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Use of a smartphone electrocardiogram to diagnose arrhythmias during exercise in athletes: a case series

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Background While athletes are generally very fit, intense exercise can increase the risk of atrial fibrillation. Moreover, other arrhythmias such as atrial flutter or supraventricular tachycardia can cause distressing, exercise-related symptoms. Given symptoms are infrequent and may occur during intense exertion, traditional monitoring devices are often impractical to use during exercise. Smartphone electrocardiograms (ECGs) such as the Alivecor Kardia device may be the portable and reliable tool required to help identify arrhythmias in this challenging population. This case series highlights the use of such devices in aiding the diagnosis of arrhythmias in the setting of exercise-related symptoms in athletes.

Case summary The six cases in this series included one elite non-endurance athlete, two elite cricketers, one amateur middle-distance runner, and two semi-elite ultra-endurance runners, with an age range of 16–48 years. An accurate diagnosis of an arrhythmia was obtained in five cases (atrial fibrillation/flutter and supraventricular tachycardias) using the smartphone ECG, which helped guide definitive treatment. No arrhythmia was identified in the final case despite using the device during multiple symptomatic events.

Discussion The smartphone ECG was able to accurately detect arrhythmias and provide a diagnosis in cases where traditional monitoring had not. The utility of detecting *no* arrhythmia during symptoms in one case was also highlighted, providing the athlete with the confidence to continue exercising. This reassurance and confidence across all cases is perhaps the most valuable aspect of this device, where clinicians and athletes can be more certain of reaching a diagnosis and undertaking appropriate management.

Keywords Sports cardiology • Atrial fibrillation • Arrhythmias • Monitoring • Smartphones • Case series

ESC Curriculum 5.1 Palpitations • 5.3 Atrial fibrillation • 5.5 Supraventricular tachycardia • 8.1 Sports cardiology

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Learning points

- Exercise-related arrhythmias can be infrequent and difficult to capture, therefore smartphone-based electrocardiograms (ECGs) may be a convenient solution in these situations.
- Smartphone ECGs have potential to be an easy-to-use, affordable, portable, and reliable method for detecting arrhythmias during exercise-related symptoms.
- Provisional diagnoses provided by smartphone ECGs should be verified by a cardiologist with further investigation and can guide further treatment where traditional diagnostic methods have failed.

Introduction

Regular exercise is associated with improved health outcomes and is overwhelmingly of benefit.[1] While athletes are considered very fit and healthy, intense exercise can potentially raise the risk of arrhythmias and, in rare cases, sudden cardiac death.[2] Atrial fibrillation (AF) can cause symptoms that can be distressing and detrimental to performance, and has been shown to be more prevalent in those who undertake strenuous, high-intensity exercise on a regular basis.[3] Other arrhythmias such as atrial flutter, supraventricular tachycardia (SVT) [e.g. atrioventricular (AV) re-entrant tachycardias] and non-sustained ventricular tachycardias can also cause distressing symptoms during exercise.

Identifying the cause of symptoms as an arrhythmia vs. another non-cardiac cause can be challenging. Symptoms often occur infrequently and in specific situations during high-intensity exercise, where traditional monitors are ineffective or impractical.[4] It may be difficult to capture infrequent arrhythmias using Holter monitors or stress electrocardiograms (ECGs), which do not always allow the athlete to replicate the conditions in which they experience symptoms. Implantable monitoring devices are up to 10 times more effective than a 7 day Holter at identifying intermittent AF, but are substantially more invasive and therefore present other risks.[5,6]

Smartphone ECG (iECG) devices are highly portable and can record an ECG trace without the need for bulky or invasive equipment.[7] The original iECG has two sensors and can record a single-lead ECG, which is either Lead I (right and left hand), an approximation of Lead II (right hand to left knee) or a pre-cordial lead (direct to chest). The new six-lead iECG has three sensors and can record all the limb leads simultaneously (I, II, III, aVR, aVL, and aVF) when placed on both hands and the left leg (*Figure 1*). The single-lead device is accurate in detecting AF in the general population with an in-built algorithm[8,9] and is able to produce a trace that is interpretable by a cardiologist in 95% of cases.[10] Pilot data for the six-lead device have recently shown high levels of agreement with 12-lead ECGs in athletes for rhythm analysis, but not ischaemia.[11,12]

To date, there is very little data on the use of iECG devices in athletes. A case series of six college athletes described its utility in ruling out dangerous arrhythmias during exercise-related symptoms.[13] Another case has been described of a former marathon runner who had years of palpitations until a diagnosis of SVT was made using an iECG device.[14] Finally, a recent case report outlined the use of a smartphone-based ECG device in a 17-year-old rugby player to identify paroxysmal SVT.[15]

We have previously suggested ways in which the iECG may be useful in sport and exercise medicine.[16,17] This case series describes six cases in which the AliveCor Kardia device, the only smartphone iECG registered by the Therapeutic Goods Administration (TGA) in Australia, played a key role in investigating symptoms of transient arrythmias in athletes.

