# Stereotactic ablative radiotherapy in ventricular fibrillation with left ventricular thrombus

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## Introduction

There is a lack of robust clinical evidence for management of refractory ventricular tachycardia (VT) storm in patients who have failed or are not amenable to catheter ablation. We present here a case of postinfarct premature ventricular contraction (PVC)-triggered polymorphic VT complicated by left ventricular (LV) thrombus, treated with stereotactic ablative radiotherapy (STAR).

## Case report

A 48-year-old man with morbid obesity, paroxysmal atrial fibrillation treated with amiodarone, and ischemic cardiomyopathy with prior infarct in the territory of the left anterior descending artery presented to an outside hospital with chest pain. He was admitted with late presentation of anterolateral ST-elevation myocardial infarction complicated by cardiogenic shock, treated with Impella CP mechanical circulatory support, and transferred to our quaternary care hospital. Initial transthoracic echocardiogram revealed severely reduced LV ejection fraction (10%–14%) with akinesis of the basal inferior, basal lateral, apical inferior, and apical lateral segment with apical thinning. Additionally, a 3 × 2.7 cm thrombus was noted, in the LV anteroseptum. The Impella CP was immediately exchanged for a TandemHeart ventricular assist device percutaneously. Coronary angiography showed significant obstructive disease in all 3 vessels and multiple high-risk percutaneous interventions were performed, resulting in revascularization of all territories.

His hospital course was complicated by PVC-triggered polymorphic ventricular tachycardia (VT), as shown in Figure 1. As shown in Figure 1A, these PVCs have an atypical right bundle branch block morphology, a right superior axis, and predominantly negative complexes in $V_3$–$V_6$, consistent with apical LV exit. Interrogation of the implantable cardioverter-defibrillator (ICD) implanted during this hospitalization confirmed VT triggered by a monomorphic PVC with the same coupling interval (Figure 1B).

He was initially managed with intravenous antiarrhythmic medications including amiodarone, lidocaine, and magnesium but continued to have PVC-triggered polymorphic VT, requiring multiple external defibrillations. He was intubated and heavily sedated with intravenous propofol and fentanyl infusion. Overdrive pacing was performed in an attempt to suppress the PVC-induced VT, without success. Despite these treatments, PVC-induced VT frequently recurred and worsened his cardiogenic shock.

The LV thrombus made the patient an unsuitable candidate for intracardiac catheter ablation. Clinical decision making was further complicated by presence of comorbidities (active tobacco use, morbid obesity, and concern for peripheral vascular disease) that excluded his candidacy for advanced heart failure therapies. After a multidisciplinary discussion and owing to limited additional available therapies for management of recurrent PVC-induced VT, the decision was made to attempt STAR. We discussed extensively the downside of existing lack of understanding of long-term effect of radiation therapy in a young patient. However, given the scarcity of options and the critical condition of our patient, we decided to pursue STAR on compassionate grounds.

### KEY TEACHING POINTS

- Stereotactic ablative radiotherapy (STAR) was a treatment option in an otherwise refractory case of life-threatening ventricular tachycardia.
- This case highlights a unique utilization of STAR in the novel setting of left ventricular thrombus in a patient not a candidate for catheter ablation.
- The long-term safety and efficacy of STAR is still under evaluation in prospective trials.

