS.** The aim of this study was to introduce a new palliative therapy for cardiac tumors. However, due to the rarity of cardiac tumors, our study population was small and not suitable for performing power analysis. Consequently, our study was likely underpowered to demonstrate a statistically significant benefit. Furthermore, despite the promising efficacy of this procedure, our study is based on findings from a single center, and the applicability of transapical radiofrequency ablation for cardiac tumors (TARFACT procedure) may not extend to most patients at this time.

## CONCLUSIONS

The TARFACT procedure offers a potential palliative option for minimally invasive therapy in patients with cardiac tumors who are ineligible for surgical resection or chemotherapy. As a palliative intervention, TARFACT effectively reduces tumor size, restores impaired hemodynamics in carefully selected patients, and alleviates clinical symptoms. Future studies will include exploration of the TARFACT procedure combined with neoadjuvant chemotherapy in the treatment of inoperable malignant cardiac tumors.

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## PERSPECTIVES

**COMPETENCY IN MEDICAL KNOWLEDGE:** Surgical resection combined with chemotherapy and/or radiation therapy represent the standard and most effective treatment for cardiac malignant tumors. However, patients who are not suitable candidates for surgery or who have poor clinical conditions may benefit from alternative complementary treatment. We have developed a novel, minimally invasive transapical radiofrequency ablation technique aimed at reducing tumor size and improving cardiac hemodynamics. In this small case series of 5 patients with symptomatic cardiac tumors, the TARFACT procedure resulted in a reduction in cardiac tumor size and improvement in symptoms.

**TRANSLATIONAL OUTLOOK:** Continued enrollment and follow-up of appropriately selected patients with cardiac tumors are ongoing. We aim to compare the effectiveness and safety of tumor reduction using TARFACT in nonsurgical candidates with those undergoing chemotherapy and/or radiation therapy.

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**KEY WORDS** cardiac tumors, transapical radiofrequency ablation for cardiac tumors TARFACT, tumor debulking ablation