Journal of Arrhythmia 30 (2014) 428–432

Contents lists available at ScienceDirect

Journal of Arrhythmia

journal homepage: www.elsevier.com/locate/joa

Review

Device therapy in pediatric and congenital heart disease patients

Naokata Sumitomo, MD, PhD*

Department of Pediatric Cardiology, Saitama Medical University, International Medical Center, 1397-1 Yamane, Hidaka-City, Saitama 350-1298, Japan

ARTICLE INFO

Article history:
Received 4 April 2014
Received in revised form
18 April 2014
Accepted 25 April 2014
Available online 20 June 2014

Keywords:
Implantable cardioverter-defibrillator
Cardiac resynchronization therapy
Sudden cardiac death
Nonendocardial electrode placement
Congenital heart disease

ABSTRACT

Background: Device therapy is an established therapy for preventing sudden cardiac death or managing refractory congestive heart failure in adults. However, it is performed less commonly in pediatric populations. This review aimed to examine the indications and problems associated with implantable cardioverter-defibrillator (ICD) and cardiac resynchronization therapy (CRT) device implantations in pediatric and congenital heart disease (CHD) patients.

Results: In a multicenter study in Japan, the cardiac condition of CHD patients improved by 83% after CRT device implantation. The need for CRT devices is more common in children than in adults. After ICD implantation, 44% of the patients experienced appropriate shocks, and epicardial lead implantation was performed in one-third of the patients. Nonendocardial electrode placement is mandatory for ICD implantation in small infants and patients with certain CHDs. Although inappropriate ICD discharges due to sinus tachycardia or other supraventricular tachycardias are common in children, the indication for ICD implantation may be higher than that reported in children.

Conclusions: Despite the limited experience, limitations of device implantations owing to the size of the devices, and necessity for nonendocardial electrode placement, device implantations are required in more pediatric and CHD patients than expected.

Contents

1. Introduction

Device therapy is a well-established treatment for preventing sudden cardiac death or managing drug-refractory congestive heart failure in adults [1–6]. However, device therapy is performed less commonly in pediatric populations, and the indications for implantable cardioverter-defibrillator (ICD) or cardiac resynchronization therapy (CRT) device implantations are unclear in pediatric patients. This review aimed to examine the indications for ICD and CRT device implantations in pediatric and congenital heart disease (CHD) patients.

2. Present situation of device therapy in Japan

In a multicenter survey of device therapy performed before 2012 in Japanese children [7], the most frequent indications for device therapy included hypertrophic cardiomyopathy, long QT syndrome, and catecholaminergic polymorphic ventricular tachycardia for ICD patients and dilated cardiomyopathy (DCM), cardiac failure due to right ventricular pacing in congenital complete

* Tel.: +81 429 84 4111x8625; fax: +81 429 84 4121.
E-mail address: sumitomo@saitama-med.ac.jp

