Prevention of sudden cardiac death (SCD) has become an important issue in today’s cardiovascular field, together with various developments in secondary prevention of basic cardiac diseases. The importance of the implantable cardioverter defibrillator (ICD) is now widely accepted because it has exhibited significant improvement in patients’ prognoses in ischemic and non-ischemic cardiovascular diseases. However, there is an unignorable gap between the ICD indication in the guidelines and real-world high-risk patients for SCD, especially in the acute recovery phase of cardiac injury. Although various studies have demonstrated a clinical benefit of defibrillation devices, the studies of immediate ICD use in the acute recovery phase have failed to exhibit a benefit in patients from the point of the view of a decrease in total deaths. To bridge this gap, the wearable cardioverter defibrillator (WCD) provides a safer observation period in the acute phase and eliminates inappropriate overuse of ICD in the subacute phase. Here, we discuss the usefulness of the WCD and current understanding of its indications based on various clinical data. In conclusion, WCD is a feasible bridge to therapy and/or safe observation for patients at high risk of SCD, especially in the acute recovery phase of cardiac diseases.

Key Words: Defibrillation device; Sudden cardiac death; Ventricular arrhythmia; Wearable cardioverter defibrillator

Prevention of sudden cardiac death (SCD) has become an important issue in the current cardiovascular field, together with various developments in the secondary prevention of basic cardiac diseases. The importance of the implantable cardioverter defibrillator (ICD) is now widely accepted because it has exhibited significant improvements in patients’ prognoses in ischemic and non-ischemic cardiovascular diseases. Even for patients undergoing cardiac resynchronization therapy (CRT), a CRT device with defibrillation function (CRT-D) has a better prognosis than a simple CRT (CRT-P), probably because of successful prevention of SCD in patients with poor left ventricular function who are at high risk for life-threatening arrhythmia, such as ventricular tachycardia (VT) or ventricular fibrillation (VF), and thus are typical candidates for primary prevention of SCD. These concepts are now widely accepted in various countries, and the Japanese Circulation Society has also established “guidelines” for these implantable defibrillation devices by strongly referring to the evidence and the guidelines of the AHA/ACC/HRS and/or ESC. However, there is a strange but unignorable gap between the ICD indication in the guidelines and real-world high-risk patients for SCD, especially in the acute recovery phase of cardiac injury. Although various studies, such as MADIT I & II, SCD-HeFT etc., have demonstrated a clinical benefit of defibrillation devices, studies of immediate ICD use in the acute recovery phase failed to exhibit a benefit in patients from the viewpoint of a decrease in total deaths. This discrepancy may be explained by the imposition of an invasive procedure (i.e., ICD implantation) in patients with unstable condition and/or mis-selection of patients with resuscitatable left ventricular dysfunction in the acute recovery phase of the disease, at least in the cases of myocardial infarction. On the other hand, the VALIANT study demonstrated that the acute recovery phase, less than 3 months from disease onset, has the highest risk for SCD. Therefore, a feasible bridge to therapy has been...
desired for realistic prevention of SCD in patients in the acute recovery phase.

**Concept of WCD**

The wearable cardioverter defibrillator (WCD: LifeVest, Zoll Medical Corporation, USA) is a unique defibrillation system that provides automatic defibrillation therapy for life-threatening arrhythmia in patients at risk of SCD. The system includes a body-fitting elastic vest, contact-type body surface ECG electrodes, defibrillation pads with self-releasing gel, and a code-connected controller that automatically diagnoses life-threatening arrhythmia and delivers a defibrillation shock if it is not cancelled. The whole system can be set up simply and non-invasively, but achieves high sensitivity and specificity for the therapy, which is almost comparable with the latest model of ICD and/or CRT-D systems.14 17 The high specificity of arrhythmia diagnosis is assisted by the patient’s own cancellation of the defibrillation sequence triggered by a misdiagnosed arrhythmia. WCD also has a wireless connection to the “LifeVest Network System”, which provides high-quality patient monitoring similar to pacemaker/ICD remote monitoring. Because this system can be applied or quitted immediately and non-invasively, it is a feasible bridging option to implantable device therapy for patients at risk of SCD.