Timeline

Case history	Investigations	Use of iECG device	Subsequent investigation and/or treatment
Case 1 • 26-year-old male elite non-endurance athlete • Episodes of rapid palpitations post exercise	All normal: • Echocardiogram • 2× 24 h Holter monitor	• Patient's iECG • Captured wide-complex tachycardia and return to sinus rhythm	• Electrophysiology study showing concealed postero-septal accessory pathway causing atrioventricular re-entrant tachycardia • Successful ablation
Case 2 • 16-year-old male elite cricketer • Multiple exercise-related episodes of diaphoresis and palpitations	All normal: • Baseline ECG • 24 h and 3 day Holter monitor • Echocardiogram	• Patient's iECG • Captured paroxysmal supraventricular tachycardia	• Electrophysiology study showing AV junctional re-entrant tachycardia, requiring two ablations • 3 years later a new, wide-complex tachycardia captured with iECG • Electrophysiology study showing persisting dual AV nodal pathway due to concealed bypass tract, then successfully ablated
Case 3	All normal:		• Pill-in-the-pocket regime

• 28-year-old male elite cricketer • Palpitations and light-headedness while batting	• Baseline ECG • Echocardiogram	• Attending clinician's iECG • Captured atrial fibrillation	• Cardiologist comfortable with plan due to iECG trace confirming diagnosis
Case 4 • 48-year-old male middle-distance runner • Light-headedness post 12 km race • History of atrial flutter	Baseline ECG and CT coronary angiogram normal Echocardiogram with moderately dilated right ventricle and left atrium	• Attending clinician's iECG • Atrial flutter captured in medical tent with iECG	• Electrophysiology study and atrial flutter ablation • Patient had recurrent episode so purchased own iECG device
Case 5 • 38-year-old male ultra-endurance runner • Multiple exercise-related episodes of dyspnoea and weakness post presumed myopericarditis illness	All normal: • Resting ECG and echocardiogram • CT coronary angiogram • Stress ECG and echocardiogram • Holter monitor	• Patient's iECG • Captured paroxysmal supraventricular tachycardia	• Awaiting electrophysiology study and ablation • Credits diagnosis to use of iECG
Case 6 • 28-year-old female ultra-endurance runner • Multiple exercise and non-exercise-related episodes of palpitations and pre-syncope/ syncope	• Holter monitor, stress ECG and stress echocardiogram all normal • Loop recorder removed due to infection	• Patient's iECG • Multiple normal traces during symptoms	• After discussion with cardiologist, the patient is comfortable that symptoms are not cardiac • Continuing running at shorter distances

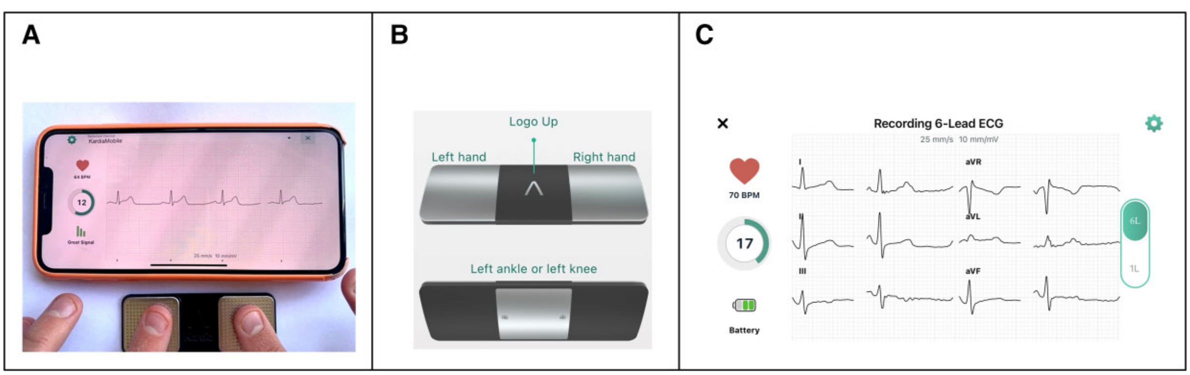

Figure 1 (*A*) A single-lead smartphone electrocardiogram device in use. (*B*) A six-lead smartphone electrocardiogram device screenshot. (*C*) A six-lead smartphone electrocardiogram recording screenshot.