http://dx.doi.org/10.1016/j.joa.2014.04.013
1880-4276/

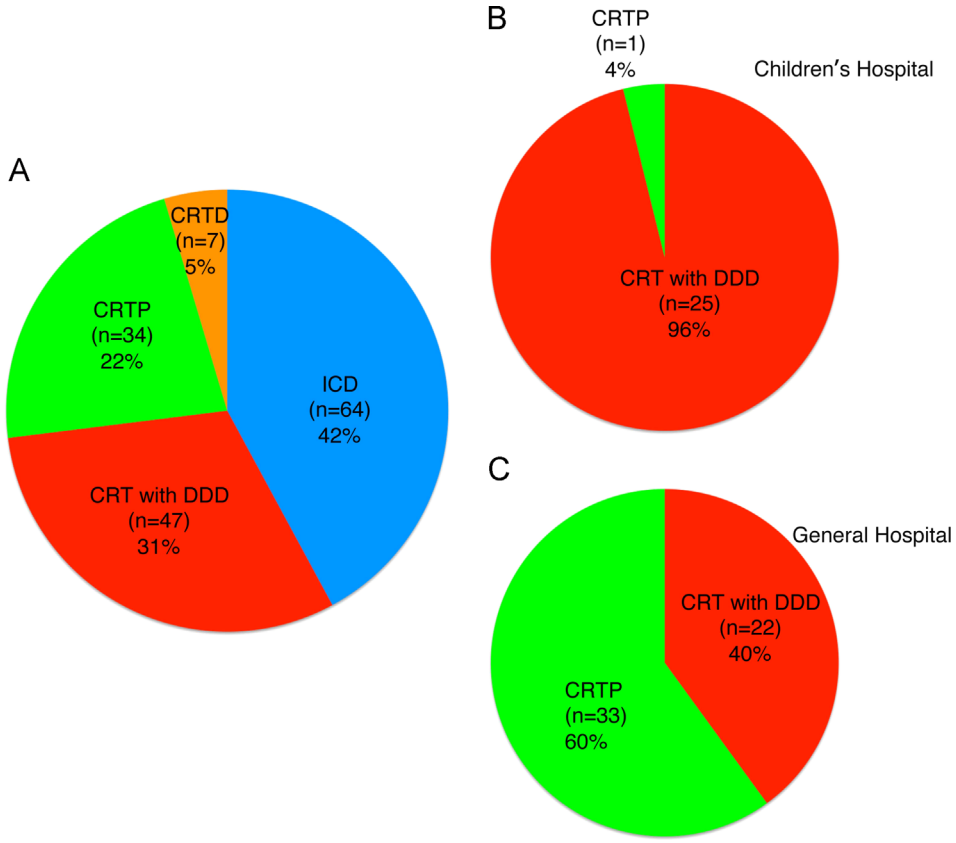

Fig. 1. Pediatric use of ICD, CRT-D, CRT-P, and CRT-DDD over the past 13 years [7]. ICD, CRT-DDD, CRT-P, and CRT-D implantations were performed in 64 (42%), 47 (31%), 34 (22%), and 7 (5%) cases, respectively, in the participating hospitals (A). Of CRT-P and CRT-DDD implantations, CRT-DDD implantations accounted for 96% of the therapy used in children's hospitals (B) vs. 41% in general hospitals (C). CRT-D, cardiac resynchronization therapy with a defibrillator; CRT-P; cardiac resynchronization therapy with a biventricular pacemaker; CRT-DDD, cardiac resynchronization therapy with a dual-chamber (DDD) pacemaker; ICD, implantable cardioverter-defibrillator.

atrioventricular block, polysplenia, asplenia, tetralogy of Fallot, and atrioventricular septal defect for patients with CRT with a biventricular pacemaker (CRT-P) and those with CRT with a dual-chamber (DDD) pacemaker (CRT-DDD). DCM was the most common condition that required CRT with a defibrillator (CRT-D).

ICD, CRT-DDD, CRT-P, and CRT-D implantations were performed in 64 (42%), 47 (31%), 34 (22%), and 7 (5%) of 152 patients, respectively.

Among 81 CRT-P and CRT-DDD patients, CRT-DDD was used in 41% of the patients at general hospitals vs. 89% at children's hospitals (Fig. 1). Furthermore, CRT-DDD and CRT-P were effective in improving heart failure in 67 patients (83%). These results show that the number of CRT-P and CRT-D implantations needed in children may be higher than that believed previously. In contrast to general hospitals, children's hospitals have no choice but to use DDD pacemakers for CRT, because CRT-P devices are not allowed to be used for biventricular CRT-P. In Japan, the institutional criteria for CRT implantation are as follows:

(1) The hospital should have both cardiology and cardiovascular surgery departments.
(2) The hospital should perform more than 50 electrophysiological studies (EPS) per year, and more than 5 of these EPS should focus on ventricular arrhythmias.
(3) The hospital should perform more than 50 open-heart surgeries or aortocoronary bypass surgeries per year and more than 10 pacemaker implantations per year.
(4) The hospital should have extensive experience in treating severe congestive heart failure using internal or external ventricular assist devices.
(5) More than 2 fulltime cardiologists and cardiovascular surgeons should be employed by the hospital, and more than 2 doctors should have undergone authorized training for CRT device implantations.
(6) The hospital should have adequate instruments for blood tests, biochemical examinations, and diagnostic imaging.

