Recurrent ventricular tachycardia originating from the "left ventricular summit" effectively eliminated by stereotactic irradiation – A case report

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Introduction

Cardiac stereotactic body radiation therapy (cSBRT) is an innovative and promising noninvasive treatment option for recurrent, therapy-refractory ventricular tachycardia (VT). Although long-term efficacy and safety is still under evaluation in multicenter studies, it is associated with a significant short-term reduction of VT burden and implantable cardioverter-defibrillator (ICD) shocks.[1–3] To date cSBRT is not a first-line treatment strategy either for VT ablation or for premature ventricular contractions (PVC), but encouraging results have been reported.[1,2,4]

VT from the left ventricular (LV) summit are particularly difficult to ablate owing to an anatomically complex and inaccessible region.[5,6] The LV summit is the highest point of the left ventricle and is determined by the triangular region located between the bifurcation of the left anterior descending artery (LAD) and the left circumflex artery (LCX). Current standard mapping and ablation techniques are not sufficient, with particularly poor results.[5] cSBRT seems to be a safe and highly effective option to eliminate arrhythmogenic substrates from the LV summit.[7]

In this clinical case report we present a patient with PVC and recurrent VT from the inaccessible LV summit

KEY TEACHING POINTS

- Catheter ablation of ventricular tachycardia and premature ventricular contractions originating from the left ventricular summit is particularly challenging owing to myocardial wall thickness, epicardial fat, and proximity of coronary arteries. Cardiac stereotactic body radiation therapy (cSBRT) might provide an effective and safe treatment option in refractory cases.
- Owing to anatomic proximity, special consideration should be given to radiation doses to the coronary arteries, although no dose constraints are currently defined.
- The use of mixed-reality devices like a holographic lens might be very helpful to integrate and visualize different imaging modalities, enabling precise target volume delineation for cSBRT in interdisciplinary teams.

KEYWORDS Cardiac SBRT; Ventricular tachycardia; Left ventricular summit; Electrical storm; Radiation planning
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with failed endocardial and epicardial ablation attempts. Target evaluation and planning for cSBRT was performed by using HoloLens™ (Microsoft Inc, Redmond, WA) technology to improve communication between electrophysiology and radiotherapy and therefore optimize target definition.

Case report

A 74-year-old male patient with dilated cardiomyopathy and electrical storm owing to recurrent monomorphic VT from the LV summit was referred to our hospital for cSBRT with therapy refractory after failed endocardial and epicardial ablation attempts in another electrophysiology center (Figure 1A and 1B). In addition, the patient had developed a retrosternal hematoma from anterior epicardial access during the second procedure, requiring surgical decompression. The patient had experienced multiple therapies of his ICD and transient VT suppression was only achieved with a combination of amiodarone (oral dose 200 mg twice a day), propranolol (120 mg per day), and continuous intravenous ajmaline (15 mg/h) (Figure 2A and 2B). On admission the patient presented in stable New York Heart Association class II heart failure with reduced LV ejection fraction of 35%. Neither heart transplantation nor implantation of an LV assist device were considered because of the patient's age and the lack of severe heart failure. The 12-lead electrocardiogram on admission revealed monomorphic PVC with early precordial QRS transition in V_1, qS pattern in lead I, and an inferior axis matching the clinical VT. Owing to treatment-refractory VT storm, cSBRT was planned as a bail-out strategy after discussion of the case in an interdisciplinary conference and obtaining written informed consent from the patient.

For radiation planning, a native 4D computed tomography (CT) scan was performed. Furthermore, electrocardiogram-triggered multiphase cardiac CT scan (Spectral CT 7500; Philips Healthcare; Andover, MA) with late iodine enhancement sequences and consecutive segmentation (inHEART(Pessac, France) Models Shaper v1.1.1) was performed (Figure 3). The CT segmentation revealed an intramural anterior and septal fibrosis as defined by late iodine enhancement. The endocardial and epicardial 3D maps obtained with high-resolution mapping catheter[8] from the previous procedures during endocardial and epicardial ablation (CARTO™ V7.2; Biosense Webster Inc, Irvine, CA) were analyzed to predefine the target volume.

