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Clinical paper

Exercise related versus non exercise related out of hospital cardiac arrest – A retrospective single-center study

K. Finke[a,1,*], M.M. Meertens[a,b,1], S. Macherey-Meyer[a], S. Heyne[a], S. Braumann[a], S. Baldus[a], S. Lee[a], C. Adler[a,c]

Abstract

Background: Physical activity prevents cardiovascular disease, but it may also trigger acute cardiac events like sudden cardiac death in patients with underlying heart disease. The chance of surviving an out-of-hospital cardiac arrest remains low, despite improving medical treatment and rescue chain. Prior studies signaled increased survival in exercise related out-of-hospital cardiac arrest.

Objective: The aim of this study was to evaluate the differences between exercise related out-of-hospital cardiac arrest and out-of-hospital cardiac arrest during daily activity in an urban setting.

Methods: Retrospective analysis of all out-of-hospital cardiac arrests from 2014 to 2021 treated at a cardiac arrest center of a tertiary hospital. The primary outcome was survival to discharge. Secondary outcomes included differences in pre-hospital care, in-hospital treatment, hypoxic ischemic encephalopathy, and laboratory parameters.

Results: 478 OHCA patients were reviewed of which 432 patients (exercise related 36 (8.4%) vs. daily activity 396 (91.6%)) were included in the analysis. Patients suffering an exercise related arrest were younger (57 vs 65 years, $p = 0.002$) and mostly male (88.9 vs 74.5%, $p = 0.054$). The exercise related cohort received bystander cardiopulmonary resuscitation (77.8 vs 53.4%, $p = 0.005$) to a higher extent and had a shorter no-flow time (1.5 vs 2 min, $p = 0.049$). Exercise related arrest patients more often presented with a shockable rhythm (80.6 vs 64.1%, $p = 0.032$). At hospital admission exercise related arrest patients had a higher initial pH (7.24 vs 7.19, $p = 0.015$). In the exercise related group, a cardiac cause was numerically more frequent compared to the daily activity group (80.6 vs 68.7%, $p = 0.09$). In both groups myocardial infarction (47.2 vs 43.2%) was the most common cause, but a primary arrhythmic event (33.3 vs 25.5%) was more often documented in exercise related arrest patients. Exercise related arrest was mostly related to endurance training (52.8%) followed by ball sports (19.4%) and occurred directly during exercise in 77.8% of cases. Patients suffering exercise related arrest had higher survival till discharge (66.7 vs 47.7%, $p = 0.036$).

Conclusion: Based on this observational data from a highly selected group of out-of-hospital cardiac arrest patients treated at a cardiac arrest center, patients suffering an exercise related out-of-hospital cardiac arrest, differed in substantial characteristics and in the first line response compared to daily activity out-of-hospital cardiac arrest patients. The better survival to discharge of the exercise related out-of-hospital cardiac arrest group might be driven by these beneficial differences. This study underlines the need for public awareness for the importance of a fast first response and a broad distribution of automated external defibrillators in public sport areas since most of the exercise related out-of-hospital cardiac arrest patients presented with a cardiac cause and an initial shockable rhythm.

Keywords: Out of hospital cardiac arrest, Sudden cardiac arrest, Exercise, Myocardial infarction, Sport, Sudden cardiac death

Abbreviations: OHCA, Out-of-hospital cardiac arrest, ER OHCA, Exercise related out of hospital cardiac arrest, EMS, Emergency medical services, DA OHCA, Daily activity related out of hospital cardiac arrest, CPR, Cardiopulmonary resuscitation, CVD, Cardiovascular disease, AED, Automated external defibrillator, mCPR, Mechanical cardiopulmonary resuscitation, ECMO, Extracorporeal membrane oxygenation, IABP, Intraaortic balloon pump, ROSC, Return of spontaneous circulation

* Corresponding author at: Department III of Internal Medicine, Heart Center, Faculty of Medicine and University Hospital Cologne, University of Cologne, Kerpener street 62, 50937 Cologne, Germany.

E-mail address: Karl.finke@uk-koeln.de (K. Finke).

[1] Both authors contributed equally.

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Introduction

Regular exercise has proven benefits on health and longevity and is a cornerstone in prevention of cardiovascular disease.[1] However, strenuous exercise can trigger acute coronary and arrhythmic events in patients with underlying cardiovascular disease (CVD) contributing to sudden cardiac death.[2] Mechanistically, a vulnerable cardiac substrate is exposed to exercise-induced increased oxygen demand, electrolyte imbalances and dehydration.[3] Out-of-hospital cardiac arrest (OHCA) still has a high mortality and morbidity despite continuous efforts to improve rapid treatment through public campaigns on cardiopulmonary resuscitation (CPR) and distribution of automated external defibrillators (AED).[4,5]Prognosis after OHCA remains poor, with survival rates till hospital discharge described as low as 7% accompanied by mostly unfavorable neurological outcomes.[6,7,8]