The institutional criteria for ICD and CRT-D implantations are as follows:

(1) The hospital should have both cardiology and cardiovascular surgery departments.
(2) The hospital should perform more than 50 EPS per year, and more than 5 of these EPS should focus on ventricular arrhythmias.
(3) The hospital should perform more than 50 open-heart surgeries or aortocoronary bypass surgeries per year and more than 10 pacemaker implantations per year.
(4) More than 2 fulltime cardiologists and cardiovascular surgeons should be employed by the hospital, and more than 2 doctors should have undergone authorized training for CRT device implantations.
(5) The hospital should have adequate instruments for blood tests, biochemical examinations, and diagnostic imaging.

Almost none of the children's hospitals met criteria (2) and (3) for CRT device implantations and criterion (2) for ICD and CRT-D implantations. On the other hand, the institutional criteria for pacemaker implantations include that more than 1 fulltime cardiologist and cardiovascular surgeon with >5 years' experience in cardiology or cardiovascular surgery should be employed by the hospital. Therefore, owing to the government criteria requiring

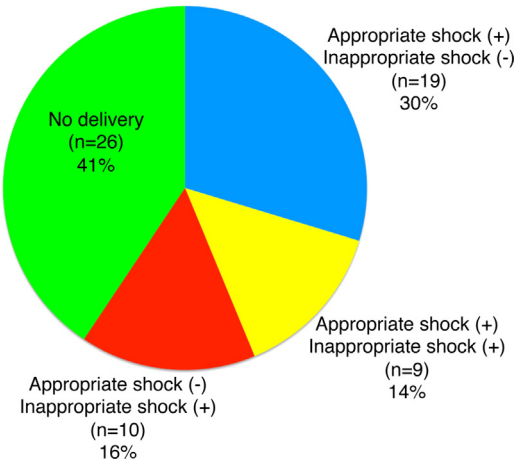

Fig. 2. Outcomes after ICD implantation [7]. Nineteen patients (30%) experienced appropriate but not inappropriate shocks, 9 (14%) experienced both appropriate and inappropriate shocks, and 10 (16%) experienced inappropriate but not appropriate shocks. Twenty-six children (41%) experienced no shocks. Overall, approximately one-third of the ICD patients experienced inappropriate shocks.

regulatory approval for those devices, CRT-P is not covered by the National Health Insurance at children's hospitals.

Given the promising role of CRT in CHD treatment in addition to the 83% improvement rate in cardiac condition after CRT-P and CRT-DDD implantations and the increasing demand for pediatric CRT especially in preschool-age children, it is crucial that CRT-Ps become available for children. The need for CRT-Ps is more common in children than in adults.

Of 64 ICD patients, 28 (44%) experienced appropriate shocks, and **19** (29%) experienced inappropriate shocks (Fig. 2). This may also suggest that the number of patients with an indication for ICD implantation may be higher than that reported in children.

Lead implantation in children also differs from that in adults. The Japanese multicenter survey [7] showed that of 152 patients, epicardial leads were used in 94 (62%), transvenous leads were used in 53 (35%), and both leads were used in 5 (3%) patients. Epicardial leads were used in approximately two-thirds of the patients and in almost all of the patients aged <9 years. Moreover, epicardial leads were used for most of the CRT patients, regardless of their age or bodyweight. However, the use of transvenous leads for ICD implantations was higher in patients >8 years of age or with a bodyweight of >30 kg. Epicardial lead implantation was performed in approximately one-third of the patients, and left subcutaneous lead implantation was performed in most of the patients.

3. Associated heart disease in children with ICD implantations

In a multicenter ICD registry of 443 patients [8], 69% of the patients had CHD and 23% had cardiomyopathy. The most common heart disease was tetralogy of Fallot (19%), followed by hypertrophic cardiomyopathy (14%) (Fig. 3). In structurally normal hearts, long QT syndrome was the most prevalent disease, and it accounted for 31% of the heart disease cases including Brugada syndrome and catecholaminergic polymorphic ventricular tachycardia (Fig. 4).

