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S-ICD: DEVICE POSITION MATTERS

This clinical update firstly reviews a recent cost-efficacy analysis of transvenous lead extraction. This is followed by a discussion of data showing the potential for the use of S-ICD in patients with coronary artery disease (CAD), a subgroup of patients for whom data are lacking. Finally, the lowest inappropriate shock rates reported to date, and data highlighting the importance of optimal device placement, are discussed.

1. THE COST OF TRANSVENOUS LEAD EXTRACTION

A previous cost efficacy analysis, by Honarbakhsh *et al.*, concluded that the higher initial cost of S-ICD compared with TV-ICD is likely to be mitigated by the increased cost of treating device-related complications with TV-ICD over time.[1] Most recent data report lead extraction rates as 29 per million inhabitants (Germany and Austria), and 27 per million inhabitants (Poland) in 2015.[2] However, data relating to the total cost of transvenous lead extraction are limited; partly because lead extraction is complex, and the exact use of resources during extraction is often excluded from consideration.[3]

Lead extraction in the UK

Brough *et al.* calculated the true costs of transvenous lead extraction at a single centre in the UK and defined the difference between the cost incurred and the reimbursement for transvenous lead extraction at patient level. The centre used a service line reporting system to track detailed costs associated with length of stay, procedure duration, clinical activity and consumables for all transvenous lead extractions during financial year 2013/4.[3]

Lead extractions were performed in 74 patients (a number representing an extraction rate of 25 per million inhabitants), with infection the most frequent indication for extraction (n=47, 64 %). In patients without infection, non-functional leads accounted for 81 % of extractions, and of those 27 % had a lead under an advisory.[3] Patients with lead infections were significantly older than those without infections (median age 74 years vs 50 years, $p<0.0001$). Of the devices extracted, 46 % were pacemakers, 23 % were ICDs and 31 % were CRTs. Device implantation duration was 0–26 completed years, with 47 (64 %) devices implanted for more than five years.

Complete clinical success (removal of all target leads and lead material from the vascular space or retention of a small portion of the lead, without negative outcomes) was achieved with 148 (95 %) leads. One patient needed an emergency conversion to open extraction, and another needed surgical oversewing of the vascular access site. Further complications occurred only in the infected subgroup: two were major complications (two cardiac avulsions), and two were minor (one subclavian thrombosis and one blood transfusion).[3]

The post-extraction mortality rate was 8 % in the first year and 4 % in the first 30 days post-extraction. In the first 30 days, three patients died: two with endocarditis and one with a localised infection; the 30-day readmission rate was 8 %.[3]

Tariff-based reimbursement for lead extraction is inadequate

The total inpatient extraction cost was £682,892, translating to a mean patient cost of £9,228 ± £4,099. When reimplantation cost was included, total cost rose to £1,300,509 (translating to a mean patient cost of £17,574 ± £12,822). The main cost drivers were consumables, bed costs and physician costs, which together accounted for 61 % of the total. Overall, the median length of stay in hospital was three days but was longer for patients with infection (median seven days) than without (median one day). Longer hospital stays contributed to increased bed costs for patients with infections compared with those without.[3]

In patients with infections, the mean cost per extraction was £10,727, rising to £22,615 when including reimplantation costs. During the study period, the national tariffs for acute and elective extractions were £4,764 and £2,530: less than half of the true total cost. This disparity placed a significant financial burden on the extraction centre, even before the reimplantation cost was considered. Including the reimplantation costs, the deficit over the one-year study period was over £600,000.[3]

UK national tariffs cover less than half of the total cost of transvenous lead extraction.

These data demonstrate that there is a substantial difference between the true cost of transvenous lead extraction procedures and the UK tariff. This is likely to be the case in other countries too, although this will depend on their individual cost drivers and reimbursement models. In any case, the high costs of possible lead extraction should be considered when assessing cost-benefit ratios for TV-ICDs.[3] Alternative solutions, such as S-ICD, should be considered as primary prevention against TV-ICD infection and reoperation, reducing the financial burden and positively influencing the quality adjusted life year calculations for the benefits of device therapy.

