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Case Report

A new approach to prevent critical cardiac accidents in athletes by real-time electrocardiographic tele-monitoring system: Initial trial in full marathon

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ABSTRACT

The majority of marathon deaths are caused by sudden cardiac arrest (SCA), which occur in approximately 1 in 57,000 runners. Such deaths are more common among older males and usually occur in the last 4 miles of the racecourse. Although prompt resuscitation, including early use of an automated external defibrillator (AED), improves survival, the deployment of enough trained medical staff and AEDs is difficult due to increased cost. Moreover, most victims of exercise-related SCA have no premonitory symptoms. Therefore, we tried to use a novel approach to prevent sudden cardiac deaths (SCD) related to SCA using real-time electrocardiographic tele-monitoring system, as an initial trial to assess operative possibility in a full marathon. As a result, 3 out of 5 runners had reasonable measurement results and sufficient tele-monitoring without complications related to this trial was possible. However, many investigations and improvements, such as improving cost-effectiveness, reducing noise, and automating the monitoring system, are needed for practical application of these devices for athletes. As a next step, we would establish a novel strategy to reduce SCDs in athletes using next-generation devices, which include an alarm system associated with early application of AED.

<**Learning objectives:** Sudden cardiac arrest (SCA) is a major problem in sports cardiology. Here we investigated a novel approach using a real-time tele-monitoring system of electrocardiogram (ECG) to prevent sudden cardiac deaths by making use of an advanced alarm system which responds to SCA risk. Three out of five cases we monitored showed reasonable measurement of ECG with centralized observation in full marathon. This is the first report of this method, which may lead to the effective application of automated external defibrillator in athletes.>

Introduction

Recently, the marathon has gained worldwide popularity due to increasing participation; however, 107 sudden cardiac arrest (SCA) cases have been reported in the past 10 years (2002–2011) in Japan [1]. Most SCAs during marathons are caused by cardiogenic disorders, including ischemic heart disease; in addition, about half of the victims die. In the USA, a previous report has shown that SCA occurs in approximately 1 in 57,000 marathon runners, is more common in older males, and many accidents arise during the last 4 miles [2]. Importantly, both reports have suggested that prompt resuscitation including the early application of an automated external defibrillator (AED) improves survival in runners with SCA. Although trained medical staff and sufficient AEDs are needed throughout the racecourse, both requirements are limited because of high cost in many such competitions. On the other hand, cardiac screening test using electrocardiogram (ECG) before the marathon has been applied to prevent SCAs; however, these cases are still

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controversial because of high cost and many false positive results [3]. In addition, most victims of exercise-related SCA have no premonitory symptoms ;[4] therefore, we need to develop a novel strategy to prevent the sudden cardiac death (SCD) related to SCA in athletes.

On the other hand, the tele-monitoring device in the healthcare system has emerged following social issues such as improving health consciousness and medical cost inflation related to the aging society. ECG tele-monitoring, including that with duranta® (ImageONE Co., Ltd., Tokyo, Japan), is useful in the diagnosis of some diseases such as cerebral infarction underlying atrial fibrillation [5]. Although the duranta® is a wireless patch-type electrocardiographic monitoring system developed and commercialized for medical use [6], it has not been investigated as an application in sports cardiology for marathon runners.

Here, we propose a new method to emphasize the early application of AED and employment of the auto-alarm system using a real-time electrocardiographic tele-monitoring system. This case report is an initial trial to test the possibility and usability of this new medical approach in a full marathon. All volunteers provided informed consent, and the study was approved by the Institutional Review Board at Okayama University Hospital (Okayama, Japan). In addition, all volunteers received medical screening such as both stable and exercise 12-lead ECG, echocardiography, and questionnaires by medical physicians.

