SBRT for Cardiac Ablation in Patients With Refractory Ventricular Tachycardia

Morgan Vozzolo, R.T.(T)
Kylie Giller, R.T.(T)

Background This case details a 44-year-old man with end-stage ischemic cardiomyopathy with refractory ventricular tachycardia (VT). The patient has a single-chamber implantable cardioverter-defibrillator, has had 2 VT ablations, and uses medication to manage his VT. Despite these interventions, he continued to have episodes of VT. The patient underwent stereotactic body radiation therapy (SBRT) to help reduce the burden of his VT. The patient received a dose of 25 Gy to his right inferior lateral region of the heart and a dose of 15 Gy to the inferior portion of the heart closer to the stomach. The patient followed up 1 month later and reported that his energy levels improved and that no arrhythmias had occurred since his SBRT treatment.

Discussion The options for treating end-stage VT are limited. However, a treatment option using SBRT has been introduced to reduce the VT burden in patients. Cardiac SBRT is a noninvasive outpatient procedure that, while still awaiting U.S. Food and Drug Administration approval, reduces arrhythmia episodes and offers favorable short-term benefits for patients who have not responded to traditional treatment modalities.

Conclusion Cardiac SBRT is a novel treatment for VT in patients where standard treatments have failed. This case study demonstrates that SBRT effectively reduced arrhythmias in a patient with VT. The long-term clinical outcomes are not known, but the opportunity SBRT offers for treatment-refractory patients is favorable and should be considered.

Keywords | ventricular tachycardia, stereotactic body radiation therapy, cardiac ablation, refractory treatment

Ventricular tachycardia (VT) is an abnormal heart rhythm, or arrhythmia, which occurs when the heart rate exceeds 100 beats per minute in addition to having 3 abnormal rapid heartbeats continuously (see **Figure 1**).[1] The current treatment for VT is catheter ablation, which is not considered curative and has a high rate of recurrence. Stereotactic body radiation therapy (SBRT) is a type of radiation therapy used to treat small tumors with high precision that has recently been explored as a treatment for VT. Cardiac SBRT is a promising treatment for patients with VT where standard treatments are ineffective.

Figure 1. *Electrocardiogram of ventricular tachycardia. Reprinted under the Creative Commons Attribution-ShareAlike 3.0 Unported license. creativecommons.org/licenses/by-sa/3.0/deed.en*

Literature Review

Cardiac SBRT is a relatively new and underused treatment, so the literature available is limited. The original research for cardiac SBRT was conducted in 2015 and involved 5 patients.[2] All 5 patients were high risk and in critical condition. In the 3 months before their radiation treatments, the 5 candidates had a combined total of 6577 instances of VT.[2] Six weeks after radiation ablation, the 5 candidates had a combined total of 4 instances of VT.[2] The patients followed up with their electrophysiologists at 1 month, 6 months, and 12 months after radiation.[2] There was no effect on the functioning of the implantable cardioverter-defibrillator (ICD) for any of the patients.[2]

An additional phase I and phase II study was performed with 19 patients that also showed promising outcomes. Physicians at Washington University School of Medicine in St Louis concluded that after 2 years of radiation ablation, 80% of patients continued to see a decrease in VT episodes. They also determined that the overall 1-year survival rate in patients who received cardiac SBRT was significantly higher compared with those who did not.[3] Patients who received cardiac SBRT had a 1-year survival rate of 72% compared with 20% for patients who did not receive the treatment.[3]

Case Description

The case study presents a patient with VT who had exhausted all other treatment options. He was chosen to receive cardiac SBRT, a novel treatment for VT. This case study was exempt from institutional review board approval.

A 44-year-old man with a history of smoking and heavy drug use received a diagnosis of VT in 2016. The patient had an extensive cardiac medical history. He suffered a myocardial infarction when he was aged 32 years and was diagnosed with hypertension, atrial fibrillation, hyperlipidemia, and coronary artery disease. In December 2018, he suffered cardiac arrest resulting in the placement of an ICD. The patient was found to have atrial scarring and underwent an ablation in October 2022. The patient continued to report syncopal episodes; during 1 episode, he lost consciousness. The patient has undergone numerous stress tests, echocardiograms, and ICD shocks, and takes several medications. He was enrolled in a VT study because he had numerous ICD shocks, symptoms, and failed treatments with ablations and medications.