Case 1

A 26-year-old Caucasian male exercise physiologist and elite non-endurance athlete in an Olympic programme with no significant medical history or regular medications presented with acute onset palpitations a few minutes after exercise. The symptoms corresponded with a sudden increase in heart rate to 226 beats per minute (b.p.m.) on his heart rate monitor. The episode lasted approximately 30 s before resolving. His initial cardiovascular examination was unremarkable and an echocardiogram confirmed normal cardiac structure and function. He also had two separate 24 h Holter monitors, inclusive of training sessions, that were normal (other than a few atrial and ventricular ectopic beats). The options of proceeding to an electrophysiology study or attempting to capture the rhythm with an iECG were discussed, and he chose the latter as the symptoms were very uncommon.

Five months later, the athlete contacted his cardiologist with an iECG tracing of a broad complex tachycardia at nearly 300 b.p.m. (*Figure 2*) that was associated with similar symptoms. He was contacted immediately and told to attend hospital for admission. The following day, an electrophysiology study was performed revealing a concealed postero-septal accessory pathway causing AV re-entrant tachycardia. This was successfully ablated and he has been symptom-free for the subsequent 10 months.

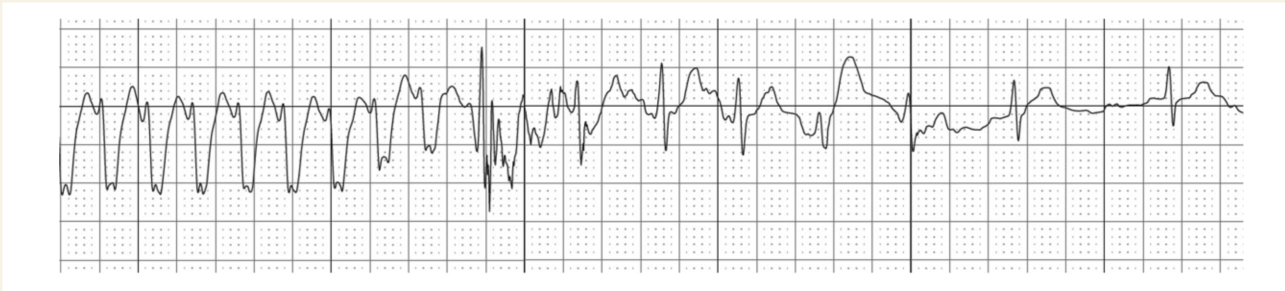

Figure 2 Smartphone electrocardiogram trace from Case 1 showing a broad complex tachycardia at almost 300 b.p.m. reverting into sinus rhythm.

Figure 3 (*A*) Smartphone electrocardiogram trace from Case 2 showing a narrow-complex tachycardia at 206 b.p.m. (*B*) Smartphone electrocardiogram trace from Case 2, 3 years later, showing a wide-complex tachycardia of 196 b.p.m.

Case 2

An elite, Caucasian male cricketer aged 16 years with no significant medical history or regular medications had experienced multiple episodes of palpitations and diaphoresis. These typically lasted 10–120 s, but once up to 40 min, and occurred about once every 2 weeks over the previous 12 months. These were usually in between bouts of submaximal exercise at cricket training.

At his initial cardiology appointment, clinical examination showed sinus bradycardia at 46 b.p.m., blood pressure 110/70 mmHg, heart sounds dual with no significant murmur and a clear chest examination. The athlete was presumed to have a paroxysmal SVT, however, a resting ECG, 24 h Holter monitor and 3 day Holter monitor (inclusive of training sessions but with no symptoms throughout) were all normal. An echocardiogram showed normal left and right ventricular size and systolic function with normal atrial size and no significant valvular abnormality. The athlete eventually purchased an iECG device and captured a trace confirming paroxysmal SVT at training during an episode of symptoms (*Figure 3A*).

