

# Sports-related sudden cardiac death in Switzerland classified by static and dynamic components of exercise

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## Abstract

**Background:** Sports-related sudden cardiac deaths (SrSCDs) occur most frequently in highly dynamic and/or static sports. We aimed to assess the incidence and characteristics of SrSCDs in Switzerland and to compare SrSCD occurrence according to sports categories with the sports participation behaviour in the general population.

**Methods:** Between 1999 and 2010, forensic reports of SrSCDs in young individuals (10–39 years of age) were retrospectively reviewed and categorised based on peak static (increasing from I to III) and dynamic sports components (increasing from A to C). Data were compared to the sports participation behaviour of the Swiss population.

**Results:** Sixty-nine SrSCDs were identified. Forty-eight (69.6%) occurred during recreational sports (REC) and 21 (30.4%) during competitive sports (COMP). Incidences (per 100,000 athlete person-years) for COMP and REC were 0.90 and 0.52, respectively ( $p = 0.001$ ). Most SrSCDs occurred in IC (23 cases, 33.3%), followed by IIC (13, 18.9%), IIIA and IIIC (11 each, 15.9%), IIIB (6, 8.7%), IIA (4, 5.8%) and IB sports categories (1, 1.5%). No SrSCDs were found in IA and IIB sports categories. Incidences between sports categories (IIIA 0.25, IB 0.25, IC 0.18, IIC 0.33 and IIIC 0.25) were not significantly different except to IIA (0.94,  $p < 0.001$ ), due to the fact that few people were involved in this sports category. Coronary artery disease (CAD) was the most common underlying pathology of SrSCD.

**Conclusions:** In this Swiss cohort, incidence of SrSCD was very low and similar in all sports categories classified by their static and dynamic components. However, the incidence was higher in COMP compared to REC, and CAD proved to be the most common underlying cause of SrSCD.

## Keywords

Sudden cardiac death, athlete, competitive, sports, dynamic, static, coronary artery disease

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## Introduction

Sports-related sudden cardiac death (SrSCD) in the young is rare, but always catastrophic. Although performing sports is related to decreased overall mortality, temporary maximum physical performance is associated with a higher risk for SrSCD during and up to 1 hour after cessation of sports.<sup>1,2</sup> It is suggested that sports might be a strong trigger for a cardiovascular event, particularly in congenital heart disease or coronary artery disease (CAD).<sup>2,3</sup> Recommendations for a pre-participation screening (PPS) with or without resting ECG exist in most countries and is well accepted

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by athletes.<sup>4,5</sup> In Switzerland, mandatory PPS including an ECG exists for elite athletes and in certain sports associations (e.g. football, athletics and cycling). For all other athletes, PPS is offered on a voluntary basis.<sup>6</sup>

For physiologic purposes, different sports can be divided into dynamic (isotonic) and static (isometric) components. Dynamic components are represented by the maximal oxygen uptake (max O<sub>2</sub>), and result in increased cardiac output (volume load), whereas static components are related to the percentage of maximal voluntary contraction (MVC), with the consequence of increased pressure load.<sup>7,8</sup> In athletes, absolute numbers of SrSCDs are highest in sports with high dynamic and/or static components.<sup>9,10</sup> Importantly, sports in these categories are very popular. It is unknown which sports categories based on their dynamic and static exercise components are at high risk for SrSCD in a population with a selective PPS program. We aimed to assess the incidence, characteristics and underlying causes of SrSCD and to compare SrSCD occurrence according to sports categories with the sports participation behaviour in the general population of Switzerland.

