Chapter

# Possibility of the Subcutaneous Implantable Cardioverter-Defibrillator for Prevention of Sudden Cardiac Death in Patients with Arrhythmogenic Right Ventricular Cardiomyopathy

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## Abstract

The EMBLEM™ entirely subcutaneous implantable cardioverter-defibrillator (S-ICD) system (Boston Scientific, Marlborough, Massachusetts, USA) was introduced as a new alternative to the conventional transvenous implantable cardioverter-defibrillator and has been expected to reduce device-related complications, especially in young patients who require long-term lead placement. Arrhythmogenic right ventricular cardiomyopathy (ARVC) is a well-known hereditary disease recognized as a cause of sudden cardiac death (SCD) in young adults. However, the precise clinical role of S-ICD in patients with ARVC remains to be defined because of the low QRS amplitude of subcutaneous electrocardiogram (S-ECG) followed by the high incidence of inappropriate shock (IAS) delivery due to oversensing. It is well known that the sensing of S-ICD is largely dependent on the QRS/T ratio of S-ECG. The decrease in the QRS amplitude is more likely to lead to oversensing such as T wave or myopotential oversensing. In patients with ARVC, the decrease in the QRS amplitude due to degeneration of the right ventricular myocardium progresses overtime. In this chapter, we would like to discuss the usefulness of S-ICD lead repositioning for young adult patients with ARVC based on our experience of patients with IAS.

**Keywords:** arrhythmogenic right ventricular cardiomyopathy, subcutaneous implantable cardioverter-defibrillator, inappropriate shock, lead repositioning

## 1. Introduction

The EMBLEM™ entirely subcutaneous implantable cardioverter-defibrillator (S-ICD) system (Boston Scientific, Marlborough, Massachusetts, USA) has been used as a new alternative to the conventional transvenous implantable cardioverter-defibrillator (TV-ICD). Recently, the PREATORIAN study has shown that S-ICD

is as useful as TV-ICD for prevention of sudden cardiac death (SCD), mainly in patients with ischemic cardiomyopathy [1]. Furthermore, the UNTOUCHED study also demonstrated that the inappropriate shock (IAS) rate in S-ICD-implanted patients with left ventricular ejection fraction (LVEF) ≤ 35% for primary prevention was non-inferior to that in transvenous ICD (TV-ICD)-implanted patients with similar programming as in the high-rate cutoff and long-delay therapy groups in the MADIT-RIT [2, 3].

Arrhythmogenic right ventricular cardiomyopathy (ARVC) is a well-known hereditary disease recognized as a cause of SCD in young adults [4]. However, the usefulness of S-ICD in patients with ARVC has not been established because of the low QRS amplitude of subcutaneous electrocardiogram (S-ECG) followed by the high incidence of IAS due to oversensing [5, 6]. We recently reported the usefulness of S-ICD lead repositioning to avoid IAS in patients with ARVC [7]. In this chapter, we will discuss the effectiveness of S-ICD lead repositioning for young adult patients with ARVC based on our clinical experience of patients with IAS.

## 2. Characteristics and problems of S-ICD sensing in patients with ARVC

The S-ICD uses a far-field bipolar electrocardiogram detected between two electrodes of S-ICD lead, or between one of the two electrodes and pulse-generator. This far-field bipolar electrocardiogram is called as subcutaneous electrocardiogram (S-ECG) and is used for detection and discrimination of tachyarrhythmias in current S-ICD system. The S-ECG shows lower QRS amplitude (0.3–4.0 mV) compared to intracardiac ECG, and longer QRS duration with many low frequency components. Since the basic morphology of S-ECG resembles a body surface ECG, it is easily affected by P wave and T wave, and is also easily affected by changes in the QRS complex to T wave (QRS/T) ratio during exercise. And S-ECG has a potential risk of myopotential interference (MPI) in certain periodic movements.

It has been suggested that fatal events occurring before overt structural myocardial changes in patients with ARVC may be caused by a primarily electrical mechanism as a consequence of the cross talk of genetically defective desmosomal proteins with the voltage-gated sodium channel complex, leading to reduced sodium currents and arrhythmogenic mechanisms similar to those in Brugada syndrome [8]. It has also been known that the phenotype of fatal arrhythmias in patients with ARVC is age-dependent. Older patients with advanced disease more often experience re-entrant ventricular tachycardia (VT) around a myocardial fibro-fatty scar, whereas young patients commonly experience sudden onsets of ventricular fibrillation (VF) reflecting acute electrical instability in the early phases of the disease. Furthermore, S-ICD has been reported to have fewer lead-related complications than TV-ICD [1], and is also useful in younger patients who require long-term lead placement. Therefore, S-ICD is expected to prevent SCD, especially in young patients with ARVC.