The athlete then underwent an electrophysiology study and ablation for AV junctional re-entrant tachycardia (slow pathway ablation). Nine months later, the athlete presented again with a recurrence of symptoms, due to a presumed incomplete response to the ablation. In lieu of attempting to re-capture the arrhythmia, the athlete went directly to a repeat electrophysiology study. This confirmed the recurrence of the arrhythmia, and a second ablation was undertaken. These steps were taken in an attempt to defer the need for medication which could impact exercise capacity and performance.

However, at the age of 19 years, the athlete experienced symptoms on two occasions which felt different to the original SVT. He described these occurring near maximal exertion levels, during which he felt slightly unwell, but resolved within 5 min. He purchased another iECG device (as he had lost his previous device) and captured a trace which showed a very different wide-

Figure 4 (*A*) Smartphone electrocardiogram from Case 3 showing atrial fibrillation at 145 b.p.m. (*B*) A 12-lead electrocardiogram from Case 3, 3 days after the original event, showing sinus rhythm at 55 b.p.m.

Figure 5 Smartphone electrocardiogram trace from Case 4 showing a narrow-complex tachycardia, likely atrial flutter, at 160 b.p.m.

complex tachycardia (*Figure 3B*). A subsequent electrophysiology study revealed persisting dual AV nodal pathway with a concurrent left-sided postero-septal concealed bypass tract, which were ablated. At the time of each study, no additional arrhythmogenic focuses were noted other than those ablated. Since his most recent ablation, the athlete has reported no further symptoms and had normal results on his most recent athlete cardiac screening tests.

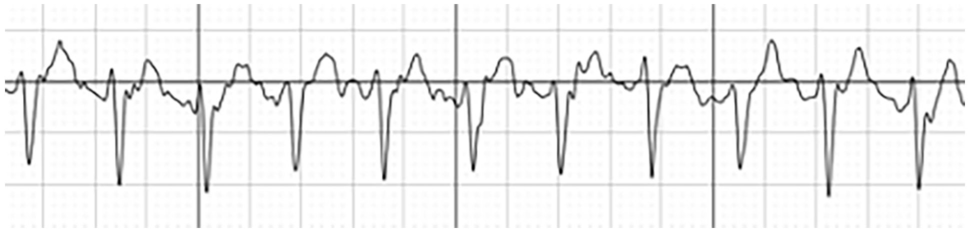

Figure 6 Smartphone electrocardiogram trace from Case 5 showing supraventricular tachycardia at 176 b.p.m.

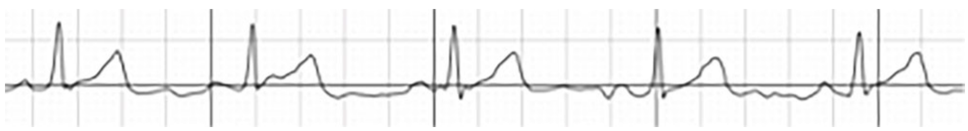

Figure 7 Smartphone electrocardiogram trace from Case 6 showing sinus rhythm at 72 b.p.m.

Case 3

An elite, Caucasian male cricketer aged 28 years with no significant medical history or regular medications was batting in hot conditions during a match when he suddenly felt rapid palpitations. He initially felt lightheaded but continued for the last 30 min of the day's play. The athlete stated he was sleep-deprived and dehydrated.

After finishing play, his physical examination revealed a blood pressure of 130/80 mmHg, normal heart sounds, and a clear chest. The team doctor then recorded an iECG trace which showed AF (*Figure 4A*). The athlete returned to his room, cooled down, and self-reverted to sinus rhythm 2 h later. The player continued to play the following morning without any problems. Follow-up examination 3 days later showed a regular heart rate of 54 b.p.m., blood pressure of 120/70 mmHg, and other cardiovascular features remained normal. His follow-up resting 12-lead ECG at this time confirmed he remained in sinus rhythm (*Figure 4B*), while his exercise stress test and echocardiogram were also normal.

The athlete saw a sports cardiologist 6 weeks later where his physical examination remained unremarkable. The cardiologist prescribed a pill-in-the-pocket regimen, whereby if the player had symptoms (ideally confirmed with the iECG), he could take 50 mg of metoprolol followed 15–20 min later by 200 mg of flecainide. The cardiologist reported being very comfortable with this regime because of the proof that the arrhythmia was AF on the iECG. The player has not required the pill-in-the-pocket as he has not had any symptom recurrence in the 2 years following the incident, and he continues to play cricket at the elite level.