Exercise related OHCA (ER OHCA) has received increasing media attention due to cases occurring in athletes during high-profile international competitive sports events.[9] Sudden cardiac death remains the leading cause of death in young athletes.[10] Several studies suggested that exercise related cardiac arrest has a better outcome and prognosis than cardiac arrest during daily activity.[11,12,13] While there have been some improvements in the last years, regarding workflows and in-hospital management of OHCA patients, further studies of OHCA during exercise are needed to improve prevention, care and survival in this specified patient group.[11,14,15] Earlier studies have focused mostly on outcomes as survival in this group, laboratory findings and in hospital treatment like mechanical circulatory support are mostly neglected. The aim of this study was to evaluate differences regarding survival, laboratory parameters, pre-hospital and in-hospital treatment in patients suffering from ER OHCA or OHCA during daily activities (DA) treated at a cardiac arrest center in an urban setting.

Methods

Setting and study population

A retrospective analysis of a prospectively maintained registry of all OHCAs from January 2014 to November 2021 treated at the cardiac arrest center of a German metropolitan tertiary university hospital was performed. The registry excludes all traumatic arrest and arrests due to drowning. The metropolitan area covers approximately 1.1 million inhabitants and regional emergency medical services (EMS) includes paramedics but also trained acute care physicians. In case of OHCA acute care physicians are always dispatched with the first line response and decision to transport the patient to the cardiac arrest center is done by the acute care physician on scene. Often patients with presumed cardiac origin of the cardiac arrest are allocated to the cardiac arrest center and the hospital is the only regional hospital providing extracorporeal mechanical support.

OHCA was considered as exercise related if it occurred during or up to one hour after exercise as considered in the 2020 guideline on sports cardiology.[2] Exercise was defined as a physical activity that is structured, repetitive and has the goal to improve or maintain physical fitness.[2] OHCA occurring during other activities was considered as related to daily activities. The cases were reviewed by one author and in case there was doubt if the OHCA was exercise or daily activity related the senior author was consulted. Patients with more than > 80% missing data or missing data on whether their OHCA occurred exercise related or not were excluded. Endurance sport was defined as any prolonged aerobic exercise. OHCA related to cycling was considered as exercise related if cycling was performed in the form of exercise.

Data collection

Demographic, clinical, and echocardiographic data were reviewed from the electronic hospital documentation system and EMS documentation. Lactate levels, partial pressure of oxygen (pO_2), partial pressure of carbon dioxide (pCO_2), and hemoglobin (Hb) were assessed by blood gas analysis at admission. If available echocardiography parameters were included for the ER group. No-flow time was defined as time without any CPR and reported as stated in the EMS documentation. The cause of arrest was determined as stated in the medical records by the treating physicians after completion of diagnostics. Left ventricular hypertrophy was assessed by echocardiography as described elsewhere.[16] Hypoxic ischemic encephalopathy was diagnosed by consultants from the neurology department using clinical, laboratory, electrophysiological and imaging criteria.[17]

The primary outcome was survival to discharge.[18] Secondary outcomes included differences in pre-hospital care, in-hospital treatment, hypoxic ischemic encephalopathy, and laboratory parameters.

This study was performed in accordance with the ethical standards of the Declaration of Helsinki and approved by the Ethics Committee of the Medical Faculty of the University of Cologne (Reference No. 17–071). The Ethics Committee waived the need for informed consent due to retrospective and observational design of the study.

Statistical analysis

Normal distribution was tested for all variables using the Shapiro-Wilk test. Continuous variables were not normally distributed and were presented as median with interquartile range (IQR). Numbers and percentages were used to present nominal and ordinal data. Continuous variables were compared using the Mann-Whitney-*U* test. Nominal data was tested for significant differences using the Pearson Chi-squared-test or the Fisher s exact test. A two-tailed p-value of $p < 0.05$ was considered statistically significant. Statistical analysis was performed using IBM SPSS Statistics (Version 29.0.1.1, 2023, IBM Corporation, New York, USA).

Results

Incidence of ER OHCA

In total 478 OHCA patients were registered in the observational period and 432 were included in the final analysis (Fig. 1). 36 patients (8.4%) suffered ER OHCA and 396 (91.6%) suffered OHCA during daily activities.

Demographics and first line response

Patients in the ER OHCA group were significantly younger (ER 57 vs DA 65 years, $p = 0.002$). In both groups patients were predominantly male (ER 88.9 vs DA 74.5%, $p = 0.054$). There was no difference in witnessed OHCA between the groups (ER 88.9 vs DA 77.1%, $p = 0.139$) but no-flow time was significantly shorter in the ER group (ER 1.5 vs 2 min, p = 0.049). ER OHCA patients significantly more often received bystander CPR (ER 77.8 vs 53.4%, $p = 0.005$) and initially more frequently had a shockable rhythm (ER 80.6 vs DA 64.1%, $p = 0.032$). (Table 1).