However, the precise clinical role of S-ICD in patients with ARVC remains to be defined. One reason is that S-ICD does not have a function of anti-tachycardia pacing that is expected to be highly effective in terminating scar-related re-entrant VT, which is often observed in patients with ARVC. Another reason is that morphological changes in S-ECG with age may lead to cardiac oversensing and IAS delivery. In an Italian multicenter registry, which enrolled 44 young ARVC patients undergoing S-ICD implantation (mean age of 37 years; mean LVEF of 53%; primary prevention of 59%), 6 (14%) experienced 8 IAS deliveries, consisting of 4 cardiac oversensing and 4 non-cardiac oversensing [5]. Furthermore, in a transatlantic cohort study [6], which enrolled 29 young ARVC patients undergoing S-ICD implantation (mean age

of 34 years, mean LVEF of 56%, primary prevention of 59%), 6 (21%) experienced 39 IAS deliveries due to oversensing. These studies indicate a high incidence of IAS delivery in S-ICD-implanted ARVC patients, leading to a potential limitation of S-ICD use in these patients.

## 3. Usefulness of lead repositioning of S-ICD in patients with ARVC

The conventional S-ICD system that we are using to date was developed and evaluated in the initial study [9]. In that study, the substernal lead was placed parallel to and 1 to 2 cm to the left of the sternal midline, and the pulse generator was placed over the sixth rib between the midaxillary line and the anterior axillary line. And the distal sensing electrode was positioned adjacent to the manubriosternal junction, and the proximal sensing electrode was positioned adjacent to the xiphoid process. The final position of S-ICD system was determined by the defibrillation threshold or the effectiveness of defibrillation. Notably, the positioning of S-ICD system was guided exclusively by anatomical landmarks, thus no fluoroscopy was required.

Recently, we reported the usefulness of S-ICD lead repositioning to avoid IAS in young patients with ARVC [7]. The most important benefit of S-ICD lead repositioning is an improved S-ECG sensing due to changes in QRS amplitude of S-ECG. The sensing of S-ICD is largely dependent on QRS/T ratio of S-ECG, which is vulnerable to changes caused by physical activities or the progression of underlying heart diseases. It has been well known that the decrease in QRS amplitude of S-ECG due to degeneration of the right ventricular myocardium progresses overtime in ARVC patients. **Figure 1** shows ECG examples of a patient with ARVC in whom a decrease in QRS amplitude of surface ECG was confirmed over time. Of note, such changes in QRS amplitude were reflected more clearly in S-ECG compared with surface ECG. In such patients, S-ICD has a potential risk of IAS due to oversensing.

The SMART pass technology (SP) is a high-pass filter which enables to avoid sensing below 9 Hz and is expected to decrease IAS due to cardiac oversensing [10]. However, the decrease in QRS amplitude is more likely to lead to cardiac and