**Japanese Statement for Clinical Use of WCD**

The WCD system became clinically available in Japan from 1 January 2014, and the Japanese Heart Rhythm Society has a recommended statement for appropriate clinical use.18 Such indications are also scheduled to be involved in future clinical guidelines of the Japanese Circulation Society. In the statement,18 the clinical indications for consideration of WCD use are as follows:

- **Cases within 40 days after the onset of acute myocardial infarction with left ventricular ejection fraction (LVEF) ≤35% and heart failure symptoms of NYHA class II or III.**
- **Cases of LVEF ≤35% and within 90 days after coronary artery bypass or NYHA class II or III heart failure symptoms within or after percutaneous coronary intervention (PCI).**
- **Cases of LVEF ≤35% and within 90 days after non-ischemic acute heart failure onset.**
- **Cases of irreversible severe heart failure satisfying heart transplant standby condition.**
- **Cases in which ICD is indicated but surgery cannot be performed immediately because of other physical conditions.**
- **Cases in which secondary prevention of SCD by ICD is considered but priority is given to determination of the effect of clinical follow-up and preventive treatment.**
- **Cases in which ICD is temporarily removed for any reason, such as infection.**

Additionally, the Japanese statement has restricted automobile driving during WCD therapy, which is not mentioned in the American or European guidelines. This is in conformity with the automobile driving restriction for ICD patients to prevent traffic accidents. Even though the WCD might be prescribed for patients as primary prevention for SCD who are considered to have a lower risk than as secondary prevention, the WCD user should be considered to have a higher risk for shock therapy than ICD patients.13 and a specific cancelling procedure (i.e., pushing 2 buttons simultaneously) will be necessary in case of an inappropriate alarm, which may distract the driver while in charge of a motor vehicle.

**WCD Indication in Ischemic Heart Disease (IHD)**

As discussed, the first 3 clauses of the statement refer to the MADIT I & II and SCD-HeFT studies.1 3 Although the VALIANT study has reported that the sudden death rate was high within 30 days after onset in patients with myocardial infarction and reduced cardiac function,19 the DINAMIT and IRIS studies, which examined the usefulness of ICD early (6–40 days) after the onset of myocardial infarction failed to exhibit a difference in total deaths, even though they showed a decrease in arrhythmic deaths in the ICD group.22 24 Similar to the American and European guidelines, the Japanese guideline also states the indication for ICD implantation should be considered after 1 month after the onset.5 In a report of using the WCD in cases of cardiac dysfunction in the acute-stage myocardial infarction patient, 104 patients with LVEF ≥35% had no appropriate WCD activation events, whereas 341 patients with LVEF ≤35% had 3% (10 cases, 12 events) appropriate WCD activation events, which was effective for SCD prevention.21 22 Although the number of cases is limited, similar cases of appropriate WCD activation events have been reported in Japan.19 Even in secondary preventive cases of VT/VF, ICD is not indicated in cases of VT/VF clearly caused by a temporal cause (acute ischemia, electrolyte abnormality, medicine, etc.), but ICD can be indicated as Class IIb when a similar risk is highly considered even after adequate treatment.5 In such cases, the WCD may be applicable to provide a safer condition when the observation period is expected to be relatively long. However, the decision for ICD indication should be made as early as possible to avoid unnecessarily long-term use of the WCD.