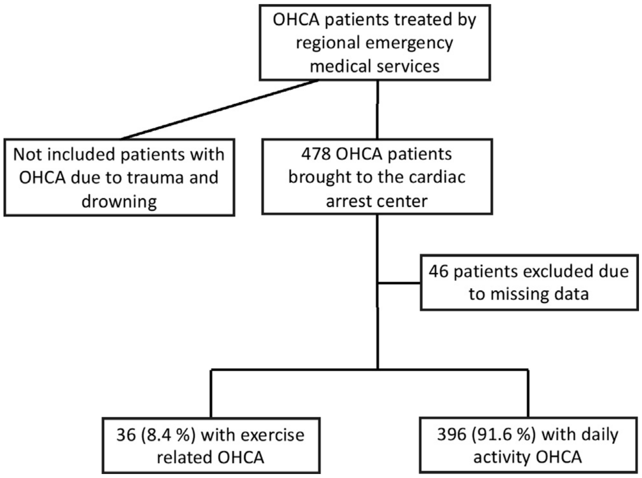

Fig. 1 – Study population and incidence of the exercise related out of hospital cardiac arrest (OHCA) and OHCA during daily activity.

Characteristics at admission and treatment

At admission there were no significant differences in lactate, hemoglobin as well as arterial pO_2 and pCO_2 levels. In the ER OHCA group there was a significantly higher pH (ER 7.24 vs DA 7.19, $p = 0.015$). No significant differences in time to return of spontaneous circulation (ROSC) at any time were observed (ER 20 vs DA 20 min, $p = 0.823$). No ROSC was achieved in 11.1% of cases in the ER OHCA group and 9.8% in the DA OHCA group. More extracorporeal membrane oxygenation (ECMO) was implemented in the ER group (ER 16.7% vs DA 6.8%, $p = 0.046$), while other variances of mechanical circulatory support were equally distributed between the groups. (Table 1).

Cause of OHCA and outcomes

Acute coronary syndrome was the most common cause of OHCA in both groups (ER 47.2 vs DA 43.2%). Numerically primary arrhythmia was more often documented in the ER OHCA group (ER 33.3 vs DA 25.5%), which was not statistically significant. In the ER OHCA group a cardiac cause was numerically more often diagnosed than in the DA group (ER 80.6 vs DA 68.7%, $p = 0.09$). ER OHCA patients had significantly better survival to discharge (ER 66.7 vs DA 47.7%, $p = 0.036$) and longer hospitalization (ER 14.5 vs DA 10 days, $p = 0.010$) compared to DA OHCA. No difference in hypoxic ischemic encephalopathy was observed (Table 2).

Exercise and timing of OHCA in the ER group and echocardiographic characteristics

In most cases, ER OHCA occurred during endurance sports (52.8%), followed by ball sports (19.4%). In 13.9% there was no documentation on type of exercise (Fig. 2). Detailed information on type of exercise in ER OHCA is summarized in Supplementary table 2. OHCA occurred most frequently directly during exercise (77.8%) or immediately after (<5 min, 16.7%).

In echocardiography 41.7% of patients of ER-OHCA subgroup had normal and 19.5% severely reduced ejection fraction. 33.3% had documented left ventricular hypertrophy. (Supplementary table 1). A primary arrhythmic event was determined as the cause of the

Table 1 – Characteristics of the exercise related (ER) out of hospital cardiac arrest (OHCA) compared to OHCA occurring during daily activities (DA) regarding the first line treatment, characteristics at admission, and utilization of mechanical circulatory support. CPR = Cardiopulmonary resuscitation, Hb = Hemoglobin, ROSC = Return of spontaneous circulation, IABP = Intraaortic balloon pump, ECMO = Extracorporeal membrane oxygenation, mCPR = mechanical CPR, min = minutes, * p < 0.05. Binary variables are presented as numbers, all values in paracentesis are percentages unless indicated otherwise. Continuous and ordinal data is presented as median.

Parameter	ER OHCA (n = 36)	DA OHCA (n = 396)	P – value
Age years (IQR)	57 (15)	65 (20)	**0.002***
Male gender	32 (88.9)	295 (74.5)	0.054
First line response			
Witnessed OHCA	32 (88.9)	299 (77.1)	0.139
No-flow time, min (IQR)	1.5 (2.6)	2 (5)	**0.049***
No-flow time unknown	6 (16.7)	116 (29.4)	0.104
Bystander CPR	28 (77.8)	211 (53.4)	**0.005***
Initial shockable rhythm	29 (80.6)	254 (64.1)	**0.032***
Characteristics at admission			
Lactate mmol/L (IQR)	7.39 (6.45)	6.6 (9.05)	0.362
pH	7.24 (0.2)	7.19 (0.29)	**0.015***
Hb, g/dL (IQR)	15.5 (4.75)	14 (4)	0.175
pO_2, mmHg (IQR)	141.5 (49.5)	152 (85)	0.499
pCO_2, mmHg (IQR)	50 (10.2)	51 (18.5)	0.888
No ROSC	4 (11.1)	39 (9.8)	0.771
Time until ROSC at any time min (IQR)	20 (16)	20 (16)	0.823
Coronary angiography performed	32 (88.7)	326 (82.3)	0.317
Mechanical circulatory support			
mCPR	6 (16.7)	77 (19.8)	0.827
IABP	1 (2.8)	6 (1.5)	0.459
Impella	2 (5.6)	6 (1.5)	0.138
ECMO	6 (16.7)	27 (6.8)	**0.046***

Table 2 – Cause of out of hospital cardiac arrest (OHCA) and outcomes. * p < 0.05. Binary variables are presented as numbers, all values in paracentesis are percentages unless indicated otherwise. Continuous and ordinal data is presented as median.