Case 4

A Caucasion male aged 48 years was participating in a 12 km running race when he presented to the medical tent after the race with lightheadedness and diaphoresis. The man was an experienced amateur runner who had been diagnosed with paroxysmal atrial flutter about 8 months prior to this race. He had previously unremarkable resting ECG and computerized tomography coronary angiogram (CTCA), with an echocardiogram showing a moderately dilated right ventricle and left atrium. He was an ex-smoker of 17 pack years but had no other significant family or medical history and did not take any regular medications. He stated that he previously had similar symptoms on longer runs.

On examination 10 min post race, the man's radial pulse was regular, rapid and weak, at 160 b.p.m. and his blood pressure was 105/70 mmHg. The event doctor used his iECG device to obtain a trace (*Figure 5*), which revealed a narrow-complex tachycardia of 160 b.p.m. with a saw-tooth pattern, consistent with atrial flutter. Fortunately, the athlete self-reverted to sinus rhythm in the medical tent and his haemodynamics normalized.

The iECG trace was sent directly to the athlete to show to his cardiologist at his next appointment. Three months after the episode, the athlete then underwent an electrophysiology study, which confirmed a diagnosis of atrial flutter, and subsequent ablation procedure of the cavotriscupid isthmus with confirmed bidirectional block. About 12 months after this procedure, the patient had one episode of symptom recurrence and purchased his own iECG device but has since had no further symptoms.

Case 5

A competitive Caucasian male amateur ultra-endurance athlete aged 38 years presented to a sports cardiologist with multiple episodes of exercise-related shortness of breath and generalized weakness. These events started after a presumed episode of myopericarditis 12 months prior, in the context of a viral illness and exhaustion post race. Since then, the athlete had experienced these symptoms about 30 min into most exercise sessions, four times per week.

The athlete's examination with his sports cardiologist revealed a regular heart rate of 64 b.p.m. and blood pressure of 130/85 mmHg. His jugular venous pressure was not elevated and he had a clear chest and no cardiac murmurs. The athlete then had multiple unremarkable investigations, including resting and stress ECGs and echocardiograms, as well as a CTCA. He also wore a 24 h Holter monitor, inclusive of a training session; however, no symptoms were experienced at the time.

The athlete was then advised to purchase an iECG, which captured multiple episodes of paroxysmal SVT (*Figure 6*). The athlete is currently awaiting an electrophysiology study and possible ablation with his cardiologist and credits his diagnosis to the use of the iECG, without which he feels he would still be searching for answers.

Case 6

An experienced, semi-professional Caucasian female ultra-endurance athlete aged 28 years presented to a sports cardiologist with multiple episodes of palpitations and pre-syncope. She had a medical history of well-controlled asthma on a fluticasone/salmeterol preventer and occasional salbutamol, as well as anxiety treated with escitalopram at that time. Her family history included significant valvular heart disease, coronary artery disease, and arrhythmia on her paternal side.

The athlete had first experienced these symptoms when pregnant with her second child, which became more frequent once she increased her competitive running distances to >100 km. Symptoms occurred several times per month, immediately after longer runs and when lying in bed before going to sleep. She also had two episodes of syncope, with one post exercise.

The athlete's cardiovascular examination at rest was unremarkable. Multiple investigations were performed, including Holter monitoring, stress ECG, and stress echocardiogram. No major abnormalities were identified, as symptoms were not experienced during these tests and the Holter monitor could not be worn comfortably during training. In addition, a loop recorder had to be removed within 2 weeks, due to infection of the site after a 100 km run. Her sports cardiologist therefore suggested the use of an iECG.

The athlete proceeded to record multiple normal rhythm strips on the iECG over the following 2 years during episodes of exercise-related symptoms, as well as at rest (*Figure 7*). While her cardiologist has recommended reconsidering the use of a loop recorder, the patient is reassured by the fact that no significant arrhythmia has been identified and opted to cease investigation. The patient is now running distances up to 40 km and while she has symptoms occasionally, she feels confident to continue.

Discussion

This case series describes the utility of an iECG device in detecting exercise-related arrhythmias in athletes. The device has previously been shown to be an accurate, non-invasive method of recording an ECG trace during a symptomatic period by an attending clinician or the patient themselves.[10] These cases reinforce the device's utility in the exercising/athletic population. They include a range of demographics and scenarios in which the device can be used, while the patient is exercising at a high intensity during training or competition, as well as for infrequent symptoms.

