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Original research

Epidemiology of sudden cardiac death and sudden cardiac arrest with resultant disability during high school organized sport in Japan

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ABSTRACT

Objectives: To examine the incidence and survival rates of sudden cardiac arrest that were documented during school organized sports in Japan.
Design: Retrospective cohort study.
Methods: Insurance claim data of cardiac events (sudden cardiac death and sudden cardiac arrest with resultant disabilities) that occurred during Japanese high school organized sports between 2009 and 2018 were retrieved. Participation data from All Japan High School Athletic Federation and Japan High School Baseball Federation were used for incidence rate calculations. Incidence rate ratios with 95 % confidence interval were calculated to compare the risk by sports and sex. The survival rate was calculated with the proportion of resuscitated cases to total number of cardiac events in this dataset.
Results: A total of 55 cardiac events (25 survivors and 30 deceased) were identified in the dataset. The majority affected male student-athletes (92.7 %). The frequency and incidence rate of cardiac events were highest in male baseball ($n = 16$ [29.1 %], incidence rate: 0.91 per 100,000 athlete-years). Incidence rate ratio revealed that male basketball (2.19, 95 % confidence interval: 1.04–4.60), male baseball (2.31, 95 % confidence interval: 1.32–4.03), and first-year male baseball (4.11, 95 % confidence interval: 2.10–8.07) had significantly higher risk of cardiac events, compared to the overall incidence rate (0.38 per 100,000 athlete-years). The survival rates were 37.5 % in the first half (2009–2013) and 56.5 % in the latter half (2014–2018) of the study period.
Conclusions: The risk of cardiac events was highest in male, baseball, first-year student-athletes. Rapid AED application by bystanders should be advocated to enhance better survival.

Practical Implications

- Targeted prevention strategies can be developed to address the high risk of sudden cardiac arrest reported in male, baseball, and/or freshman student-athletes in Japan.
- The intensity of conditioning sessions may need to be adjusted to the individual athlete's fitness level to minimize the risk of cardiac incidents.
- Improvement in bystander automated external defibrillator application may increase the chance of survival from sudden cardiac arrest in Japanese high school sports.
- The necessity of written, well-designed emergency action plan which is rehearsed regularly should be rigorously and continuously advocated to enhance efficient response to a cardiac emergency.

1. Introduction

Sudden cardiac arrest (SCA) is the leading cause of deaths that occur during sports activities among young athletes worldwide and in Japan.[1–5] Examination of SCA incidence among athletes has been a research interest worldwide[1,6–8]; however, only a few studies have investigated this topic specific to Japanese athletes.[4,5]

Currently, Japan Sports Council (JSC) Injury and Accident Mutual Aid Benefit System is the only database that systematically documents SCA cases in student-athletes. Almost all high schools in Japan (97.7 % of high school students in 2018 academic year) enroll in this system that provides benefits (e.g., medical expense, disability and death

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compensations) for accidents that occurred during school activities. Previous study that analyzed this database reported that exercise-related out of hospital SCA incidence rates are 0.17, 0.22, and 0.39 per 100,000 person-years in elementary, middle, and high schools, respectively.[9] However, there is a paucity of information about SCA risk comparison among different sports that schools offer. Thus, the primary purpose of this study was to retrospectively examine the incidence rate of SCA that occurred during high school organized sports by different sports, using JSC Injury and Accident Mutual Aid Benefit System database. Additionally, secondary purpose of this study was to evaluate the survival rate from SCA.