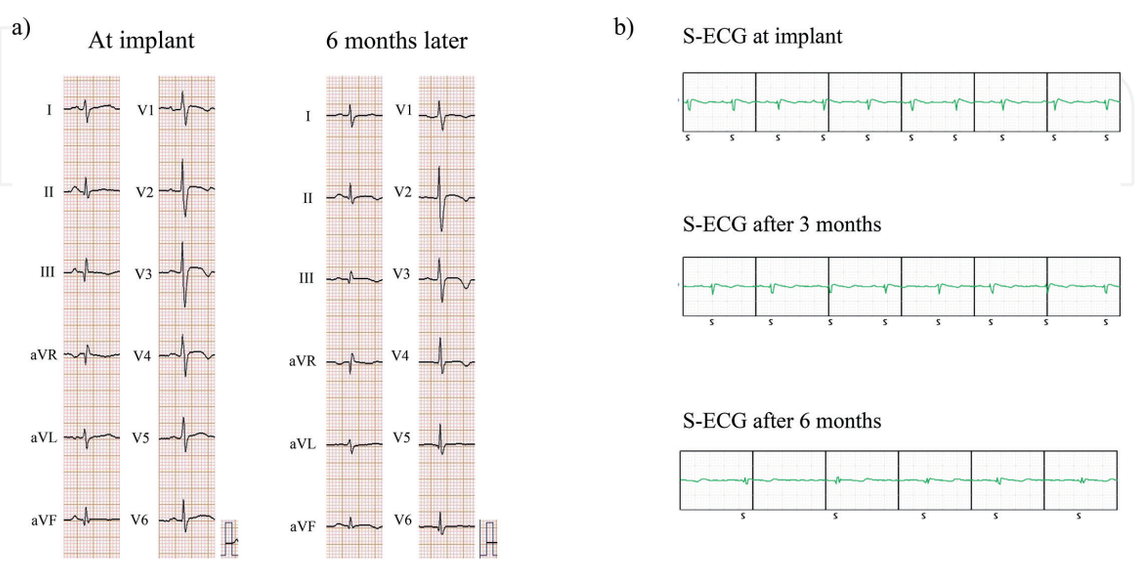


**Figure 1.**
*Comparison of changes over time between body surface electrocardiogram and subcutaneous electrocardiogram (S-ECG). (a) Comparison of body surface ECG over time. The QRS amplitude decreases slightly over time in bipolar limb leads. (b) Comparison of S-ECG over time in the supine position. S-ECG was detected by alternate sensing vector with same detection sensitivity. The QRS amplitude of S-ECG decreases over time.*

non-cardiac oversensing such as T wave or MPI, even if the SP is working properly. The SP can be set-up manually or automatically, but QRS amplitude of S-ECG is required to be higher than 0.5 mV. Furthermore, the SP is automatically terminated when there is no cardiac sensing for 10 seconds or when QRS amplitude of S-ECG decreases under 0.25 mV for 1.4 seconds or more. Therefore, there is a limitation to avoid IAS due to oversensing by SP alone in ARVC patients. For these reasons, lead repositioning of S-ICD can be a useful alternative to prevention of IAS in ARVC patients, even though the SP has been already activated.

## 4. Clinical practice of S-ICD lead repositioning in patients with ARVC

The potential efficacy of lead repositioning can be estimated by preoperative screening test. If two or more vectors do not pass the screening test, other sensing vectors suitable for S-ICD sensing must be searched and lead repositioning or movement of the pulse generator, or both may be required.

Here is an example of S-ICD lead repositioning. The patient was a 17-year-old man who developed VF and was resuscitated by an automated external defibrillator. He was diagnosed with ARVC based on the task force criteria [11] and underwent S-ICD implantation for secondary prevention of SCD. Alternate vector was selected for S-ICD sensing by exercise tests after S-ICD implantation, and the SP algorithm was activated. Six months later, an emergency alert was transmitted via remote monitoring to notify the occurrence of the event just before the shock delivery. A close examination immediately after the alert