In cases of ventricular dysfunction caused by IHD, conventional pharmacological therapy showed a 31% 2-year survival rate.20 In contrast, percutaneous coronary angioplasty (PCI) and coronary artery bypass surgery (CABG) showed 3-year survival rates of 67% and 73%, respectively, in patients with low LVEF of 15–30%.21 Therefore the effect of such revascularization procedures on the improvement of patients’ prognoses is obvious. However, the same report documented 8% deaths in PCI and 7% deaths in CABG cases, mainly from life-threatening arrhythmia events,22 suggesting the importance of prevention of fatal arrhythmic events in the acute phase after these procedures. According to the Society of Thoracic Surgeons Adult Cardiac Surgery Database, cases of patients with a preoperative low LVEF ≤30% or and CABG alone (n=348,341, age ≥65 years) showed a lower 5-year survival rate after surgery by 25% in comparison with patients with better LVEF (>30%). When comparing ICD cases (n=446) and controls (n=454) after CABG in patients with low LVEF (≤36%), the arrhythmic death rate was lower among the ICD cases.23

According to the Cleveland clinic’s report, the 90-day mortality rate after CABG surgery (n=1,951) decreased from 6.1% to 3.1% by using the WCD, and the importance of prophylactic use of the WCD in the postoperative acute phase was concluded.24 Similarly, in 4,958 cases of PCI in patients with low LVEF (≤35%), a reduction in mortality risk of 39% was documented on average in the observation period of 3.2 years by using the WCD.21 In the WEARIT-
II Registry,17 which was held in the USA and European countries, 2,000 cases of WCD usage were prospectively observed, and the appropriate shock event rate was even higher than in the MADIT-RIT study.24 Even though the initial mean LVEF was 25% in this registry, it improved to 39% under WCD usage during the observation period, and 39% of patients avoided subsequent ICD surgery because the WCD can provide a safer observation period for high-risk patients for SCD in the acute phase and can reduce unnecessary usage of ICD in the subacute phase.17

WCD Indication in Non-IHD

Non-ischemic cardiomyopathy includes various types of diseases, such as post-myocarditis cardiomyopathy, so-called takotsubo cardiomyopathy, postpartum cardiomyopathy, tachycardia-induced cardiomyopathy as well as dilated cardiomyopathy of unknown cause. We may often experience patients who show acute heart failure at the beginning and the presence of basic heart disease becomes clear later. Most of these patients with low LVEF are considered to be high-risk cases for SCD, but the IMAC-2 trial demonstrated that 25% of patients with low LVEF (≤50%) would recover to LVEF ≥50% under the standard medication using β-blockers, angiotensin-converting enzyme inhibitor inhibitors, anti-aldosterone antagonists etc.26

Teeter et al reported that 43% of patients with acute heart failure and low LVEF (≤30%) in the acute phase can recover to normal cardiac function within 6 months.27 According to the SCD-HeFT trial,3 ICD is recommended for NYHA class II or III non-ischemic cardiomyopathy with low LVEF (≤35%) at 3 months after diagnosis, but in the HRS/ACC/ AHA Expert Consensus Statement (2014) ICD therapy is not recommended within 3 months of newly diagnosed non-ischemic cardiomyopathy.6.8 In non-ischemic cardiomyopathy, it is often difficult to predict the course of cardiac function after the acute phase, and it is considered reasonable to use the WCD for the purpose of providing a safer observation period (i.e., bridge to the ICD decision).18.26

Acute myocarditis is also a condition that can indicate a transient risk of SCD. In a study of 35 patients who used the WCD for acute heart failure accompanying myocarditis, 5.7% VT/VF was found in the 3-month wearing period. All cases were successfully defibrillated by the WCD, and subsequent ICD implantation was indicated in 25% of cases.27 Takotsubo cardiomyopathy is also a transient reversible myocardial disorder, but the rate of sudden death during hospitalization is not small but high at 5%, and the VT/VF rate is reported to reach 9%.28.29 Perinatal cardiomyopathy is a rare cardiomyopathy, but sudden death has been reported to be as high as 38% in severe cases.30 In a study using the WCD for perinatal cardiomyopathy, VT/VF was observed in 4 of 7 cases during a mean

