Orthostatic increase in defibrillation threshold leading to defibrillation failure and prolonged cardiac arrest in a sitting position: Lessons from a patient's near-fatal experience

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Introduction

It has previously been reported that patients with an implantable cardioverter-defibrillator (ICD) may have a slightly higher defibrillation threshold (DFT) in an upright position compared to a supine position.[1] However, the significance of this and the potential impact on clinical practice remains unclear. We report a case of defibrillation failure caused by an increase in DFT in the upright position, leading to prolonged, near-fatal cardiac arrest in a patient who had previous ICD implantation including successful DFT testing in a supine position. ICD system revision with addition of an azygos vein coil successfully corrected this condition, as demonstrated by orthostatic DFT testing.

Case report

The patient is a 47-year-old man with a prior history of nonischemic, dilated cardiomyopathy and ejection fraction 15%–20%. He underwent initial implantation of a single-chamber, single-coil ICD (Protecta VR D334VRG; Medtronic, Minneapolis, MN) for primary prevention in October 2012. The patient's past medical history is also significant for morbid obesity, hypertension, type II diabetes, and renal insufficiency. Because of the patient's body habitus, nonischemic cardiomyopathy, and young age, DFT testing was performed at the time of implant. After induction of ventricular fibrillation (VF) by T wave shock, a 15 J shock failed but a follow-up 25 J shock from the ICD successfully restored sinus rhythm. The patient's device has a 35 J maximal output with a 10 J safety margin maintained. After the uneventful ICD implantation, he remained stable until recently, when he developed an episode of VF during sleep, with successful cardioversion by a single 35 J shock from the ICD. An evaluation including stress echocardiography was negative for ischemia. No additional coronary angiogram was performed owing to baseline renal insufficiency and because he already had two previous coronary angiograms within the last 5 years that showed no significant obstructive coronary artery disease. Conservative medical management was therefore recommended and the patient's heart failure management was intensified with close follow-up by his cardiologist.

Five months after the initial VF event and despite an apparent stable heart failure status, the patient developed sudden syncope without prodrome while sitting in a chair at home and was later found to be in cardiac arrest. According to the family, the patient was able to maintain an upright position in the chair. Subsequent ICD interrogation showed VF that was appropriately detected and six consecutive, maximal-energy shocks at 35 J (including a reversed polarity with the last shock) were delivered but failed to terminate the VF (Figure 1A–C). After exhaustion of device therapy, the patient remained in VF for approximately 6–7 minutes until paramedics arrived with an automated external defibrillator. The patient was immediately placed in the supine position and a single shock from the automated external defibrillator successfully converted the patient back into sinus rhythm (Figure 1D). After the patient was placed in the supine position, he subsequently developed 3 more VF episodes in the field, all of which were successfully detected and treated by the ICD (Figure 1E and F). The patient was initially transferred to a nearby hospital but was subsequently transferred to Borgess Medical Center for definitive management. Two days after the initial event, the patient did develop another episode of VF while supine in the hospital, which was again successfully detected and treated by the ICD with a 35 J shock. Following successful resuscitation including a cooling protocol, he was able to make a complete recovery with minimal residual neurologic deficit. Of note, chest

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KEY TEACHING POINTS

- A clinically significant increase in defibrillation threshold (DFT) may occur in the upright body position, especially in patients with severe obesity.
- Implantation of an azygos vein coil may substantially reduce DFT.
- Orthostatic DFT testing may help identify and reduce the chance of failure to defibrillate in high-risk patients.

x-ray performed in both the supine and upright positions demonstrated an orthostatic shift in the ICD can position relative to the heart, but no significant change in the lead position was found as compared to the one at initial implant (Figure 2A–D).

Because of the apparent dependence of successful defibrillation on body position and the relatively high DFT during the initial implant, we elected to revise the patient's ICD system with addition of an azygos vein coil and subsequently performed DFT testing in a supine as well as in an upright position.