4. ICD placement in children

ICD placement in teenagers and those with anatomically normal hearts may not differ from that in adults. However, in young patients, the size of the ICD generator and the growth rates and activity levels of the patients should be considered. Given the long life expectancy of

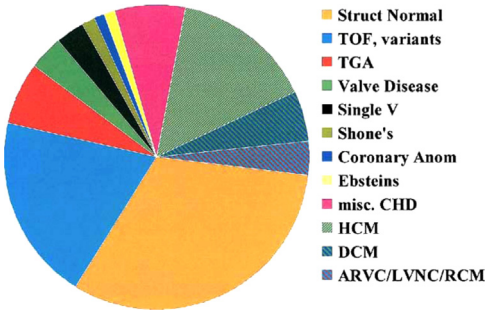

Fig. 3. Anatomic diagnoses of pediatric and CHD ICD recipients [8]. Struct Normal, structurally normal hearts; TOF, tetralogy of Fallot; TGA, transposition of the great arteries; Single V, single ventricle; CHD, congenital heart disease; Coronary Anom, coronary anomaly; HCM, hypertrophic cardiomyopathy; DCM, dilated cardiomyopathy; ARVC, arrhythmogenic right ventricular cardiomyopathy; LVNC, left ventricular noncompaction; RCM, restrictive cardiomyopathy.

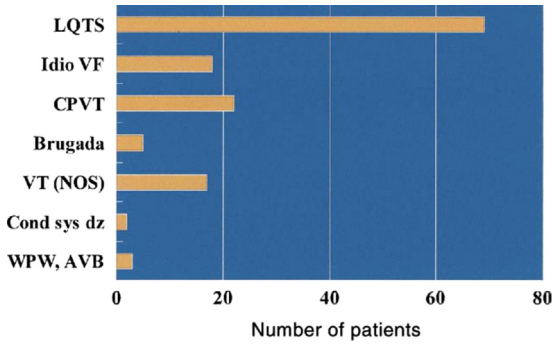

Fig. 4. Electrical diagnoses of pediatric ICD recipients with structurally normal hearts [8]. LQTS, long QT syndrome; Idio VF, idiopathic ventricular fibrillation; CPVT, catecholaminergic polymorphic ventricular tachycardia; Brugada, Brugada syndrome; VT, ventricular tachycardia; NOS, not otherwise specified; Cond sys dz, conduction system disease; WPW, Wolff–Parkinson-White syndrome; AVB, atrioventricular block.

children, those with ICD implantations may need complex lead extractions and multiple lead replacements. Development of venous occlusions and the potential risk of thromboembolisms should also be considered in patients with intracardiac shunts. In the treatment of some CHDs or postoperative CHDs using the Glenn procedure or extracardiac total cavopulmonary connection, transvenous lead placement is often impossible.

Consequently, nonendocardial electrode placement is mandatory for ICD implantations in small infants and patients with certain CHDs. No subcutaneous arrays or patches are available at present, and in most studies [9–12], the ICD shock leads were placed either in the pericardial space or subcutaneously (Fig. 5). The advantages and disadvantages of these lead routes are listed in Table 1. Furthermore, nontransvenous ICD systems reportedly survive for a significantly shorter time than do transvenous ICD systems [13].

Nontransvenous ICD systems are now available [14,15]; however, they are not suitable for small children, because the size of the generator is very large.

Table 2 lists the ICD system-related complications [16]. Because of sinus tachycardia or other supraventricular tachycardias, nearly 50% of children with ICD implantations have inappropriate ICD discharges. Depression or anxiety associated with ICD discharges is another problem in children.