Parameter	ER OHCA (*n* = 36)	DA OHCA (*n* = 396)	p − value
Cause of OHCA			
Acute coronary syndrome	17 (47.2)	171 (43.2)	
Primary arrhythmic event	12 (33.3)	101 (25.5)	
Asphyxia	2 (5.6)	33 (8.3)	
Other	5 (13.9)	91 (23)	
			0.487
Outcomes			
Survival to discharge	24 (66.7)	188 (47.7)	**0.036***
Hypoxic ischemic encephalopathy	9 (25)	92 (23.3)	0.838
Hospitalization days (IQR)	14.5 (12)	10 (14)	**0.010***

OHCA in 7 patients with left ventricular hypertrophy while in 5 patients the cause was acute coronary syndrome. Except of one of case mitral annular disjunction no valvular pathologies were documented.

Discussion

The aim of this study was to evaluate the differences between patients undergoing exercise related (ER) OHCA and OHCA during daily activity (DA).

Incidence of ER OHCA in this study was 8.4%, higher than in other larger registries which describe incidences from 2.2 to 6.6%.[11,12,19,20] This might be due to several reasons: in the present study only OHCA patients brought to a certified cardiac arrest center with capabilities for mechanical circulatory support were analyzed. This might have led to more ER OHCA patients being transported to our center since those patients were younger and more often had cardiac causes of OHCA. Furthermore, the conducted study excludes traumatic cardiac arrest patients and patients who did suffer a cardiac arrest due to drowning, this might have led to an increase of the relative portion of ER OHCA patients. Recently it was shown that accrediting a hospital as a cardiac arrest center improves neurological outcomes, shortens time to coronary angiography and increases implementation of extracorporeal CPR.[14] Furthermore the study was conducted at a single center and detailed hospital records were available and such detailed information might be missing in nationwide registry-based studies. Still the incidence of ER OHCA is low, considering coverage of a metropolitan area of more than one million citizens and the inclusion period of approximately 7 years. This might be driven by the fact that the urban area of the study has a high density of fifteen other hospitals and that a proportion of OHCA patients die before reaching the hospital.[6] The latter were not included in the present registry.

In this study mostly males experienced ER OHCA which is in conjunction with earlier studies and might be driven by the higher frequency of coronary artery disease in males.[12,21,22] Data from a large Swedish registry showed women undergoing ER OHCA had a longer no-flow time and a higher mortality, indicating that in further investigations special attention should be given to female ER OHCA patients.[12] Opposingly, an analysis of several European registries showed a similar first line response and survival of women compared to men in ER OHCA.[21] A study from France even showed a higher likelihood of successful resuscitation in female ER OHCA.[23] The differences might be explained by a closer examination of their results. In the Swedish registry, women more frequently experienced unwitnessed OHCA, whereas there was no such difference noted in the European analysis.[12,21] A possible, albeit speculative, reason could be that men are more likely to participate in team sports, which may lead to a higher number of witnessed events.[24,25]

The finding that ER OHCA patients had significantly better survival to discharge, is in line with previous studies.[11,12] Factors that might have led to improved survival in ER OHCA included younger age, more bystander CPR and more shockable rhythms.[12,26,27] One might also speculate that the patients in the ER OHCA group were healthier. Beneficial characteristics in first line response in

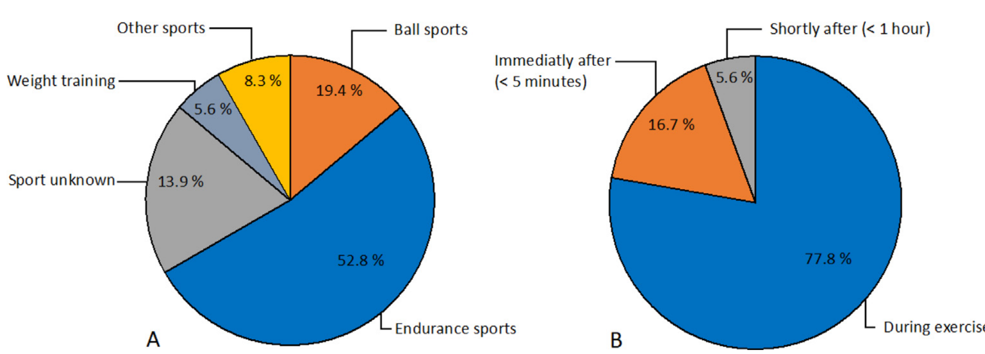

Fig. 2 – A) Type of exercise related to out of hospital cardiac arrest (OHCA). B) Timing of OHCA related to exercise.

