Circumstances and Outcomes of Out-Of-Hospital Cardiac Arrest in Elementary and Middle School Students in the Era of Public-Access Defibrillation – Implications for Emergency Preparedness in Schools –
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**Background:** Circumstances and outcomes of out-of-hospital cardiac arrest (OHCA) in elementary and middle school students while at school in the era of public-access defibrillation are unknown.

**Methods and Results:** We conducted a nationwide hospital-based survey of elementary and middle school students who had had OHCA of cardiac origin and received prehospital resuscitation in 2005–2009. Among 58 cases recruited, 90% were witnessed by bystanders; 86% had ventricular fibrillation as the initial rhythm; 74% were resuscitated by bystanders; 24% were defibrillated by bystanders; 55% occurred at school; 66% were exercise-related; 48% were followed up before the event; 67% had structural heart disease. In total, 53% of overall patients and 79% of those initially defibrillated by bystanders had a favorable neurological outcome. Patients were more likely to be defibrillated by bystanders (38% vs. 8%, \( P=0.012 \)) and had a more favorable neurological outcome in schools (69% vs. 35%, \( P=0.017 \)) than in other locations. The majority of arrests in schools were exercise-related (84% vs. 42%, \( P=0.001 \)), occurred at sports venues, and students were resuscitated by teachers; half of the cases at school occurred in patients with a pre-event follow-up.

**Conclusions:** After OHCA, children were more likely to be defibrillated by bystanders and had a better outcome in schools than in other locations, which may be relevant to the circumstances of events. (Circ J 2014; 78: 701 – 707)

**Key Words:** Defibrillation; Pediatric arrhythmias; Resuscitation; Sudden cardiac death

Sudden cardiac death in elementary and middle school students is a rare but devastating condition that has a tremendous effect on the family and local community, including schools, parent groups and family doctors.1-7 Previously, early recognition and management of the underlying disease was believed to be the only possible approach toward preventing such events.8,9 Recently, emergency response at school using automated external defibrillators (AED) has been con-
considered a potentially effective strategy, because multiple studies, including a randomized trial, have demonstrated that public-access defibrillation (PAD) improves the outcome among adults after out-of-hospital cardiac arrest (OHCA) in specific public locations. Schools have been regarded as particularly advantageous locations for an emergency responses with respect to the high proportion of witnessed arrests, bystander cardiopulmonary resuscitation (CPR), and bystander use of AED. Although few studies have addressed the effect of PAD on cardiac arrests in students at school, a recent questionnaire survey demonstrated a substantial proportion of high-school athletes with sudden arrest survived to hospital discharge when early defibrillation with CPR was provided at sports venues staffed by athletic trainers. However, the effect of PAD on OHCA in ‘ordinary elementary and middle school students’ at school and the related circumstances and outcome in the school setting are largely unknown. This question is important because it could be the rationale for efficient placement of AED and focused training of staff at schools.

Since the use of AEDs by any citizen was approved in July 2004, the number of public-access AED devices in Japan has increased to 203,924 in 2009, as many as 28.9% of those public-access AEDs in Japan were deployed in schools: nationwide, AEDs were placed in up to 72.0% and 89.8% of elementary and middle schools, respectively, by 2009. Despite perceived concern over the low prevalence of ventricular fibrillation (VF) in children and the low success rate in defibrillating young athletes even in VF, recent Japanese Utstein studies demonstrated that early defibrillation was associated with improved outcome in these children after cardiac OHCA. However, the lack of a more detailed reporting system of OHCA, including specific location (ie, in schools), cardiac etiology, and related circumstances (high-risk situation, location, and population), has hindered the investigation of such issues in elementary and middle school students.

We therefore investigated whether elementary and middle school students after OHCA of cardiac origin are more likely to be defibrillated by bystanders and exhibit more favorable neurological outcome in schools than in other locations, and under what circumstances this occurs. We conducted a nationwide hospital-based observational study of such students who had OHCA of cardiac origin in Japan.

**Methods**

**Study Design**

This was a retrospective, nationwide hospital-based questionnaire survey of OHCA of definitive or presumed cardiac origin in elementary and middle school students who were treated by emergency medical service (EMS) personnel and transported to hospitals between January 2005 and December 2009. This was an official research project endorsed by the Japanese Society for Pediatric Electrocardiography, a branch of the Japanese Society for Pediatric Cardiology and Cardiac Surgery. The ethics committee in the Mie University Graduate School of Medicine approved this study.