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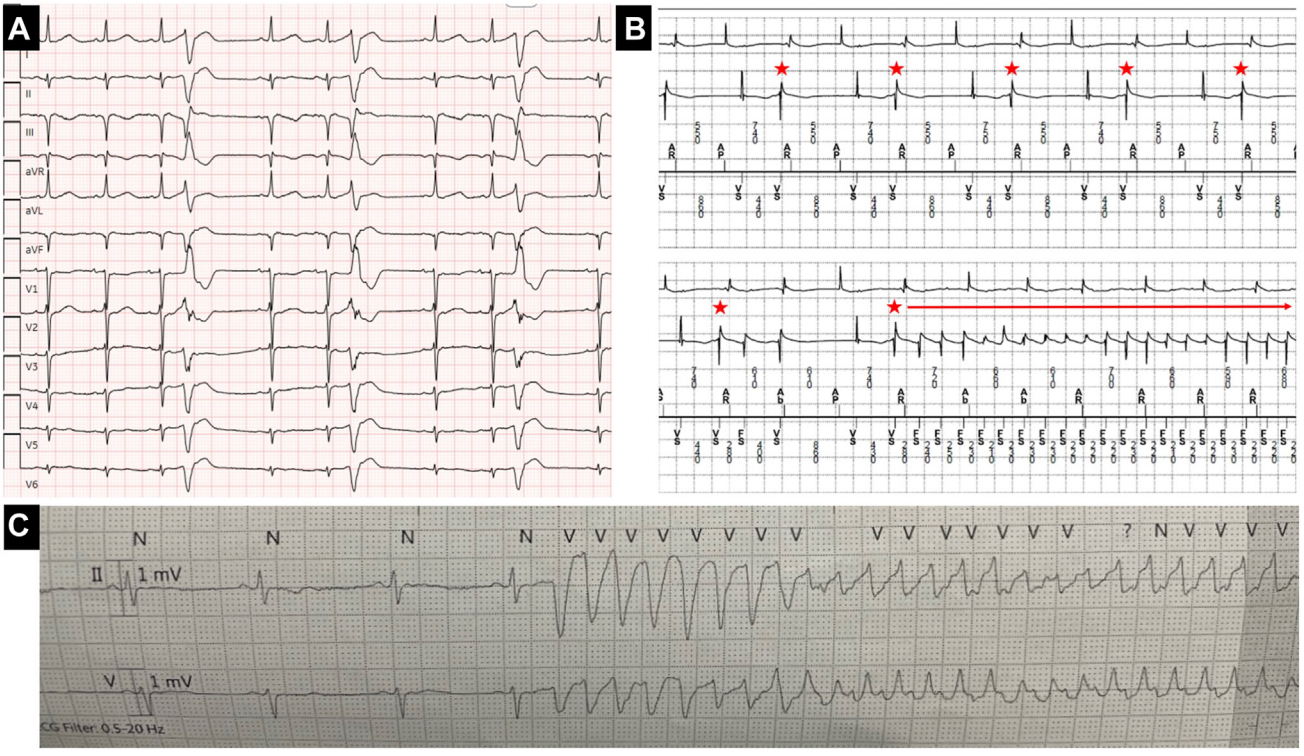


**Figure 1** Twelve-lead electrocardiogram (**A**) of premature ventricular contraction (PVC)-triggering polymorphic ventricular tachycardia shown in the rhythm strip (**B**). The PVC has a right bundle morphology, a right superior axis with predominantly negative complexes in $V_3$–$V_6$, consistent with left ventricular apical exit; it localizes to the area adjacent to the thrombus. **C:** Device interrogation marked with red stars shows the same PVCs triggering the sustained polymorphic ventricular tachycardia marked with the red line.

For planning of STAR, institutional protocol used for previous cases had to be modified for this case. Image acquisition was performed by obtaining a coronary computed tomography (CT) angiogram using a dual-source multidetector CT device during inspiratory breath-holding (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany) with prospective high-pitch gating at end-diastole. None of the current treatment delivery systems can gate with such short bursts of X-rays to coincide with diastole and it is impractical and dangerous to slow the cardiac cycle to a level where gating is able to be used. Therefore, the images obtained from electrocardiogram-gated breath hold CT were then translated, by fusion, onto a nongated radiation treatment planning CT. To further compensate for this issue, we used a standard radiotherapy practice internal target volume, which is constructed using a 4-dimensional free breathing scan and accounts for the cardiac and respiratory motion. The internal target volume was measured as 149.31 cc. A 5 mm margin was added for the planning target volume, which was 193.35 cc. The final target volume and treatment plan (as shown in Figure 2) were agreed upon by a multidisciplinary group of electrophysiologists, radiation oncologists, and medical physicists. The selection of arcs was based upon minimizing dose to organs at risk, including the skin, esophagus, lungs, and spinal cord. The small bowel and stomach were included for ablative targets located near the apex of the heart. Beams were arranged using a volumetric modulated arc radiotherapy technique. A flattening-free filter was also used to reduce treatment time. At the time of treatment, patients were placed in their custom immobilization device, aligned using the kilovoltage cone beam CT with additional verification of this alignment using kV orthogonal images, and treated without use of any additional imaging during the treatment delivery.

Following review and approval, all plans were subjected to standard internal quality assurance prior to treatment delivery to ensure accurate delivery of the dose to the patient. Treatment was delivered on an Elekta Versa-HD® (Elekta, Stockholm, Sweden) linear accelerator with an approximate beam/treatment time of 10 minutes. The patient was treated with a single dose of 25 gray of radiation therapy delivered to the target, without any untoward event.