Target volume delineation was done together by experienced electrophysiologists and radiation oncologists (Raystation 11B; RaySearch Laboratories, Stockholm, Sweden). As no native cardiac scar could be identified, the major challenge was transferring the information of the electrophysiologic examinations to the transversal slices of the native planning CT scan. For visualization of the defined target the left main coronary artery, LAD, and LCX, as well as both atria, septum, ventricles, and valves, were segmented and exported. For discussion and visualization of the first target definition datasets (CT segmentation, CARTO and the structure set derived from the treatment planning software) were imported into a HoloLens 2 (Microsoft Inc) and used for interdisciplinary target refinement (Figure 3). Therefore, a specified software system was developed by InspirationLabs GmbH (Heidelberg, Germany) for data transformation from the various clinical systems, import, display, and handling of the 3D objects in augmented reality. The various data sets could be analyzed and processed simultaneously in 3D by several physicians.

The internal target volume was derived from the 4D CT to compensate for internal physiologic movement of the target. Owing to his limited general condition and psychologic distress and anxiety following the ICD shocks, the patient was not suitable for longer-lasting techniques like deep inspiration breath hold or target-tracking. The final planning target volume (PTV) amounted to 49 cm^3. Treatment was performed with 24 Gy prescribed to the 80% isodose encompassing the PTV at the linear accelerator (volumetric arc therapy, flattening filter free, 6 MeV, 2 arcs, 4D-CBCT image guidance, Elekta Versa, HD), as reported previously.[9]

Post cSBRT the interrogation of the ICD showed a regular ICD function of all components; no other acute side effects could be detected, and pericardial effusion was excluded by echocardiography. In continuous monitoring the PVC burden and number of VT episodes decreased. Four days after the cardiac stereotactic radiation the intravenous ajmaline infusion could be weaned (Figure 2). At discharge the AAD therapy could be de-escalated to amiodarone, propranolol, and oral prajmaline.

In the outpatient follow-up at 1 and 3 months, ICD interrogation revealed no VT episodes or ICD therapies since the cSBRT. The PVC burden was $<1\%$ at 1 month follow-up and the AAD therapy could be further de-escalated to amiodarone (200 mg twice a day) and propranolol (120 mg per day). No signs of radiation-induced side effects were found; echocardiographic evaluation showed a stable cardiac function. The patient also reported a relevant improvement regarding his quality of life owing to a decreasing concern of recurrence of ICD shocks. In a telemonitoring follow-up at 6 months only 1 VT episode treated with a single antitachycardia pacing was transmitted.

Discussion

cSBRT of the LV summit for recurrent VT

To the best of our knowledge the presented case is the first cSBRT approach of incessant and recurrent monomorphic VT from the LV summit in a patient with dilated cardiomyopathy and reduced LVEF. cSBRT was performed safely and effectively without significant physical and psychological stress for the patient.