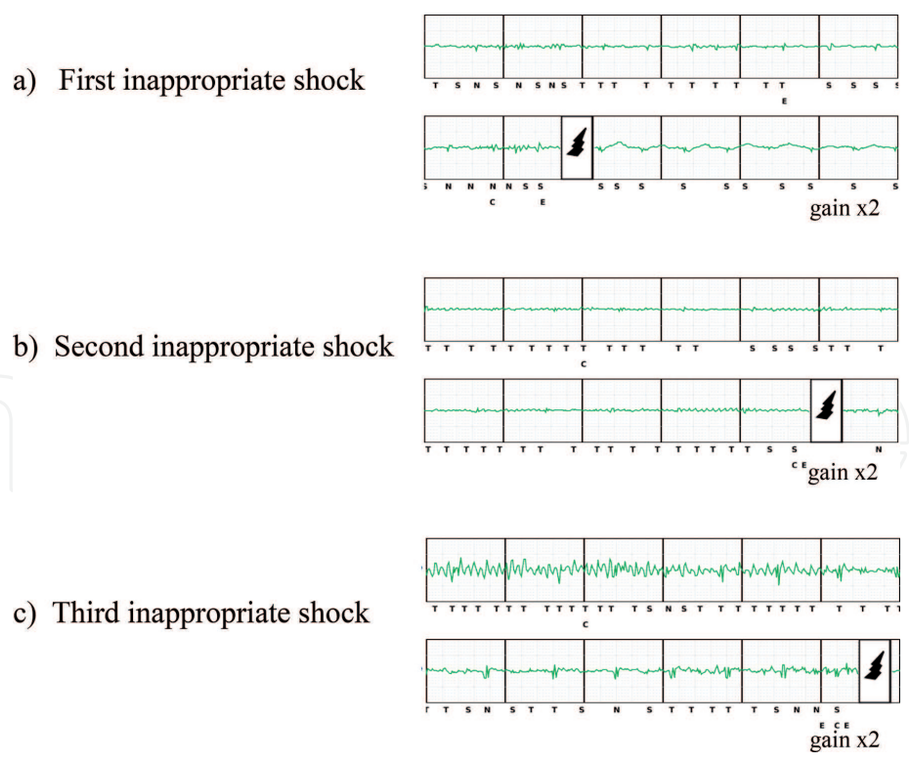


**Figure 2.**
*Subcutaneous electrocardiogram (S-ECG) at inappropriate shock (IAS) deliveries. (a) S-ECG during the first IAS. The first IAS occurred when the patient was wiping his hair with a towel after bathing. The S-ICD was set to use the primary sensing vector at the time of IAS, and the Smart pass (SP) algorithm turned off automatically due to attenuated QRS amplitude. (b) S-ECG during the second IAS. The sensing vector was changed to alternate vector based on the results of exercise test. The IAS occurred when the patient was operating the smartphone in the left lateral position. Same as the first IAS, the SP algorithm turned off automatically due to attenuated QRS amplitude. (c) S-ECG during the third IAS. The IAS occurred when the patient was resting on the bed. The SP algorithm could not avoid IAS due to high-frequency MPI.*

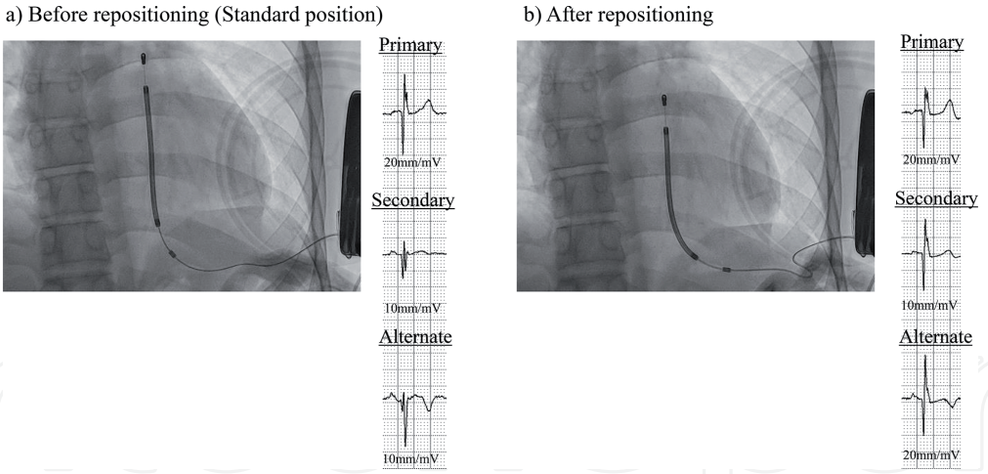


**Figure 3.**
*Comparison of fluoroscopic images before and after lead repositioning and changes in S-ECG. The previously implanted S-ICD lead was placed at standard position based on the result of AST (a) This lead was moved to the lower left and QRS amplitude of S-ECG increased in 2 (secondary and alternate) out of 3 sensing vectors (b).*

confirmed a decrease in QRS amplitude of S-ECG over time (**Figure 1**), and we changed sensing vector from the alternate vector to the primary vector. Seven months after the change of S-ICD sensing vector, the patient experienced a first IAS delivery. The S-ICD was set to use the primary sensing vector at the time of IAS, and the SP was turned off automatically due to attenuated QRS amplitude. S-ECG showed MPI that led to IAS delivery due to oversensing. After the changing the sensing vector to the alternate one, the patient had repeated IAS deliveries and eventually experienced IAS deliveries in all sensing vectors (**Figure 2**). Therefore, we performed an automated screening test (AST) on surface ECG again with a different electrode position. We performed an AST by moving the distal electrode approximately one intercostal space downward, and the proximal electrode was moved to the left, so that left ventricular electrocardiogram was more reflected on S-ECG. As a result, the QRS amplitude of S-ECG increased in 2 out of 3 sensing vectors and passed the AST. Thus, we performed repositioning of S-ICD lead under fluoroscopy (**Figure 3**). After repositioning of the S-ICD lead, the QRS amplitude of S-ECG increased and 2 (secondary and alternate sensing vectors) out of 3 vectors were suitable for S-ECG sensing, and there was no IAS for 15 months thereafter.