5. Criteria for ICD implantations in children

The indications for ICD implantations in children were primary prevention in 52% and secondary prevention in 48% of the

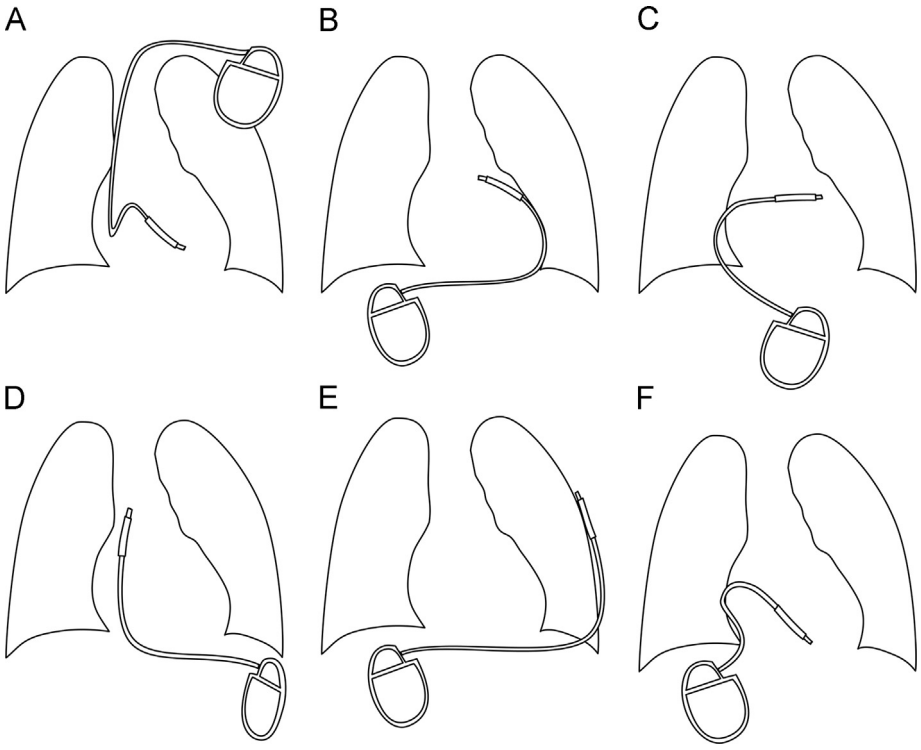

Fig. 5. Various ICD lead placement methods in children. (A) Transvenous lead implantation with the lead looped or curved in the right ventricle to allow for a sufficient length of the lead to account for the growth of the child. (B) Epicardial lead implantation [10]. (C) Lead implantation posteriorly behind the heart and superiorly toward the transverse sinus by a subxiphoid incision through a pericardial window [11]. (D) Lead implantation in a substernal position with the ICD placed in the left abdomen. (E) Lead implantation in a left subcutaneous position with the ICD placed in the right abdomen. (F) Endocardial lead implantation through the right atrial appendage [12].

Table 1
Implantable cardioverter-defibrillator lead route options in pediatric patients [9].

	Advantages	Disadvantages
Transvenous	Relatively easy to use; common use; approved indication	Lead fractures; extraction difficult; vascular obstruction
Epicardial patch	Long history, follow-up; approved use; surgeons familiar with its use; good DFT	Patch failure; buckling; restrictive pericardial physiology
Subcutaneous array or coil	No transvenous coil or epicardial patch; minimally invasive	Limited long-term data; higher DFT
Pericardial coil	No need for transvenous access or epicardial patch; low DFT	Requires surgeon; adhesions may limit video-assisted thoracoscopic surgery; limited follow-up data
Subcutaneous leadless implantable cardioverter-defibrillator	No need for transvenous or epicardial access; minimally invasive	Limited long-term data; higher DFT; no chronic pacing or antitachycardia pacing

DFT = defibrillation threshold.

Table 2
ICD system-related complications in children [16].

Inappropriate ICD therapy: 11–50%, owing to sinus tachycardia, supraventricular tachycardia, lead failures, T-wave oversensing, and QRS complex double sensing
Lead failures: 7–30% (youngest and smallest patients; with growth, the proximal shock electrode tends to become stretched and distorted)
Depression and/or anxiety: 44%
Increase in defibrillation threshold: failure of the first ICD shock in 7%
Electrical storm
Patient death: sudden death (4%), death due to recurrent ventricular arrhythmias (1%)

Table 3
Secondary prevention in pediatric and CHD patients [17].