In July 2022, the patient met with an electrophysiologist to review cardiac SBRT as a treatment option. Together, they agreed to send his records to Washington University in St Louis to be reviewed. The patient was instructed to have a noninvasive electrical program simulation to stimulate VT via ICD and to get an electrocardiogram to map the VT.

In October 2022, the patient met with a radiation oncologist to discuss the option of cardiac SBRT in more detail. Short- and long-term adverse effects, risks, and the treatment planning and process were reviewed.

Radiation Simulation

In October 2022, the radiation simulation was performed. The staff present at the simulation included 2 radiation therapists, a radiation physicist, and the radiation oncologist. The equipment used for immobilization included:

- compression belt
- index bars
- knee sponge
- SBRT board
- SBRT Vac-Lok bag (CQ Medical)
- wing board

The SBRT board was indexed to the computed tomography (CT) table, and subsequently the wing board, knee sponge, and Vac-Lok bag were indexed to the SBRT board. A respiratory gating camera was attached to the foot of the table to track respiratory motion. The intravenous contrast injector was set up, and the appropriate protocol was set.

The patient verified he had not ingested anything by mouth for 3 hours before the procedure, which is necessary to ensure the stomach is avoided for treatment. He was assisted onto the table, straightened, and positioned in the Vac-Lok bag with his arms over his head and head in a neutral position. Leveling marks were placed on the Vac-Lok bag and patient to ensure reproducibility for treatment. The SBRT compression belt was placed snugly over the patient's abdomen and inflated to minimize chest movement.

A free breathing SBRT scan was conducted using the appropriate scanning protocol with a 2 mm slice thickness. Next, a 4-D scan was performed in which the radiation oncologist set a target scan range with a 20 cm margin. The last scan was the 4-D scan with intravenous contrast that repeated the target scan range set by the radiation oncologist. Set-up photos were acquired, and the patient received 3 permanent tattoos.

After the scans, a team of staff physicians and physicists worked with Washington University in St Louis to create the treatment plan using data from previous imaging studies to create the target. After the patient's treatment target was identified from the electrophysiology mapping, the physicists, alongside the radiation oncologist, created a plan to deliver 25 Gy to the right inferior lateral region of the heart. A separate volume in the inferior portion of the heart, closer to the stomach, received 15 Gy (see **Figure 2**).

Radiation Treatment

In December 2022, the patient underwent radiation treatment. Nurses from the cardiac floor and the electrophysiologist were present for treatment. Before treatment the patient had his ICD interrogated and vital signs measured. After being cleared, the patient was shown into the treatment room where the procedure was explained again by the radiation oncologist and radiation therapists. The patient was set up according to simulation documentation and aligned using his tattoos (see **Figure 3**).

A cone-beam CT (CBCT) with respiratory gating was performed with the TrueBeam radiotherapy system (Varian Medical Systems, Inc). The therapists aligned the CBCT while the radiation physicist and radiation oncologist were present. Cardiac and respiratory motion were reviewed to ensure the target area was not moving out of the planning target volume. The patient was treated with a 3-arc plan using a 6-MV flattening filter-free beam. The patient tolerated the treatment with ease and experienced no issues immediately after treatment. After treatment, the patient's ICD was interrogated, and vital signs were measured. The patient was instructed to follow up in 1 month with the radiation oncologist.

Follow-Up

The patient had his follow-up examination in February 2023 with the radiation oncologist. He reported experiencing fatigue for 1 week after treatment and an isolated case of double vision that lasted 20 minutes. His energy level greatly improved, and he was able to exercise without difficulty. The patient has had no reported arrythmias since treatment. The patient and his team are hopeful that he will be able to stop taking 1 to 2 of his antiarrhythmic medications. He was scheduled for a follow-up in 3 months.

