Incidence of sudden cardiac arrest and sudden cardiac death after unstable angina pectoris and myocardial infarction

Minna Koivunen, MD [a], Juho Tynkkynen, MD, PhD [b], Niku Oksala, MD, PhD [a,c,d], Markku Eskola, MD, PhD [e], and Jussi Hernesniemi, MD, PhD [a,d,e] *Tampere, Finland*

Background Sudden cardiac arrests (SCA) and sudden cardiac deaths (SCD) are believed to account for a large proportion of deaths due to cardiovascular causes. The purpose of this study is to provide comprehensive information on the epidemiology of SCAs and SCDs after acute coronary syndrome.

Methods The incidence of SCA (including SCDs) was studied retrospectively among 10,316 consecutive patients undergoing invasive evaluation for acute coronary syndrome (ACS) between 2007 and 2018 at Tays Heart Hospital (sole provider of specialized cardiac care for a catchment area of over 0.5 million residents). Baseline and follow-up information was collected by combining information from the hospital's electronic health records, death certificate data, and a full-disclosure review of written patient records and accounts of the circumstances leading to death.

Results During 12 years of follow-up, the cumulative incidence of SCAs (including SCDs) was 9.8% (0.8% annually) and that of SCDs 5.4% (0.5% annually). Cumulative incidence of SCAs in patients with ST-elevation myocardial infarction, non-ST-elevation myocardial infarction and unstable angina pectoris were: 11.9%,10.2% and 5.7% at 12 years. SCAs accounted for 30.5% ($n = 528/1,732$) of all deaths due to cardiovascular causes. The vast majority of SCAs (95.6%) occurred in patients without implantable cardioverter defibrillator (ICD) devices or among patients with no recurrent hospitalizations for coronary artery disease (89.1%).

Conclusions SCAs accounted for less than a third of all deaths due to cardiovascular causes among patients with previous ACS. Incidence of SCA is highest among STEMI and NSTEMI patients. After the hospital discharge, most of SCAs happen to NSTEMI patients. (Am Heart J 2023;257:9–19.)

Keywords: Epidemiology; Sudden cardiac arrest; Sudden cardiac death; Ventricular arrhythmia

Cardiovascular diseases are the leading cause of death worldwide.[1] Sudden cardiac death (SCD) and sudden cardiac arrest (SCA) are thought to account for approximately 50% of all cardiovascular deaths in the general population, but the statistics are highly dependent on the methodology by which these events are defined.[2-7]

In patients with a history of myocardial infarction, the proportion of SCDs out of all deaths has been estimated to be 20% to 35%.[8-11] The most prevalent condition behind these events is coronary artery disease (CAD).[2,7]

Sudden cardiac arrest (SCA) can be defined as an unexpected cessation of the heartbeat, which leads to unconsciousness.[5,12] Sudden cardiac death (SCD) is generally defined as a death of cardiac origin within an hour from the start of the symptoms or a death in an individual last seen asymptomatic within 24 hours.[2,3,5] Most SCDs and SCAs are thought to be caused by arrhythmias with ventricular fibrillation (VF) in most cases, either with or without preceding ventricular tachycardia (VT). More infrequent mechanisms include VT without VF, as well as pulseless electrical activity (PEA) or asystole.[13]

There are some clear risk factors that guide interventions in the prevention of SCD. For example, if the left ventricular ejection fraction (LVEF) is 35% or less 40 days after a myocardial infarction (MI), the implantation of

From the [a]Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland, [b]Department of Radiology, Tampere University Hospital, Tampere, Finland, [c]Department of Surgery, Division of Vascular Surgery, Tampere University Hospital, Tampere, Finland, [d]Finnish Cardiovascular Research Center Tampere, Faculty of Medicine and Health Techonology, Tampere University, Tampere, Finland, [e]Heart Center, Department of Cardiology, Tampere University Hospital, Tampere, Finland

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Reprint requests: Minna Koivunen, MD, Tampere University, Kalevantie 4, 33100 Tampere, Finland.

E-mail address: minna.koivunen@tuni.fi.

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an implantable cardioverter defibrillator (ICD) is recommended to prevent SCD.[5,14] Furthermore, previous sudden cardiac arrests have been shown to increase the risk of subsequent events.[15] Cardiovascular risk factors, such as male sex, smoking, diabetes, renal dysfunction, and hypertension, are also considered important for the risk profiling of SCD.[7,15] Underlying this problem, the risk of suffering an SCA or SCD is increased especially within the first 30 days after a myocardial infarction, which also offers a good opportunity for therapeutic measures.[4,10]

The purpose of this study was to clarify the true long-term incidence of SCA and SCD among patients treated for ACS. This information is essential in updating the epidemiology of sudden cardiac arrests as well as improving risk prediction and prevention of SCA and SCD.

Methods

Study population

The study population consisted of 10,316 consecutive patients who had been admitted to Tampere University Hospital due to ACS between January 1, 2007, and December 31, 2018. ACS was classified as unstable angina pectoris (UAP), non-ST-elevation myocardial infarction (NSTEMI) or ST-elevation myocardial infarction (STEMI) according to ESC Guidelines.[16] If a patient had more than one episode of ACS during the study period, the first episode was selected as the index event. Data were collected retrospectively from the MADDEC (Mass Data in Detection and Prevention of Serious Adverse Events in Cardiovascular Disease) database as well as electronic health records (EHR), death certificates, and Statistics Finland. This non-interventional, retrospective study is based on a large registry data.

