

Subcutaneous ICD: Current standards and future perspective

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ABSTRACT

The subcutaneous implantable cardioverter-defibrillator (S-ICD) system is an established therapy for prevention of sudden cardiac death (SCD) and an alternative to a transvenous implantable cardioverter-defibrillator (ICD) system in selected patients. Since introduction of S-ICD in 2010, the device has undergone further development. Based on the unique feature of an entirely extracardiac implantation, S-ICD is able to reduce the known common perioperative and long-term complications of conventional transvenous implanted ICD systems. Especially for patients with a complex anatomy and no option of an endovascular lead implantation, the S-ICD offers a potential alternative. Initial uncertainty existed, questioning whether this ICD approach would be reliable in detecting and terminating ventricular arrhythmias. Multiple clinical studies, however, provided evidence for an effective treatment. Based on obvious advantages compared to conventional ICD systems, the question arises whether the S-ICD should actually be the first choice in the majority of all primary prevention patients in the future. Recent data from large registries show that S-ICD indications are also expanding in secondary prevention patients. As a consequence, the S-ICD was listed in the 2015 ESC guidelines as an alternative therapeutic option with a class-IIa recommendation in patients with an ICD indication not requiring pacing for bradycardia, cardiac resynchronization therapy or anti-tachycardia pacing (ATP). In addition, the American Heart Association guidelines refer to class-I recommendation for patients with a complex anatomy and venous access problems or at a high risk for infections who need ICD therapy. Limitations with respect to the not available pacing option of S-ICD might be also overcome by a potential combination with a leadless pacemaker in the near future. This article provides an overview of recent developments of S-ICD and reviews the most recent literature and ongoing studies.

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1. Introduction

The implantable cardioverter defibrillator (ICD) is an established therapy for the prevention of sudden cardiac death [1–3]. Since the introduction of the ICD in 1980 by Michael Mirowski, ICD technology has undergone continuous development. In addition to reduction of generator size and prolonged battery longevity, the focus was set on various function and therapy algorithms. Device-associated problems and complications are relevant and may have serious consequences on prognosis. These problems also occur in long term and then usually relate to problems with transvenous leads. Surgical revision is not uncommon facing a failure rate of transvenous leads of up to 40% in 8 years [4]. In addition to lead fractures, inappropriate shocks, access problems in vascular occlusions, there is also the complication of lead-associated systemic infections with lead endocarditis. Subcutaneous ICD (S-ICD), with its complete extra-thoracic and extra-vascular localization,

therefore represents a significant advantage, particularly with respect to lead-associated issues. Problems like complex venous accesses, lead fracture or lead-related endocarditis can be avoided. Especially for young patients with a longer life expectancy, bearing a higher cumulative risk for lead-associated complications, the S-ICD offers a valid and relevant alternative. Since 2009, the S-ICD has undergone further development. A significant reduction of device size, an increased battery longevity and improved detection algorithms allow prevention of inappropriate shocks.

The objective of this article is to provide an overview of the development of the S-ICD during the last decade, update on surgical techniques, review of the most current research as well as perspectives for the future.

2. Description of the system

The system of the S-ICD as such is built in analogy to conventional ICD systems, consisting of two components, the generator and a defibrillation lead. The 45 cm long lead is isolated with polyurethane and has a distal and a proximal sensing ring electrode. Including the generator serving as a separate pole, three distinct sensing configurations are

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possible, which allow the analysis of the cardiac rhythm and the detection of ventricular arrhythmias. The actual shock coil is 8 cm long. In combination with the generator the shock polarity can be chosen as coil-to-generator (standard) or generator-to-coil (reverse). The system automatically saves and chooses the last successful shock polarity as a default setting. An adaptive shock polarity function allows the automated switch of the polarity after a failed therapy. The first-generation generator had a volume of 69.9 cm³ and had a weight of 146 g, being twice as heavy and double in a size as a conventional ICD generator. The estimated battery longevity was 5 years. The advancement to the 2nd generation EMBLEM™ S-ICD came along with a reduced size by 20% and improved battery life span by 40%. In addition, telemedicine monitoring was enabled in the new version via the LATITUDE™-system.

In comparison with conventional systems, the subcutaneous ICD provides a sole shock therapy. The system can deliver a maximum of 5 shocks per episode with 80 J biphasic each, whereas a so-called overstimulation ("anti-tachycardia pacing", ATP) is not possible. The shock zone can be programmed in a range of 170–250/min. A post-shock-stimulation is possible for a maximum of 30s with 50/min demand-based.

