

Anatomy of a steam pop – Acute histopathology in human myocardium after ventricular tachycardia ablation



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Introduction

Despite an improved understanding of the biophysics of radiofrequency (RF) energy delivery, steam pops remain a potentially serious complication of RF catheter ablation. Excessive heating and boiling resulting in intramural gas eruption from myocardial tissue can lead to cardiac perforation and may require emergent surgical repair.^{1,2} Visualization of the histopathologic changes, the degree of tissue destruction, and comparisons to non-steam pop RF ablation have not been reported in human myocardium in the acute phase.

Case report

A 65-year-old man with a history of ischemic cardiomyopathy and left ventricular ejection fraction of 15% was referred for catheter ablation of recurrent scar-related ventricular tachycardia (VT) despite medical therapy. High-density 3-D electroanatomic mapping of the endocardial left ventricle revealed extensive fibrotic substrate in the antero-septal and inferior walls. Activation mapping of VT was performed, demonstrating a reentrant circuit with a diastolic corridor in the antero-septal region (Figure 1A) corresponding to discontinuous activity and intermediate scar observed in sinus rhythm (Figure 1B). An open-irrigated RF ablation catheter (FlexAbility; Abbott Medical, Abbott Park, IL) was used to deliver RF energy to areas with diastolic activation during VT. System impedance was measured between 75 and 80 ohms during initial RF delivery with a gradual decrease to an average of 65 ohms per lesion. Power was maintained between 35 and 40 watts (W) with a temperature cut-off of 40°C. During 1 application of RF energy using 40 W on the antero-septal endocardial surface, the catheter was

KEY TEACHING POINTS

- A steam pop is a potentially serious complication of radiofrequency (RF) ablation, during which excessive tissue heating results in tissue boiling and gas vaporization with localized tissue destruction.
- Histopathologic analysis of an acute steam pop lesion in fibrotic human myocardium after a ventricular tachycardia ablation procedure reveals an area of substantial local tissue destruction with the presence of cellular dissolution unlike a non-steam pop lesion.
- Acute or subacute architectural destabilization of the myocardium owing to cellular dissolution may have important implications for the presence and timing of mechanical complications after a steam pop lesion.

moved slightly to a more anterior position and an audible popping sound was heard after 49 seconds. During this delivery a gradual decrease in impedance was observed without an abrupt rise, and maximum catheter temperature was 37°C. The audible pop was suggestive of steam formation and eruption from the myocardium. The patient remained hemodynamically stable, with no pericardial effusion visualized on intracardiac echocardiography. Total RF time was 34 minutes. No immediate postoperative complications were noted.

The patient underwent orthotopic heart transplantation 3 days after the procedure owing to recurrent VT and progressive congestive heart failure. Standard recipient cardiectomy was performed and the specimen was sent to the pathology laboratory for analysis.

Gross examination of the explanted heart showed features of dilated cardiomyopathy with left ventricle dilatation, wall thinning, and myocardial fibrosis throughout. An area of