MADDEC is a project launched in 2016, and it retrospectively combines data collected from 2007 onwards from different electronic databases used in specialized health care to create a comprehensive study registry focusing on high-risk cardiologic patients treated at Tays Heart Hospital.[17] Tays Heart Hospital, operating under Tampere University Hospital, is the sole provider of specialized health care for cardiac patients in the Pirkanmaa region (Finland), with a catchment area of 0.5 million residents.

Follow-up and end point definitions

All patients were followed-up from their first angiography for ACS to 31st of December 2018. The main end points used in this study were SCA and SCD (end point adjudication explained in next section). The exact definitions of SCA and SCD were based on the AHA/ACC/HRS and ESC guidelines.[5,14] SCA is defined as sudden cessation of cardiac activity with resulting in hemodynamic collapse due to presumable cardiac cause (not due to trauma, drowning, respiratory failure, or asphyxia electrocution, drug overdose or other noncardiac cause). Furthermore, if a written event description in death certificates or in hospital medical records did not indicate a death being sudden or unexpected and of cardiac etiology, the death was not classified as SCA (or SCD). More specified, we excluded events that were not unexpected, such as cardiac arrests in hospitalized patients with prolonged symptoms of cardiac origin and in very poor or deteriorating clinical condition, or in whom the event description was usually vague, or the patient was in palliative care and/or had very poor functional capacity or severe dementia.

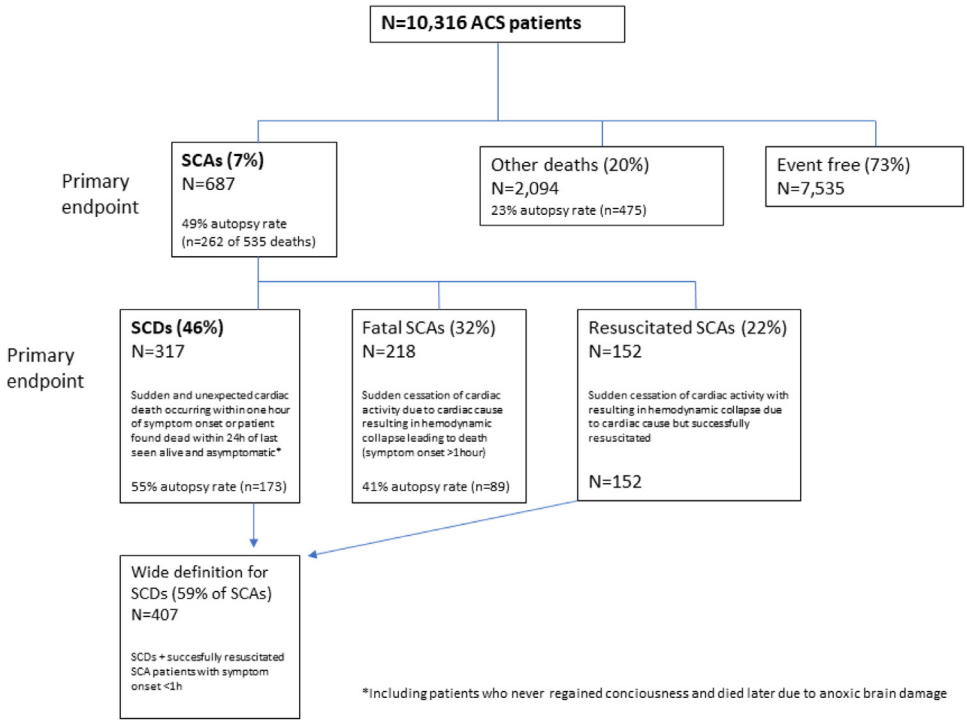
SCD is defined as sudden and unexpected death occurring within an hour of the onset of symptoms or occurring in patients found dead within 24 hours of being asymptomatic and presumably due to a cardiac arrhythmia or hemodynamic catastrophe. Patients in whom the cardiac arrest otherwise fulfilled the criteria of SCD but who died later than within the first hour because of successful initial resuscitation efforts but who suffered a permanent anoxic brain damage were included to SCD group.

For presentation, we included all SCDs to the larger group of SCA (many events fit both definitions). In order to capture all possible SCD events, an expanded sensitivity variable for SCD was also formed by additionally including all patients with symptom onset <1 hour before SCA and with undisputed cardiac origin for cardiac arrest but who were successfully resuscitated (if not witnessed and resuscitated these cases would have been classified as SCDs) and survived without permanent anoxic brain damage. SCAs not resulting in SCD were further subdivided according to outcome (successful resuscitation or death). The definitions of these end points are presented in Figure 1.

End point adjudication

The adjudication of the selected end points was based on in-depth review of all written hospital medical records and written accounts in death certificates of the circumstances leading to death. The Finnish legislature mandates that death certificates also must include a written account of all significant prevalent diseases of the patient and the events and circumstances leading to death along with the normal standardized data which includes causes of death in ICD-10 format, place of death (home, hospital, or other health care facility), class of death (accident, suicide, homicide, disease). The written accounts of the death and death certificate data are comprised by the last physician treating the patient, based on clinical information of the circumstances leading to death accompanied by medical autopsy results if the cause of death is not determinable by (pre-mortem) clinical information and post-mortem inspection, or by a medicolegal expert based on legally mandated forensic autopsy if the death was sudden or unexpected or preceded by a medical procedure within one month. The end point adjudi-

Figure 1



Enrolment and outcomes.

cation was made by two members of the research team (M.K. and J.H.) and in uncertain cases, the adjudication was decided after a joint review of the event.