2. Methods

High school student-athletes (ages 15–18) who experienced SCA during and immediately after high school organized sports activities were studied. The primary data source was insurance claim data of fatalities and severe injuries during sports activities submitted to JSC Injury and Accident Mutual Aid Benefit System for disability or death compensations between 2009 and 2018. A severe injury was defined as a catastrophic injury that resulted in permanent disability. JSC classifies the severity of disability by their grading system into 14 classes (Grade 1 through 14, Grade 1 most severe). After screening brief summaries of all severe injury cases available on the JSC website, Grade 7 was used as a cut-off point for data retrieval from JSC because cases indicative for SCA (e.g., sudden collapse, implantable cardioverter-defibrillator placed post incident) and cases with unclear etiology were included in Grade 7 or severer disability classes. Principal investigator (MSY) acquired insurance claims data of all fatalities and Grade 7 or severer injuries, which included sex and year in school of the victim, sports played, activity type, diagnosis of the medical condition, underlying medical condition, and automated external defibrillator (AED) use. Brief summary of each incident was available on the JSC website, and case information regarding fatalities and severe injuries was retrieved in February and December 2020, respectively (https://www.jpnsport.go.jp/anzen/anzen_school/anzen_school/tabid/822/Default.aspx). Case information retrieved directly from JSC and the website were matched based on the pre-designated identification number by JSC.

After retrieval of insurance claim data from JSC, cases that met the following criteria were excluded: 1) the onset is not related to school organized sports (e.g., incidents from physical education [PE] class and school-hosted sports events), 2) the onset is not related to sports participation (e.g., traffic accidents, natural disaster) or the association between the onset and sports participation cannot be established, and 3) the etiology is not cardiac-related. We examined cardiac events that occurred due to participation in school organized sports and excluded incidents reported during PE classes in our analysis because school organized sports present with a unique context that is different from PE that may influence our interpretation of sudden cardiac event risks (e.g., year-long commitment to a single sport, a single session is longer than a typical class duration, greater physical and skill demands).

Hereafter, the cases which resulted in survival after cardiac arrest with successful resuscitation and defibrillation are referred as SCA. Due to the disability-based case screening protocol used in this study, SCA cases in this dataset were all with resultant disability. The cases which resulted in death by a cardiac cause are defined as sudden cardiac death (SCD). Cases were categorized as SCA when a sudden collapse that required AED application and shock delivery were identified in the case report. Cases were categorized as SCD when a cardiac disease that is associated with SCD (e.g., hypertrophic cardiomyopathy, dilated cardiomyopathy, long QT syndrome) was identified in the case report. Common cardiac diseases that are associated with SCD have been described elsewhere.[1,10,11] Further, sudden unexpected deaths with a history consistent with cardiac related incident in a structurally normal heart with no other explanation for death were labeled as SCD and confirmed upon consultation to an experienced researcher in cardiological pathologies (MA). The specific etiology of each case was determined based on the record of the medical diagnosis, underlying medical condition, and AED use status on the insurance report. The cases where an AED detected ventricular fibrillation (VF) were labeled as idiopathic VF when no other cause was identified in the report.[9]

Overall incidence rates between 2009 and 2018 were calculated and expressed per 100,000 athlete-years (AY) with 95 % confidence interval (CI). Incidence rates were calculated for groups in which five or more incidents occurred during the study period to ensure the accuracy of the estimate.[4,10] Participation data of all sports except baseball was retrieved from All Japan High School Athletic Federation website (https://www.zen-koutairen.com/f_regist.html). Since baseball is independently governed by Japan High School Baseball Federation, participation data for baseball was retrieved separately (http://www.jhbf.or.jp/data/statistical/index_koushiki.html).

Frequency of SCA and SCD were determined by academic year and sports. To compare the risk among respective sports and sex, incidence rate ratios (IRR) were calculated with 95 % CI.[12] The difference in risks is interpreted as statistically significant if the 95 % CI for IRR does not include 1.00. Furthermore, incidence rates of SCA and SCD and IRR with 95 % CI were calculated for first half (2009–2013) and latter half (2014–2018) to examine the risk over time during the study period. Differences in survival (SCA vs. SCD) based on demographic information (sex, year in school) and resuscitation details (witness, AED application status) were analyzed with Chi-square tests. Additionally, a difference in activity type at time of arrest based on sports (baseball vs. non-baseball) was also examined using Chi-square test. This study was exempted from ethical review because it only involves the use of existing collections of data. Additionally, the data only contains non-identifiable information about human beings.