Case report

The overview of ECG tele-monitoring using duranta® is shown in Fig. 1. The main body of the device by Kinowhite® (Nitto Co., Ltd., Tokyo, Japan), is placed on the chest in a precordial position in a NASA induction arrangement, which connects to an iPhone (Apple Inc., Cupertino, CA, USA) through Bluetooth. Acquired ECG waves are transferred timely to the cloud server (named duranta Server), via cellular network. Real-time tele-monitoring is available using both the iPhone and the iPad (Apple Inc.) via a network, whereas detailed data analysis is achieved by a personal computer with Windows OS (Microsoft Inc., Redmond, WA, USA). Five runners enrolled in this initial trial as healthy volunteers, whose backgrounds are demonstrated in Table 1. In the full marathon, which was held in Okayama city on November 11th, 2018, 4 out of 5 runners had completed the marathon, whereas one runner retired at 32 km due to time over. Importantly, all participants with a duranta® device had available tele-monitoring, however, two runners lacked the great mass of monitoring due to a technical issue. Three out of five runners had reasonable measurements (63% to 99%), which means percentage of analyzable data duration per all running time (Table 1). In other words, about 14% of ECG waveforms on average in these 3 runners were not available to distinguish the abnormality due to unmeasurable data associated with poor contact of the electrode or the presence of physical noise.

We have illustrated the overview of this trial in Fig. 2. Five runners had their ECG waveform monitored remotely in the central office using an iPhone with Global Positioning System (GPS) information with a mobile application called iSharing (iSharingSoft Inc., Irvine, CA, USA). ECG overview in this trial is shown in Fig. 2 as the representative data, which includes detailed waveform and heart rate trend during marathon. This is the first study to investigate the usability of duranta® for athletes in a full marathon.

Discussion

The vast majority of marathon deaths are caused by SCAs, defined as the sudden termination of cardiac activity with hemodynamic failure [7]. Most of these victims are male, about 75% are more than 40 years old, and about 70% of accidents occur in the last 25% of the racecourse. In terms of cause of SCA, more than

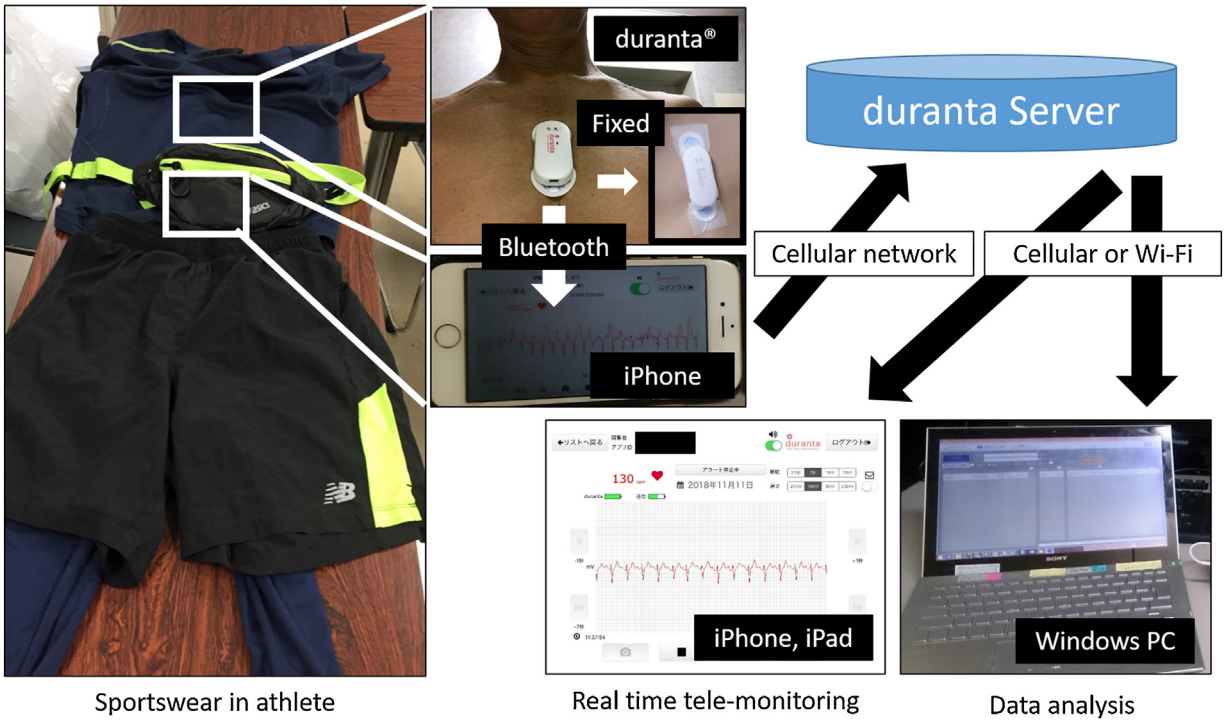

Fig. 1. Overview of the electrographic tele-monitoring system by duranta® in athlete. The main body of the device is placed on the chest, which is connected to an iPhone through Bluetooth. Acquired electrocardiogram waves are transferred to the cloud server, via 3G/4G/LTE network. Real-time tele-monitoring data is available using both an iPhone and an iPad via the network, whereas detailed data analysis is achieved by a personal computer with Windows OS.