The patient was taken to the electrophysiology lab, where the left precordium was prepared and draped in the usual fashion. The axillary vein was accessed and the azygos vein was engaged using a 6 F Judkins-right-4 (JR4) diagnostic coronary catheter, as described by Cooper et al,[2] and a Storq wire (Johnson & Johnson Medical, NV, Diegem, Belgium). A 9 F long sheath was advanced over the JR4 and Storq wire, passing the initial torturous portion of the azygos vein. This allowed successful implantation of an azygos coil posterior to the heart (Figure 2E and F). At the end of the procedure, VF was induced and a 15 J shock from the device was able to successfully defibrillate the patient (not shown). The patient underwent further DFT testing the next morning in an upright position. The head of the bed was propped up about 70–80 degrees until the patient was in an upright posture similar to the one that he was in during the initial prolonged cardiac arrest. VF was again induced by T wave shock. Following successful detection of VF, an initial 25 J shock was purposefully delivered using the previous right ventricular (RV) coil–to–ICD can configuration to confirm that the failure to defibrillate was due to an increase in DFT in the upright position (Figure 3A). This indeed failed to terminate the VF. Immediately after that, with the patient still in VF in an upright position, a second 15 J manual shock using the new configuration (B > AX, RV coil to azygos coil/ICD can) incorporating the azygos coil was delivered within 10 seconds and successfully defibrillated the patient (Figure 3B). The patient tolerated the procedure well and was discharged home on amiodarone to suppress ventricular arrhythmias that may trigger further VF. At his post hospital follow-up one month after the event, the patient had completely recovered, with no residual neurologic deficit or recurrent VF episodes.

Discussion

This case illustrates the potential critical impact of orthostatic increase in DFT on survival in certain clinical situations, and it is thought-provoking that orthostatic DFT testing is yet to become part of our routine electrophysiology practice even in patients at high risk for VF. It also demonstrates that modification of the shock vector utilizing an azygos coil can substantially reduce the DFT in both supine and upright positions.

Influence of body position on DFT has long been studied by Schauerte et al,[1] who found a significant increase in DFT in an upright position compared to the supine position. However, the mean magnitude of this increase is relatively small, about 1.9–2.0 J, which would not be expected to cause complete failure to defibrillate in the patient presented here, since a 10 J safety margin was observed during the initial implant.[1,3] Our patient's relatively increased DFT at baseline and subsequent treatment with amiodarone in the hospital may have contributed to the failure to defibrillate. However, the main factor in this case appears to be the orthostatic increase in DFT when the patient was in an upright position. This is supported by the three consecutive, successful shocks from the device when the patient was placed in a supine position shortly after he had already failed 6 maximal-energy shocks in a sitting position and after greater than 7 minutes of continuous VF. Presence of VF as short as 10 seconds has been shown to increase DFT significantly, and prolonged cardiac arrest due to VF was reported to markedly increase the energy requirement for successful defibrillation.[4,5] All five spontaneous VF episodes (one before the recent cardiac arrest and four afterward) occurring when the patient was supine were successfully defibrillated by the ICD. Additional evidence supporting an orthostatic increase in DFT came from failure to defibrillate at 25 J during repeat DFT testing in an upright position using the original configuration when the DFT was estimated at 25 J or less at initial implant in a supine position, although the patient's true DFT may have gradually increased over the years.[6,7] We did not observe any other clear etiology (such as significant change in the lead position on x-ray or worsening heart failure and ejection fraction) to explain the increased DFT, other than the change in body position.

The mechanism underlying the increased DFT in the upright position remains speculative.[1] The inferior and anterior displacement of the ICD can relative to the intravenous lead system after the patient assumes an upright position, especially in patients who have severe obesity such as the one presented here, may have contributed to the increased DFT. As shown in Figure 2, owing to the anterior shift in the can position, the shock vector between the can and RV coil may encompass less of the cardiac mass in the upright position compared to the supine one, thereby potentially increasing the DFT. Additionally, hemodynamic changes and increased sympathetic tone in an upright position may also influence the DFT.[1,8] Having a dual venous coil system, especially with addition of an azygos

