The Case of an Unusual Defibrillation Vector in the Management of High Defibrillation Threshold

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ABSTRACT. We report a case of extremely high defibrillation threshold where the final optimal vector configuration was from the coronary sinus (CS) coil to the subcutaneous coil. By using this shock vector, we were able to restore the defibrillation threshold (DFT) testing to a safe level. The right ventricular (RV) coil was capped; therefore, the RV lead was purely a sensor/pacer in this configuration. Implantable cardiac defibrillators (ICDs) reduce the incidence of lethal arrhythmias in high-risk patients. However, sudden deaths possibly due to these lethal rhythm disturbances have been reported in patients with ICDs. Likely explanations include failed or ineffective defibrillation as a result of high defibrillation thresholds, postshock electromechanical dissociation (EMD), shock failure, and primary EMD. Defibrillation threshold testing has long been performed to fine-tune device ability to deliver appropriate and effective therapy in individual patients with an adequate safety margin. Electrode polarity and shock vector are important determinants of high DFT. The literature reports both invasive and non-invasive management strategies for high DFT. RV lead repositioning; superior vena cava (SVC) coil manipulation; the addition of subcutaneous arrays; and coil implantation in azygous vein, CS, and epicardial space are validated techniques for altering the shock vector and reducing the energy required for successful defibrillation. The available body of evidence suggests that in current ICDs, the RV coil should be the anode and that polarity reversal to reduce the DFT is only useful if initial testing was performed using a cathodal RV coil.

KEYWORDS. Defibrillation threshold, electromechanical dissociation, ICD, RV lead, vector.
threshold was 0.5 V, and the pacing impedance was 580 ohms. The chronic right ventricular (RV) lead and new atrial and left ventricular leads were attached to a new pulse generator; however, abnormal impedance was noted on evaluation of the shocking coil through this device. The lead was detached and attached to the old device, and again a highly abnormal shocking impedance was noted, indicating a damaged RV shocking coil. Therefore, a new RV lead was placed. This was placed in an apical position that was near but clearly not touching the chronic RV lead, which was cut and capped. A very high value was noted on defibrillation threshold (DFT) testing, so a subcutaneous pocket was created on the left side of the chest, and the subcutaneous coil was tunneled from the pocket to a small incision at the lower end of the sternum. A helpful lateral position was noted with the left ventricle in between the RV/shocking coil and the subcutaneous coil. However, the
position of the subcutaneous coil was suboptimal as it did not reach all the way across the left side of the chest to the posterior position. A total of three ventricular fibrillation inductions were given. Initial shocks using vectors from the RV coil to the superior vena cava (SVC) coil and RV coil to the can failed to defibrillate. During the last ventricular fibrillation induction, even with the vector from the RV coil to the subcutaneous coil, the defibrillation threshold was extremely high.

At this point, as the procedure had gone on for an extended period of time, and the patient was retaining carbon dioxide, so it was stopped. The plan was to perform non-invasive DFT testing after medications had been optimized in 2 days, as well as a possible subcutaneous coil revision. During non-invasive testing under temporary general anesthesia (etomidate) 2 days later, ventricular fibrillation was induced on two occasions using the direct current fiber method. Internal defibrillation was unsuccessful on both occasions, and the patient required external defibrillation with 360 joules. A new subcutaneous coil was inserted and placed in an excellent posterior position with tunneling. The coil
wrapped around from behind the heart, laterally, to slightly anterior to the heart. The lead was tunneled from the pocket and attached to the SVC port. The device was placed into the pocket. Using the RV coil to SQ coil, Defibrillation threshold remained unacceptably high; therefore, a Coronary sinus (CS) coil was placed through the left subclavian vein and into the coronary sinus. Immediately after the shock, there was a large amount of noise noted on the RV sensing lead. Initially, we thought this had to do with the lead rubbing against the close pre-existing RV lead, which was therefore moved to a more septal location. However, this continued to be a problem and was present in both the RV and atrial leads and therefore was attributed to shock-induced myopotentials. Testing with the vector from the CS coil to the RV coil also revealed a very high defibrillation threshold requiring 30.2 joules of shock energy and therefore was not sufficient to ensure successful defibrillation. On further evaluation, a better vector from the CS coil to the subcutaneous coil was identified. The RV coil was...
unplugged from the device, the subcutaneous coil was plugged into the RV port, and the device was placed into the pocket. Ventricular fibrillation was induced, and a 25-joule shock succeeded in restoring sinus rhythm. The RV coil was capped and therefore only served a sensor/pacer function. The subcutaneous coil was plugged into the RV port and CS coil plugged into the SVC port. There were no complications. The patient was stable at the end of the procedure and was taken to the recovery room.