## 5. Limitation and future perspectives

As we described in the previous chapter, repositioning of the S-ICD lead to the lower left creates a new sensing vector that reflects more electrocardiograms of ventricular septum and left ventricle (**Figure 4**). Improved S-ECG sensing by the repositioning of the lead may be useful for patients not only with hereditary degenerative disease of the right ventricular myocardium such as ARVC, but also with acquired right ventricular myocardial damage such as right ventricular myocardial infarction. However, a concern in the method used in our case was that repositioned electrodes, especially the proximal electrode that was directly above or near the pectoralis major muscle, would be more vulnerable to MPI. Certainly, even after repositioning, slight MPI was observed in some sensing vectors, but it was possible to avoid MPI by selecting the optimal sensing vector based on the results of treadmill or other exercise test [12]. Furthermore, substernal tunneling method in

which the distal electrode is placed on the sternum may also be useful for avoiding IAS due to MPI (**Figures 5** and **6**). More experiences and long-term follow-up may be necessary in order to establish the usefulness of the S-ICD lead repositioning in patients with ARVC. Further studies are clearly warranted.

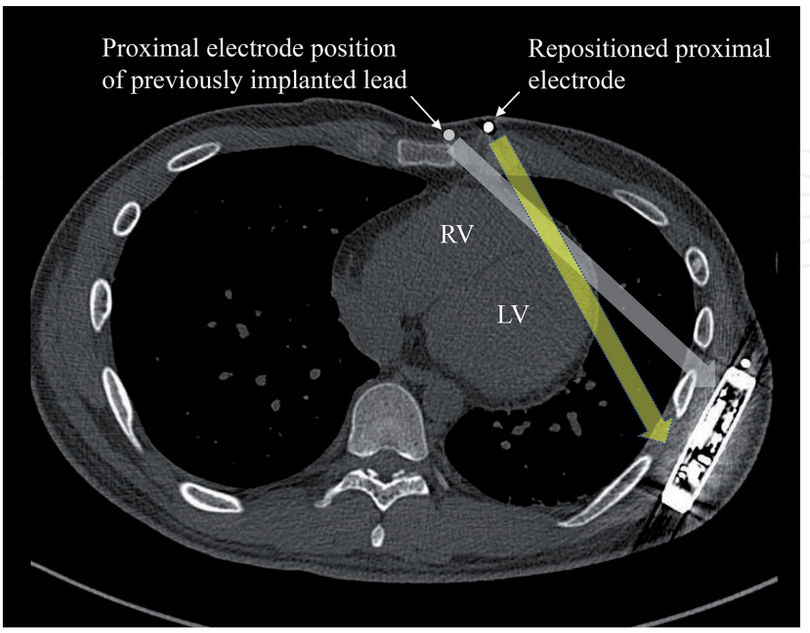


**Figure 4.**
*Computed tomographic images after lead repositioning. It can be seen that the sensing vector between the repositioned proximal electrode and pulse generator is mediated by more left ventricular myocardium than the previously implanted proximal electrode position. The electrode position of previous implanted lead is illustrated based on previously captured CT image.*