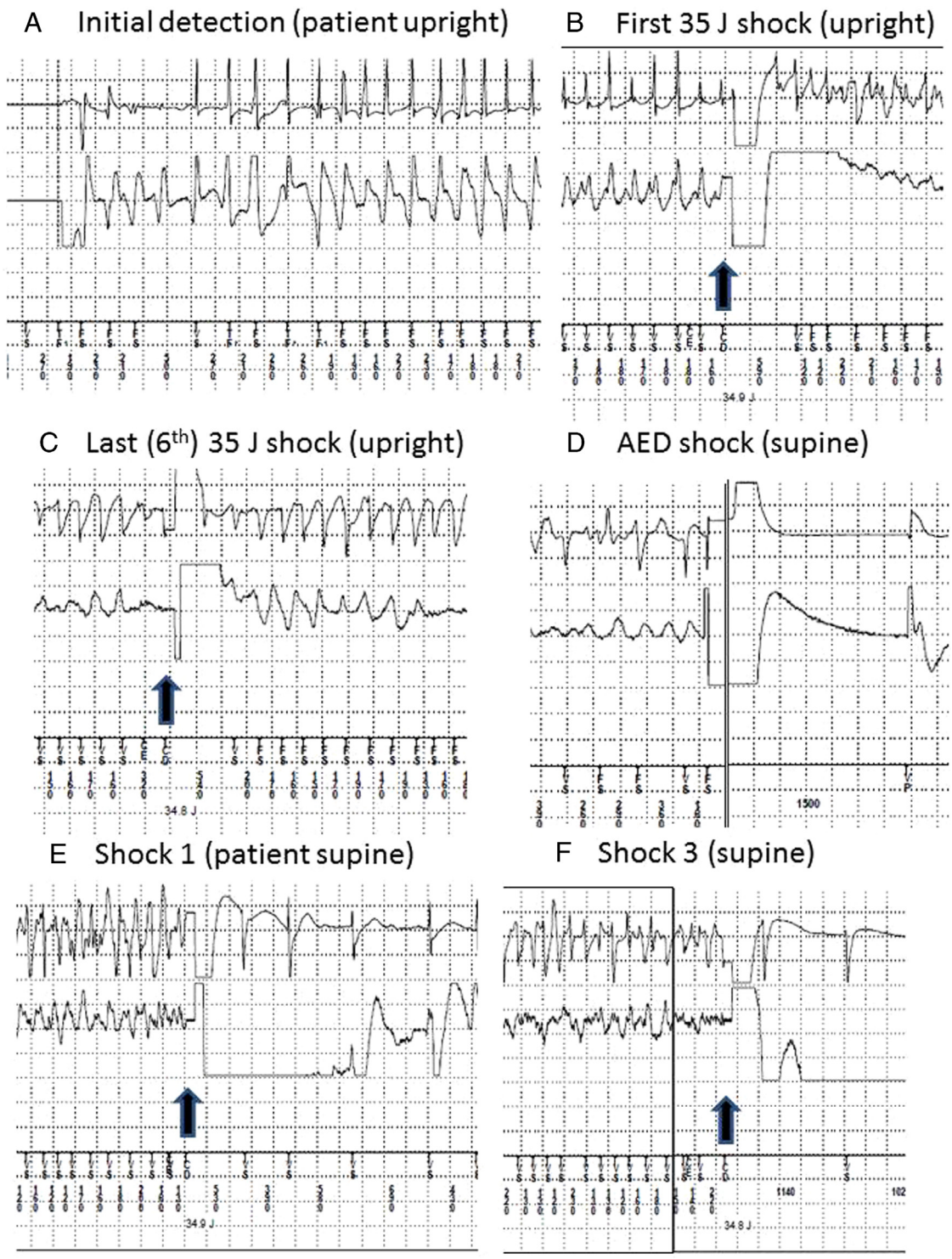

Figure 1 Detection and treatment of ventricular fibrillation (VF) in both the upright and supine positions. **A:** Initial detection of VF when patient was sitting up in a chair. **B, C:** Six consecutive shocks from the implantable cardioverter-defibrillator (ICD) failed to defibrillate. Only shocks 1 (B) and 6 (C) are shown. **D:** Successful defibrillation by an automated external defibrillator (AED) after patient was placed in a supine position. **E, F:** Patient developed 3 additional VF episodes in the field after being placed in the supine position. All these were successfully treated by the ICD. Only episodes 1 (E) and 3 (F) are shown. Arrows indicate the time when shock was delivered by the ICD.

coil, not only improves the shock vector but may also mitigate these position-related changes. In our own experience of six patients including this one, addition of an azygos shocking coil was successful in all and led to substantially reduced DFT in most cases (unpublished personal observation). There are other potential alternatives to reduce the DFT and increase the safety margin, such as addition of a superior vena cava coil or subcutaneous array, switching to a higher-energy device with 41 J output, or utilizing alternative devices that allow adjustable tilt.[9,10] However, a superior