ER OHCA in this study, including a shorter no-flow time, higher prevalence of bystander CPR and shockable rhythms, reinforce the evidence for those factors driving the improved survival. Bystander CPR and a short no-flow time increase survival and might contribute to a better neurological outcome after OHCA.[28,29] Notably the rates of bystander CPR in both the ER and DA OHCA group in this study were much lower compared to studies from the Netherlands, and Scandinavia, where rates of up to 95% are described.[11,12,19] In several studies from countries without public awareness of bystander CPR and accessibility of AED‘s the OHCA survival rate is close to zero.[30,31,32] This indicates Germany is still in need of increased public awareness regarding the importance and necessity of CPR to improve patient outcomes.

To our knowledge this is the first study to describe laboratory findings and the implementation of mechanical circulatory support in ER OHCA. On admission pH levels were significantly higher in ER OHCA. Higher pH might also indicate better tissue perfusion as acidosis is associated with refractory shock and worse outcome after OHCA.[33] However, there was no statistical difference in lactate. These similar lactate levels on admission might be explained by exercise-induced increase in baseline lactate in ER OHCA, even despite the shorter no-flow time in this group.[34,35] But this remains speculative. Lower lactate levels are associated with survival and good neurological outcome even after prolonged CPR due to refractory shockable rhythms.[36] Further studies are warranted to continue the investigation of lactate kinetics after exercise related ER OHCA.

The ER OHCA patients received an ECMO more often. This is likely biased due to the younger age, shorter no-flow time and initial shockable rhythm in ER OHCA. These factors drive the indication for ECMO implantation in our hospital CPR workflow if patients are unstable or in refractory cardiac arrest.[37]

As in DA OHCA acute coronary syndrome was the most frequent cause of OHCA in the ER group. In the ER OHCA group a cardiac cause (ER 80.6 vs. DA 67.7%) was numerically more common than in the DA OHCA group. This suggests that in case a young athlete collapses a cardiac cause is most likely. Thus, CPR plus AED defibrillation to treat shockable rhythms should be applied as fast as possible as the success rates are even higher than in other OHCA patients. As a second step transport to a specialized center with interventional cardiological capabilities is required, to offer the appropriate care to those patients and potentially improve prognosis.[14] In an additional analysis we found no significant differences in the median age of patients having an acute coronary syndrome versus primary arrhythmic event as a cause of OHCA in either of the groups. This is surprising since one would suspect patients with primary arrhythmic events to be younger.[38] The limited sample size of this study might restrict the validity of this finding. Within the ER OHCA group OHCA occurred most frequently during endurance and ball sports. As ball sports are performed in teams this gives more possibilities for bystander CPR. Witnessed, media covered, cardiac arrests during large international sports events demonstrated that CPR is usually not started by other athletes but by well-educated and trained medical teams present.[39] While a lot of attention is given to cardiac arrests in professional athletes, ER OHCA occurs mostly during recreational sports in the general population.[40]

Recent evidence from Sweden suggests that outcome of ER OHCA occurring at sports arenas or public fitness centers is better, likely due to bystander CPR and AED use.[41] The European 2022 guidelines on ventricular arrhythmias and sudden cardiac death prevention recommend the availability of public access defibrillation at sites where cardiac arrest is likely to occur.[38] What this exactly means for public sport clubs and fitness centers is not defined. In this study ER OHCA occurred during or shortly after exercise, with a high rate of initial shockable rhythms, thus increased CPR training and broader AED distribution in sport clubs and fitness centers might further improve outcomes.

Also, it might be advisable to teach sport teams CPR and how to use an AED, as they might be more likely to be confronted with such an event than the broad public.[42] In some American states like Florida all sports coaches must be CPR and AED certified by law, this would also be a proper approach.[43] Further Drezner *et al* demonstrated that AED programs at high schools are highly effective in improving outcomes after OHCA and that OHCA mostly occurred at athletic facilities on school grounds.[44] Overall, it is still of utmost importance to set up effective campaigns on how to perform bystander CPR and how to use an AED, a role model being campaigns from northern European countries with high bystander CPR rates.[6] Special efforts should be made to identify and improve care in regions with worse outcomes.[45]

Another interesting finding is that within the ER group 33.3% had documented left ventricular hypertrophy, which is higher than incidences described in the general population.[46,47] Left ventricular hypertrophy is associated with an increased risk of sudden cardiac death.[48] The 2020 European guidelines on sports cardiology already recommend cardiac screening for athletes above 35 years, especially if risk factors for coronary artery disease are present.[2] Basic tests include a resting electrocardiogram, which also aids in detecting channelopathies in young athletes.[2,38] Thus improving prevention and screening for cardiovascular disease in the exercising population might potentially aid in the prevention of ER OHCA.