Statistical analysis

Differences between categorical and continuous variables were analyzed using Pearson's $\chi 2$ test and the independent samples T-test, respectively. Since death for other reasons is a competing event for SCA, we used cumulative incidence functions (CIF) to analyze the true incidence of SCA rather than using normal unadjusted Kapplan-Meier curve that overestimates the cumulative incidence of any given event in the presence of competing events.[18] IBM SPSS Statistics 27 and R (version 4.0.3) with RStudio (version 1.3.1093) and packages (haven, survival, cmprsk, ggplot2, survminer, and ggpubr) were used for analyses. Reported *P*-values are 2-sided. *P*-values under .05 were considered statistically significant. All reported percentages are valid percentages.

Outside contribution

The authors are solely responsible for the design and conduct of this study, all study analyses and drafting and editing of the paper.

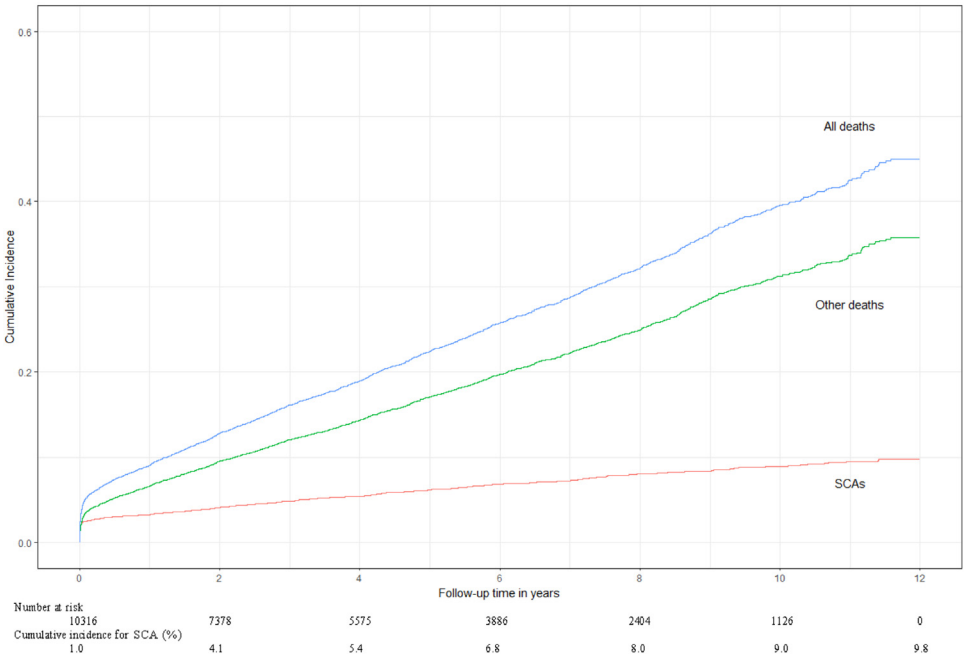
Results

The mean age of the population at baseline during the hospitalization for ACS was 68.2 years (±11.8 SD), and 67.2% ($n = 6{,}935$) of the patients were men. Most common ACS type was NSTEMI (45.8%, $n = 4{,}722$), following STEMI (35.5%, $n = 3{,}667$) and UAP (18.7%, $n = 1{,}927$). Approximately one third (66.4%, $n = 6{,}854$) of the patients were treated with a percutaneous coronary intervention (PCI), 10.9% ($n = 1{,}123$) with coronary artery bypass grafting (CABG), and 1.4% (144) with both methods (PCI and CABG), while 24.1% ($n = 2{,}483$) were treated conservatively.

Mortality and the incidence of SCA and SCD

The median follow-up time was 4.4 years (IQR 1.7-7.8), during which 2,677 deaths occurred (no loss to follow-up). In 70.8% ($n = 1{,}894$) the cause of death was determined by a clinical investigation; in 22.5%, it was determined by a medico legal and in 5.6% by a medical autopsy. In 1% ($n = 28$) the cause of death was determined by a forensic diagnosis without autopsy, and in three cases (0.1%) the cause of death remained undetermined because the patient had died abroad. In one case the diagnosis was based on registry information. In SCA

Figure 2



Cumulative incidence function for SCAs, other deaths, and all deaths during the follow-up. SCA = Sudden cardiac arrests.

and SCD, the autopsy rates were 49.0% (n = 262/535 for SCA) and 54.6% (n = 173/317 for SCD).

Overall mortality during the maximal 12-year observation period reached 44.9% (Figure 2). During the follow-up, a total of 687 patients suffered an SCA. Of these events, 46.1% (n = 317) were classifiable as SCDs, while 22.1% (n = 152) were SCAs that were aborted by successful resuscitation and 31.7% (n = 218) were classified as fatal SCAs. In some of the successfully resuscitated patients, the symptom onset was less than one hour before the arrest and the patient would have suffered an SCD had they not been resuscitated. If these cases are also considered SCDs, 59.2% (n = 407) of all events could be classified as SCDs. SCAs accounted for 30.5% (n = 528/1,732) of the deaths due to cardiovascular causes and 34.4% (522/1,519) of the deaths due to cardiac causes.