### Table. Summary of Clinical Studies of Wearable Cardioverter-Defibrillator

<table>
<thead>
<tr>
<th>Publication</th>
<th>Patients background</th>
<th>Patients (n)</th>
<th>Study type</th>
<th>Observation period</th>
<th>Adherence (h/d)</th>
<th>Appropriate shocks</th>
<th>Inappropriate shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEARIT/BROAD (2004)14</td>
<td>HF, IHD, other</td>
<td>289</td>
<td>Prospective</td>
<td>Mean 3.1 months</td>
<td>NA</td>
<td>1.0%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Klein et al (2013)27</td>
<td>Nationwide experience in Germany</td>
<td>354</td>
<td>Retrospective</td>
<td>Mean 106 days</td>
<td>Mean 21.3</td>
<td>27.6%</td>
<td>0%</td>
</tr>
<tr>
<td>Saltzberg et al (2012)48</td>
<td>ICM/NICM</td>
<td>258</td>
<td>Retrospective</td>
<td>Mean 75/56 days</td>
<td>Mean 18.3/17.0</td>
<td>0%/0.8%</td>
<td>0%/0%</td>
</tr>
<tr>
<td>Dillon et al (2010)24</td>
<td>HF, IHD, ICM, others</td>
<td>2,015</td>
<td>Retrospective</td>
<td>Median 36 days</td>
<td>Median 21.3</td>
<td>2.6%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Chung et al (2010)14</td>
<td>ICM, PPCI, HF, others</td>
<td>3,569</td>
<td>Retrospective</td>
<td>Mean 52.6 days</td>
<td>Mean 19.9</td>
<td>2.1%</td>
<td>1.9%</td>
</tr>
<tr>
<td>Rao et al (2011)46</td>
<td>CHD/IA</td>
<td>162</td>
<td>Retrospective</td>
<td>Mean 27/29 days</td>
<td>Mean 19</td>
<td>0.2%</td>
<td>0%/3%</td>
</tr>
<tr>
<td>Epstein et al (2013)14</td>
<td>Post MI</td>
<td>8,453</td>
<td>Retrospective</td>
<td>Mean 69 days</td>
<td>Median 21.8</td>
<td>1.6%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Zishiri et al (2013)23</td>
<td>PPCI with low LVEF</td>
<td>4,958</td>
<td>Cohort</td>
<td>NA</td>
<td>NA</td>
<td>0.2%</td>
<td>NA</td>
</tr>
<tr>
<td>Tanawuttiwat et al (2014)49</td>
<td>Bridge to ICD</td>
<td>97</td>
<td>Retrospective</td>
<td>Median 21 days</td>
<td>Mean 20</td>
<td>4.1%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Sasaki et al (2014)19</td>
<td>HF, VT/VF episode, others</td>
<td>9</td>
<td>Retrospective</td>
<td>Mean 21 days</td>
<td>Mean 23.7</td>
<td>11.1%</td>
<td>0%</td>
</tr>
<tr>
<td>Duncker et al (2014)27</td>
<td>PPCI, ICM</td>
<td>9</td>
<td>Prospective</td>
<td>Mean 133 days</td>
<td>Mean 22.0</td>
<td>44.4%</td>
<td>0%</td>
</tr>
<tr>
<td>Opreanu et al (2015)26</td>
<td>Bridge to cardiac transplant</td>
<td>122</td>
<td>Retrospective</td>
<td>Mean 127 days</td>
<td>Mean 17</td>
<td>5.8%</td>
<td>1.6%</td>
</tr>
<tr>
<td>WEARIT-II (2015)17</td>
<td>ICM, NICM, IHD, others</td>
<td>2,000</td>
<td>Prospective</td>
<td>Median 90 days</td>
<td>Median 22.5</td>
<td>2.1%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Niwano et al (2017)29</td>
<td>HF, ICD candidate, ICD removal</td>
<td>27</td>
<td>Retrospective</td>
<td>Mean 42 days</td>
<td>Mean 23.0</td>
<td>7.4%</td>
<td>3.7%</td>
</tr>
</tbody>
</table>