3. Results

Out of 263 fatal ($n = 114$) and severe ($n = 149$) sports-related incidents reported to JSC, 55 cardiac incidents (25 SCA and 30 SCD) were identified after excluding 66, 45, and 97 incidents due to exclusion criteria 1, 2 and 3, respectively (see Supplementary material, Appendix 1). The major causes of death excluded by criteria 2 included traumatic asphyxia by a natural disaster, cerebral stroke, lightning, drowning in a river/sea, and suicide. The major etiologies excluded by criteria 3 included exertional heat stroke and trauma to the head and neck. Male victims accounted for 92.7 % ($n = 51$) of overall cardiac cases, while females accounted for 7.3 % ($n = 4$). Participation data of male and female student-athletes were reported in Appendix 2 (see Supplemental material). All incidents were witnessed regardless of the outcome (SCA or SCD). AED application status was statistically different between SCA and SCD groups; the proportion of cases that AED was applied by bystander was higher in SCA group than that of SCD group (84.0 % vs. 46.7 %) Demographic and resuscitation details and specific etiology are found in Table 1. Baseball accounted for the largest proportion ($n = 16$, 29.1 %) of overall cardiac cases, followed by basketball and soccer/futsal (both $n = 9$, 16.4 %). Complete data by sports is shown in Fig. 1. Additionally, the activity type at time of arrest was statistically different when comparing baseball-specific incidents and overall incidents (see Supplemental material, Appendix 3); the proportions of cardiac events that occurred during conditioning were 75 % in baseball and 34.5 % when all sports combined ($p < .001$).

Overall incidence rate of all cardiac events (SCA and SCD) during the study period was 0.39 (95 % CI = 0.24–0.54) per 100,000 AY. The incidence rates and IRR of all cardiac events in male, male baseball, male basketball, male soccer/futsal, and first-year male baseball athletes are summarized in Fig. 2 and Appendix 2 (see Supplementary material). The risk of cardiac incidents were statistically higher in male basketball (IRR = 2.19, 95 % CI = 1.04–4.60), male baseball (IRR = 2.31, 95 % CI = 1.32–4.03), and first-year male baseball (IRR =

Table 1
Demographic and resuscitation details and etiology for cases of sudden cardiac events that occurred during high school organized sports between 2009 and 2018 in Japan.

	SCA with survival ($n = 25$), N (%)	SCD ($n = 30$), N (%)	Total ($n = 55$), N (%)
Sex			
Male	22 (88.0)	29 (96.7)	51 (92.7)
Female	3 (12.0)	1 (3.3)	4 (7.3)
Mean age (range)	16.4 (15–18)	16.2 (15–18)	16.3 (15–18)
Year in school			
First-year students	9 (36.0)	13 (43.3)	22 (40.0)
Second-year students	13 (52.0)	11 (36.7)	24 (43.6)
Third-year students	3 (12.0)	6 (20.0)	9 (16.4)
Witnessed arrest?			
Yes	25 (100)	30 (100)	55 (100)
No	0 (0)	0 (0)	0 (0)
AED applied?*			
Yes, by bystander	21 (84.0)	14 (46.7)	35 (63.6)
Yes, by EMS personnel	3 (12.0)	7 (23.3)	10 (18.2)
No	1 (4.0)	5 (16.7)	6 (10.9)
Unknown	0 (0)	4 (13.3)	4 (7.3)
Etiology of SCA/SCD			
Idiopathic VF	18 (72.0)	13 (43.3)	31 (56.3)
Hypertrophic cardiomyopathy	4 (16.0)	3 (10.0)	7 (12.7)
Aortic dissection	0 (0.0)	3 (10.0)	3 (5.5)
Coronary artery anomalies	1 (4.0)	2 (6.7)	3 (5.5)
Brugada syndrome	1 (4.0)	0 (0.0)	1 (1.8)
Dilated cardiomyopathy	1 (4.0)	0 (0.0)	1 (1.8)
Fulminant myocarditis	0 (0.0)	1 (3.3)	1 (1.8)
Tetralogy of Fallot	0 (0.0)	1 (3.3)	1 (1.8)
Unknown	0 (0.0)	7 (23.3)	7 (12.7)

Abbreviation, SCA: sudden cardiac arrest, SCD: sudden cardiac death, AED: automated external defibrillator, EMS: emergency medical service.
* Distribution (SCA vs. SCD) statistically different by Chi-square test ($p = .03$).