2. S-ICD USE IN PATIENTS WITH CORONARY ARTERY DISEASE

The use of S-ICD in patients meeting the criteria for an ICD and who have inadequate vascular access or are at high risk of infection has a Class I recommendation in American Heart Association, American College of Cardiology and Heart Rhythm Society guidelines.[4] Despite this recommendation, long-term data are limited in patient subgroups, such as those with CAD.[5]

While patients with CAD are at a high risk of infection, CAD can sometimes lead to ischaemic cardiomyopathy (ICM). Scars resulting from ICM are potential substrates for ventricular tachycardia (VT), which may require anti-tachycardia pacing (ATP). Therefore, the use of S-ICD in this patient subgroup has been questioned.[5]

Willy *et al*. reported outcomes from 45 patients with CAD from a single centre, receiving an S-ICD for primary or secondary prevention of sudden cardiac death. Of these patients, 15 (33.3 %) received an S-ICD following extraction of a TV-ICD resulting from lead-related endocarditis, and 28 patients (62 %) were implanted because of primary prevention (left ventricular ejection fraction [LVEF] ≤35 %). Mean follow-up was 22.5 ± 8.3 months, with no S-ICD system-related infections reported during this time.[5]

Three patients experienced three appropriate shocks. In all cases, ventricular arrythmia was terminated with the first shock. Despite concerns that patients with ICM would be more prone to monomorphic VT because of their myocardial scarring, only one episode of monomorphic VT was treated in this study, although five VT episodes self-terminated before therapy was delivered.[5]

Three patients required replacement of their S-ICD due to battery depletion, after a median of six-and-a-half years. A further two patients changed to a TV-ICD: one who developed a need for cardiac resynchronisation therapy and one who developed a need for anti-bradycardia pacing.

Inappropriate shock occurred in only one patient (2.2 %). This was due to T-wave oversensing, which was resolved by changing the sensing vector. This IAS rate is lower than previously reported, even in patients with SMART Pass filters enabled (4.3 %).[6]

The authors concluded that due to its high efficacy and low event rate, S-ICD is a potential first option for primary prevention of sudden cardiac death in patients with ICM, and a valuable alternative in patients with lead-related infective endocarditis, in whom S-ICD caused no further infection.[5]

S-ICD could be the first-choice treatment for primary prevention of sudden cardiac death in patients with CAD and ICM.

3. S-ICD PERFORMANCE

a) Multicentre experience with optimised implantation techniques and the second-generation S-ICD

The most recent advances in S-ICD technology are the second-generation (EMBLEM) S-ICD and the optimisation of the implant via the intermuscular (creation of the pocket between the anterior surface of the serratus anterior and posterior surface of the latissimus dorsi muscles) and two-incision (removal of the superior parasternal incision) implantation techniques. Migliore *et al.* reported mid-term outcome data from a large population of patients with EMBLEM S-ICDs implanted using the intermuscular and two-incision techniques.[7]

In this retrospective, multicentre study, 101 consecutive patients received an EMBLEM S-ICD (EMBLEM model A209 or EMBLEM MRI model A219), of whom 29 % received the S-ICD for secondary prevention of sudden cardiac death and 24 % had had a previous TV-ICD. Left ventricular dysfunction (LVEF ≤ 50 %) was present in 44 % of patients.[7]

The intermuscular, two-incision S-ICD implantation procedure was carried out under local anaesthesia with sedation in most patients (n=75, 74 %). General anaesthesia was used in 24 (24 %) patients, and ultrasound-guided serratus anterior plane block in two (2 %) patients. Defibrillation testing was done in 80 (79 %) patients, with a successful VT conversion rate of 98.8 % at ≤ 65 J.[7]

Median follow-up was 21 months, during which no local or systemic infections were reported. A total of 31 appropriate and successful shocks were recorded in 10 patients. The inappropriate shock rate was very low, with only three patients (2.9 %) experiencing an inappropriate shock; one was managed with catheter ablation, one was managed with device reprogramming, and the third required device extraction and replacement with a TV-ICD.[7] No patients had the device removed because of a perceived need for ATP or bradycardia pacing.