Limitations

Limitations of this study include its observational, retrospective, and single-center design and a limited sample size. In this study only patients transported to a cardiac arrest center with immediate capabilities of percutaneous coronary intervention and extracorporeal CPR were analyzed. Usually young and highly unstable patients are brought to such centers which leads to a highly selected patient population in this study. Also, the fact that trauma and drowning patients are not referred to the cardiac arrest center leads to further restriction of the study cohort which might lead to a referral bias. Furthermore, due to missing data in the study population, there was no discrimination between ER OHCA occurring during competitive versus recreational sports as well as in athletes and non-athletes.

Conclusion

Within this observational cohort, patients suffering an ER OHCA, had more favorable prognostic factors compared to DA OHCA. This translated to better survival to discharge.

Patients with ER OHCA mostly had a cardiac cause of arrest, and these patients might benefit from treatment at a cardiac arrest center with capabilities of coronary angiography and extracorporeal CPR. While ischemic etiology was similar, the prevalence of malignant arrhythmia was higher compared to DA OHCA. These findings underline the need for public awareness of the importance of a fast first response, CPR and AED usage, especially for people involved in team and endurance sports.

CRediT authorship contribution statement

K. Finke: Conceptualization, Formal analysis, Investigation, Visualization, Writing – original draft. **M.M. Meertens:** Conceptualization, Data curation, Formal analysis, Investigation, Supervision, Validation, Visualization, Writing – original draft. **S. Macherey-Meyer:** Writing – review & editing. **S. Heyne:** Writing – original draft. **S. Braumann:** Writing – review & editing. **S. Baldus:** Writing – review & editing. **S. Lee:** Supervision, Writing – review & editing. **C. Adler:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100742.

Author details

[a]Department III of Internal Medicine, Heart Center, Faculty of Medicine and University Hospital Cologne, University of Cologne, Cologne, Germany [b]Center of Cardiology, Cardiology III - Angiology, University Medical Center of the Johannes Gutenberg-University, Mainz, Germany [c]Emergency Department, Leverkusen Medical Center, Leverkusen, Germany