4.11, 95 % CI = 2.10–8.07), compared to the incidence rate in overall student-athletes.

The incidence rates of cardiac events documented during the first half (2009–2013) and latter half (2014–2018) of study period was 0.46 per 100,000AY and 0.32 per 100,000 AY, respectively (Appendix 4). The IRR of overall cardiac events of the latter half to the first half was 0.70 (95 % CI = 0.41–1.20). The IRR of SCD and SCA of the latter half to the first half was 0.49 (95 % CI = 0.23–1.04) and 1.06 (95 % CI = 0.48–2.32), respectively. Overall survival rate during the study period was 45.5 % (25 survivors, 30 deaths). The survival rate of first and latter halves were 37.5 % (12 survivors, 20 deaths) and 56.5 % (13 survivors, 10 deaths), respectively.

4. Discussion

In the current study, the number and incidence rates of SCA with resultant disability and SCD that occurred during and immediately after school organized sports were examined. Overall incidence rate of cardiac events during the study period was 0.39 per 100,000 AY. The incidence rates of SCA and SCD recently reported in the United States (US) for the similar age population ranged from 1.14 to 4.40 per 100,000 AY.[6,7,10] Although the incidence rates from the studies that utilized different methodology cannot be compared directly, the incidence rate from this study was overall lower than those from the literature reported in the US. The difference in the risk of a cardiac event may be partially explained by the difference in ethnicity of studied population. It has been consistently reported that African American student athletes have an increased risk of cardiac events in the US.[10,13] While there is lack of research that directly compares the difference in overall cardiac incident rates between African American and Asian athletes, the homogeneous ethnic background in Japan (i.e., mostly Asian) could have influenced the low incidence rates.

Another possible reason why the incidence of cardiac events was lower in Japan is the adoption of well-structured cardiac screening program in Japanese school system for all students attending elementary, middle, and high schools.[14] In this cardiac screening program, ECG assessment is mandated in the first year of respective school systems, in addition to history questionnaire distributed every year for all students.[14] In a primary screening, 12-lead ECG is not mandated, but it is recommended for better accuracy.[14] When the need for further assessment is identified, the student undergoes additional 12-lead ECG, chest X-ray, echocardiogram, exercise stress test, Holter ECG, and any other tests upon necessity by a cardiologist as a secondary screening.[14] Thus, a significant proportion of students with pre-existing cardiac disease would have been disqualified or consulted to modify their level of sports participation. We also acknowledge that the relatively low incidence rates of cardiac events were likely affected by the methodology, and we discuss that later in this section.

Among all sports that were examined, baseball marked the highest number and incidence rate of cardiac events. Although this was the first study to examine the incidence rate of cardiac events in Japanese high school organized sports, it was consistent with our previous studies that the greatest number of sports-related fatalities occurred in baseball.[4,5] This consistent finding is unique to Japanese high school sports since baseball is considered as lower risk sports for sudden death in the US.[15] For example, Peterson et al.[10] revealed that the risk of a cardiac event was 70 % lower in baseball, compared to that of overall high school student-athlete population. Meanwhile, the risk of a cardiac event of baseball student-athletes in our current study was 2.31 times higher than overall risk.