The EMBLEM S-ICD implanted using the two-incision and intermuscular techniques is effective, with low rates of complication. The rates of inappropriate shocks in this analysis were extremely low at just 2.9 %.

In conclusion, S-ICD implantation using intermuscular and two-incision techniques resulted in no postoperative complications needing surgical revision, and no device-related infections. These data demonstrate that the S-ICD has good efficacy in terminating arrhythmias, and a low inappropriate shock rate.[7]

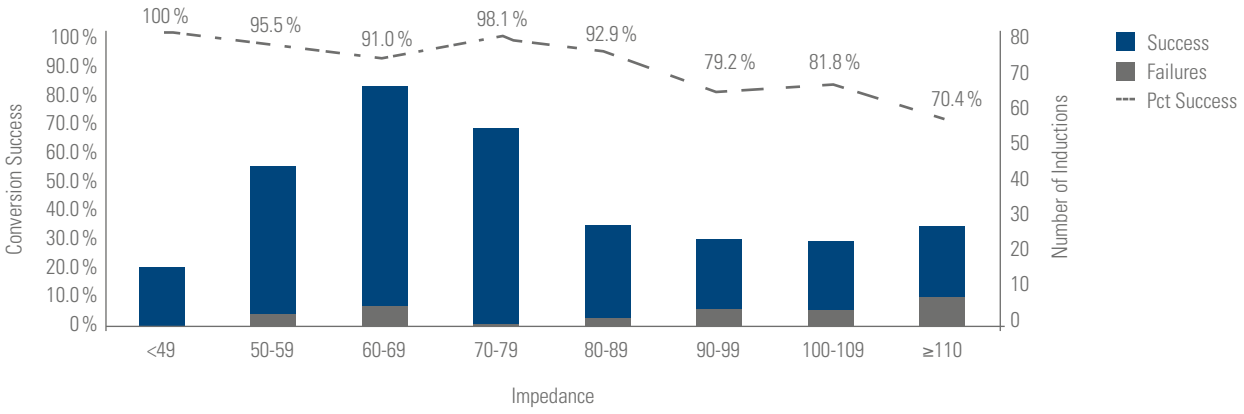
b) Factors associated with high-voltage impedance and S-ICD conversion success

Defibrillation testing is Class I recommended for patients undergoing S-ICD implantation. However, its risk of complications and the need for heavy patient sedation during this testing means it may occasionally be omitted.[8] Having the ability to predict defibrillation efficacy at the time of implant without the need to induce ventricular fibrillation (VF) may eliminate or reduce the need for defibrillation testing in these high-risk patients.[9]

Amin *et al.* analysed the association between high-voltage (HV) impedance (a measurement of the resistance between the S-ICD coil and generator) and ventricular fibrillation conversion success rates in a group of 282 patients from the Investigational Device Exemption (IDE) trial, of whom 81.1 % received an S-ICD for primary prevention of sudden cardiac death.[9] HV impedance is dependent on generator-lead distance, body tissues between the electrode and the generator, and, particularly, on adipose tissue.[9]

The authors aimed to determine whether HV impedance is independently associated with VF conversion success at 65 J. Conversions at 65 J were recorded in 637 inductions, with 62 conversion failures in 42 (14.9 %) patients. First shock efficacy was highest for impedances ≤89 Ω (Figure 1). Low body mass index (BMI) and low high-voltage impedance were associated with a higher conversion success rate.[9]