The device provides a diagnostic feature, which allows storage of >40 arrhythmic events. In addition, regular up-dated data on lead impedance and system status, remaining battery lifespan, and warning notes can be retrieved. For appropriate detection of arrhythmias and prevention of inappropriate shocks a further developed morphology algorithm ("SMART-PASS") as well as a special high-pass-filter was established and implicated in the system, which reduces potential interfering signals in 9 Hz range. The SMART-PASS sensing filter is an advanced algorithm that filters out certain signals that are the primary reason for inappropriate shocks. In transvenous ICD patients, supraventricular arrhythmias are the main cause for inappropriate discharges, whereas T wave oversensing (Fig. 1) is the main cause in S-ICD patients. The S-ICD SMART-PASS incorporates a high-pass filter (9-Hz) and filtering reduces the amplitude of lower-frequency (slower-moving) signals such as T waves, by applying an additional high-pass filter. For higher-frequency (faster-moving) signals such as R waves, amplitudes remain almost unchanged. Since the frequency targeted by SMART-PASS is the T wave, inappropriate operation from myopotentials cannot be prevented by SMART-PASS.

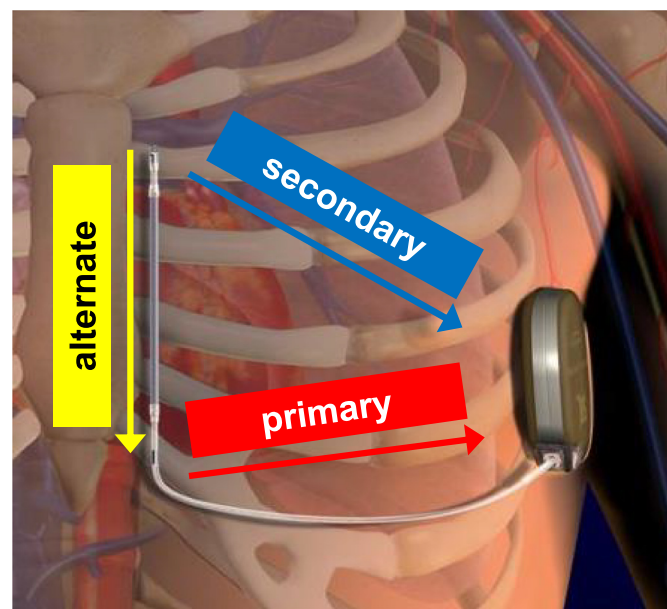


Fig. 1. The S-ICD provides three distinct sensing vectors for arrhythmia detection and discrimination: primary vector (from proximal electrode ring to can), secondary vector (from distal electrode ring to can) and alternate vector (from distal to proximal electrode ring).

3. Implantation

S-ICD utilize one of three electrograms recorded between two sensing electrodes and the pulse generator for ventricular sensing (Fig. 2). In certain patients, subcutaneous electrograms are inadequate for sensing. S-ICD requires preimplant screening to ensure appropriate sensing and reduce risk of inappropriate shocks. Screening can be performed using either the manual screening tool or a novel automated screening tool (AST) with an ICD programmer (Boston Scientific). Screening should be performed in supine and sitting/standing positions. The technique of implantation of S-ICD differs in many aspects from the procedure of conventional transvenous systems, mainly by the purely extra-thoracic position of the generator and lead. While the implantation was performed almost exclusively in general anesthesia in the beginning, the intervention is mostly performed in conscious sedation in combination with analgesia or pure local anesthesia nowadays. According to the anatomical landmarks the desired generator and lead position is marked before the procedure, thereby allowing a non-fluoroscopic procedure.

The anticipated pocket of the generator was initially thought to be at the insertion of the fascia of musculus latissimus dorsi subcutaneously. However, after gaining some experience and adaption of the technique the generator positioning underwent a change with placement preferably in an intramuscular position, between the musculus latissimus dorsi and on top of musculus serratus anterior. This technique change was based on cosmetic, but also especially defibrillation-specific reasons.

Furthermore, the technique of lead-implantation was also adapted, omitting the caudal manubriosternal incision, thereby switching the a so-called "two incision technique" [5]. Using the intermuscular two-incision technique avoids the superior parasternal incision for the lead placement and consists of creating an intermuscular pocket between the anterior surface of the serratus anterior and the posterior surface of the latissimus dorsi muscles instead of a subcutaneous pocket. Intermuscular two-incision technique offer a better cosmetic outcome, especially for female and younger patients. In our centre S-ICD implantation procedures are performed with local anesthesia under conscious sedation using two-incision and intermuscular technique [6].