When a competing risk of death due to other causes was considered in the analyses, the cumulative incidence of all SCAs was 9.8% (Figure 2) at 12 years. The cumulative incidence of STEMI patients' SCA was double that of UAP patients': STEMI 11.9%, NSTEMI 10.2% and UAP 5.7% (Table I, Figure 3). The incidence of SCA during the first few weeks increases rapidly in the beginning, but it then levels out after first three months of follow-up (Table I, Figure 2). In fact, most of these first weeks' SCAs happened to STEMI patients (Figure 3, supplementary Figure I). Overall, 36.0% of the SCA events occurred before discharge and this proportion was clearly highest among STEMI-patients (58.2%) when compared to NSTEMI (19.5%) or UAP-patients (10.1%). If the deaths before discharge from hospital were not classified as SCA, the cumulative incidence of SCA was 7.3% at 12 years in the entire study population and for STEMI, NSTEMI and UAP the corresponding cumulative incidences were: 6.8%, 9.0% and 5.3% (Figure 4. and supplementary Table I).

The 12-year cumulative incidence of SCD was 5.4% (Table I). The proportion of SCDs occurring before discharge was 9.4%. Alternatively, if all successfully resuscitated patients with a symptom onset less than one hour before the SCA were combined with patients who ultimately suffered an SCD, the 12-year cumulative incidence of SCD would be 6.2% (Table I). If the deaths before discharge from hospital were not classified as SCD, the cumulative incidence of SCDs after discharge was 4.9% in the entire study population at 12 years and for STEMI, NSTEMI and UAP the corresponding cumulative incidences were: 4.9%, 6.1% and 3.2%. The cumulative incidences for these events after discharge are presented in supplementary Table I.

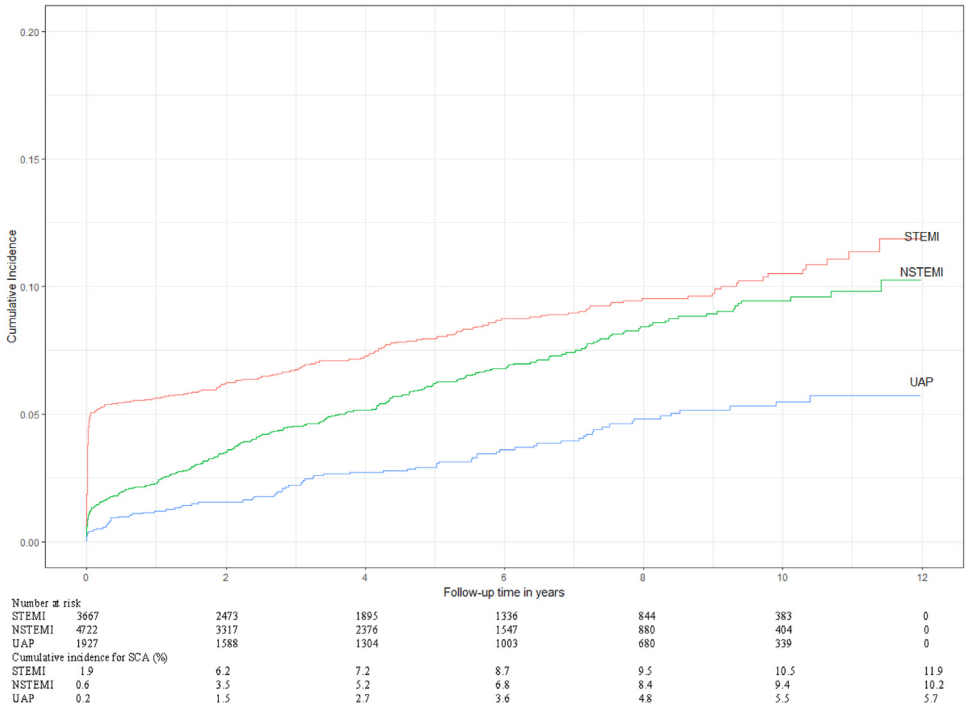
The cumulative incidence of SCA and SCD in different subpopulations (only patients with myocardial infarct or only patients with left ventricular ejection fraction) are presented in supplementary data (Supplementary Tables II and III).

Table I. Cumulative incidence of SCAs, SCDs, and SCAs within 1 hour from symptom onset or in individuals last seen in good health within 24 hours, as well as overall mortality of all patients and by ACS type