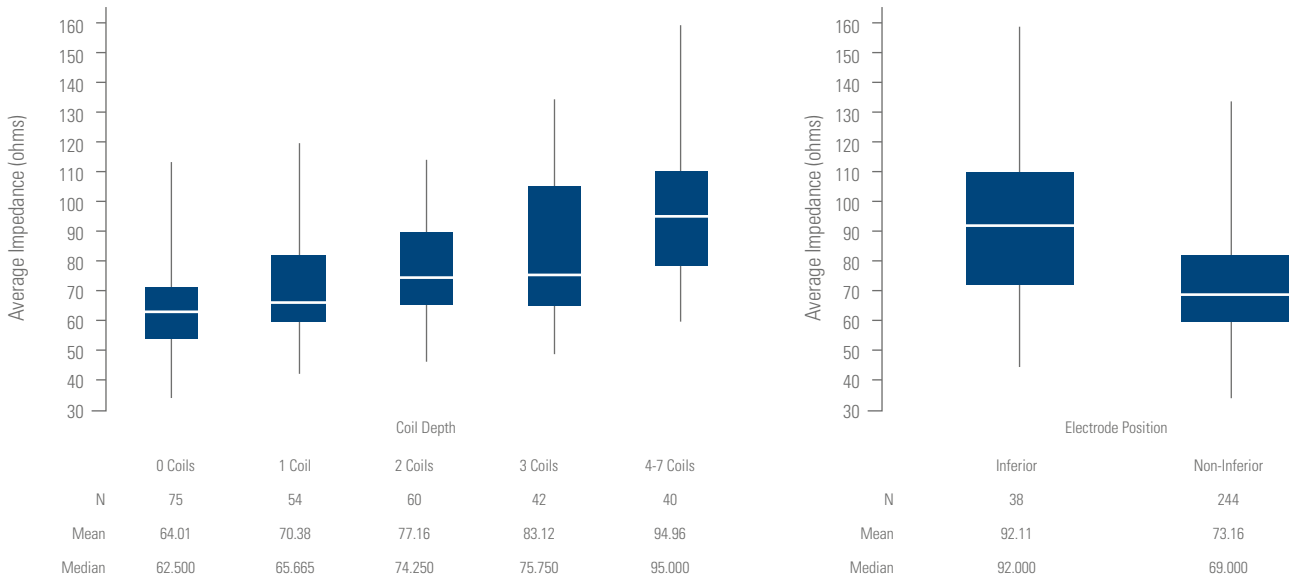
Figure 1. Conversion success by impedance: first test (65 J) in the final position.[9]



Pct success indicates percentage of success.
Figure courtesy of Dr. Amin, OhioHealth Heart and Vascular Physicians.

Amin *et al.* also analysed the association between device position and HV impedance, using post-implantation chest radiography. In patients with optimal device positioning and average impedance (<90 Ω), the first shock success rate was 94.7 %. Inferior device positioning or inadequate coil depth was associated with higher impedance and a lower conversion success rate than optimal positioning (79.5 % vs 94.7 %, p=0.0002) (Figure 2).[9]

Figure 2. Impedance by coil depth (left) and electrode position (right).[9]



Coil depth: the number of additional coil depths from the sternum.
Figure courtesy of Dr. Amin, OhioHealth Heart and Vascular Physicians.

Inferior device positioning and subcutaneous fat underneath either the coil or the generator is associated with higher impedance and a lower shock conversion rate.

In patients with a high BMI (≥30 kg/m^2), appropriate device positioning was achieved in only 21 (20.0 %) patients. This is compared to appropriate positioning in 84 (50.6 %) patients with a BMI less than 30 kg/m^2 (p<0.001). When appropriate system positioning was achieved, high BMI was not associated with conversion failure, with a successful first conversion rate of 95.2 % in both groups (p=1.0) and total conversion success rates of 95.2 % in the high BMI group and 90.5 % in the lower BMI group (p=0.68) (Table 1).[9]

Table 1. Device position by BMI.[9]

	System Position					
	Appropriate Position			Suboptimal Position		
	Noninferior Electrode and PG, Coil Depth ≤1 mm (n=105; 38.8 %)			PG or Electrode Inferior or Coil Depth >1 mm (n=166; 61.3 %)		
	BMI >30 kg/m^2 (n=21; 20.0 %)	BMI <30 kg/m^2 (n=84; 80.0 %)	*P* Value	BMI >30 kg/m^2 (n=84; 50.6 %)	BMI <30 kg/m^2 (n=82; 49.4 %)	*P* Value
Impedance, Ω	72.3 ± 20.3	64.9 ± 13.9	0.05	87.9 ± 23.0	75.2 ± 17.9	<0.0001
First VF conversion successful	20 (95.2 %)	80 (95.2 %)	1.00	73 (86.9 %)	73 (89.0 %)	0.81
All VF conversion successful	20 (95.2 %)	76 (90.5 %)	0.68	68 (81.0 %)	68 (82.9 %)	0.84

BMI: body mass index; PG: pulse generator; VF: ventricular fibrillation.
Figure courtesy of Dr. Amin, OhioHealth Heart and Vascular Physicians.