4. Current studies

The Investigational Device Exemption (IDE) study was completed in 2011 providing the basis for the approval of the first device generation in 2012 by the Food and Drug administration (FDA). The aim of the study was the assessment of safety and effectivity of ventricular arrhythmia by S-ICD system. The results of the study of 314 patients, equipped with a S-ICD, showed that the system could be used in treating life-threatening ventricular arrhythmias during a follow-up period of 11 months. With respect to safety the 180-days-complication-free rate was shown to be 99%, while in >90% of cases all episodes of ventricular fibrillation were successfully terminated [7].

After the device was launched in 2009, the international, non-randomized, multicenter registry EFFORTLESS S-ICD (Evaluation of Factors Impacting Clinical Outcome and Cost Effectiveness of the S-ICD System) was introduced. This registry enrolled 985 patients. Follow-up data was collected systematically over 5 years after implantation to evaluate factors affecting clinical outcome and cost-effectiveness of the S-ICD system. The primary endpoint was freedom from any complications between 30 and 360 days after implantation. The first experiences with the S-ICD already showed a complication-free rate of 99.7% after 30 days and 98% after one year [8]. After a median observation period of 3.1 years, the registry revealed that 97.4% of all tachycardia episodes were successfully terminated [9]. The mean age of patient enrolled was 48 years in the study cohort and 65% of the implantations were performed based on a primary prevention indication. System changes were required in 9 patients, mainly due to a new pacemaker indication in majority of these cases. The 1- and 5-year rates of

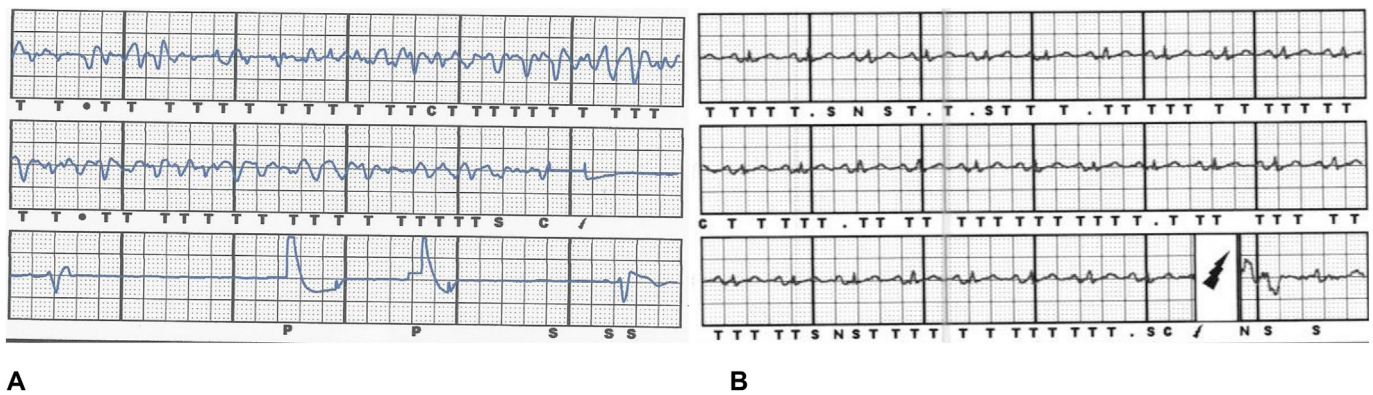


Fig. 2. A: Sensing and detection of ventricular fibrillation (VF) treated by appropriate S-ICD shock therapy. First C denote capacitor charging, second C denotes end of capacitor charging. S = Sensing T = Tachycardia P = Post-Shock-Pacing. A dot indicates sensing of an unclassifiable event that is discarded. B. Demonstrating oversensing of P and T waves resulting in an inappropriate shock therapy.

appropriate shock therapies were 5.8% and 13.5%, respectively. However, inappropriate therapies occurred in 8.1% at one year and 11.7% after 3.1 years. Based on these results and the overt advantages of the S-ICD system, S-ICD therapy was first implemented in the current European guidelines as an alternative to a VVI-ICD in 2015, unless there is an overt bradycardic pacemaker indication [10]. In addition, since November 2017, there has been a Class-I indication for S-ICD implantation in patients with difficult vascular access or a high risk of infection (and no pacemaker indication) according to the guidelines of the American heart association [11].