Table 1 Characteristics and measurements in each participant.

	Case 1.	Case 2.	Case 3.	Case 4.	Case 5.
Characteristics					
Gender	Male	Male	Male	Male	Male
Age (years)	30	40	35	26	59
Height (cm)	179	170	171	177	168
Weight (kg)	67	72	67	62	67
Medical history	None	None	None	None	Hypertension
Results of Marathon					
Finished running	Completed	Retired (at 32 km)	Completed	Completed	Completed
Running time (minutes)	343	265	324	349	262
Measurements					
Tele-monitoring	Available	Available	Available	Available	Available
Analyzable data duration (minutes)	334	76	203	347	49
Percent of reasonable measurement (%)	97.4	28.7	62.7	99.4	18.7
Heart rate average (beat per minute)	149	165	150	155	161
Total QRS complex	49755	12479	30486	53718	7829

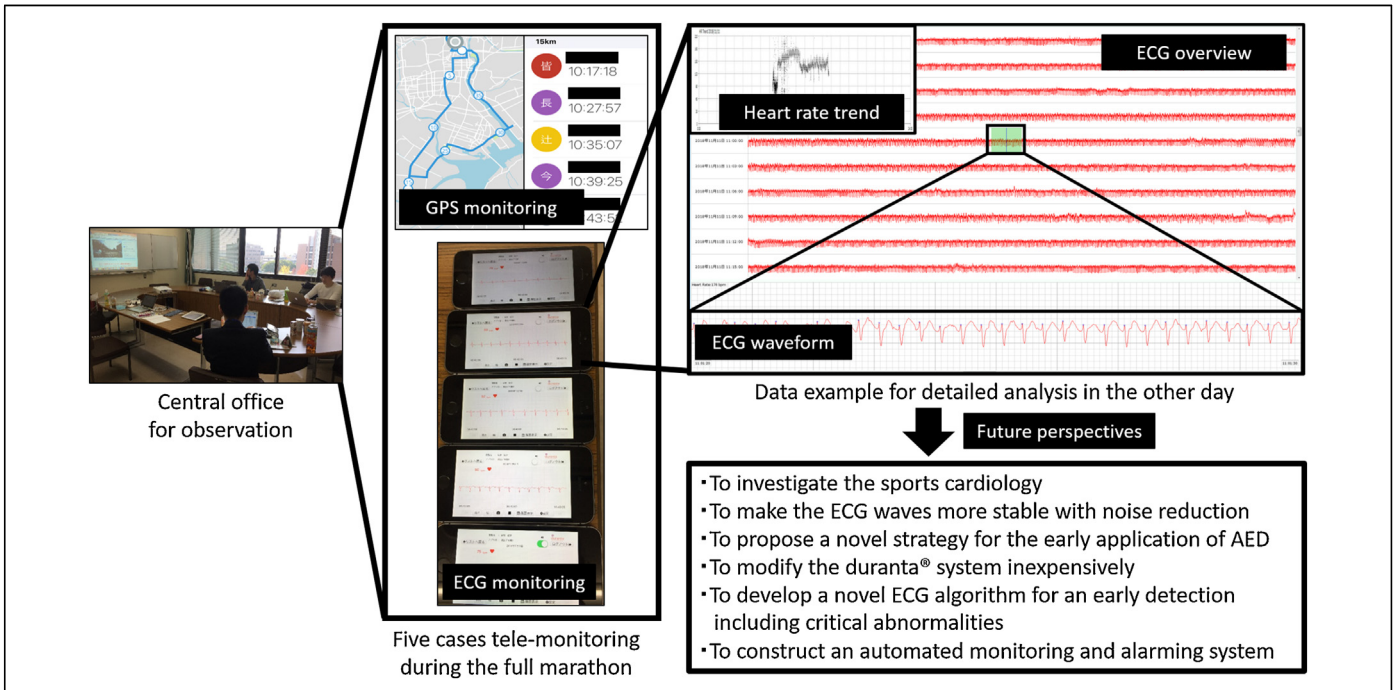

Fig. 2. Proposed approach and future perspectives to prevent cardiac death during marathon. Five runners had their electrocardiogram (ECG) waveform monitored remotely in the central office using an iPhone with Global Positioning System (GPS) information. ECG overview in this trial is shown as representative data, which includes detailed waveform and heart rate trend during marathon. In addition, our future perspectives are indicated following this initial trial. AED, automated external defibrillator.