It is unlikely that underlining cardiac diseases that heightens the risk of cardiac arrest is more prevalent among baseball athletes in Japan. Thus, it is prudent to assume that environmental cause may be the contributing factor that influenced their high rates of cardiac events. Anecdotally, it appears that a key characteristic of Japanese high school baseball that may have possibly influenced the increased risk of a cardiac event is its high intensity and prolonged endurance training. In Japanese baseball, long-distance running and high intensity interval running have been traditionally emphasized over other forms of conditioning. In fact, a majority of cardiac events in baseball reported in our dataset occurred during long-distance running or interval running (see Supplementary material, Appendix 5). Additionally, a culture of playing through pain has rooted deeply in Japanese baseball, which may have contributed to accept overexertion.[16] This is supported by our finding that 75 % of cardiac events in baseball occurred during conditioning, which was unique to baseball as revealed by a Chi-square test. Moreover, the risk of cardiac event was highest among first-year student-athletes, who are generally less fit compared to upper-classmen. Suboptimal aerobic fitness has

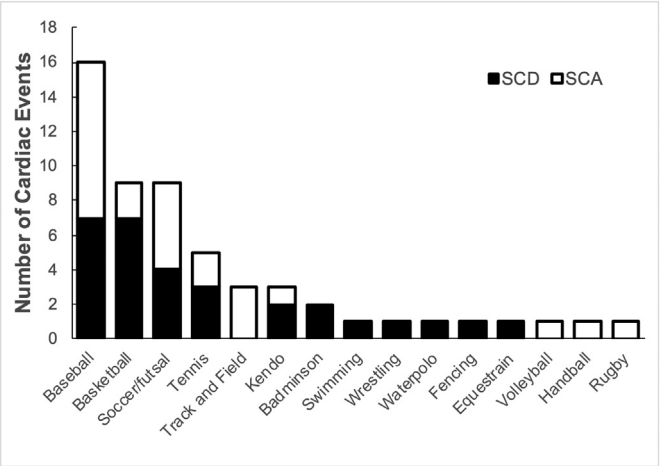

Fig. 1. Number of SCA and SCA with resultant disability during high school organized sports in Japan between 2009 and 2018. Abbreviations, SCD: sudden cardiac death, SCA: sudden cardiac arrest.

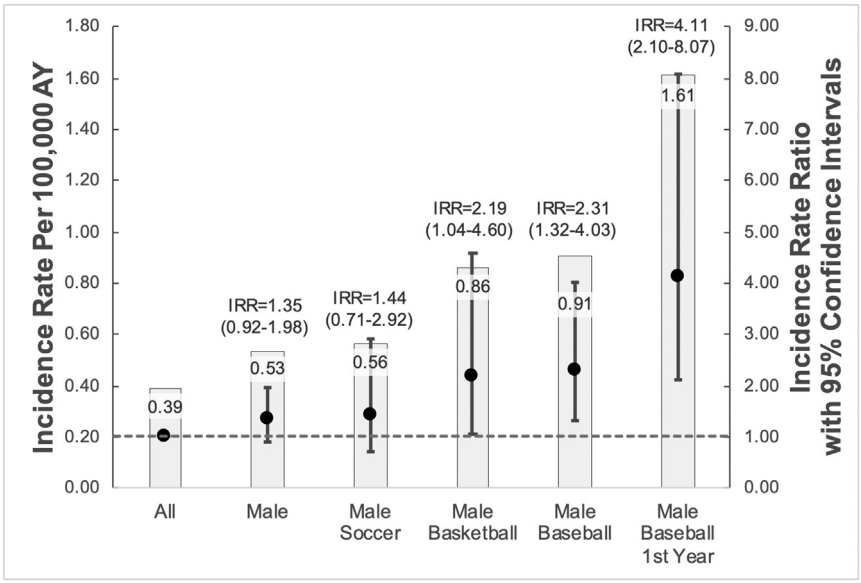

Fig. 2. Incidence rates by sports and comparison of risk of cardiac event using incidence rate ratio with 95 % confidence interval. Abbreviation, AY: athlete-years, IRR: incidence rate ratio.

been identified as one of the key factors associated with sudden death in sport.[17] While the study by Boden et al.[17] did not report age as the risk factor, we must consider that Japanese high school organized sports typically conduct practice and training sessions in one team, with students of all ages and levels take part in the same session. In traditional US school organized sports, teams are divided by age and skill levels (e.g., freshman, junior varsity, varsity), which may help nullify the influence of age as a risk factor.