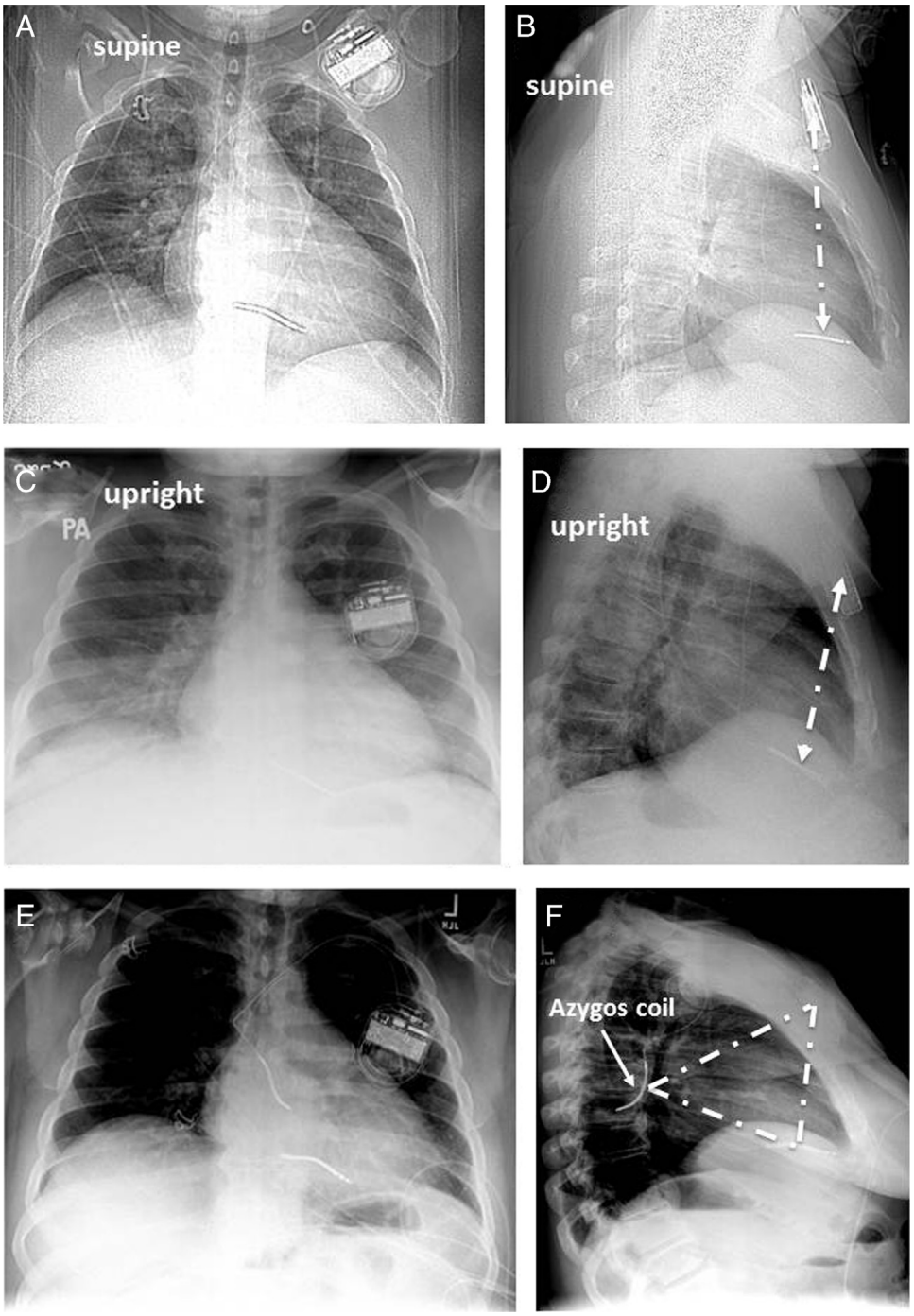

Figure 2 Posterior-anterior (PA) and lateral views of the implantable cardioverter-defibrillator (ICD) system in both supine and upright positions. **A, B:** Chest x-ray in the supine position. **C, D:** Patient's ICD can was seen to be inferiorly (C) and anteriorly displaced (D) in the upright position compared to the supine one (A, B). In the upright position, the shock vector between the right ventricular coil and can (their midpoints connected with dashed lines) appears to encompass less of the cardiac mass, especially the left ventricle (D). **E, F:** PA (E) and lateral (F) views in the upright position after addition of an azygos vein coil (*arrow*). The shock vector between the coils and can now encompasses more of the left ventricle in the upright position (F).

vena cava coil may not lead to as much reduction as the azygos coil,[11] and the subcutaneous array or other methods may not adequately address the issue of orthostatic changes and may not offer enough safety margin for this high-risk patient.