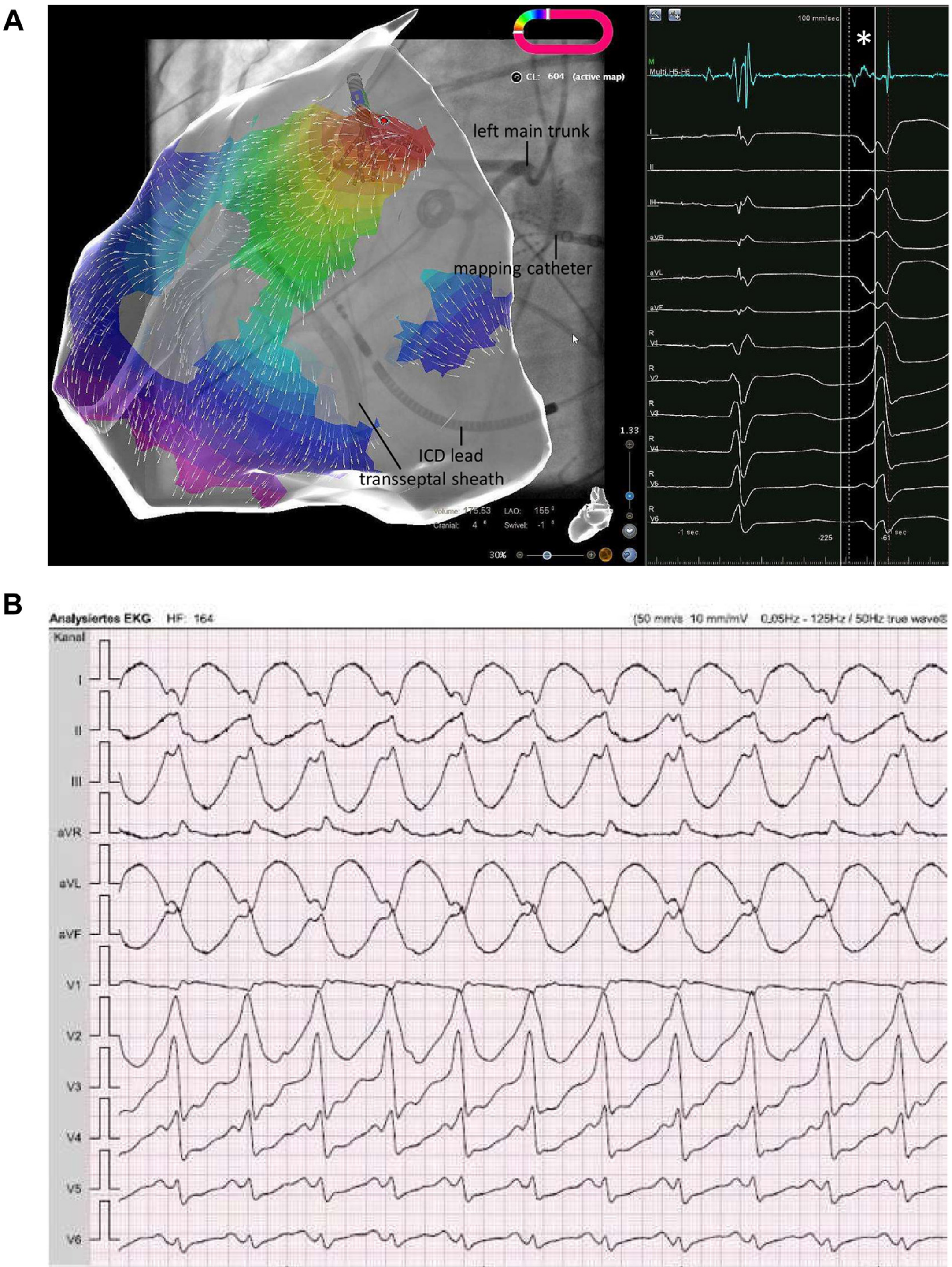

Figure 1 **A:** Epicardial local activation time map of the left ventricular summit premature ventricular contractions (PVC) in a posterior-anterior-like (left anterior oblique 155°) projection with the 8-spline mapping catheter (Octaray, Biosense Webster). The color-coded scale visualizes earlier activated regions (red) in comparison to later activated areas (purple). Overlay with a fluoroscopic image in similar projection: angiography of the left main trunk, transseptal sheath, mapping catheter, and implantable cardioverter=defibrillator lead as marked in the image. On the right side 12-lead electrocardiography (ECG) morphology of a normal beat and PVC (*). **B:** Ventricular tachycardia morphology in 12-lead ECG.

Different ablation strategies for LV summit arrhythmias have been proposed, including intracoronary wire ablation, septal coronary venous ablation, alcohol ablation, intramural needle ablation, coil embolization, bipolar ablation, and surgical cryoablation.[5,10] Percutaneous epicardial approaches are also limited by epicardial fat and proximity to large coronary arteries.[11] The numerous approaches yield a moderate success rate and alternative treatment options are warranted.

The proximity of the LV summit to relevant cardiac structures such as LAD and LCX should be taken into