**Study Setting**

The EMS system and training programs for CPR/AED use in Japan have been reported previously in detail. Briefly, Japan has an area of approximately 378,000 km², with a population of 127 million in 2005. There were 807 fire stations with a dispatch center in 2007. EMS is provided by municipal governments. Life support is provided around the clock by the local EMS system. The placement of AEDs in public areas was driven by either public or private initiatives. Elementary (grades 1–6 at 6–12 years of age) and middle (grades 7–9 at 12–15 years of age) school education is compulsory in Japan. The cumulative number of public-access AEDs, excluding those in medical facilities and EMS institutions, increased from 9,906 to 203,924 (160.6/100,000 population) during the 5-year study period. A total of 96.5% of public-access AEDs are located in public locations, 28.9% in schools. The proportion of elementary and middle schools equipped with at least 1 AED device among all private and public schools across Japan increased from 18.1% and 38.3% in 2007 to 72.0% and 89.8%, respectively, in 2009. Teachers and other school staff participated in CPR training programs conducted by EMS providers or other instructors, voluntarily or under the guidance of local school boards. In Japan, approximately 1.4–1.5 million citizens per year participate in CPR/AED training programs, which are typically provided by local fire departments. Mandatory school ECG screening was legislated by the national government in 1995 and has been performed for all first graders in elementary and middle schools across Japan.

**Data Collection**

Questionnaires were sent to 191 hospitals across Japan, including all hospitals registered as teaching hospitals by the Japanese Society for Pediatric Cardiology and Cardiac Surgery or to which any councilor of the society belonged, and an additional 34 hospitals, from which any doctor in any scientific meeting meeting web-searchable OHCA cases that met the criteria for inclusion. Registry data were collected retrospectively by a doctor in charge with the aid of hospital records and pertinent EMS information.

**Definition of Terms in the Questionnaire**

The terms and questionnaire items were defined in accordance with the Utstein-style guideline in the all-Japan registry, which included initial cardiac rhythm, return of spontaneous circulation (ROSC) before hospital arrival, 1-month survival, and neurological status after the event. The specific items in the questionnaire are reported in detail in Supplementary File: Methods.

Cardiac arrest was defined as cessation of cardiac mechanical activity confirmed by the absence of signs of circulation. The arrest was presumed to be of cardiac origin unless of noncardiac origin (respiratory disease, malignant tumors, central nervous system disorders, anaphylaxis, endocrine disease, etc.), or external (traffic accident, trauma, hanging, drug overdose, bleeding, asphyxia, etc.), which was determined clinically by the physician in charge according to the EMS information. Comatose cordis was therefore excluded in this study. When a layperson delivered defibrillation by an AED, the initial rhythm of the patient was regarded as VF, including pulseless ventricular tachycardia. A patient initially defibrillated by a bystander was defined as one in which a public-access AED was used and defibrillation was delivered; if the public-access AED was applied but defibrillation was not delivered, the patient was not included in this category. Exercise was defined as any activity that would increase heart rate: jogging, swimming, playing sport, cycling or stair climbing were regarded as exercise-related, whereas walking, standing or sitting was not regarded as exertional. Neurological outcome at 1 month after successful resuscitation was determined by the doctor in charge, using the Cerebral Performance Category (CPC)
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by Mann-Whitney U test, adjusted for multiple comparisons. Categorical data are expressed as a value or frequency of occurrence. The difference of the proportions of categorical variables among groups was assessed by chi-square analysis. All tests were 2-tailed, and \( P<0.05 \) was considered to indicate statistical significance.

Results

The primary response rate in the present questionnaire survey was 57%; 58 elementary and middle school students (median age [interquartile range]: 12 years [11–14]; males: 64%) after an

<table>
<thead>
<tr>
<th>Table 1. Clinical characteristics and outcomes of out-of-hospital cardiac arrests in school children at or out of school</th>
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<tbody>
<tr>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>No. of events, n</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
</tr>
<tr>
<td>Median age (interquartiles)</td>
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<tr>
<td>Calendar year 07-09, n (%)</td>
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<tr>
<td>Bystander witness, n (%)</td>
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<tr>
<td>Nonfamily witness, n (%)</td>
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<tr>
<td>Events in public locations, n (%)</td>
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<tr>
<td>Initial VF, n (%)</td>
</tr>
<tr>
<td>Bystander's CPR, n (%)</td>
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<tr>
<td>AED use, n (%)</td>
</tr>
<tr>
<td>Bystander AED, n (%)</td>
</tr>
<tr>
<td>EMS AED, n (%)</td>
</tr>
<tr>
<td>Exercise-related, n (%)</td>
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<tr>
<td>Followed-up cases, n (%)</td>
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<tr>
<td>Favorable neurological outcome, n (%)</td>
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<tr>
<td>Survival at one month</td>
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<tr>
<td>Pre-hospital ROSC</td>
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</table>