These data show that both HV impedance and system positioning were associated with defibrillation efficacy, and that implantation of the device in the recommended location (positioning of electrode close to the sternum, with the device close to the chest wall, in a posterior position) could improve the rate of conversion success.

c) The PRAETORIAN score to evaluate implant position and predict defibrillation success

Quast *et al.* have developed a non-invasive scoring system, the PRAETORIAN score, which uses routine post-operative chest radiographs to evaluate implant position and identify those at risk for unsuccessful conversion.[10]

The score consists of three steps:[10]

1. Assessment of the amount of adipose tissue insulating the shock coil (Panel 1; Figure 3).
2. Assessment of the generator position to ensure that the electric field is directed towards the critical mass of the heart (Panel 2; Figure 3).
3. Measurement of the amount of adipose tissue between the generator and the thorax (Panel 3; Figure 3).

The individual components are multiplied to give the final PRAETORIAN score. The minimum score is 30 (≤1 coil width of adipose tissue [30 points], generator positioned on the midline [x1] and <1 generator width of fat between generator and thorax [x1]). The maximum score is 900 (Figure 3).[10]

Figure 3. The PRAETORIAN score.[10]

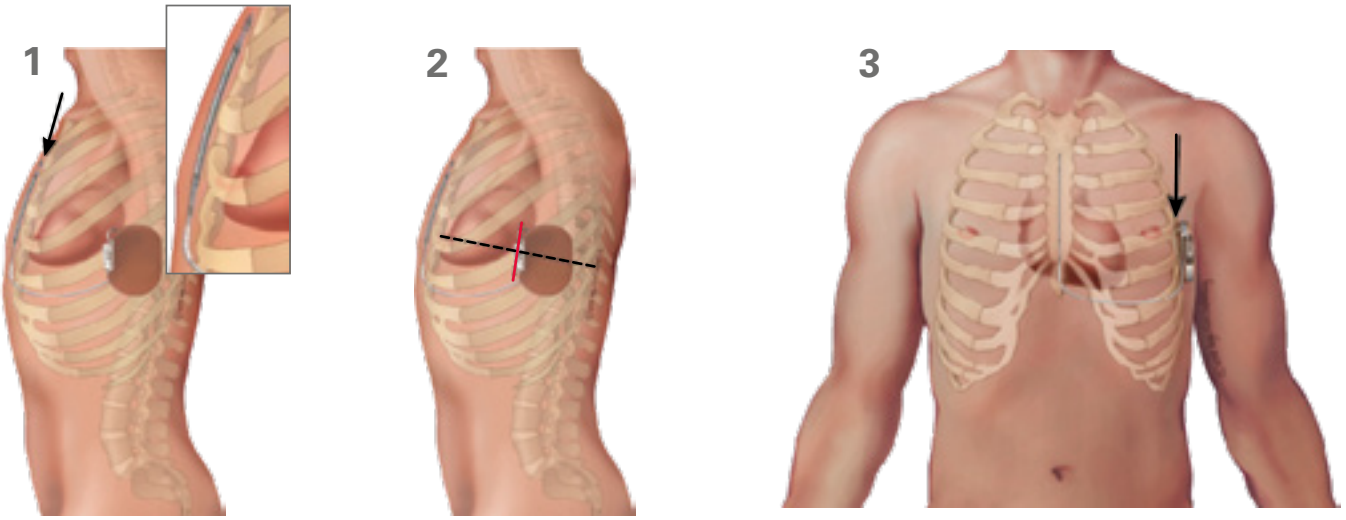


Figure courtesy of Dr. Quast, Academic Medical Center, University of Amsterdam.