CHD, congenital heart disease; HF, heart failure; IA, inherited arrhythmia; ICM, ischemic cardiomyopathy; IHD, ischemic heart disease; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NA, not analyzed; NICM, non-ischemic cardiomyopathy; PPCI, post percutaneous coronary intervention; VT/VF, ventricular tachycardia/fibrillation.
observation period of 81 days, and 3 cases were rescued with proper WCD activation.\textsuperscript{27} Although the usefulness of the WCD is thought to be high in these transient myocardial injuries, cases of patients who took more than 3 months to recover have been reported. Because currently WCD usage in Japan is limited to 90 days from the point of view of insurance coverage, future study will be necessary to assess whether this period should be extended according to the pathological condition.\textsuperscript{18}

In heart transplant standby cases, it is not uncommon for a fatal arrhythmia to cause sudden death from severe irreversible heart failure.\textsuperscript{31,32} According to a meta-analysis, the mortality rate of heart transplant standby cases was 27\%, of which sudden death was 32\%.\textsuperscript{33} In the case of ICD implantation, ICD worked properly in 87\% of cases within a cardiac transplant standby period of approximately 6 months (median). Because there are many patients whose general condition deteriorates because of multiple organ failure, etc., the ICD implantation procedure itself may have considerable risk. In such cases, the usefulness of the WCD, which can be applied with minimal invasiveness, may be quite high. Klein and colleagues used the WCD for 22 patients waiting for heart transplantation and demonstrated proper activation of WCD because of VT/VF in 2 patients during the mean heart transplantation standby period of 5.4 months.\textsuperscript{34} Having the WCD while waiting for heart transplantation is considered to be useful, but the transplant standby period in Japan is an average of 2.3 years in Status 1, which is much longer than that in Europe or the USA.\textsuperscript{35} At present, WCD usage in Japan is limited to 90 days, but in future we may have to reconsider extended usage, especially in such heart transplant standby cases.

Even though there are definite candidates for ICD usage, in some cases ICD implantation has to be postponed because of infection and other patient conditions, including the status of systemic diseases. Because such a patient group is basically exposed to the risk of sudden death, proactive prevention therapy is necessary during the standby period. Such patients should be good candidates for WCD usage. According to a survey study in the USA,\textsuperscript{14} the most common indications are low LVEF (≤35\%) in the acute phase of acute disease (49.5\%), cases of withdrawal of the ICD because of device infection (23.4\%), and cases of postponement of ICD implantation for any reason (16.1\%). Similarly, in a German report (n=354), the indications for WCD usage were risk evaluation of other preventive therapy (5\%) and refusal or postponement of the ICD implantation schedule (2\%).\textsuperscript{36} In the report from the USA, appropriate WCD activation was observed in 33/638 (5\%) cases of ICD removal and in 6/439 (1.4\%) cases of standby phase for ICD implantation during a mean observation period of 52.6 days.\textsuperscript{14} Japanese reports are few, but Sasaki et al have reported appropriate WCD activation in a patient during hospitalization in the acute phase after myocardial infarction.\textsuperscript{19} Similarly, Kishihara et al have reported appropriate WCD activation in an out-of-hospital setting in a patient who was hesitant about ICD implantation.\textsuperscript{38}

ICD removal because of device infection is another important issue and in such cases the patient should be a good candidate for WCD usage.\textsuperscript{39} In cases of device infection, adequate infection control is required before reoperation, but careful monitoring is also necessary because patients will not be protected from lethal arrhythmia during device removal. According to the AHA statement, even if it is only a pocket infection, blood culture is required to be negative for at least 72h before reoperation. When the valve is involved in the vegetation, it is recommended that re-implantation be scheduled at least 14 days after the time of achieving negative blood culture.\textsuperscript{40} During this time, the WCD is a good option for safe follow-up observation. Additionally, temporary removal may be necessary to avoid interference of the ICD with radiation therapy, such as for lung cancer, and a similar application of WCD will be necessary.\textsuperscript{41,42}