**Discussion**

This case illustrates the concept of implantable cardiac defibrillator (ICD) defibrillation vectors. This patient had a very high defibrillation threshold during the procedure that required subcutaneous coil placement, but he continued to have a very high defibrillation threshold with no safety margin. We stopped the procedure, optimized his medications, and performed non-invasive...
testing 2 days later, but the DFT remained high. He was taken back to the electrophysiology lab for subcutaneous coil revision and possible further measures to optimize his DFT.

Shock vector or ICD defibrillation vector is the three-dimensional orientation of the distribution of energy delivered by the coil system and is considered an important determinant of DFT. It is crucial that energy encompassing the left ventricle be uniformly distributed. RV lead positioning; manipulation of the SVC coil; addition of subcutaneous arrays; and implantation of azygous vein, CS, and epicardial space coils are some of the techniques designed to alter the shock vector. The addition of an azygous vein or CS coil improves the shock vector and therefore lowers the DFT. Subcutaneous array implantation is the most effective strategy for managing high DFT, but it is an invasive, painful procedure requiring general anesthesia. Malpositioning of the generator or electrodes alters the electric field in such a way that leads to aberrant conduction, reducing the amount of current flow through the left ventricle.

Several clinical, laboratory, and echocardiographic factors that increase the risk of encountering high DFT have been reported in the literature. Among the clinical variables, left ventricular mass and resting heart rate were found to be the only independent predictors of defibrillation in a multivariate analysis. The electric field of a certain threshold gradient must be applied to >90% of the involved critical mass to successfully terminate ventricular fibrillation. This explains the correlation of DFT with body mass index and heart mass. In patients with non-dilated Hypertrophic cardiomyopathy (HCM), QRS (A wave complex in Electrocardiogram representing electrical conduction through the ventricles) was found to be the most consistent predictor of high DFT during ICD implantation. Sodium channel inhibition increases DFT with monophasic shocks. Prolonged cardiac repolarization by inhibiting potassium conductance...
has been shown to reduce the DFT.\textsuperscript{8,9} There is evidence that a septal location of the ICD coil close to the RV outflow tract significantly reduces DFT.\textsuperscript{5} Postimplantation DFT changes are found to be time, drug, and comorbidity dependent. Microdislodgement and increased resistance due to fibrous tissue capsule formation, medications, and clinical conditions may increase DFT after implantation.\textsuperscript{1}

The management of high defibrillation thresholds involves both invasive and non-invasive strategies. Preventable causes should be identified in a timely manner. These include medications (cardiac and non-cardiac), electrolyte disturbances (hypomagnesaemia, hypocalcemia, hyperkalemia) and acidosis. Medical therapy for heart failure should be optimized before DFT testing. Identifying hypoxia, hypercapnia, and resultant acidosis during the procedure is equally important. Pneumothorax and pleural effusions can also lead to high DFT by altering the shock impedance and vector. High sympathetic tone secondary to prolonged myocardial depression, hypotension, and myocardial ischemia can also lead to high DFT. High-energy devices should be used if anticipating a high DFT before ICD implantation.

High DFT is known to be associated with older age, low ejection fraction, worse NYHA functional class, recent amiodarone use, and right-sided prepectoral implants, and high-output/high-energy devices should be employed in such patients. Sotalol has been shown to decrease DFT. Dofetilide reduces DFTs sufficiently to prevent the need for more complex lead systems. This strategy should be considered in the context of an inadequate defibrillation safety margin.\textsuperscript{10}

Evidence supports the hypothesis that shock vector alteration by various techniques leads to significant reductions in DFT. The recommendations include: reversing shock polarity, changing the shock configuration (tip to generator, ring to generator and generator to coil), modifying the waveform, adding an SVC coil or subcutaneous array, or moving the generator to the left if it is located on the right.\textsuperscript{11}

High DFT is the result of a complex interplay between molecular, clinical, electrical, mechanical, anatomical, neurohumoral, and pharmacological factors. Because of the increasing number of ICD implantations, high DFT is increasingly encountered in clinical practice. Its management needs to be tailored to specific clinical situations and requires complete understanding of the various mechanisms involved. High-risk patients need to be identified before the procedure, and appropriate measures should be taken to minimize the risk. In situations where high DFT is encountered during the procedure, the above-mentioned techniques should be employed to optimize the shock vector and energy delivery. By using the vector from the CS coil to the subcutaneous coil, we were able to reduce the patient’s DFT to a safe level. To our knowledge, this is the only such case reported in the medical literature to date.

Conclusion

ICDs are not 100% effective at reversing lethal ventricular arrhythmias. Several studies have shown that 32% of ICD cardiac death is sudden versus 54% in control groups, with a 22% increase in relative benefits with ICDs. ICDs do not work as well as we think, but they are still the best therapy available for sudden and lethal arrhythmia. With better implant practices, we can prevent sudden cardiac deaths in patients with ICDs. Among other factors, high DFTs are a potential target that deserves special attention during ICD implantation. Improving the safety margin for defibrillation thresholds can help prevent large numbers of patient deaths.

References