## Methods

### Study population

We defined a SrSCD as an unexpected cardiovascular death occurring during or within 1 hour after physical activity.<sup>11</sup> After the publication of the first PPS recommendation in 1998 in Switzerland, we retrospectively reviewed all forensic reports of German- and French-speaking parts of Switzerland from 1999 to 2010 (with an overall population of 7,030,900) for SrSCDs in young individuals (10–39 years of age). We included only German- and French-speaking parts of Switzerland as some of the SrSCD cases of the Italian-speaking parts of Switzerland were investigated in Italy. Data were retrospectively collected in an anonymised fashion in the Swiss Registry of Athletic Related Death ([www.swissregard.ch](http://www.swissregard.ch)).<sup>12</sup> The heart examination was performed by the local forensic pathologist, and the diagnosis of the cause of death was established based on macroscopic findings. In selected cases, microscopy and toxicology were performed. The criterion for hemodynamically relevant CAD was a lumen narrowing of  $\geq 50\%$ .<sup>13</sup> We classified SrSCDs into two groups depending on whether they occurred during recreational sports (REC) or competitive sports (COMP). COMP is defined as sudden cardiac death of athletes who participate in organised teams or individual sports that require systematic training and regular competition against others and requiring a high degree of athletic excellence and commitment.<sup>14</sup> REC are defined as

involving engagement in physical activity of low, moderate or vigorous intensity and with no participation in competitions. Sports in which SrSCDs occurred were further classified based on the peak static and dynamic components achieved during training or competition as suggested in the Task Force 8 of the American College for Cardiology.<sup>7</sup> I to III characterises an increasing static component, whereas A to C represents an increasing dynamic component. I represents  $<20\%$  MVC, II represents 20–50% MVC and III represents  $>50\%$  MVC, whereas A describes  $<40\%$  of max O<sub>2</sub>, B describes 40–70% of max O<sub>2</sub> and C describes  $>70\%$  of max O<sub>2</sub>.<sup>7</sup> Incidences and underlying conditions of SrSCDs were analysed. The denominators for the calculation of incidences were derived from the Swiss Federal Office of Statistics<sup>15</sup> and a survey from the year 2008 on sports participation in Switzerland from the Swiss Federal Office of Sports. According to the survey, 73% of the Swiss population participate regularly in sports. Thereof, 80% are engaged in REC and 20% in COMP.<sup>16</sup> The survey also lists participation numbers within the 67 different sports disciplines. We calculated the sports participation rate (multiple sports exposures possible) according to the different sports categories classified by dynamic and static components of sports, based on the aforementioned survey.<sup>16</sup>

In Switzerland, sudden unexpected deaths are reported to the district attorney, which in turn initiates an inquiry. The preliminary forensic examination is a scene investigation of the corpse, mostly performed by a forensic pathologist. The district attorney may mandate further examination such as an autopsy. In a recent study in the Swiss canton of Vaud, the autopsy rate of sudden cardiac death in the young was found to be as high as 47.5%.<sup>13</sup> Although this autopsy rate is lower compared to other countries, based on clinical experience and internal communications with other forensic institutes in Switzerland, the autopsy rate seems valid for non-SrSCDs and SrSCDs and applicable to all cantons in Switzerland.<sup>17</sup> Our cohort includes only autopsied SrSCDs. SrSCDs based on only a scene investigation were not included. Therefore, our recorded numbers of SrSCDs were multiplied by 2.1 for the adjusted calculated incidences. Incidences between sports categories with reference of the lowest incidence (minimum one case of SrSCD) were compared.

### Statistical analysis

All statistical analyses were performed using SPSS Statistics for Windows, version 22 (IBM Corporation, Armonk, NY) and MedCalc, Software bvba version 15.10.0 (Belgium). Data are reported as

median  $\pm$  interquartile range (IQR; 25th–75th percentile), mean  $\pm$  standard deviation (SD) or percentages, as appropriate. Continuous variables were analysed using the Student's *t*-test or Mann–Whitney *U*-test, where appropriate. Categorical data were analysed with the chi-squared test or Fisher's exact test in case of low field numbers. For comparison of the SrSCD rates, the lowest incidence category (categories without a single SrSCD were excluded) was defined as the reference category. All other incidences of sport categories were compared to that reference category. *p*-values of all outcomes were two-sided; a value of less than 0.05 was considered significant. Confidence intervals (CIs) were defined as 95%.