The PVC frequency reduced substantially in the acute period post STAR. No further episodes of PVC-induced VT occurred. Post STAR, the patient was weaned off intravenous lidocaine and switched to previous dose of amiodarone 200 mg daily. His device was programmed for a zone for detection $\geq$20 ms slower than the slowest clinical VT. He was discharged 7 days after the procedure. The ICD was remotely monitored as part of routine clinical care, on a regular basis (every 2 months). The patient was arrhythmia free for 18 months. His LV ejection fraction improved to 35%–39% on his most recent echocardiogram. He did not have any further hospitalizations. Follow-up chest imaging after STAR showed no evidence of pneumonitis. A small pericardial effusion visualized along the posterolateral base was

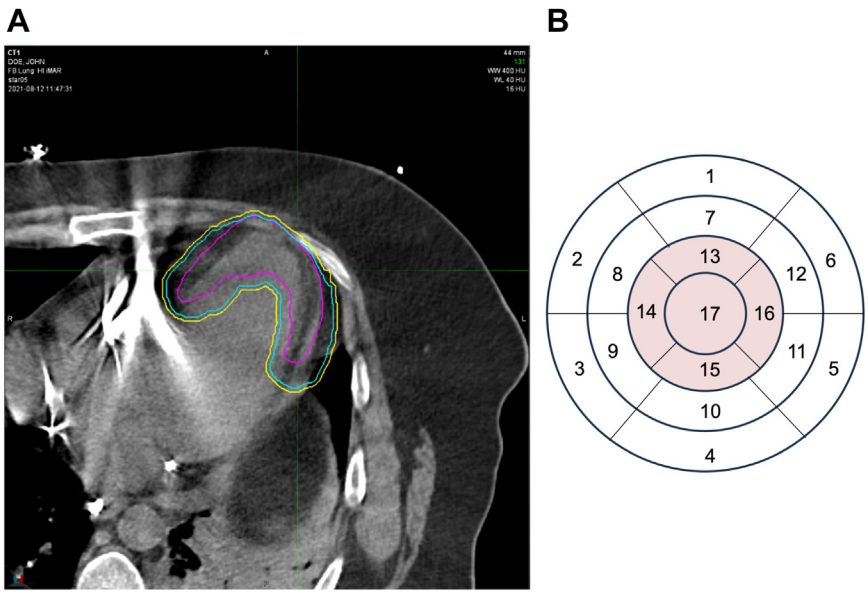


**Figure 2** **A:** Stereotactic ablative radiotherapy planning. The internal target volume, marked by the blue line, was constructed using a 4-dimensional free breathing scan, measured as 149.31 cc. A 5 mm margin was added for the planning target volume, marked by the yellow line, measured at 193.35 cc. **B:** A 17-segment left ventricular segmentation model depicting localization of ventricular tachycardia. The region of interest is shaded pink in the model, as also demarcated on the left in the computed tomography scan.

confirmed to be of trace quantity on echocardiogram (Figure 3).

## Discussion

STAR technique was first published in the *New England Journal of Medicine* in 2015 in a case series of 5 cases of treatment-refractory ventricular tachycardia.[1] The clinical evidence on efficacy and safety of STAR has since been reported in small case series from select centers globally. Robinson and colleagues[2] enrolled 19 patients in their study, including 3 patients who did not undergo catheter ablation prior to STAR (1 of which had an LV thrombus), who were treated with STAR and followed for 12 months. Efficacy and safety outcome analysis indicated a significant reduction in VT burden with minimal adverse effects.[2] Subsequently, a French retrospective study[3] of 17 patients in electrical storm (10 of 17 had ischemic cardiomyopathy) treated with STAR corroborated the results from the previous studies. Fourteen of 17 patients had failed catheter ablation and antiarrhythmic drugs, and 3 were not candidates for catheter ablation (2 of 3 patients had LV thrombus). The authors report an efficacy of 91% in reduction of VT burden during a 6-month follow-up period. In those with initial presentation of incessant VT, response was seen within 1–7 weeks. Moreover, the mean cycle length in those with recurrent VT was longer. A total of 36% required antitachycardia pacing and ICD shocks for recurrent VT and 1 patient required catheter ablation 18 months after the STAR procedure, with pace maps indicating a different exit site than the one from the time of STAR. In terms of safety data, mortality at 6 months was reported in 4 patients (3 of whom died of refractory cardiogenic shock, 1 of whom had hemodynamically unstable VT), pericardial effusion in 1 patient, and radiation pneumonitis in 1 patient at 6 months. No coronary stenosis or ICD-related issues were reported by the authors.[3]