ALL N = 10316	Follow-up time					
	1 mo	6 mo	1 y	5 y	10 y	12 y
SCA % (*N* = 688)	2.5	3.0	3.3	6.2	9.0	9.8
SCD % (*N* = 318)	0.5	0.7	0.9	2.6	4.8	5.4
Expanded SCD* % (*N* = 407)	1.2	1.5	1.7	3.5	5.6	6.2
Overall mortality % (*N* = 2,677, 25.9%)	4.9	7.2	8.9	22.2	39.2	44.6
ST-ELEVATION (*N* = 3667)	1 mo	6 mo	1 y	5 y	10 y	12 y
SCA % (*N* = 311)	5.1	5.4	5.6	7.9	10.5	11.9
SCD % (*N* = 118)	0.9	1.1	1.3	2.8	4.9	5.6
Expanded SCD* % (*N* = 177)	2.4	2.6	2.8	4.5	6.5	7.2
Overall mortality % (*N* = 1003, 27.3%)	8.8	11.3	12.9	24.8	39.0	44.2
NON-ST-ELEVATION (*N* = 4722)	1 mo	6 mo	1 y	5 y	10 y	12 y
SCA % (*N* = 297)	1.3	1.9	2.3	6.2	9.4	10.2
SCD % (*N* = 158)	0.3	0.6	0.8	3.0	5.7	6.5
Expanded SCD* % (*N* = 186)	0.7	1.1	1.4	3.6	6.3	7.1
Overall mortality % (*N* = 1207, 25.6%)	3.6	5.9	7.7	23.2	42.9	48.2
UNSTABLE ANGINA PECTORIS (*N* = 1927)	1 mo	6 mo	1 y	5 y	10 y	12 y
SCA % (*N* = 79)	0.4	1.0	1.2	2.9	5.5	5.7
SCD % (*N* = 42)	0.1	0.2	0.3	1.5	3.0	3.2
Expanded SCD* % (*N* = 44)	0.1	0.2	0.3	1.5	3.2	3.4
Overall mortality % (*N* = 467, 24.2%)	1.9	3.6	5.0	16.3	33.8	39.8

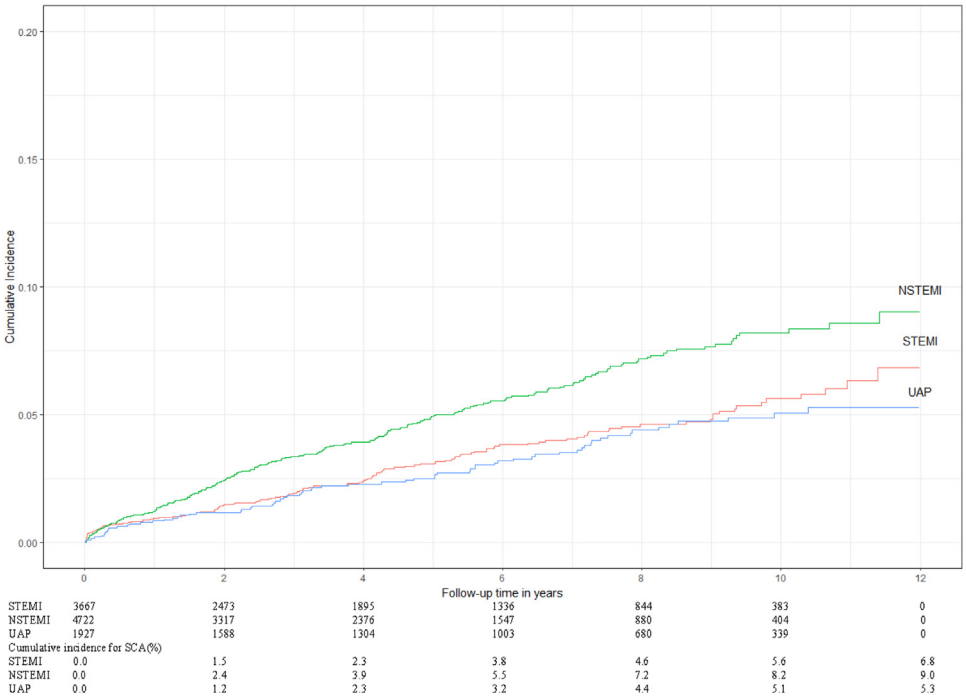
* SCDs combined with SCAs occurring within 1 h of symptom onset

Figure 3



Cumulative incidence function of SCA by ACS type during the follow-up. ACS = acute coronary syndrome; SCA = = Sudden cardiac arrests

Figure 4



Cumulative incidence of SCA by type of ACS during the follow-up. Deaths before discharge after ACS are excluded from the analysis. ACS = acute coronary syndrome; SCA = = Sudden cardiac arrests

Baseline characteristics of the study population stratified by the outcome

A comparison of the baseline characteristics between subsequent SCA victims, patients who died of other causes, and those who were still alive at the end of the follow-up revealed that many traditional risk factors associate with both the risk of SCA and the risk of death from other causes (Table II). As expected, the baseline prevalence of several traditional risk factors was higher among patients who later suffered an SCA than among survivors (Table II). However, the distribution of these risk factors at baseline did not differ significantly between SCA victims and patients who died of other causes, suggesting that these risk factors may yield poor discriminatory value in differentiating between subjects who are at risk of SCA and those at risk of dying by some other mechanisms.

Risk factors that seemed more specific for SCA included STEMI as the cause of ACS, LVEF measured during hospitalization, and male sex. STEMI was more common among SCA victims (45.2%, $n = 311$) when compared to patients who died of other causes (36.3%, $n = 760$) and to those who remained alive at the end of the follow-up (34.5%, $n = 2,596$; $P < .001$ for both comparisons). The mean LVEF during hospitalization was also lower among SCA victims (45.5 ± 12.4) when compared to patients who died of other causes (47.6 ± 12.8) and those who remained alive at the end of follow-up (52.9 ± 11.2; $P < .001$ for both comparisons). The proportion of men was also significantly higher among SCA victims (72.9%, $n = 501$) than among patients who died of other causes (62.4%, $n = 1,306$) or those who survived the follow-up (68.1%, $n = 5,128$; $P \leq .01$ and $P = .009$, respectively).