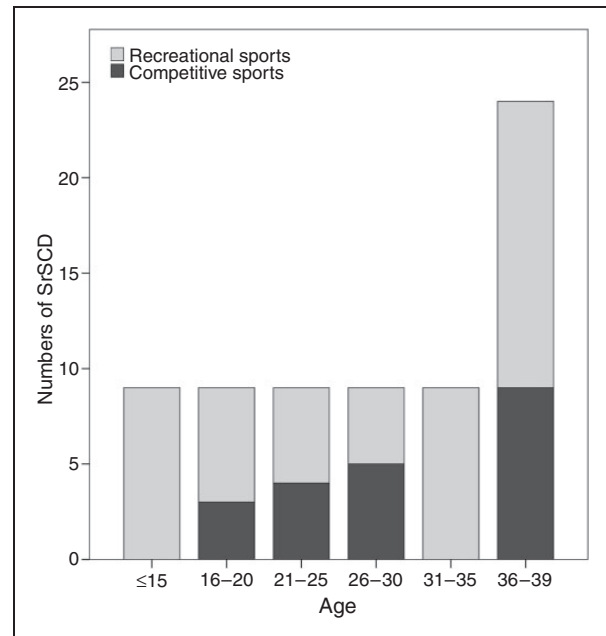
### Ethics

This study was evaluated by the Ethics committee of the Canton of Bern, Switzerland. Based on Swiss Human Research Law, informed consent for the analysis of anonymised, and retrospective data were not necessary.

### Results

In the 12-year period under investigation, a total of 72 SrSCDs were recorded. One professional Canadian volleyball player, one American and one German handball player, who died in Switzerland during a sports event, were excluded from the study. Of the 69 remaining SrSCDs used for analyses, six (8.7%) concerned females and 63 (91.3%) concerned males ( $p < 0.001$ ). Of these, 48 (69.6%) died during REC and 21 (30.4%) died during COMP. The male:female ratio was comparable between REC and COMP at 45 (93.8%) versus 3 (6.3%) and 18 (85.7%) versus 3 (14.3%), respectively ( $p = 0.36$ ). Mean age at time of SrSCD in REC was 27.6 years ( $\pm 9.9$ ) versus 30.0 years ( $\pm 7.9$ ) in COMP ( $p = 0.29$ ). The numbers of SrSCDs in COMP and REC with regards to age classes are shown in Figure 1. The calculated incidence corrected for autopsy rate was higher for COMP at 0.90/100,000 than REC at 0.52/100,000 ( $p = 0.001$ ; see Table 1).

The underlying diagnoses of the 69 SrSCDs are displayed in Figure 2. Notably, under "other" ( $n = 5$ ), the following cases were summarised: one commotio cordis, one dextro-transposition of the great arteries with patent ductus arteriosus, one Wolff–Parkinson–White syndrome, one sarcoidosis and one uncertain case. In REC, CAD with or without myocardial infarction (MI) was the main cause of SrSCD (12, 25%), followed by hypertrophic cardiomyopathy (8, 16.7%) and unremarkable findings at autopsy (8, 16.7%). Similarly, in COMP, CAD with or without MI was



**Figure 1.** Sports-related sudden cardiac death distributions between recreational sports and competitive sports according to age.

SrSCD: sports-related sudden cardiac death.

the most common cause of SrSCD (8, 38.1%) followed by dilated cardiomyopathy and aortic valve stenosis (each 2, 9.5%). Of the COMP athletes, three (14%) were elite athletes and all three died of a MI. All athletes who suffered from SrSCD were Caucasian, except one Swiss athlete who had African–American roots.

Based on the classification of peak static and dynamic components achieved during training or competition,<sup>7</sup> most SrSCDs occurred in IC (23, 33.3%), followed by IIC (13, 18.9%), IIIA and IIIC (each 11, 15.9%), IIIB (6, 8.7%), IIA (4, 5.8%) and IB (1, 1.5%). However, as indicated in Table 2 and Figure 3, incidences between sport categories were similar based on sports behaviour.<sup>16</sup> Only in sports category IIA was the incidence of SrSCD significantly greater than in the reference sports category IIIB. No SrSCDs were found in low-static and -dynamic and moderate-static and -dynamic sports (IA and IIB).