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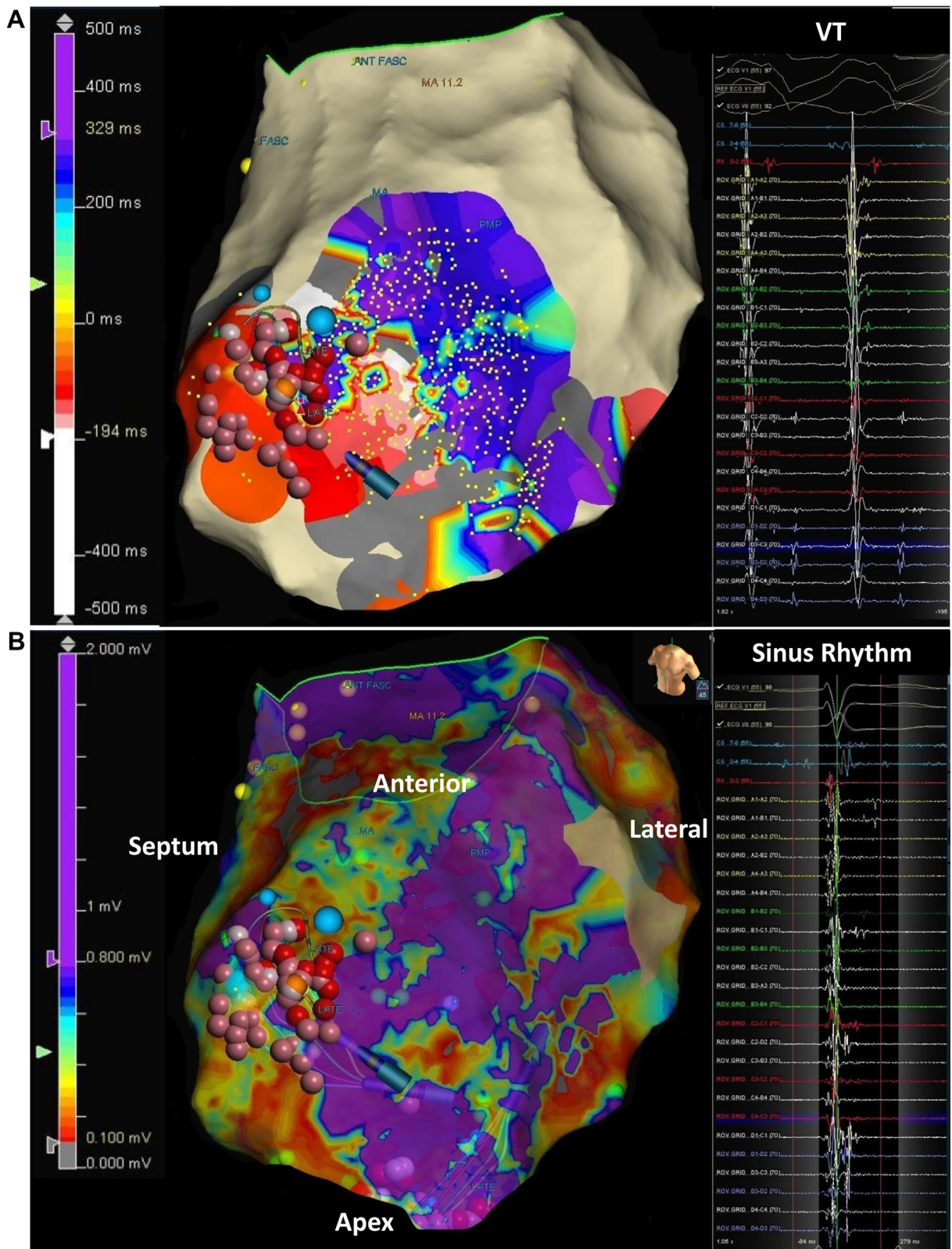


Figure 1 Three-dimensional electroanatomic maps of the endocardial left ventricle. **A:** Ventricular tachycardia (VT) activation map with corresponding intracardiac electrograms demonstrating a diastolic corridor in the anteroseptal region. Red and pink dots represent radiofrequency ablation lesions. **B:** Voltage map with corresponding intracardiac electrograms showing a gradient of late activation with multielectrode recordings.

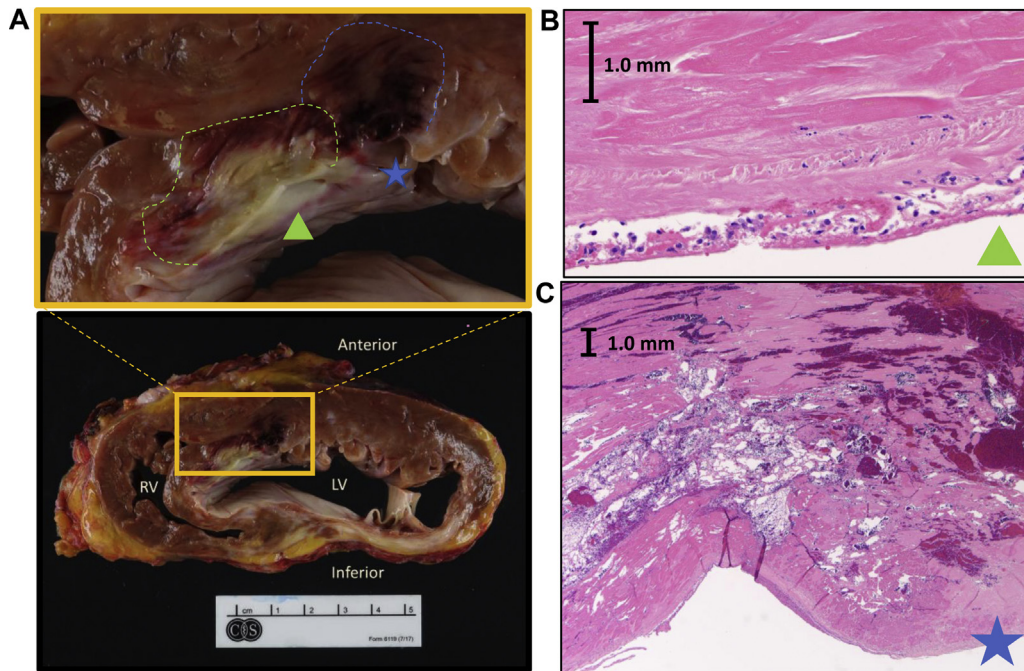


Figure 2 Acute gross pathology and histopathology of human ventricular endocardium after radiofrequency ablation. **A:** Gross pathology of non–steam pop lesion with myocardial necrosis and peripheral hemorrhage (green dotted line and triangle) and steam pop lesion with coagulative necrosis and diffuse hemorrhage (blue dotted line and star). **B:** Microscopic analysis of the green area in panel A demonstrating myocardial necrosis with neutrophilic infiltration. **C:** Microscopic analysis of the blue area in panel A demonstrating coagulation necrosis, complete tissue destruction, and cellular dissolution. LV = left ventricle; RV = right ventricle.