Incidence of SCAs by age group

Although a large part (31.3%) of all SCAs (including SCDs) occurred among individuals over the age of 80 years, the proportion of SCDs and SCAs was clearly the highest among younger age groups when compared to other causes of death (Figure 5). In brief, SCAs (resuscitated or fatal) occurred more often when compared to deaths due to other causes among patients under 60 years at death or non-fatal SCA. (Figure 5).

Events before SCA

The rates of ICD implantations and recurrent ACS episodes were calculated only for people residing in the Pirkanmaa Hospital District during the entire follow-up period (78.0% of the entire population, $n = 8,049$) due to missing data for these end points from other hospital districts outside the region.

Table II. Baseline characteristics at the index event according to SCA, other causes of death, or non-SCA and alive.

	SCA (*N* = 687)	Other deaths (*N* = 2,094)	Non-SCA and alive (*N* = 7,535)	*P*-value*	*P*-value†
Demographics					
Age, years (SD)	70.2 ± 11.5	75.8 ± 9.7	66.0 ± 11.5	< .001	< .001
Men % (N)	72.9 (501)	62.4 (1306)	68.1 (5,128)	< .001	.009
BMI (kg/m2) ‡	28.7 ± 5.9	27.5 ±5.5	28.2 ± 5.1	.001	.093
Diabetes % (any) (N) ‡	33.3(228)	33.6 (702)	22.3 (1,671)	.890	< .001
Hypertension %(N) ‡	61.3 (420)	67.4 (1,409)	58.6 (4,372)	.003	.166
Dyslipidemia%(N) ‡	55.1 (377)	56.3 (1,172)	58.9 (4,379)	.600	.054
CKD% (N) ‡	7.0 (48)	7.8 (163)	5.8 (434)	.499	.186
VHD% (N)	9.9 (68)	13.6 (285)	5.1 (382)	.011	< .001
Previous MI %(N)	24.5 (168)	27.0 (566)	13.7 (1,028)	.184	< .001
Previous PCI %(N)	11.4 (78)	11.9 (250)	10.6 (797)	.680	.528
Previous CABG % (N)	14.4 (99)	12.5 (261)	6.4 (480)	.187	< .001
PAD % (N)	14.7 (101)	15.2 (318)	4.9 (371)	.751	< .001
Cancer % (N) ‡	9.4 (63)	13.4 (277)	6.6 (466)	.006	.007
Dementia % (N) ‡	2.5 (12)	6.3 (82)	0.9 (45)	.006	.002
Smoker % (N) ‡	40.4 (127)	38.1 (381)	44.9 (2,279)	.456	.126
Previous ICD % (N)	0.4 (3)	0.3 (6)	0.3 (20)	.548	.416
LVEF %(SD)	45.5 ± 12.4	47.6 ± 12.8	52.9 ± 11.2	< .001	< .001
Status During Admission					
Hemoglobin (g/l) ‡	123.5 ± 16.0	121.8 ± 15.9	132.7 ± 15.1	.017	< .001
Creatinine (μmol/l) ‡	107.7 ± 93.8	105.7 ± 84.2	81.2 ± 42.3	.602	< 0.001
Killip class % (N) ‡				.250	< .001
1	56.4 (316)	57.1 (930)	86.9 (4917)		
2	22.5 (126)	24.0 (390)	9.5 (539)		
3	14.3 (80)	14.4 (235)	3.2 (179)		
4	6.8 (38)	4.4 (72)	0.4 (21)		
Type of ACS % (N)				< .001	< .001
STEMI	45.2 (311)	36.3 (760)	34.5 (2,596)		
NSTEMI	43.2 (297)	45.0 (942)	46.2 (3,483)		
UAP	11.6 (79)	18.7 (392)	19.3 (1,456)		
Treatment Modality					
PCI % (N)	67.5 (464)	58.9 (1,234)	68.4 (5,156)	< .001	.632
Heart surgery % (N)	9.6 (66)	13.2 (277)	10.4 (780)	.012	.539
Conservative % (N)	24.3 (167)	29.7 (621)	22.5 (1,695)	.007	.277

Percentages are valid percentages. Continuous variables are mean ± standard deviation. Categorical values are frequencies.
ACS, acute coronary syndrome; BMI, Body Mass index; CKD, chronic kidney disease; ICD, implantable cardioverter defibrillator; LVEF, left ventricular ejection fraction; NSTEMI; non-ST-elevation myocardial infarction; PAD, peripheral arterial disease; PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; UAP, unstable angina pectoris; VHD, valvular heart disease.

* Between SCA and other deaths.

† Between SCA and alive.

‡ Missing data: <1% for diabetes, hypertension, dyslipidemia, CKD, hemoglobin, and creatinine; 45.9% for BMI; 2.1% for cancer; 30.5% for dementia; 46.2% for smoking; and 18.2% for Killip classification.

In total, 3.2% ($n = 255$) of the ACS patients from the Pirkanmaa Hospital District had an ICD implanted before an outcome or the end of the follow-up. The majority (95.6%, $n = 498/521$) of the SCAs occurred among patients with no ICD. Similarly, the prevalence of SCAs was higher among patients with a recurrent hospitalization for an MI (10.4%, $n = 58/558$ vs 6.2%, $n = 463/7{,}491$, $P < 0.001$), but 89.1% ($n = 464/521$) of all SCAs occurred among patients with no rehospitalizations for an MI.