The results of clinical studies regarding the WCD are summarized in the Table.\textsuperscript{46-48} Although most of the studies used retrospective data and the study populations were heterogeneous, 0.2-44.4\% patients had appropriate defibrillation shocks, indicating a considerable number of patients were saved from SCD by the WCD.

Extended Usage of the WCD and Its Future

Although the ICD is powerful device for prevention of sudden death, its usage is strictly regulated in the guidelines of various countries based on various clinical evidence.\textsuperscript{5-7} This restriction is appropriate when considering the cost and the invasive procedure, and inappropriate overuse must be avoided. However, there are various “gray zone” patients in the real world; for example, patients with hereditary arrhythmias, such as long QT syndrome, Brugada syndrome etc., for whom the indication of WCD is still controversial. Of course, they will be recommended for ICD therapy when they are identified as a “high risk” group, but it will not be recommended for low- or intermediate-risk patients. Such risk stratification has been constructed according to various clinical evidence; however, for example, even in intermediate-risk of Brugada patients, there is still a much higher probability of sudden death compared with normal subjects. In such cases, long-term use of the WCD may be a realistic option. Of course, the WCD system also has a considerable cost in today’s insurance system, so another option of WCD use, separate from regular insurance coverage, should be considered in future, just as with an automated external defibrillator system, depending on the patient’s choice even though such usage may put a burden on the patients themselves. If it might be possible, systematic long-term monitoring of such low or intermediate-risk patients will then be available. Conversely, data accumulation in a safe environment using the WCD may give us the opportunity to reconsider the deadline for ICD implantation. Because there are some patients, although rare, who exhibit late recovery (i.e., 6-12 months) of LV dysfunction after acute cardiac injury, and ICD implantation might be avoided in such cases. To establish such new understanding of the timing of ICD implantation, prospective long-term observation of a considerable number of patients using the WCD will be necessary.

Another issue is in-hospital-use of the WCD. Sasaki et al\textsuperscript{19} discussed about in-hospital-use of WCD in their institute. One would be concerned about overuse of WCD because regular ECG monitoring is available for in-hospital conditions. However, because VT/VF is serious condition that requires immediate and appropriate therapy, including defibrillation, the patient may suffer from serious damage even under continuous ECG monitoring when admitted in a general ward. However, the number of beds in the intensive care unit is limited and intensive monitoring itself will increase the cost of admission. In-hospital-
use of the WCD is probably not its main purpose but may play an ancillary role in the care of high-risk patients, especially while in general wards of hospitals.

The last and serious issue is the imbalance between its cost and insurance coverage, although the cost is almost comparable to that in Western countries such as the USA or Germany. Under the present conditions, the institute has to pay more money than the insurance coverage to use the WCD system, meaning that “WCD use causes money loss” in each patient. WCD use in Japan is strongly limited for this very reason. From the standpoint of Japanese WCD users who desire to decrease the risk of SCD, we hope that this problem of cost imbalance is solved as soon as possible. Probably this economic imbalance is not the only factor, but there is a serious discrepancy between the number of actual WCD users and the number of patients at risk for sudden death.18,43 This point should be realized by creating a nationwide registry and such inappropriate underuse of WCD should be solved in the near future.

Conclusions

By summarizing various reports regarding the WCD, it is considered that it is a feasible bridge to ICD therapy and/or safe observation for patients at high risk for SCD, especially in the acute recovery phase of cardiac diseases. Additionally, WCD might provide a safe environment for long-term observational studies even in patients at higher risk for SCD.

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