acute myocardial necrosis with hemorrhage was seen in the anteroseptal wall, corresponding to the region of RF lesion delivery. This region spanned 2 cm lengthwise along the endocardium and extended approximately 5–12 mm from the endocardial surface deep into the myocardium (Figure 2A).

Microscopic analysis of the region localized to the septal area demonstrated acute coagulative necrosis associated with neutrophilic infiltration, tissue edema, and peripheral hemorrhage extending 5 mm deep to the endocardial surface. The endocardial surface had a thin fibrin thrombus. The histologic features were compatible with timing of RF ablation 3 days prior to transplantation. (Figure 2B).

Microscopic analysis of the region localized to the anterior area corresponding to the site of steam pop demonstrated complete tissue destruction, with dissolution of all cells, seemingly replaced by open spaces representing non-tissue fluid or gas. Tissue immediately surrounding this area showed complete coagulative necrosis of the myocardial fibers. The rim of tissue beyond this showed marked interstitial edema and hemorrhage, with early influx of neutrophils. The central area of tissue dissolution was located about 2–4 mm deep to the endocardium. The rim of edematous and hemorrhagic tissue was found up to 12 mm from the endocardial surface (Figure 2C).

Discussion

To our knowledge this is the first description of acute histopathologic changes and extent of destruction from a steam

pop lesion vs a non–steam pop lesion in human myocardium during a VT ablation procedure. Steam pop refers to a potentially serious complication of RF ablation owing to excessive tissue heating. Intramyocardial temperatures above 100°C during RF lesion formation may lead to tissue boiling and gas vaporization with localized eruption. Transmural eruption can lead to tissue perforation and cardiac tamponade in certain cases.^{1,2} Notably, this complication from RF catheter ablation occurred in the absence of any worrisome early rapid decline or abrupt rise in system impedance, which have been associated with impending steam pop formation.²

Characterization of the histopathologic changes after steam eruption have been reported subacutely in human heart specimens several weeks after ablation and acutely in ex vivo animal models. Although an audible steam pop was observed during RF application in 1 human study, the gross histopathologic specimen was not subjectively different than non–steam pop applications of RF energy.¹ In ex vivo thigh muscle preparations, crater formation after acute steam eruption was sporadically observed.² Variation among observations may be due to remodeling after the acute phase and the inherent differences between ex vivo and in vivo tissue and lesion characteristics. Our findings of cellular dissolution and architectural distortion after steam eruption in the acute phase have not been reported previously.

The effects of RF ablation on atrial and ventricular myocardium has been well studied in preclinical models. RF energy delivery typically results in predictable histopathologic changes showing a central necrotic core with acute coagulation necrosis and a peripheral border zone of

contraction band necrosis.^{1,3} The degree of gas formation and eruption may be variable, leading to potentially inaudible steam eruption without clear visualization by intracardiac echocardiography. Therefore, the incidence of steam pop formation may be under-reported.

A better understanding of the effects of acute gas eruption on the cellular and extracellular components of human myocardium may enhance our ability to predict complications. For one, acute cellular dissolution, coagulative necrosis, and denuding of the subendocardial layer after steam eruption may result in a higher local thrombogenic milieu and may pose a higher risk for thromboembolic complications as compared to non-steam pop lesions. In addition, the extent of tissue destruction observed at more than a 10 mm depth from the endocardial surface may not cause direct perforation but may potentially lead to acute or subacute architectural destabilization. Chronic changes observed after steam pop formation, including focal crater and aneurysm formation, are consistent with this hypothesis.⁴ Architectural disarray and extracellular matrix fragmentation was observed more frequently in steam pop lesions as compared to non-steam pop lesions in an animal study of RF energy application at the aortic root.⁵ Cellular dissolution and matrix fragmentation may result in weakening of the extracellular space and

potential aneurysm formation without perforation. This suggests that even if perforation does not occur, there could be alterations in tissue mechanics—especially in thicker left ventricular myocardium. This may have important implications in the immediate postoperative period, where late complications are not infrequent and hemodynamic parameters vary considerably, as compared to the intraoperative period.

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