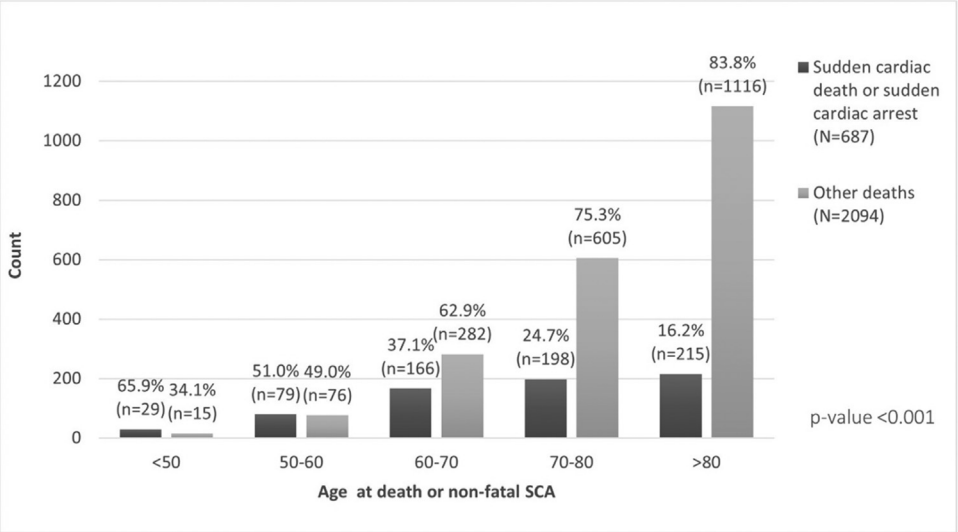
Discussion

The observations of this retrospective registry study outline the cumulative incidence of SCDs and all SCAs after ACS. Our observations are based on a full-disclosure review of written hospital records and death certificates detailing the circumstances leading to death. These data update the epidemiology of these events in a contemporary setting.

EuReCa ONE-27 study reports the incidence for out-of-hospital cardiac arrests (OHCA) throughout Europe, mean incidence being 84 of 100 000 annually in general population, and 126 of 100 000 in Finland.[19] Also, a study from De Vreede-Swagemakers et al found 1 of 1000 annual incidence of SCA in general population.[20] In our study with acute coronary syndrome patients, the annual incidence is approximately 5 to 8-fold to these incidence rates depending on the definitions used.

Most previous studies on the incidence of SCA or SCD after acute coronary syndromes or myocardial infarction

Figure 5



The number of SCA and SCD events vs deaths due to other causes according to age group. *$\chi 2$ test for the distribution of SCAs/SCDs and other deaths between age groups. SCA = Sudden cardiac arrests; SCD = sudden cardiac deaths.

have reported slightly higher estimates for SCA and SCD when compared to our findings.[8-11,21] Besides using only the Kaplan-Meier estimator, which leads to an upwards-biased cumulative incidence in the presence of competing events (deaths due to other causes),[10,18,22] many of the studies are based on epidemiological data from previous decades and mostly rely on specific subsets of ACS patients (only patients with an MI or only patients with significant left ventricular dysfunction or decompensated heart failure). In line with previous observations, in our study population the cumulative incidence for SCA and SCD was clearly higher among STEMI and NSTEMI patients when compared to patients with UAP. Interestingly, while the proportion of SCA cases before discharge is clearly highest among STEMI patients, the incidence of SCA (and SCD) after discharge is highest among NSTEMI patients.

In a previous large retrospective registry study by Solomon et al. with 14,609 post-AMI patients with heart failure or a low LVEF, the incidence of all SCAs (including SCDs) was 5.5% after 1 year (data collected in 1998-2001),[10] which is 63.5% higher than the incidence observed in our study, which included all ACS patients. However, when our analyses were restricted to patients with a LVEF of <45%, the incidence of SCA slightly exceeded the incidence reported by Solomon et al. (5.9% at 1 year). Similarly, in a very large pooled multitrial material (from 2006 to 2011) with over 37,000 NSTEMI patients (excluding patients with ICD), the cumulative incidence of SCD was observed to be 0.8%, 1.7%, and 2.4% at 6 months, 1.5 years, and 2.5 years, respectively.[9] These numbers are more in line with our estimates, although they are higher that what was observed in our study (0.7%, 1.1%, and 1.6%).

In another small prospective study by Huikuri et al.,[21] 700 post-AMI patients were actively followed (data collected from 1996 onwards, with 95% of the patients using betablockers). In this selected group of patients, the incidence of SCD during approximately 3.5 years of follow-up was 3.2%, which is significantly closer to our estimate. However, the sample size and event rates were very small, and due to selection bias, the estimate is not representative of all AMI patients. In a study by Mäkikallio et al.,[23] 2,130 consecutive acute MI patients were recruited in 1996-2000. The annual incidence of SCD was 0.4% in patients who received optimized treatment, which is almost similar to our study. In patients with unoptimized treatment, the incidence was clearly higher (annual incidence of SCD 1.4%). However, patients who were at least 76 years old at baseline were excluded, which is likely to have had a reducing effect on the incidence.