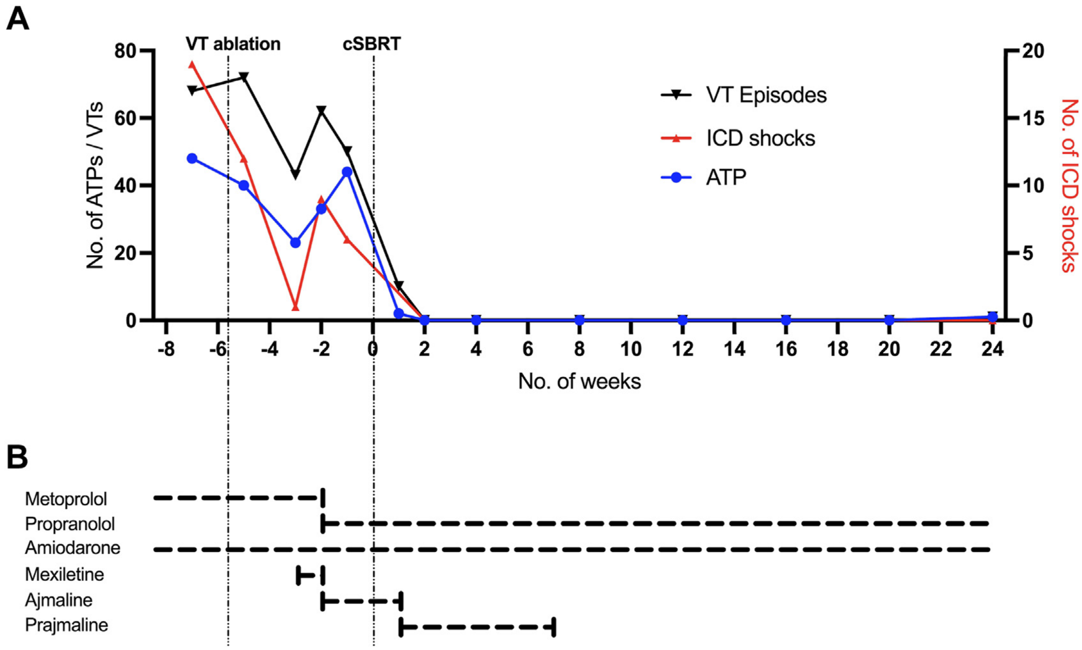

Figure 2 **A:** Ventricular tachycardia (VT) episodes and implantable cardioverter-defibrillator (ICD) interventions and VT episodes and **B:** overview of antiarrhythmic drug (AAD) therapy before and after cardiac stereotactic body radiotherapy (cSBRT). Despite AAD therapy with nonselective beta-blocker, amiodarone, and mexiletine, VT burden remained high until addition of continuous intravenous ajmaline. ICD interventions declined immediately after cSBRT, and AAD could be de-escalated. ATP = antitachycardia pacing.

account for long-term safety evaluations of developing coronary stenosis.[12] PVC triggering VT were refractory to the escalated AAD and radiofrequency treatment and hemodynamically not tolerated in this patient. The dose applied to the coronary arteries for LAD and LCX was predicted to be approximately 5 Gy and 17 Gy, respectively, when a dose of 24 Gy was delivered to the PTV. Owing to treatment urgency, patient age, reduced patient condition, and limited possibilities of breath hold or target tracking, this dose was accepted. The majority of general dose constraints for the heart are derived from stereotactic body radiation therapy treatments in the field of oncology. However, it is worth noting that a distinct dose constraint for the left anterior descending artery (LAD) has recently been defined exclusively for breast cancer patients.[13] However, since the heart is considered a high-risk organ in oncologic radiation therapies, the objectives are entirely different from those of cSBRT. Until today there have been no generally accepted dose constraints for the coronary arteries in cSBRT, which—especially in the region of the LV summit—would be difficult to comply with. The significance of close monitoring and long-term follow-up for patients undergoing cSBRT for LV summit VTs, along with the importance of individualized treatment planning, adherence to stringent dose considerations, and implementation of the latest advances in image-guided radiotherapy techniques to minimize potential adverse effects, are emphasized.

Currently a single dose of 24–25 Gy is widely accepted as a sufficient irradiation dose to achieve an antiarrhythmic effect without relevant side effects. It remains unclear if lower doses are sufficient to induce an immediate antiarrhythmic effect and if irradiation can directly affect cellular electrophysiology by shortening or prolonging refractory periods. In the present case, time to effect and the current dose were not enough to induce transmural fibrosis.

Using an augmented-reality device for radiation planning

Definition and planning of the radiation target volume is challenging because of the lack of anatomical landmarks. In the present case no scar was detected in the 3D voltage map and the main coronary arteries were very close to the defined target volume. To optimize target planning we used a mixed-reality device (HoloLens).[14] Computational technologies go hand in hand with future breakthroughs in the diagnosis and treatment of cardiovascular diseases.[13] In this case the communications between radio-oncology and cardiology specialists had been facilitated using a combined image visualization.