Figure 2. *Axial computed tomography image showing isodose distribution of planning target volume. Image courtesy of Hartford Hospital.*

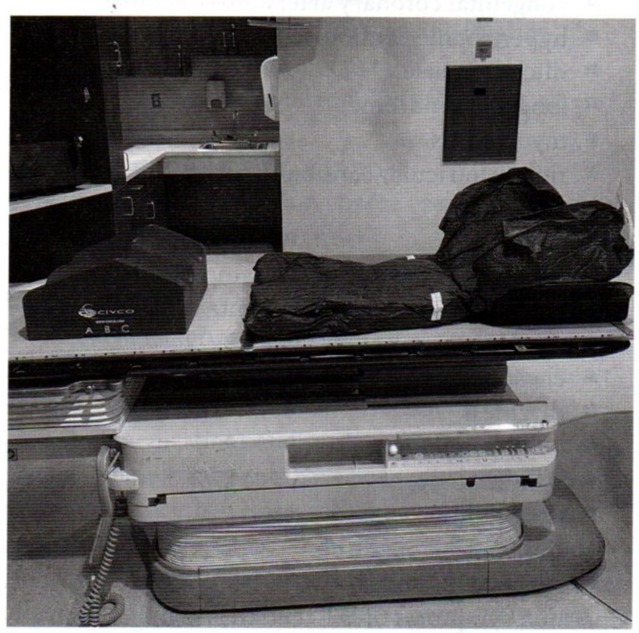

Figure 3. *Table setup for cardiac stereotactic body radiation therapy. Photograph courtesy of Hartford Hospital.*

Discussion

In the United States, approximately half of cardiac deaths and most sudden cardiac deaths occur due to VT.[1] An estimated 300 000 people in the United States die each year due to VT.[1] Men are at a higher risk of developing VT than are women, and the condition is predominately seen in adults.[1]

VT is categorized into 2 subtypes, nonsustained and sustained, which differ in the duration of the abnormal heart rhythm.[1] VT is considered nonsustained if the abnormal rhythm last less than 30 seconds and has a tachyarrhythmia with more than 3 beats of ventricular origin. It is considered sustained if the abnormal rhythm lasts longer than 30 seconds or if hemodynamic instability occurs in 30 seconds or less.[1] After a patient is given a VT diagnosis, there are further levels of classifications based on clinical findings and causation.

Etiology

Although there are many possible causes of VT, the most common cause is underlying ischemic heart disease.[1] Ischemic heart disease is caused by the hardening of arteries due to plaque buildup, which prevents the heart from receiving enough oxygen and blood flow. Other causes of VT are[1]:

- congenital coronary artery abnormalities
- hypertrophic cardiomyopathy
- illicit drug use
- long QT syndrome
- myocarditis
- right ventricular cardiomyopathy

Symptoms

Patients experience different symptoms based on how their VT is categorized. Patients with VT might experience[4]:

- chest pain or discomfort
- dizziness
- heart palpitations
- lightheadedness
- neck tightness
- shortness of breath
- syncopal episodes

Common symptoms of VT tend to last longer than a few seconds and can last up to 30 seconds.[4] Patients might experience 1 symptom, a combination of symptoms, or no symptoms.

Traditional Treatment

In addition to management medications, which often have intense adverse effects, the current treatment for refractory VT is catheter ablation. For most patients, catheter ablation is not considered curative and has a high rate of recurrence.[3] Catheter ablation is a procedure in which a thin tube is threaded into the patient's heart, and radiofrequency energy is used to destroy the area causing abnormal electrical signals. The procedure for catheter ablation has a high risk of complications, including death, and for many reasons can be unsuccessful.[3]

SBRT for Cardiac Ablation

Traditionally, radiation is used to target cancer cells, disrupt their cell cycle, and cause enough damage to prevent the cancer cells from being repaired while allowing the healthy cells to enter cellular repair. In radiation oncology, the heart typically is avoided because of radiation's adverse effects on cardiac tissue.

SBRT is a type of radiation treatment that delivers a higher dose of radiation and precisely targets a smaller tumor volume with tighter than typical treatment tolerances. This treatment has allowed for the development of noninvasive cardiac ablation using SBRT as a new treatment approach for VT. The intention of offering this as an available treatment is to minimize the complications and risks associated with the invasiveness of catheter ablations. SBRT can also target areas that might be inaccessible or too extensive for catheter ablation.[1] Currently, cardiac SBRT treatments are trialed on patients who are older, have undergone multiple failed ablations, are not surgical candidates, or are out of treatment options.[4] For example, in this case study, the patient has a single-chamber ICD, has undergone 2 VT ablations, and uses medications to manage VT but continues to have episodes; therefore, SBRT was reviewed and recommended as a treatment.