In total, the lead-induced problems are observed less in the S-ICD. This is also confirmed by the recently published data of 1160 patients in which S-ICDs and transvenous ICDs were implanted in two centers of the Netherlands [12]. Lead-complications were observed significantly less frequent in the S-ICD group compared to in the conventional transvenous group (0.8% vs 11.5%), while total complication rate of 13.7% in S-ICD group vs. 18% in the transvenous group did not show a significant difference. Still, S-ICD patients showed more non lead-associated complications compared to patients with a transvenous ICD-systems (9.9% vs 2.2%; $p = 0.047$), e.g., skin erosions and sensing problems. The general infection rate in S-ICDs was 4.1% vs. 3.5% in the transvenous ICD-group ($p = 0.36$). The median age of patients in this study was 41 years of age with 40% female proportion.

According to a retrospective analysis of 393,734 ICD implantations from the US ICD registry, S-ICD patients are younger, more often female, more frequently dialysis-dependent, and more often have a previous surviving sudden cardiac death compared to transvenous ICD patients [13]. Use of the S-ICD increased from 0.2% in 2012 to 1.9% in 2015 over the period from September 2012 to March 2015. A matched analysis showed comparable intra-hospital complication rates (S-ICD 0.9% vs. transvenous ICD 0.6%) as well as similar data on the duration of the average hospital stay [14].

The first prospective-randomized study to S-ICD, the PRAETORIAN (Prospective, Randomized Comparison of Subcutaneous and Transvenous Implantable Cardioverter Defibrillator Therapy) is currently still ongoing (<https://clinicaltrials.gov/ct2/show/NCT01296022>) [15].

In this prospective-randomized controlled study the advantages and disadvantages of S-ICD compared to a conventional transvenous ICD are investigated.

In view of the currently available data of studies and registries the S-ICD seems to be non-inferior to conventional systems with respect to efficacy and safety [7–9].

5. S-ICD patient selection

In principle, all patients with a one-chamber ICD indication are eligible to a S-ICD after the underwent a positive screening. Reasons to

withhold an S-ICD from a patient requiring an ICD are currently under an ongoing debate, e.g., the presence of a documented VT of <170/min being approachable for an ATP therapy. However, there are cases described in which S-ICD were absolutely required due to an increased infection risk and VT ablation was performed to lower the risk of occurrence of a regular ventricular tachycardia in the future [16]. The most common reason to implant a conventional transvenous system is the presence of a bradycardia representing a pacemaker indication. Patients with channelopathies, e.g., Brugada- or short-QT-syndrome, as well as patients with a hypertrophic cardiomyopathy seem also to be suitable for a S-ICD. Especially young patients with a long-life expectancy, as well as patients with risk of infections due to known risk factors, e.g., diabetes mellitus or dialysis-dependent kidney disease, should be explicitly considered for a S-ICD, to prevent lead-associated complications in the future [17].

6. Future perspectives with leadless pacemaker

The lack of a stimulation function of the S-ICD as well as the non-existing anti-tachycardia pacing therapy via ATP are the main limitation at the moment. In this context the anticipated combination with a leadless pacemaker is much awaited. Cardiac device therapy is expected to be further revolutionized by a combination of these two novel elements of a S-ICD and lead-less pacemaker, representing the next logical step in the optimal device rhythm-management of complex patients in the future. By combination of the S-ICD with a leadless pacemaker, it will be possible to add a pacing function on top of the S-ICD. The question will arise if the S-ICD will then become the device of first choice. Challenges will be the device-to-device communication ensuring a reliable anti-bradycardia and painless anti-tachycardia therapy without the risk interfere with required shock therapies.

7. Conclusion

The S-ICD device underwent a further development since its introduction. Cumulative evidence was provided establishing the S-ICD as a valid alternative therapy to conventional ICD system, and a favorable option for patients with vascular access problems or high infection risk. Future developments including the combination with a leadless pacemaker are awaited laying down further perspectives for a broader patient group.

Declaration of competing interest

Reza Wakili has received consultant fees and speaking honoraria from Medtronic, Biotronik, Boston Scientific; funding for research projects (initiated by him) from Bristol-Myers Squibb, Pfizer, and Boston Scientific.

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