Conclusion

cSBRT provides a safe and effective treatment option for recurrent VT originating from the inaccessible LV summit

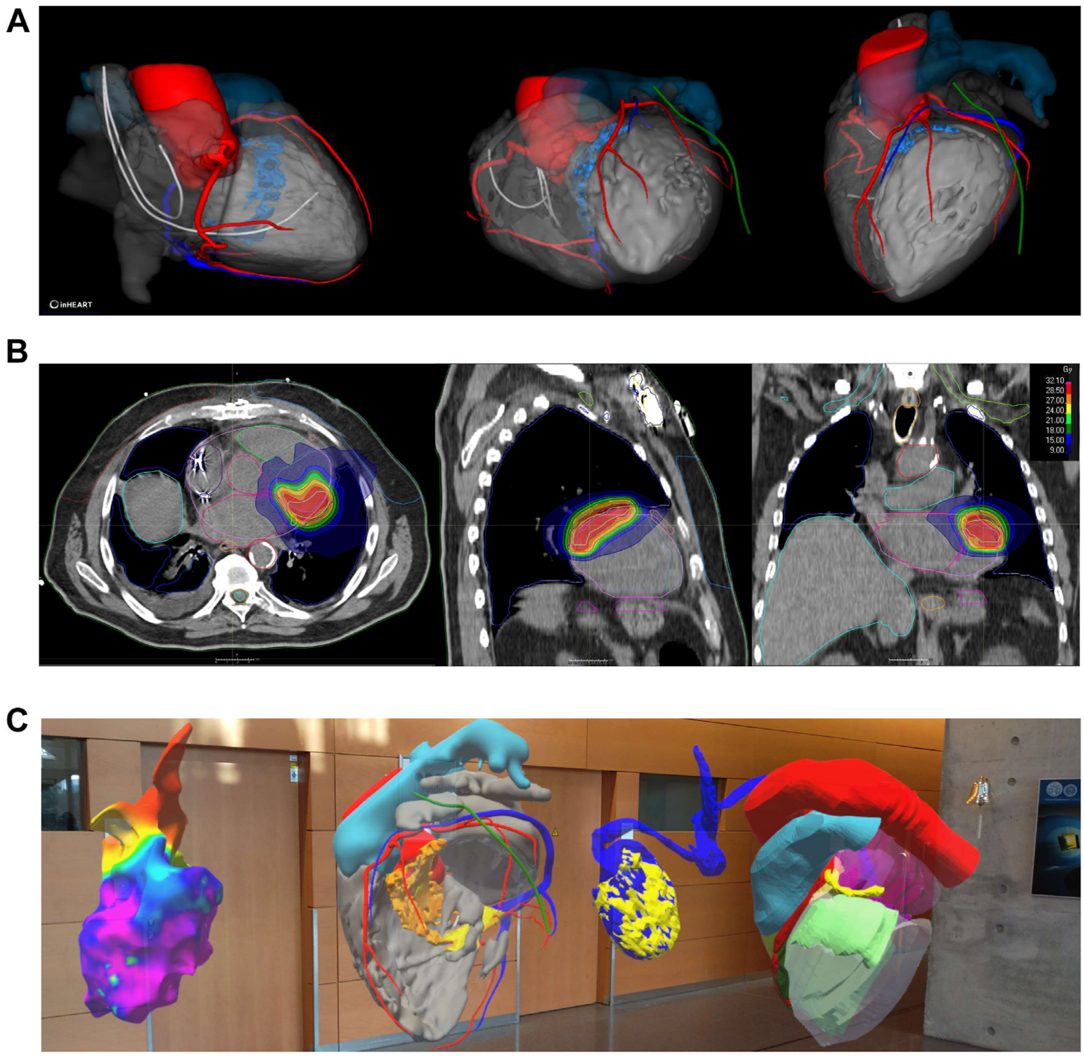

Figure 3 **A:** Segmented late iodine enhancement (LIE) computed tomography (CT) scan with intramural septal and anterior fibrosis (from left to right in right anterior oblique view, left anterior oblique view, and view to the left ventricular summit). Coronary arteries and aorta (red), coronary sinus (blue) implantable cardioverter-defibrillator (ICD) leads (white), LIE-defined fibrosis (light blue), and phrenic nerve (dark green) are depicted. **B:** Images from the final cardiac stereotactic body radiation therapy (cSBRT) plan from left to right in axial, sagittal, and frontal reconstruction, showing planning target volume in red and the corresponding dose distribution (24 Gy prescribed to the 80% isodose). **C:** Three-dimensional datasets visualized with mixed-reality device. Left: Electroanatomic bipolar endocardial map without visible scar. Middle: CT segmentation; intramural fibrosis for better visibility in orange. Right: Reconstructed cSBRT planning with target volume calculation (light green), left anterior descending artery and aorta (red), left circumflex artery (yellow), and ICD (blue/yellow).

in this case report. Target volume definition and radiation planning can be improved by using augmented-reality devices and may facilitate communication between electrophysiologists and radiation oncologists.

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