90% result from a cardiogenic disorder [1]. Moreover, another report has shown that 65-70% of all adult SCDs are attributable to coronary artery disease, 10% are due to other structural heart diseases such as hypertrophic cardiomyopathy and congenital coronary anomalies, 5–10% are due to primary cardiac conduction disorders including prolonged QT and ion channel disorders, and the remainder result from noncardiac etiologies [8].

Therefore, cardiac screening using ECG before marathon in athletes has been recommended by the European Society of Cardiology, however, the efficacy for SCA prevention is controversial due to the high financial costs involved and the occurrence of false-positive results [3].

On the other hand, prompt cardiopulmonary resuscitation (CPR) including the early use of an AED improves the survival of athletes. Defibrillation within 3 min of SCA can produce survival rates as high as 67% to 74%, whereas other trials have revealed that defibrillation less than or equal to 8 min after SCA significantly improved survival [2]. In addition, emergency planning to include trained medical staff and sufficient AEDs throughout the racecourse has been recommended [2]. Similarly, in Japan, arranging for bystander CPR with AED has been suggested [1], and more suitable strategies of early applications of AED are needed. From these findings, we should make the system of AED application within 3 min after SCA in athletes. In addition, our ultimate goal is making novel predictive strategy from ECG data, which enable to urge an athlete to stop running by a doctor or automated alert system.

The duranta® is a tele-monitoring system for patients suffering from a chronic disease, which is developed for using at home [6]. The system is constructed with a wireless ECG sensor and utilizes smart telephones as transmitters, allowing real-time remote monitoring through cloud servers via a

cellular/Wi-Fi network. Although duranta® has a known clinical significance [5], its applications in sports cardiology have not been investigated. However, recently, some devices for healthcare have emerged, including smart watches, wearable sensors [9], and sportswear with a conductive polymer which enables ECG measurements [10]. In the future, these devices are expected to lead to a novel approach, which may reduce SCAs in athletes by both early detection of cardiac abnormality and effective application of AED.

Regarding the monitoring quality, there were serious variances of data acquisition among each participant. Poor recordings associated with electrical noise due to oscillation or friction were considered, in addition, a device attachment to the skin might affect recording efficacy. Actually, our test data suggested that irregularity of the sternal shape induces recording instability (no data). Moreover, cellular network disturbance was demonstrated in a runner by mismatch of software version. On the other hand, concerning the feeling of device attachment with iPhone during marathon, all participants had no significant discontent during running time.

At the moment, one of the difficulties in the application of sufficient AEDs in full marathon is the high cost paid by the sponsor. In the approach detailed in this report, although expensive devices such as a main body, an iPhone, and a surveillance monitor, are needed, we propose that each runner prepares their own duranta® and iPhone. In order to do that, we want to modify the duranta® inexpensively or propose an alternative supply system such as a rental system. Anyway, effective application of AED associated with a tele-monitoring system may lead to better cost effectiveness for marathon sponsors. In the future, we would like to develop a sensing system for abnormal ECG waveforms, which would predict the risk of cardiac accidents for each runner.

We have reported this case as an initial trial using duranta®, which is one of the next-generation devices to be applied in the field of sports. This study concluded that 29% to 99% of collected data by duranta® were well tele-monitored and analyzable; however, some problems were shown regarding mechanical instability, electrode attachment, noise reduction, and GPS reliability. Further studies are needed to assess and develop the application of the device for athletes and to evaluate its clinical significance and usability.

Conflict of interest statement

Rental devices for this study were supplied by Image ONE Co., Ltd., Fukuda Denshi Co., Ltd., and Hitachi Co., Ltd. However, these companies had no control over the interpretation, writing, or publication of this work. The authors have no conflict of interest to declare.

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