In our study, fatal SCAs accounted for approximately one fifth of all deaths among CAD patients, which is in line with previous studies.[8,9] Even though the incidence of SCD increases with age, the proportion of SCDs is notably greater in the young population. In CAD patients who are under 50 years old, SCA (including SCD) is a major cause of death. This result is also consistent with previous studies.[3,11,24]

Only a small proportion of SCA victims had an ICD implanted before the final event in our study population. However, this observation is confounded by the fact that ICDs are effective in preventing SCA/SCDs in ischemic cardiomyopathy. Unfortunately, we did not have data of adequate ICD therapies and our observations, although providing true contemporary estimates, could slightly underestimate the potential cumulative incidence of these events. Furthermore, as a significant number of SCDs occur during the first month after an MI during which ICDs are not implanted (not been shown to be effective in preventing SCD or death from any cause), the impact of ICD implantations on the overall observation is most likely not substantial.[10,25,26] Overall, the number of unpredicted SCAs/SCDs is high, and the need for better risk assessment tools is obvious. For example, new risk stratification and intervention methods, such as prediction score or artificial intelligent devices, of the symptoms before SCA have shown to be promising.[27,28] Adding to the challenge, the vast majority of SCAs (89.1%) in our study occurred in patients who did not suffer subsequent MIs between the first hospitalization and the final SCA event. Similarly to the results of previous studies, our study also demonstrated that SCA victims are more often men and have a lower LVEF than other patients.[4,10,29] Our results also show that STEMI is a risk factor for SCA when compared to other ACS types.

This study is based in a defined geographical area in genetically quite homogenous Finland. This limits the generalizations of the observations to non-Caucasian ethnicities and societies with a lower income level and more limited access to health care. However, due to the centralized health care system in Finland, we were able to observe all major incident events with no loss to follow-up, as all patients with recurrent events in the region of Pirkanmaa are treated at the same center. Furthermore, the Finnish death certificate system is well established, with the highest proportion of autopsies (2015 21% of all deaths in 2015) in the Nordic Countries and the world.[30,31] In Finland, death certificates are mainly written by the attending physician and inspected by forensic medicine experts, or they are written directly by forensic medicine experts if the cause of death was determined in a medico legal autopsy. In addition to containing formal registry data on the classification of the causes of death in ICD format, as well as on the place of death and the estimated timeline for the events, the Finnish death certificates also contain a written narrative of the circumstances leading to the death. The written description is mandatory, since it is always reviewed by medico legal experts before the death can classified as natural or as having occurred due to some other event and possibly requiring a more in-depth inquiry. Naturally, the free-form description of the circumstances leading to death and the estimated timeline is sometimes too vague for an accurate distinction between SCD and SCA. This usually leads to the classification of SCDs as SCAs, if the timeline is uncertain.

The retrospective use of only death certificate registry data to identify SCD/SCA cases has been shown to have a low positive predictive value in the United States, but he validity can be improved by using multiple sources of information.[29] In addition to having a written account of the events leading to death available to us, we also had the possibility to review other written medical records from specialized health care to complement the adjudication of the events. Furthermore, in the present study, the cumulative incidence function was used to prevent the overestimation of incidence.

Conclusion

To the best of our knowledge, there is no prior published information on the actual stratification of sudden cardiac arrest events (including SCDs) in ACS population. According to our results, SCA accounts for 30% of all deaths due to cardiovascular causes after acute coronary syndrome, and approximately half of SCAs can be classified as sudden cardiac deaths. However, our study demonstrates SCA is still an extremely significant cause of death after ACS, especially among patients under 60 years of age. Also, only a small amount of ACS patients receives an ICD for primary prevention of SCA. These results provide reliable information of the extent of this problem and can be used in designing future observational or even interventional studies which are needed to improve risk prediction and prevention of SCA and SCD.

Data Availability Statement

The data that support the findings of this study are available from Minna Koivunen, upon reasonable request, for scientific purposes in anonymized form pending the approval of the MADDEC study.

Permissions/Approval

This study complies with the Declaration of Helsinki on the ethical principles for medical research and the study design was approved by the scientific monitoring board of Pirkanmaa hospital district. Due to the retrospective nature of the study, no patient consent was required. According to Finnish legislation retrospective registry studies do not need the approval (ie, review) of the institutional review board (IRB) because patient treatment is not affected by the study (Medical Research Act 488/1999). However, the approval of the data owner (the Pirkanmaa hospital district) is required to ensure proper scientific use of medical data and adequate data security (The Act on the Secondary Use of Health and Social Data [552/2019]). For this, the ethical approval for the study was granted by the scientific monitoring committee of the Pirkanmaa Hospital district.

Author Contribution

All authors contributed to the manuscript and discussed the results.

Minna Koivunen: writing- original draft, review & editing, investigation, formal analysis, data acquisition and curation, visualization, interpretation, Juho Tynkkynen: data validation and analysis design, interpretation, writing-original draft, review & editing, Niku Oksala: conceptualization, writing -review & editing, Markku Eskola: data acquisition, writing - review & editing, Jussi Hernesniemi: data acquisition and curation, writing-original draft, review & editing, supervision, conceptualization, supervision, interpretation.

All authors have approved the final, submitted version. All authors agree to be accountable for all aspects of the work.

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Conflict of Interest

None reported.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ahj.2022.11.009.

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