Number among available data with the percentage in parenthesis was shown.
AED, automated external defibrillator; CPR, cardiopulmonary resuscitation; EMS, emergency medical service; ROSC, return of spontaneous circulation; VF, ventricular fibrillation. Missing data on cases of initial VF at school (n=2) and pre-hospital ROSC at and out of school (1 each) were included, with percentages calculated based on the available data.

<table>
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<tr>
<th>Table 2. Clinical and Outcome Parameters in Subgroups of Patients in the Japanese Pediatric Utstein Study</th>
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<tr>
<td><strong>Parameter</strong></td>
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<tr>
<td>Defibrillated by as a bystander or EMS personnel who defibrillated the victim</td>
</tr>
<tr>
<td>Bystander, n (%)</td>
</tr>
<tr>
<td>EMS, n (%)</td>
</tr>
<tr>
<td>Favorable neurological outcome, n (%)</td>
</tr>
<tr>
<td>Survival at 1 month, n (%)</td>
</tr>
<tr>
<td>Prehospital ROSC, n (%)</td>
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</table>

Data are n (%). Family member-witnessed arrests were presumed to be in a private location; non-family member-witnessed arrests were presumed to be in a public location. Abbreviations as in Table 1.
OHCA with a definitive cardiac diagnosis (n=52) or of presumed cardiac origin (n=6) were recruited (Table 1): 52 (90%) were witnessed by bystanders (9 by family members and 43 by non-family members [30 by school teachers and 13 by others]); 48/56 patients (86%) had VF as the first documented rhythm (pulseless electrical activity in 2, asystole in 6, unknown in 2); 43 (74%) received bystander CPR (8 from family members and 35 from non-family members [27 from school teachers and 8 from others]); 44 (76%) received AED-based prehospital defibrillation (30 from EMS personnel and 14 from bystanders [11 from school teachers and 3 from other non-family members]). A total of 31 patients (53%) had a favorable neurological outcome: 33/56 (59%) had ROSC before arrival at the hospital. Among the patients initially defibrillated by a bystander, 11/14 (79%) exhibited a favorable neurological outcome. The proportion of prehospital ROSC was higher in patients with a favorable neurological outcome (26/29, 90%, P<0.001) than in those without a favorable neurological outcome (7/27, 26%). The proportion of prehospital ROSC tended to be higher in patients defibrillated by bystanders (11/13, 85%, P=0.11) than in those defibrillated by EMS personnel (18/50, 36%). The distribution of patients by witnessed arrests, 31 occurred at school, 11 in other public locations, and 1 at home. Compared with an arrest out of school, an arrest at school was associated with a higher proportion of favorable neurological outcome 1 month after OHCA than out of school (P=0.02) (Table 1).

Cardiac Etiology and Circumstances of OHCA in School Children

Figure 1 depicts the diagnosis of the cardiac disorders. Among all 58 arrests, 52 (90%), comprising 41 of 42 survivors and 11 of 16 non-survivors, were diagnosed. Of these 52 diagnosed cases, structural and nonstructural heart disease accounted for 67% and 33%, respectively. Cardiac etiology according to exercise status and follow-up status is shown in Figure 2. Arrests that occurred during or just after exercise accounted for 66%, events that occurred at rest or during walking accounted for 26%, and events that occurred during sleeping accounted for 7%. All arrests in the coronary anomaly and catecholaminergic polymorphic ventricular tachycardia (CPVT) categories were exercise-related, whereas 50% of cases of congenital heart disease (CHD) and of hypertrophic cardiomyopathy (HCM) were exercise-related. Cases of follow-up for chronic heart disease before the event accounted for 48%. All 10 CHD cases, 6 of the 8 HCM cases, 5 of the 8 other myocardial diseases, excluding 2 acute myocarditis cases, and 4 of the 9 cases of long QT syndrome were followed up. No cases of coronary anomaly, CPVT, or idiopathic VF were followed up. The proportion of these 3 diseases, which can exhibit apparently normal resting ECG, accounted for 47% of the total cases with no pre-event follow-up (Figure 2). There was a tendency toward a lower proportion of exercise-related events in followed cases (54% vs. 77%, P=0.06) than in unfollowed cases (Table 3). OHCA among the unfollowed cases of arrests at school, which were almost always exercise-related (94%), were frequently associated with these 3 diseases which could exhibit apparently normal resting ECG (63%) (Table 3). Among 27 exercise-related cases of arrests at
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Could support prioritization of the placement of AED in these locations and the focused training of school teachers, especially those in charge of physical exercise, in CPR with AED. Patients with associated chronic cardiac disease in the pre-event follow-up accounted for half of the arrests at school, suggesting that such a subgroup may be at high risk for OHCA at school.