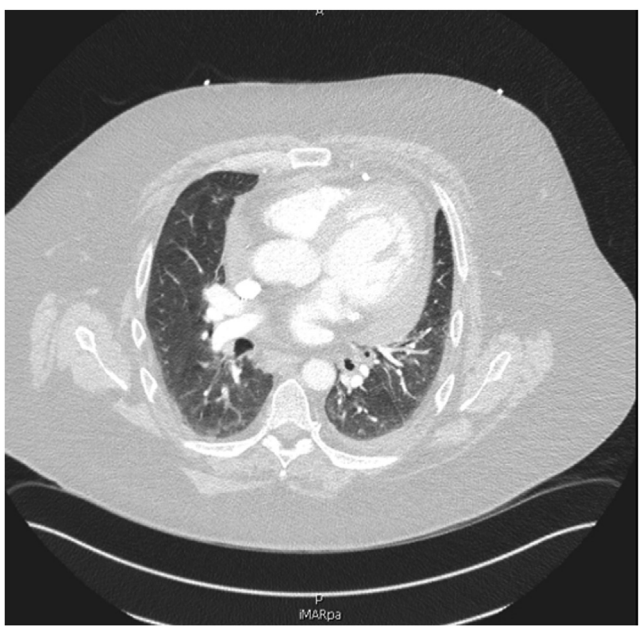


**Figure 3** Computed tomography of chest 1 year after stereotactic ablative radiotherapy showed no evidence of pneumonitis. A small pericardial effusion visualized along the posterolateral base was confirmed to be of trace quantity on echocardiogram.

STAR is based on the technique of stereotactic body radiotherapy, which allows for precise delivery of high-dose ionizing radiation therapy to a target tissue, while minimizing exposure to surrounding tissue.[4] The mechanism of STAR differs from catheter ablation at a physiological level. Evidence

from preclinical studies on animal and human hearts suggests a different mechanism by which radiation therapy modifies the target substrate. Radiation is thought to induce apoptosis and programmed cell death over time, unlike cell death in the short-term period induced by catheter ablation. The immediate effect of radiation on this patient is compelling evidence that radiobiology is more than just cell destruction. Zhang and colleagues[5] demonstrated that radiotherapy delivered in ablative doses resulted in upregulation of NaV1.5 channels, thereby increasing ventricular conduction. They further hypothesized that local increases in cardiac conduction could functionally rescue regions of conduction delay imperative for sustained reentrant tachyarrhythmia.[5] This has been further confirmed on histopathologic analysis of STAR-treated myocardial substrate. Acute changes such as endothelial swelling, vacuolization, and perivascular edema that are typically seen in radiation injury are not noted on autopsy of patients treated with STAR.[1] Cardiotoxic effects of radiation on long-term follow-up (>12 months), including valvulopathies, coronary artery disease, cardiomyopathy, and conduction disease, is still unknown.

There are a number of ongoing prospective trials in the United States and abroad currently enrolling with the primary aim to evaluate safety and efficacy of STAR. In challenging cases such as ours, STAR may be an option for treatment of VT. Further studies are warranted.

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## References

1. Cuculich PS, Schill MR, Kashani R, et al. Noninvasive cardiac radiation for ablation of ventricular tachycardia. N Engl J Med 2017;377:2325–2336.
2. Robinson CG, Samson PP, Moore KMS, et al. Phase I/II trial of electrophysiology-guided noninvasive cardiac radioablation for ventricular tachycardia. Circulation 2019;139:313–321.
3. Ninni S, Gallot-Lavallée T, Klein C, et al. Stereotactic radioablation for ventricular tachycardia in the setting of electrical storm. Circ Arrhythm Electrophysiol 2022;15:e010955.
4. Benedict SH, Yenice KM, Followill D, et al. Stereotactic body radiation therapy: the report of AAPM Task Group 101. Med Phys 2010;37:4078–4101.
5. Zhang DM, Navara R, Yin T, et al. Cardiac radiotherapy induces electrical conduction reprogramming in the absence of transmural fibrosis. Nat Commun 2021;12:5558.