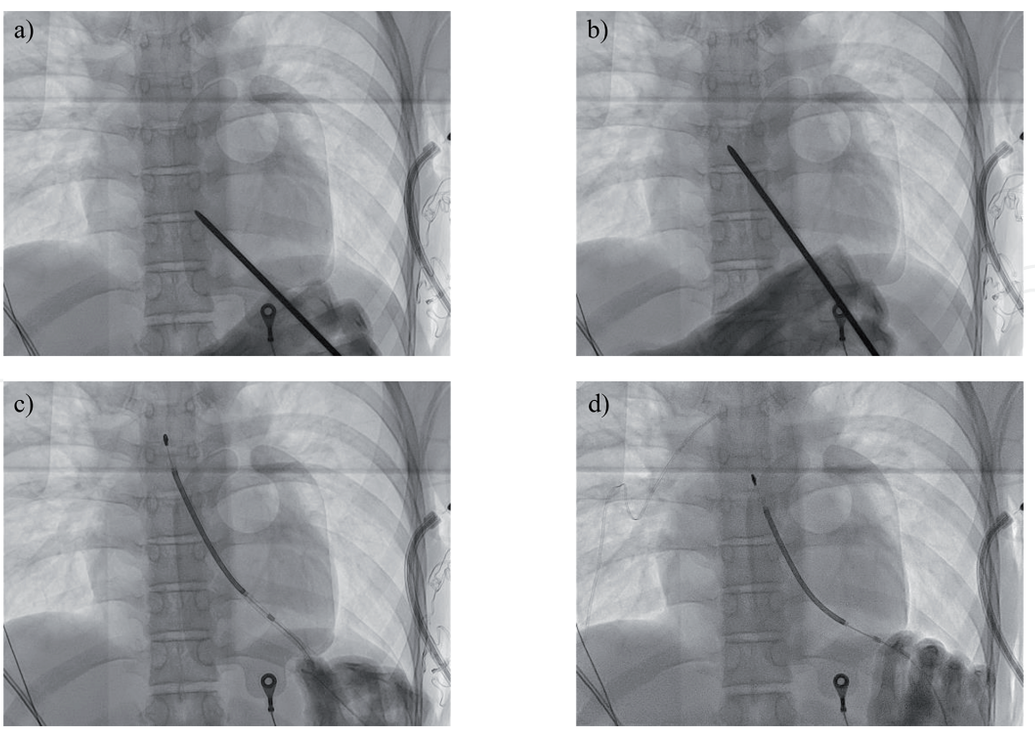


**Figure 5.**
*Method of substernal tunneling during lead repositioning. The tunneling method is shown in the order of (a to d) At first, the tip of the insertion tool was inserted diagonally to the right, and then gradually advance it toward cranial direction (a, b) After the tunneling tool was fully inserted, the lead was inserted into the introducer sheath as much as possible with two-incision technique (c) After peeling off the sheath, the lead was pulled back and placed at the pre-planned position (d).*

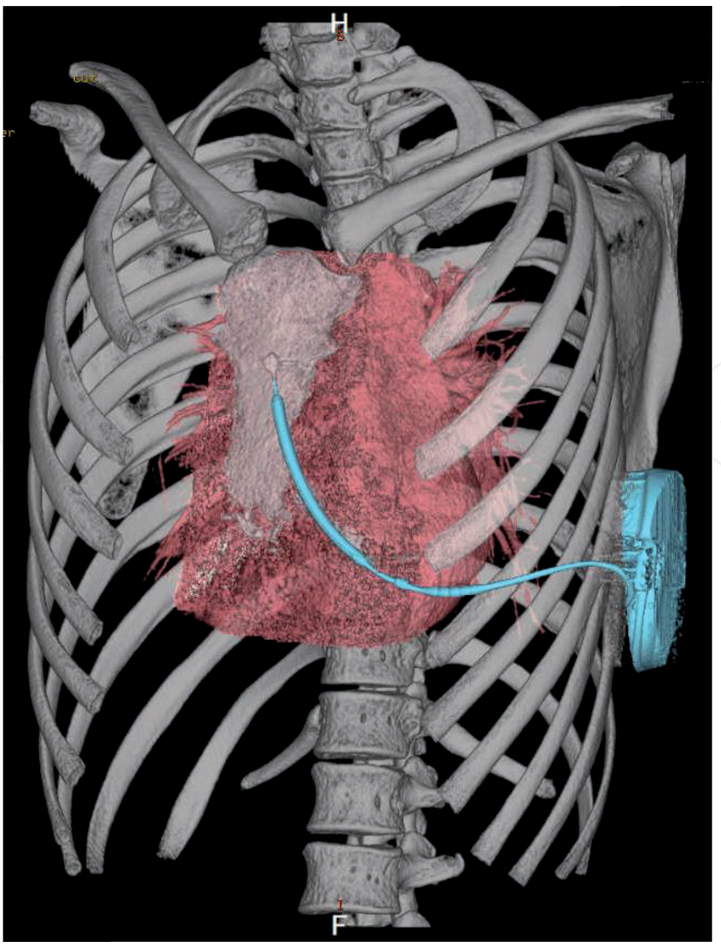


**Figure 6.**
*The 3D computed tomographic image in the left anterior oblique position after subcutaneous implantable cardioverter-defibrillator (S-ICD) implantation.*

## Conflict of interest

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