OHCA at School in the Era of PAD

In the present study, we demonstrated that an arrest in children at school was associated with a high proportion of AED use by bystanders and a favorable neurological outcome; this is in contrast with the low rate of defibrillation by bystanders out of school. These findings are consistent with our concomitant pediatric Utstein study, in which there was a high rate of AED use by bystanders (21%) and a favorable neurological outcome (37%) after OHCA occurred in a public location, although the specific location of arrests was not determined in that study. These findings are also consistent with a recent sharp decline of the incidence of sudden cardiac death in children under school supervision in the Japan Sport Council database, although the incidence of OHCA or the number of bystanders using AEDs is unknown.

Table 3. Cardiac Disease and Exercise Status by Location and Follow-up of Arrest

<table>
<thead>
<tr>
<th>Location</th>
<th>At school (n=32)</th>
<th>Out of school (n=26)</th>
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<tbody>
<tr>
<td>Follow-up (n=28)</td>
<td>(n=16)</td>
<td>(n=12)</td>
</tr>
<tr>
<td>Exercise-related</td>
<td>(n=12)</td>
<td>Exercise-related (n=3)</td>
</tr>
<tr>
<td>HCM (4), CHD (3), LQT (3), Other MD (3: DCM 1, NLVM 1, old myocarditis 1), Other arrhythmia (1: WPW), Unknown (2)</td>
<td>CHD (7), HCM (2), LQT (1), Other MD (2: DCM 1, RCM 1)</td>
<td></td>
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<tr>
<td>No follow-up (n=30)</td>
<td>(n=16)</td>
<td>Exercise-related (n=8)</td>
</tr>
<tr>
<td>Exercise-related</td>
<td>(n=15)</td>
<td>Coronary anomaly (5), HCM (2), LQT (2), Coronary anomaly (2), Other arrhythmia (5: iVF 3, CPVT 2), Other MD (1: DCM), Unknown (1)</td>
</tr>
<tr>
<td>Other MD (4: NLVM 2, acute carditis 2), Other arrhythmia (2: iVF 1, CPVT 1), Unknown (3)</td>
<td>Other MD (4: NLVM 2, acute carditis 2), Other arrhythmia (1: WPW 1), Unknown (2)</td>
<td></td>
</tr>
</tbody>
</table>

CHD, congenital heart disease; CPVT, catecholaminergic polymorphic ventricular tachycardia; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; iVF, idiopathic ventricular fibrillation; LQT, long QT syndrome; MD, myocardial disease; NLVM, noncompaction of left ventricular myocardium; RCM, restrictive cardiomyopathy; WPW, Wolff-Parkinson-White syndrome.

Discussion

According to previous Japanese Utstein registry studies, which included all age groups, it is adolescents and younger school-age children who are most likely to be defibrillated by a bystander and have a favorable neurological outcome. However, the specific locations of arrests and circumstances of events related to PAD are unknown. In the present survey, we demonstrated that elementary and middle school students were more likely to benefit from defibrillation by bystanders after OHCA and exhibited a more favorable neurological outcome for arrests occurring in schools than in other locations, suggesting that school campuses might be a specific location that is highly efficient for CPR with defibrillation by bystanders. The majority of arrests in schools were exercise-related, occurred at sports venues, and were witnessed and resuscitated by teachers, which
County study in which arrests on school campus were characterized by a higher rate of witnessed arrest (79%), bystander CPR (74%), and survival to hospital discharge (39%), although that study mainly focused on the adult population with few cases initially defibrillated by a bystander. It is also consistent with a questionnaire study of US high-school athletes, in which 93% (13/14) received AED defibrillation and 64% (9/14) survived to hospital discharge, although the non-athlete population was not addressed in that study. Therefore, the outcome in schools could be comparable to that in other specific public locations, including casinos, airlines, and airports, where the favorable effect of PAD has been highly appreciated. The high rate of initial VF in the present study was consistent with that in 2 other school-based studies [Seattle/King study (78%) and the US high-school study (83%)], as well as in our pediatric Utstein study (71% in public location arrests). In addition, the proportion of VF did not vary significantly with the underlying disease category in the present study, suggesting the therapeutic potential of early defibrillation overall in children after arrests at school.