Step 1)
Determine the number of coil widths of fat tissue between the **nearest** half of the S-ICD coil and the sternum or ribs.

≤ 1	coil-width	**30**
> 1 ≤ 2	coil-widths	**60**
> 2 ≤ 3	coil-widths	**90**
> 3	coil-widths	**150**

Step 2)
Determine the position of the S-ICD generator in relation to the mid-line (**red line**).

Generator is on or posterior of the mid-line	**x1**
Entire generator is anterior of the mid-line	**x2**
Entire generator is > 1/2 length anterior	**x4**

Step 3)
Detetrmine the amount of fat tissue between the **nearest** point of the generator and the thoracic wall.

< 1	generator-width	**x1**
≥ 1	generator-width	**x 1.5**

Step 4)
PRAETORIAN score ≥ 90:

BMI ≤ 25 kg/m^2	**- 40**
BMI ≥ 25 kg/m^2	**= Final score**

Final PRAETORIAN score

< 90	**Low risk of conversion failure**
90 < 150	**Intermediate risk of conversion failure**
≥ 150	**High risk of conversion failure**

The PRAETORIAN score: Step 1 determines the amount of subcoil fat by assessing the thickness of the adipose tissue between the coil and the sternum or ribs by using the coil width as a reference. Step 2 determines whether the generator is positioned on, or posterior to the midline (red line). As a reference, the long axis of the generator is used. Step 3 determines the amount of subgenerator fat by using the generator width as a reference, and in case one generator width of adipose tissue is present between the generator and the thorax, the score is multiplied by 1.5. Patients with a BMI of ≤ 25 kg/m^2 are rewarded by subtracting 40 points in the case of a score of ≥ 90 in step 4. This results in a final PRAETORIAN score and risk of conversion failure.

The final PRAETORIAN scores are divided into three categories, with the lower the score the better the device position:[10]

1. Less than 90: low risk of conversion failure.
2. Between 90 and 150: intermediate risk of conversion failure.
3. 150 or more: high risk of conversion failure.

The authors retrospectively validated the PRAETORIAN score by correlating this with shock efficacy from the Academic Medical Centre, Amsterdam data set (n=181) and the IDE data set (n=321). The positive predictive value (the percentage of patients with a high PRAETORIAN score who fail conversion testing) was 51.0 %. The negative predictive value (the percentage of patients with a low PRAETORIAN score who have a successful conversion test) was 99.8 %. This means that the PRAETORIAN score is almost entirely effective in identifying those patients whose device positioning means they are at higher risk of unsuccessful defibrillation.[10] The sensitivity and specificity for the PRAETORIAN score are 95 % and 95 %, respectively.[10]

The PRAETORIAN score gives feedback on device position to implanters and identifies patients with high defibrillation thresholds. A prospective validation of the score is ongoing in a randomised clinical trial – PRAETORIAN-DFT (NCT03495297).[10]

PRAETORIAN score is a non-invasive method of evaluating the S-ICD implantation position and potential predictor of successful conversion.

SUMMARY

- The total cost of transvenous lead extraction, and subsequent ICD reimplantation has been underestimated. True costs are substantially burdening extraction centres.
- The potential cost of lead extraction should be considered when using TV-ICDs, S-ICD, should be considered as primary prevention against TV-ICD infection and reoperation, reducing the financial burden and positively influencing the quality adjusted life year calculations for the benefits of device therapy.
- S-ICD has been demonstrated to be a suitable therapy in a wide range of patients, including as a potential first-choice therapy for primary prevention of sudden cardiac death in patients with CAD and ICM.
- When good implantation techniques are used, the S-ICD confers excellent efficacy and a low inappropriate shock rate.
- Inferior device positioning, and adipose tissue beneath the electrode and the generator, reduce conversion success rate compared with optimal device positioning.
- The PRAETORIAN score has been developed to evaluate device positioning and identify those at risk of unsuccessful conversion, further validation of this tool is ongoing in the randomised clinical trial – PRAETORIAN-DFT.

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