REFERENCES

1. Visseren FLJ, Mach F, Smulders YM, et al. 2021 ESC Guidelines on cardiovascular disease prevention in clinical practice. Eur Heart J 2021;42:3227–337. https://doi.org/10.1093/eurheartj/ehab484.
2. Pelliccia A, Sharma S, Gati S, et al. 2020 ESC Guidelines on sports cardiology and exercise in patients with cardiovascular disease. Eur Heart J 2021;42:17–96. https://doi.org/10.1093/eurheartj/ehaa605.
3. Han J, Lalario A, Merro E, et al. Sudden cardiac death in athletes: facts and fallacies. JCDD 2023;10:68. https://doi.org/10.3390/jcdd10020068.
4. Horriar L, Rott N, Böttiger BW. Improving survival after cardiac arrest in Europe: The synergetic effect of rescue chain strategies. Resuscitation Plus 2024;17:100533. https://doi.org/10.1016/j.resplu.2023.100533.
5. Marijon E, Narayanan K, Smith K, et al. The Lancet Commission to reduce the global burden of sudden cardiac death: a call for multidisciplinary action. Lancet 2023;402:883–936. https://doi.org/10.1016/S0140-6736(23)00875-9.
6. Gräsner J-T, Wnent J, Herlitz J, et al. Survival after out-of-hospital cardiac arrest in Europe - Results of the EuReCa TWO study. Resuscitation 2020;148:218–26. https://doi.org/10.1016/j.resuscitation.2019.12.042.
7. Gräsner J-T, Lefering R, Koster RW, et al. EuReCa ONE□27 Nations, ONE Europe, ONE Registry. Resuscitation 2016;105:188–95. https://doi.org/10.1016/j.resuscitation.2016.06.004.
8. Yan S, Gan Y, Jiang N, et al. The global survival rate among adult out-of-hospital cardiac arrest patients who received cardiopulmonary resuscitation: a systematic review and meta-analysis. Crit Care 2020;24:61. https://doi.org/10.1186/s13054-020-2773-2.
9. Guasch E, Mont L. Something is moving in sports-related sudden cardiac death is it time to change our minds? EP Europace 2023;25:255–7. https://doi.org/10.1093/europace/euac274.
10. Wasfy MM, Hutter AM, Weiner RB. Sudden cardiac death in athletes. Methodist Debakey Cardiovasc J 2016;12:76. https://doi.org/10.14797/mdcj-12-2-76.
11. Berdowski J, de Beus MF, Blom M, et al. Exercise-related out-of-hospital cardiac arrest in the general population: incidence and prognosis. Eur Heart J 2013;34:3616–23. https://doi.org/10.1093/eurheartj/eht401.
12. Frisk Torell M, Strömsöe A, Herlitz J, Claesson A, Rawshani A, Borjesson M. Better outcomes from exercise-related out-of-hospital cardiac arrest in males and in the young: findings from the Swedish Registry of Cardiopulmonary Resuscitation. Br J Sports Med 2022;56:1026–31. https://doi.org/10.1136/bjsports-2021-105151.
13. Marijon E, Uy-Evanado A, Reinier K, et al. Sudden cardiac arrest during sports activity in middle age. Circulation 2015;131:1384–91. https://doi.org/10.1161/CIRCULATIONAHA.114.011988.
14. Voß F, Thevathasan T, Scholz KH, et al. Accredited cardiac arrest centers facilitate eCPR and improve neurological outcome. Resuscitation 2024;194:110069. https://doi.org/10.1016/j.resuscitation.2023.110069.
15. Karam N, Pechmajou L, Narayanan K, et al. Evolution of incidence, management, and outcomes over time in sports-related sudden cardiac arrest. J Am Coll Cardiol 2022;79:238–46. https://doi.org/10.1016/j.jacc.2021.11.011.
16. Barbieri A, Albini A, Maisano A, et al. Clinical value of complex echocardiographic left ventricular hypertrophy classification based on concentricity, mass, and volume quantification. Front Cardiovasc Med 2021;8:667984. https://doi.org/10.3389/fcvm.2021.667984.
17. Nolan JP, Sandroni C, Böttiger BW, et al. European resuscitation council and european society of intensive care medicine guidelines 2021: post-resuscitation care. Intensive Care Med 2021;47:369–421. https://doi.org/10.1007/s00134-021-06368-4.
18. Nolan JP, Berg RA, Andersen LW, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update of the Utstein resuscitation registry template for in-hospital cardiac arrest: a consensus report from a task force of the international liaison committee on resuscitation (American heart association, European resuscitation council, Australian and new Zealand council on resuscitation, heart and stroke foundation of Canada, Interamerican heart foundation, resuscitation council of southern Africa, resuscitation council of Asia). Circulation 2019;140. https://doi.org/10.1161/CIR.0000000000000710.
19. Wolthers SA, Jensen TW, Blomberg SN, et al. Out-of-hospital cardiac arrest related to exercise in the general population: Incidence, survival and bystander response. Resuscitation 2022;172:84–91. https://doi.org/10.1016/j.resuscitation.2022.01.021.
20. Reddy PR, Reinier K, Singh T, et al. Physical activity as a trigger of sudden cardiac arrest: the Oregon Sudden Unexpected Death Study. Int J Cardiol 2009;131:345–9. https://doi.org/10.1016/j.ijcard.2007.10.024.
21. Weizman O, Empana J-P, Blom M, et al. Incidence of cardiac arrest during sports among women in the European union. J Am Coll Cardiol 2023;81:1021–31. https://doi.org/10.1016/j.jacc.2023.01.015.
22. Marijon E, Bougouin W, Périer M-C, Celermajer DS, Jouven X. Incidence of sports-related sudden death in France by specific sports and sex. JAMA 2013;310:642–3. https://doi.org/10.1001/jama.2013.8711.