CAD was the most common underlying pathology in 20 (29%) of all SrSCDs. Of those, eight (40%) presented with CAD with MI, whereas the remaining 12 (60%) had CAD without MI. CAD with or without MI was comparable between REC (12 out of 48, 25%) and COMP (8 out of 21, 38%;  $p = 0.27$ ). Out of all of the CAD-related SrSCDs, soccer was most often represented with six cases (30%), followed by wrestling (three cases, 15%) and cycling and handball (two cases each, 10%); the rest occurred in running, skiing, ice hockey, weight lifting, dancing, rowing and

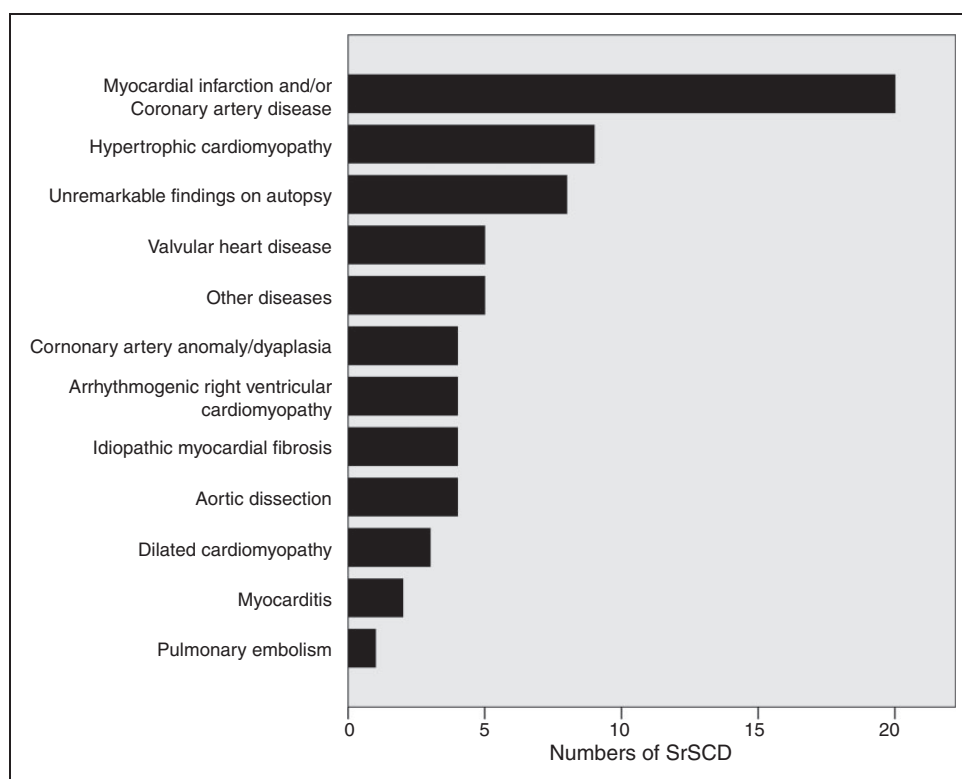
**Table 1.** Calculated incidences of sports-related sudden cardiac deaths in the German- and French-speaking parts of Switzerland between 1999 and 2010 in individuals aged 10–39 years.