Class I
Aborted SCD without reversible cause
Sustained ventricular tachycardia (VT) associated with structural heart disease
Hemodynamically significant sustained VT without reversible cause or potential cure

patients. Single-chamber ICDs were implanted in 42%, and DDD-ICDs were implanted in 58% of the patients. The suggested retrospective indication criteria for ICD implantations in children [17] are listed in Tables 3 and 4.

6. CRT in pediatric and CHD patients

In a multicenter retrospective study of CRT in pediatric and CHD patients [18], the underlying heart diseases were CHD in 71%, cardiomyopathy in 6%, and congenital complete atrioventricular block in 13% of the patients. Cecchin et al. [19] reported that 77% of patients in their institute underwent CRT, and idiopathic dilated cardiomyopathy was observed in 17%.

Table 4
Primary prevention in pediatric and CHD patients [17].

Inherited arrhythmias/electrical myopathies
Long QT Syndrome (LQTS)
Class I: SCD survivors, recurrent syncope, or VT on β-blockers
Strong family SCD history
Medication intolerance
Noncompliance
Short QT Syndrome (SQTS)
Class I: recurrent syncope and malignant arrhythmias
Catecholaminergic Polymorphic VT (CPVT)
Class I: β-blockade alone is insufficient for suppressing VT
Brugada Syndrome (BrS)
Class I:
Spontaneous coved-type electrocardiographic (ECG) pattern and aborted SCD
Patients with symptoms without a clear etiology
Class IIa:
Asymptomatic patients with either a family history and/or EPS
Symptomatic patients with an ECG pattern elicited only by a Na^+ channel blockade
Class IIb: Asymptomatic patients with both a positive family history and EPS
Cardiomyopathies
Dilated Cardiomyopathy
? Uncontrollable ventricular arrhythmias
Hypertrophic Cardiomyopathy (HCM)
Class I: Cardiac arrest
Class II:
Syncope
Abnormal ECG response to exercise testing
Strong family history/genotype
Arrhythmogenic Right Ventricular Cardiomyopathy (ARVC)
Class I: Sustained VT
Congenital Heart Disease
Class IIb: Syncope and inducible sustained VT/VF
High-risk CHD: Aortic stenosis, tetralogy of Fallot, and d-transposition of the great arteries

Table 5
Effect of CRT pacing according to the type of heart disease [18].

Type of disease	*N*	Age (years)	Ejection fraction (EF)	Improvement (EF units)
Congenital heart disease	73	12.2 (0.5–55.4)	$11.9 \pm 12.9\%$	39.1 ± 31.9
Cardiomyopathy	16	15.8 (0.3–19.6)	$12.3 \pm 13.6\%$	31.9 ± 37.9
Heart block	14	12.5 (0.3–24.3)	$16.1 \pm 12.9\%$	36.8 ± 13.0
p-Value		NS	NS	NS

Table 6
CRT indications [20].

Class IIa
Ventricular dyssynchronization by conventional single ventricular pacing
NYHA class 2

In a previous study [18], the mean QRS duration before CRT was 166.1 ± 33.3 ms, and it decreased to 37.7 ± 30.7 ms ($p < 0.01$) after CRT. In this study, the systemic ventricular ejection fraction before CRT was $26.2 \pm 11.6\%$, and it increased to $39.9 \pm 14.8\%$ ($p < 0.05$) after CRT. This improvement did not differ among the types of heart disease (Table 5).

Cecchin et al. [19] reported that of 18 patients listed for heart transplantation, the condition of 3 patients improved sufficiently and they were removed from the heart transplant list, 5 underwent heart transplantation, 2 died, and 8 others are awaiting a heart transplant after CRT.

Although data are limited, these studies show that CRT is an effective therapy in CHD patients and children with cardiomyopathy and complete heart block. Another study [20] showed that the number of nonresponders in the younger patient population was lower than that in the adult patients, and CRT in this younger group may help delay heart transplantation, and systemic right ventricle or single-ventricle patients accounted for approximately 30% of these subjects.

7. CRT indications

The current suggested indications for CRT in pediatric and CHD patients [20] are listed in Table 6.

8. Conflict of interest

The author has no conflicts of interest to disclose.