23. Marijon E, Bougouin W, Celermajer DS, et al. Characteristics and outcomes of sudden cardiac arrest during sports in women. Circ Arrhythm Electrophysiol 2013;6:1185–91. https://doi.org/10.1161/CIRCEP.113.000651.
24. Deaner RO, Geary DC, Puts DA, et al. A sex difference in the predisposition for physical competition: males play sports much more than females even in the contemporary U.S.. PLoS One 2012;7:e49168. https://doi.org/10.1371/journal.pone.0049168.
25. Eime R, Charity M, Harvey J, Westerbeek H. Five-year changes in community-level sport participation, and the role of gender strategies. Front Sports Act Living 2021;3:710666. https://doi.org/10.3389/fspor.2021.710666.
26. Basso C, Rizzo S, Carturan E, Pilichou K, Thiene G. Cardiac arrest at rest and during sport activity: causes and prevention. Eur Heart J Suppl 2020;22:E20–4. https://doi.org/10.1093/eurheartj/suaa052.
27. Pechmajou L, Sharifzadehgan A, Bougouin W, et al. Does occurrence during sports affect sudden cardiac arrest survival? Resuscitation 2019;141:121–7. https://doi.org/10.1016/j.resuscitation.2019.06.277.
28. Rajan S, Wissenberg M, Folke F, et al. Association of bystander cardiopulmonary resuscitation and survival according to ambulance response times after out-of-hospital cardiac arrest. Circulation 2016;134:2095–104. https://doi.org/10.1161/CIRCULATIONAHA.116.024400.
29. Guy A, Kawano T, Besserer F, et al. The relationship between no-flow interval and survival with favourable neurological outcome in out-of-hospital cardiac arrest: Implications for outcomes and ECPR eligibility. Resuscitation 2020;155:219–25. https://doi.org/10.1016/j.resuscitation.2020.06.009.
30. Mawani M, Kadir MM, Azam I, et al. Epidemiology and outcomes of out-of-hospital cardiac arrest in a developing country-a multicenter cohort study. BMC Emerg Med 2016;16:28. https://doi.org/10.1186/s12873-016-0093-2.
31. Raffee LA, Samrah SM, Al Yousef HN, Abeeleh MA, Alawneh KZ. Incidence, characteristics, and survival trend of cardiopulmonary resuscitation following in-hospital compared to out-of-hospital cardiac arrest in Northern Jordan. Indian J Crit Care Med 2017;21:436–41. https://doi.org/10.4103/ijccm.IJCCM_15_17.
32. Fraga-Sastrías JM, Asensio-Lafuente E, Martínez R, et al. Out-of-hospital cardiac arrest: first documented experience in a Mexican urban setting. Prehosp Disaster Med 2009;24:121–5. https://doi.org/10.1017/S1049023X0000666X.
33. Jamme M, Ben Hadj Salem O, Guillemet L, et al. Severe metabolic acidosis after out-of-hospital cardiac arrest: risk factors and association with outcome. Ann Intensive Care 2018;8:62. https://doi.org/10.1186/s13613-018-0409-3.
34. Casado A, González-Mohíno F, González-Ravé JM, Foster C. Training periodization, methods, intensity distribution, and volume in highly trained and elite distance runners: a systematic review. Int J Sports Physiol Perform 2022;17:820–33. https://doi.org/10.1123/ijspp.2021-0435.
35. Pierce K, Rozenek R, Stone M. Effects of high volume weight training on lactate, heart rate, and perceived exertion. J Strength Cond Res 1993;7:211–5.
36. Braumann S, Nettersheim FS, Hohmann C, et al. How long is long enough? Good neurologic outcome in out-of-hospital cardiac arrest survivors despite prolonged resuscitation: a retrospective cohort study. Clin Res Cardiol 2020;109:1402–10. https://doi.org/10.1007/s00392-020-01640-x.
37. Michels G, Wengenmayer T, Hagl C, et al. Recommendations for extracorporeal cardiopulmonary resuscitation (eCPR): consensus statement of DGIIN, DGK, DGTHG, DGfK, DGNI, DGAI, DIVI and GRC. Clin Res Cardiol 2019;108:455–64. https://doi.org/10.1007/s00392-018-1366-4.
38. Zeppenfeld K, Tfelt-Hansen J, De Riva M, et al. 2022 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death. Eur Heart J 2022;43:3997–4126. https://doi.org/10.1093/eurheartj/ehac262.
39. Ferrell MC, Khojasteh J, Vassar M. Public awareness of cardiopulmonary resuscitation and cardiac arrest in association with Christian Eriksen. Public Health 2022;212:42–5. https://doi.org/10.1016/j.puhe.2022.08.013.
40. Marijon E, Tafflet M, Celermajer DS, et al. Sports-related sudden death in the general population. Circulation 2011;124:672–81. https://doi.org/10.1161/CIRCULATIONAHA.110.008979.
41. Frisk Torell M, Strömsöe A, Herlitz J, Claesson A, Svensson L, Börjesson M. Outcome of exercise-related out-of-hospital cardiac arrest is dependent on location: Sports arenas vs outside of arenas. PLoS One 2019;14:e0211723. https://doi.org/10.1371/journal.pone.0211723.
42. Toresdahl BG, Rao AL, Harmon KG, Drezner JA. Incidence of sudden cardiac arrest in high school student athletes on school campus. Heart Rhythm 2014;11:1190–4. https://doi.org/10.1016/j.hrthm.2014.04.017.
43. THE FLORIDA SENATE. HB 1479: Cardiopulmonary Resuscitation Education for Athletic Coaches - GENERAL BILL by Williams. 2024.
44. Drezner JA, Toresdahl BG, Rao AL, Huszti E, Harmon KG. Outcomes from sudden cardiac arrest in US high schools: a 2-year prospective study from the National Registry for AED Use in Sports. Br J Sports Med 2013;47:1179–83. https://doi.org/10.1136/bjsports-2013-092786.
45. Marijon E, Bougouin W, Celermajer DS, et al. Major regional disparities in outcomes after sudden cardiac arrest during sports. Eur Heart J 2013;34:3632–40. https://doi.org/10.1093/eurheartj/eht282.
46. Levy D. Left ventricular hypertrophy: Epidemiological insights from the framingham heart study. Drugs 1988;35:1–5. https://doi.org/10.2165/00003495-198800355-00002.
47. Schirmer H. Prevalence of left ventricular hypertrophy in a general population; The Tromsø Study. Eur Heart J 1999;20:429–38. https://doi.org/10.1053/euhj.1998.1314.
48. Giamouzis G, Dimos A, Xanthopoulos A, Skoularigis J, Triposkiadis F. Left ventricular hypertrophy and sudden cardiac death. Heart Fail Rev 2022;27:711–24. https://doi.org/10.1007/s10741-021-10134-5.