Importantly, the iECG was able to detect arrhythmias, provide a provisional diagnosis, and guide treatment in multiple cases where traditional monitoring could not detect an abnormality. Due to the relative infrequency and/or specific circumstances required to trigger an event, Holter monitors and exercise stress tests proved ineffective in these cases. The iECG was required to capture the arrhythmia as it could be used during maximum-intensity exercise. In one case, even the use of a loop recorder, which has been shown to capture more arrhythmias than the traditional monitors,[5,6] was not ultimately helpful as it resulted in an infection (Case 6).

Perhaps just as important was the device's utility in detecting *no* arrhythmia during symptoms (Case 6), building on previous examples in collegiate athletes.[13] This gave the athlete confidence that her symptoms were not due to an arrhythmogenic cause, as she was able to use the device during multiple episodes of symptoms with no detected abnormalities.

These cases highlight how convenient, inexpensive, and easy to use the device can be for athletes and clinicians to record traces during specific episodes of symptoms. Although artefact may be an issue with a device being used in a non-resting state, it provides a rapid trace, which while not perfect, may be the only way to capture an arrhythmia before it reverts in a more rested state.[11] Other novel devices, such as smartwatches with ECG capability (e.g. Apple Watch, Withings ScanWatch), may also provide similar benefits in the future if the quality of the trace is sufficient.

We note there are several legal and ethical issues that must be considered with the increased use of smartphone and smartwatch ECG devices by consumers and patients.[18] It is important that such devices are registered with the relevant government regulator and used within their permitted indications. The AliveCor Kardia device was used in all the cases described above as it is the only smartphone iECG device registered by the TGA in Australia. It is also registered by numerous regulators around the world, including the US Food and Drug Administration and CE Mark (Europe). If used within approved indications, especially under the supervision of a treating clinician, the legal risk of using such devices in clinical practice is low. While there is the possibility of patient anxiety, this can be lessened with a shorter time to accurate diagnosis of their symptoms (which an iECG assists with) and timely communication with their treating clinician.[19]

However, we note that in many jurisdictions there are gaps in the law when it comes to protection and use of the personal health data generated by consumer ECG and wearable devices. Each individual app for these devices has its own privacy and data use policy, with a high degree of variation in the protections included. It is important that regulatory regimes continue to adapt so that data security/ownership, quality, and consumer protection aspects of ECG devices are sufficiently protected.

Conclusion

In all cases, the iECG was valuable in obtaining a provisional diagnosis to determine the best course of investigation and treatment, where other diagnostic methods failed. Whether definitive ablation procedures, medications, or observation strategies were used, the identification or exclusion of an arrhythmia allowed for targeted treatment tailored to the diagnosis and the presenting athlete. This provided a sense of reassurance for all cases, which may give other clinicians and athletes confidence the device will assist in reaching a diagnosis to guide treatment.

Lead author biography

Dr Jacob Jewson is a Sport and Exercise Medicine Registrar in Melbourne, Australia, working in private practice and with the Melbourne Football Club in the Australian Football League. Jacob has developed an interest in better investigating potential symptoms of arrhythmias in athletes, professional or amateur, after recent experiences at running events and Australian football. Jacob is also an avid cricket fan, managing to make it to Lords in 2019 to watch the Aussies retain the Ashes.

Supplementary material

Supplementary material is available at *European Heart Journal—Case Reports* online.

Slide sets: A fully edited slide set detailing these cases and suitable for local presentation is available online as Supplementary data.

Consent: The authors confirm that written, informed consent for submission and publication of this case series including images and associated text has been obtained from the participants in line with COPE guidance. All participants were >18 years of age at the time of consent.