To our knowledge, this is the first report of upright body posture being a critical factor for failed defibrillation in an out-of-hospital cardiac arrest. It has been long observed that a significant percentage of patients with defibrillators and high DFTs die of sudden cardiac death apparently owing to inadequate defibrillation energy or inadequate sensing, but orthostatic increase in the DFT may have also played a role, as presented in this dramatic case.[12] If this patient had not been successfully resuscitated, the failure to defibrillate here would have been simply attributed to high DFT alone. It is probably uncommon for patients to develop VF and still be

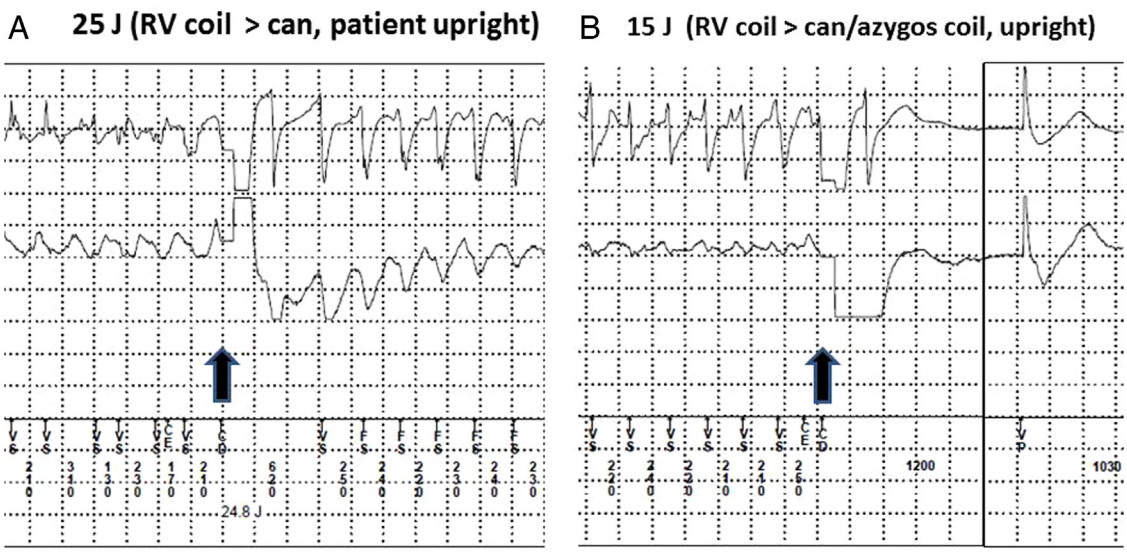

Figure 3 Defibrillation threshold testing when patient was in a sitting position with and without the azygos coil in the shock circuit. **A:** Using the initial right ventricular (RV) coil–to–ICD can configuration, a 25 J shock failed to defibrillate the patient. **B:** Immediately following the failure using the old configuration, a 15 J manual shock using the new RV coil–to–azygos vein/ICD can configuration successfully converted the patient to a paced rhythm.

able to maintain an upright position; however, failure to defibrillate early can lead to prolonged VF and may increase the chance of subsequent defibrillation failure even if patients eventually collapse and assume the supine position.

Conclusion

In patients who have risk factors for high DFT, such as severe obesity; advanced, dilated cardiomyopathy; and multiple comorbidities, orthostatic change can cause additional, clinically significant increase in DFT and may lead to potential sudden cardiac death owing to failure to defibrillate. This situation may be overlooked by the currently used DFT testing protocols, which test patients in a supine position. Orthostatic DFT testing in such patients may help predict future defibrillation failures and, if necessary, ICD system revision with addition of an azygos vein coil may help correct an excessive orthostatic increase in DFT.

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