The non-athletic level of exercise in schools, as well as strenuous exercise such as by competitive athletes in high school or university, or by young adults, has been considered a trigger for OHCA. As the proportion of exercise-related arrests was higher in than out of school in the present study, even regular exercise by elementary and middle school students at school poses a risk for an arrest in such children; sports venues were a high-risk location of arrests in schools; however, bystander CPR and defibrillation performed by teachers in such a situation worked reasonably well. These findings support prioritization of AED placement accessible to these locations in schools and focused training of school teachers, especially those in charge of physical exercise, in CPR with AED.

Cardiac Etiology and Circumstances of OHCA in School Children

Cardiac disorders related to sudden cardiac death in school children have been extrapolated from pathology-based studies of young athletes and non-athletes up to the age of 35 in Italy, the USA, and the UK. In those studies, structural heart disease, including HCM (4–36%), coronary anomaly (≤17%), myocarditis (3–12%), and arrhythmogenic right ventricular cardiomyopathy (≤14%), was the predominant cause of arrests; 6–29.2% of arrests were unexplained, and presumed to be caused by arrhythmia. The relatively high proportion of CHD in the present study was consistent with the findings in the recent King County study, which included non-athletic children with chronic diseases (21–23%). The inclusion of specific arrhythmia disorders in the present study was newly derived from clinically diagnosed aborted sudden death cases recruited nationwide. Thus, this study presents the cardiac etiology of OHCA in a specific school-age population, which could be relevant to the understanding of arrests in such students.

Because we have demonstrated that approximately half of all arrests, and of those at school, occurred in students with a pre-event follow-up of cardiac disease, as in a previous school-based study, the recognition of such a high-risk group may have implication in emergency responses at school. Despite a lower proportion of exercise-related events in followed cases, which may be explained by the effect of withdrawal from exercise in such cases or the exercise-related characteristics of the disease, ‘pre-event awareness of diseases’, including HCM and long QT syndrome, could aid in alerting school staff to otherwise unpredictable events in schools. Conversely, as OHCA in ostensibly healthy children at school was mostly exercise-related, the secondary prevention of cardiac death by using AED at sports venues may play an essential role. Although the likelihood of defibrillation by bystanders was in fact similar between the followed cases and ostensibly healthy children among the exercise-related cases of arrests at school in the present study, the recognition of a high-risk patient, as well as a high-risk situation and venue, may be relevant to optimizing the outcome of OHCA at school in the future.

Study Limitations

First, this was a retrospective, nonpopulation-based study, which may affect the interpretation of the findings. However, the present findings are consistent with our concomitant pediatric population-based Utstein study, in which we demonstrated a high rate of bystander AED use and favorable neurological outcomes after OHCA occurring in public locations. Second, specific information on the scope of the budgetary barriers and logistic issues (i.e., the locations of AEDs, training schedule for teachers) involved in implementing and refining AED/CPR programs at the national level in Japan is unavailable. Third, cardiac etiology of OHCA in followed and unfollowed patients in the present study could be influenced by the school ECG screening in Japan, although the role of the school ECG screening system was not specifically addressed. Fourth, the present study focused on the issue in children, not adults, in schools. Fifth, there might be unmeasured confounding factors (i.e., quality of bystander’s CPR) that might influence outcomes.

Conclusions

OHCA in school children is a rare event, but one of great public concern. The present study is the first to characterize cardiac arrest in ordinary elementary and middle school children in or out of school in the era of PAD, which could be relevant to the recognition of high-risk groups, the efficient placement of AEDs and the focused training of staff (CPR with AED use) in schools. The present findings warrant population-based studies on the role of CPR with AED use and related circumstances of events in schools.

Acknowledgments

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Disclosures

We declare that we have no conflicts of interest.

References

4. Atkins DL, Everson-Stewart S, Sears GK, Daya M, Osmond MH,


Supplementary Files

Supplementary File 1

Methods.

Figure S1. Distribution of patients by school grade.

Figure S2. (A) Cardiac etiology by the time of day of arrest.

Table S1. Clinical and outcome parameters by disease category (n=52) Please find supplementary file(s); http://dx.doi.org/10.1253/circj.CJ-13-1162