References

[1] Moss AJ, Hall WJ, Cannom DS, et al. Improved survival with an implanted defibrillator in patients with coronary disease at high risk for ventricular arrhythmia. N Engl J Med 1996;335:1933–40.
[2] Buxton AE, Lee KL, Fisher JD, et al. A randomized study of the prevention of sudden death in patients with coronary artery disease. N Engl J Med 1999;341:1882–90.
[3] Bardy GH, Lee KL, Mark DB, et al. Amiodarone or an implantable cardioverter-defibrillator for congestive heart failure. N Engl J Med 2005;352:225–37.
[4] Josephson M, Wellens HJ. Implantable cardioverter-defibrillators and sudden cardiac death. Circulation 2004;109:2685–91.
[5] Mirowski M, Reid PR, Mower MM. Termination of malignant ventricular arrhythmias with an implanted automatic defibrillator in human beings. N Engl J Med 1980;303:322–4.
[6] The Antiarrhythmics versus Implantable Defibrillators (AVID) Investigators. A comparison of antiarrhythmic-drug therapy with implantable defibrillators in patients resuscitated from near-fatal ventricular arrhythmias. N Engl J Med 1997;337:1576–83.
[7] Suzuki T, Sumitomo N, Yoshimoto J, et al. Current trends in use of implantable cardioverter defibrillators and cardiac resynchronization therapy with a pacemaker or defibrillator in Japanese pediatric patients. Circ J 2014, http://dx.doi.org/10.1253/circj.CJ-13-1379.
[8] Berul CI, Van Hare G, Kertesz NJ, et al. Results of a multicenter retrospective implantable cardioverter-defibrillator registry of pediatric and congenital heart disease patients. J Am Coll Cardiol 2008;51:1685–91.
[9] Berul CI. Defibrillator indications and implantation in young children. Heart Rhythm 2008;5:1755–7.
[10] Bové T, François K, De Caluwe W, et al. Effective cardioverter defibrillator implantation in children without thoracotomy: a valid alternative. Ann Thorac Surg 2010;89:1307–9.
[11] Hsia TY, Bradley SM, LaPage MJ, et al. Novel minimally invasive, intrapericardial implantable cardioverter defibrillator coil system: a useful approach to arrhythmia therapy in children. Ann Thorac Surg 2009;87:1234–8.
[12] Kantoch MJ, Rebeyka IM, Houlden LA, et al. Direct intracardiac placement of an automatic implantable cardioverter defibrillator coil lead in a small child. Europace 2007;9:669–71.
[13] Radbill AE, Triedman JK, Berul CI, et al. System survival of nontransvenous implantable cardioverter-defibrillators compared to transvenous implantable cardioverter-defibrillators in pediatric and congenital heart disease patients. Heart Rhythm 2010;7:193–8.
[14] Lieberman R, Havel WJ, Rashba E, et al. Acute defibrillation performance of a novel, non-transvenous shock pathway in adult ICD indicated patients. Heart Rhythm 2008;5:28–34.
[15] Burke MC, Coman JA, Cates AW, et al. Defibrillation energy requirements using a left anterior chest cutaneous to subcutaneous shocking vector: implications for a total subcutaneous implantable defibrillator. Heart Rhythm 2005;2:1332–8.
[16] Shah MJ. Implantable cardioverter defibrillator-related complications in the pediatric population. Pacing Clin Electrophysiol 2009;32:S71–4.
[17] Berul CI. Implantable cardioverter defibrillator criteria for primary and secondary prevention of pediatric sudden cardiac death. Pacing Clin Electrophysiol 2009;32(Suppl 2):S67–70.
[18] Dubin AM, Janousek J, Rhee E, et al. Resynchronization therapy in pediatric and congenital heart disease patients: an international multicenter study. J Am Coll Cardiol 2005;46:2277–83.
[19] Cecchin F, Frangini PA, Brown DW, et al. Cardiac resynchronization therapy (and multisite pacing) in pediatrics and congenital heart disease: five years experience in a single institution. J Cardiovasc Electrophysiol 2009;20:58–65.
[20] Janousek J, Gebauer RA. Cardiac resynchronization therapy in pediatric and congenital heart disease. Pacing Clin Electrophysiol 2008;31:S21–3.