After traditional cardiac ablation treatment, scar tissue forms over the area of tachycardia.[4] When using cardiac ablation SBRT, radiation eliminates the formation of scar tissue.[5] When the radiation interacts with the cardiac cells, it reverts the cells to a younger state where they begin to express different genes that increase cellular activity, including a signaling pathway called *Notch*.[5] The Notch signaling pathway is responsible for early cardiac development and the cardiac electrical system.[5] In adults, Notch signaling is no longer functioning. When radiation triggers the Notch signaling pathway again, sodium ion channels are increased, and the electrical signals that cause arrhythmias are shut off, resulting in a reduction in arrhythmias.[5]

Presimulation Imaging

Patients considering cardiac SBRT must complete electrocardiographic imaging to determine the area of VT. For the examination, the patient wears a vest covered in 256 electrodes and lays on the CT table while VT is induced.[2] The patient is then scanned, and a map is created to identify the circuit site.[5] The patient might have additional presimulation imaging, such as a single-photon emission CT or traditional magnetic resonance imaging, depending on what is clinically necessary.[6]

Radiation Therapy

The patient, their established cardiology team, and a team from radiation oncology work collaboratively to begin the next steps toward treatment. The first step for the patient is to have a consultation with their radiation oncologist in which the oncologist explains the risks and benefits of treatment to the patient. After the consultation, the patient returns to the department for a planning session and CT scan. During the planning session, the radiation therapists construct a full-body immobilization device that will ensure stability and reproducibility of the patient for their treatment. After the device is constructed, the radiation therapists perform a 4-D scan of the patient using intravenous contrast. This planning CT scan will aid in visualizing the target area to create an even dose distribution. In addition to this CT scan, previous imaging studies will be used in determining the planning target volume. The process of combining these different imaging studies is challenging because of uncertainties in translations in axial slices.

The standard recommended dose for cardiac SBRT to be delivered is 25 Gy in a single fraction. When planning a treatment with a high dose, careful consideration should be taken when it comes to surrounding organs at risk, including the esophagus, lung, bowel, stomach, and spinal cord. In this case study, the radiation oncologist and physicists created a plan to deliver 25 Gy to the patient's right inferior lateral region of the heart and 15 Gy to the inferior portion of the heart, closer to the stomach.

Adverse Effects

The long-term adverse effects from radiation therapy for treatment of VT are still being studied. According to Washington University in St Louis, the short-term adverse effects include:

- chest hair loss
- erythema
- fatigue
- heart burn
- nausea

More severe adverse effects can include:

- damage to the lung from radiation that results in a partial collapse of the lung
- pericarditis
- pericardial effusion

Severe and rare adverse effects include:

- damage to the heart muscle
- damage to the spinal cord (causing tingling, numbness, weakness, or paralysis)
- dysphagia from damage to the esophagus or stomach
- premature blocking of arteries
- scarring of healthy lung tissue (causing patient to need supplemental oxygen)

Conclusion

VT is characterized as an abnormal heart rhythm, or arrhythmia, often caused by underlying ischemic heart disease. Currently, the standard treatments for VT consist of medications and cardiac ablation. For many patients, these treatments have been proven ineffective or can fail altogether. Researchers began studying the use of SBRT, which treats tumors with precision and efficacy, as a novel treatment for patients with treatment refractory VT. Radiation typically is not used to treat cardiac disorders because of the potential for damage to cardiac tissues and structures. However, this case study demonstrates that the techniques and procedures behind this innovative, noninvasive treatment can offer benefits for these patients. The patient in this case study reported no arrhythmias and an increase in energy during his 1-month follow-up after cardiac SBRT treatment, and these results are in alignment with previous studies. Cardiac SBRT is a promising treatment modality for patients with VT that have proven refractory to standard treatments.

Morgan Vozzolo, R.T.(T), and Kylie Giller, R.T.(T), work at Hartford Hospital in Hartford, Connecticut.

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