The IRR calculations revealed that the risk of overall cardiac events and SCD declined over the study period. Regardless of the relatively large changes in the risk, both reductions (overall cardiac events, −30 %; SCD, −51 %) did not reach statistical significance, likely due to the large variance in incidence rate observed per year. Nevertheless, similar trend is reported in previous literature[18,19]and is attributed to gradual improvement of bystander AED. The Japanese Circulation Society published the "Aiming for Zero Deaths" statement in 2015 and advocated practical recommendations on how to prevent cardiac deaths in schools.[20]

Although improvement in bystander AED application has been reported in the literature, our data revealed that AED application was delayed until EMS arrived in 12.0 % and 23.3 % of SCA and SCD cases, respectively. Moreover, less than half of SCD victims received bystander AED. As Chi-square analysis revealed, the proportion of cases that received bystander AED was statistically higher in survivors (SCA, 84.0 %) than in deceased (SCD, 46.7 %), which suggests the delay in AED application may have affected the survival. Time to defibrillation is the critical factor to determine success in resuscitation, and the preparation to enhance efficient response to a cardiac emergency should be continuously and rigorously advocated. Multiple professional organizations emphasize the necessity to establish a written, well-designed emergency action plan and the importance of rehearsing it regularly.[21,22]

This study is not without limitations. We highlighted the relatively low incidence rates reported in this study. This can also be explained by some methodological limitations. First, we were not able to include cardiac events that happened to student-athletes outside the context of school organized sports (e.g., at rest, during sleep). Peterson et al.[10] reported that 18.1 % of cardiac events that affected student-athletes occurred at rest or during sleep. Thus, we might have missed a significant portion of cardiac events in the cohort. Second, cases that recovered with no brain damage or other disabilities were not detected by the disability-based screening protocol that we adapted for this study. Given the purpose of the insurance claims (i.e., disability or death compensations), it is highly likely that such cases would not be entered into the dataset we have used for our analyses. All in all, the incidence reported in this study is likely to represent the minimum incidence of cardiac events in this cohort. Additionally, there could be a gap between the year of incident occurrence and the year when the data is filed in the database. Thus, there may be additional cases that will become available in the future.

It is highly possible that not all deceased cases underwent detailed post-mortem examinations or were reported with a complete set of documents to confirm the cause of death, such as medical record, death certificate, and autopsy report, to JSC. This limits the reliability of reported etiology. Additionally, this also may affect the accuracy of the estimate of the SCD incidence rate by labeling cases with undetected non-cardiac etiology as presumed SCD or labeling cardiac death as non-cardiac death.

Lastly, we cannot determine the incidence rate for female student-athletes due to too few cases during the study period. In order to evaluate the incidence rate of SCA of such relatively low-risk group, longer study period should be considered in the future study.

5. Conclusion

A total of 55 incidents of SCD and SCA with resultant disability occurred during and immediately after high school organized sports between 2009 and 2018 in Japan. Most of them (92.7 %) affected male student-athletes. The risk of cardiac events was highest in male baseball (0.91 per 100,000AY). Cases reported in baseball were characterized by a higher risk among first-year student-athletes and statistically significant prevalence during conditioning. Although the change did not reach statistical significance likely due to the variance in number of cases within each academic year, the risk of SCD declined by 51 % in the latter half of the study period. Preparation for cardiac emergencies should be continuously and rigorously advocated to enhance rapid AED application and maximize survival from SCA.

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Declaration of Interest Statement

There are no competing interests to disclose.

Confirmation of Ethical Compliance

This study was exempted from ethical review because it only involves the use of existing collections of data. Additionally, the data only contains non-identifiable information about human beings.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2022.06.011.

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