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References

1. Ekelund U, Tarp J, Steene-Johannessen J, Hansen BH, Jefferis B, Fagerland MW, Whincup P, Diaz KM, Hooker SP, Chernofsky A, Larson MG, Spartano N, Vasan RS, Dohrn I-M, Hagströmer M, Edwardson C, Yates T, Shiroma E, Anderssen SA, Lee I-MWhincup P, Diaz KM, Hooker SP, Chernofsky A, Larson MG, Spartano N, Vasan RS, Dohrn I-M, Hagströmer M, Edwardson C, Yates T, Shiroma E, Anderssen SA, Lee I-M. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. *BMJ* 2019;**366**:l4570.
2. Wasfy MM, Hutter AM, Weiner RB. Sudden cardiac death in athletes. *Methodist Debakey Cardiovasc J* 2016;**12**:76–80.
3. Stergiou D, Duncan E. Atrial Fibrillation (AF) in endurance athletes: a complicated affair. *Curr Treat Options Cardiovasc Med* 2018;**20**:98.
4. Reiffel JA, Schwarzberg R, Murry M. Comparison of autotriggered memory loop recorders versus standard loop recorders versus 24-hour Holter monitors for arrhythmia detection. *Am J Cardiol* 2005;**95**:1055–1059.
5. Ritter MA, Kochhauser S, Duning T, Reinke F, Pott C, Dechering DG, Eckardt L, Ringelstein EB. Occult atrial fibrillation in cryptogenic stroke: detection by 7-day electrocardiogram versus implantable cardiac monitors. *Stroke* 2013;**44**:1449–1452.
6. Ciconte G, Giacopelli D, Pappone C. The role of implantable cardiac monitors in atrial fibrillation management. *J Atr Fibrillation* 2017;**10**:1590.
7. Bansal A, Joshi R. Portable out-of-hospital electrocardiography: A review of current technologies. *J Arrhythm* 2018;**34**:129–138.
8. Orchard J, Neubeck L, Freedman B, Li J, Webster R, Zwar N, Gallagher R, Ferguson C, Lowres N. eHealth tools to provide structured assistance for atrial fibrillation screening, management, and guideline-recommended therapy in metropolitan general practice: The AF - SMART Study. *J Am Heart Assoc* 2019;**8**:e010959.
9. Orchard J, Lowres N, Freedman SB, Ladak L, Lee W, Zwar N, Peiris D, Kamaladasa Y, Li J, Neubeck L. Screening for atrial fibrillation during influenza vaccinations by primary care nurses using a smartphone electrocardiograph (iECG): a feasibility study. *Eur J Prev Cardiol* 2016;**23**:13–20.
10. Li KHC, White FA, Tipoe T, Liu T, Wong MC, Jesuthasan A, Baranchuk A, Tse G, Yan BP. The current state of mobile phone apps for monitoring heart rate, heart rate variability, and atrial fibrillation: narrative review. *JMIR Mhealth Uhealth* 2019;**7**:e11606.
11. Orchard JJ, Orchard JW, Raju H, La Gerche A, Puranik R, Semsarian C. Comparison between a 6lead smartphone ECG and 12lead ECG in athletes. *J Electrocardiol* 2021;**66**:95–97.
12. Azram M, Ahmed N, Leese L, Brigham M, Bowes R, Wheatcroft SB, Ngantcha M, Stegemann B, Crowther G, Tayebjee MH. Clinical validation and evaluation of a novel six-lead handheld electrocardiogram recorder compared to the 12-lead electrocardiogram in unselected cardiology patients (EVALECG Cardio). *Eur Heart J Digital Health* 2021;**2**:643–648.
13. Peritz DC, Howard A, Ciocca M, Chung EH. Smartphone ECG aids real time diagnosis of palpitations in the competitive college athlete. *J Electrocardiol* 2015;**48**:896–899.
14. Tabing A, Harrell TE, Romero S, Francisco G. Supraventricular tachycardia diagnosed by smartphone ECG. *BMJ Case Rep* 2017;**2017**:bcr2016217197.
15. Phillips D, O'Callaghan P, Zaidi A. Arrhythmia in an athlete diagnosed by smartphone electrocardiogram: a case report. *Eur Heart J Case Rep* 2021;**5**:ytab186.
16. Orchard J, Semsarian C, Orchard J, Freedman B, Neubeck L. The AliveCor handheld heart monitor: turning your iPhone into a single-lead electrocardiogram (ECG). *J Sci Med Sport* 2013;**16**:e61.
17. Orchard J, Neubeck L, Semsarian C. The use of smartphone ECGs in sports and exercise medicine. *Sport Health* 2015;**33**:38.
18. Orchard JJ, Neubeck L, Orchard JW, Puranik R, Raju H, Freedman B, La Gerche A, Semsarian C. ECG-based cardiac screening programs: legal, ethical, and logistical considerations. *Heart Rhythm* 2019;**16**:1584–1591.
19. Orchard J, Lowres N, Neubeck L, Freedman B. Atrial fibrillation: is there enough evidence to recommend opportunistic or systematic screening? *Int J Epidemiol* 2018;**47**:1361.