	Individuals (10–39 years)	12 person-years	Recorded/ adjusted <sup>a</sup> number of SrSCDs	Calculated incidence (athlete person-years) of SrSCDs with adjusted <sup>a</sup> number of SrSCDs
Total population <sup>b</sup>	2,784,561			
Individuals involved in sports activities (73%) <sup>b</sup>	2,032,730	24,392,760	69/145	0.59/100,000
Competitive sports (20%)	406,546	4,878,552	21/44	0.90/100,000
Recreational sports (80%)	1,626,184	19,514,208	48/101	0.52/100,000

<sup>a</sup>Adjustment of SrSCD ( $\times 2.1$ ) based on average autopsy rate in Switzerland (47.5%).<sup>13</sup>

<sup>b</sup>The denominators for the calculation of incidences were derived from the Federal Office of Statistics ([www.bfs.admin.ch](http://www.bfs.admin.ch)) and a survey on sports-participation in Switzerland from the Federal Office of Sports ([www.baspo.admin.ch](http://www.baspo.admin.ch)).

SrSCD: Sports-related sudden cardiac death.



**Figure 2.** Underlying diagnoses of sports-related sudden cardiac deaths in recreational sport and competitive sport athletes. The group “Other diseases” comprise of commotio cordis ( $n = 1$ ), dextro-transposition of the great arteries with patent ductus arteriosus ( $n = 1$ ), Wolff–Parkinson–White syndrome ( $n = 1$ ) and sarcoidosis ( $n = 1$ ), as well as one uncertain case.

SrSCD: sports-related sudden cardiac death.

gymnastics (one case each, 5%). Performing a sub-analysis of all SrSCD cases in athletes aged  $\leq 35$  years ( $n = 45$ ), CAD with or without MI was the single cause that led to the most deaths ( $n = 12$ , 26.7%). There were no CAD cases in SrSCDs of athletes who

were younger than 23 years of age. The proportion of CAD-related SrSCDs increased with age as follows: <20 years: 0%; 21–25 years: 10%; 26–30 years: 25%; 31–35 years: 25%; and 36–39 years: 40%. No female SrSCD cases presented with CAD.

**Table 2.** Comparison of incidence based on the classification of peak static and dynamic components achieved during training or competition according to sports participation in Switzerland.

	IA	IIA	IIIA	IB	IIB	IIIB	IC	IIC	IIIC
SrSCD absolute numbers (n)	0	4	11	1	0	6	23	13	11
Adjusted <sup>a</sup> SrSCDs (n)	0	8	23	2	0	13	49	27	23
Sports participation in Switzerland classified according to sports category (multiple sports) (%)	1.4	3.5	38.0	3.3	1.8	29.8	70.0	33.7	38.2
Individuals involved in different sports categories (n)	28,458	71,145	772,437	67,080	36,792	605,753	1,422,911	685,030	776,502
Individuals involved in different sports categories (12 person-years) (n)	341,498	853,746	9,269,249	804,961	441,509	7,269,042	17,074,932	8,220,360	9,318,034
Incidence per athlete year		1:213,436	1:842,659	1:804,961		1:1,211,507	1:742,388	1:632,335	1:847,094
–95% CI		1:783,350 to 1:83,361	1:1,688,031 to 1:470,950	1:31,794,148 to 1:144,475		1:3,301,267 to 1:556,611	1:1,171,118 to 1:494,763	1:1,187,578 to 1:369,780	1:1,696,915 to 1:473,428
Incidence rate difference		1:259,080	1:2,767,772	1:2,398,784			1:1,917,231	1:1,322,715	1:2,816,201
–95% CI		1:728,945 to 1:157,535	–1:1,604,648 to 1:743,057	–1:579,087 to 1:390,531			–1:2,348,494 to 1:680,746	–1:2,863,860 to 1:537,282	–1:1,595,349 to 1:747,944
Incidence rate ratio		5.68	1.44	1.51			1.63	1.92	1.43
–95% CI		1.18 to 23.94	0.49 to 4.73	0.03 to 12.41			0.65 to 4.90	0.68 to 6.15	0.48 to 4.71
p-value	NA	<0.001	0.47	0.70	NA	Reference	0.28	0.18	0.48
Adjusted <sup>a</sup> incidence per athlete year		1:106,718	1:403,011	1:402,481		1:559,157	1:348,468	1:304,458	1:405,132
–95% CI		1:247,188 to 1:54,161	1:635,750 to 1:268,586	1:3,323,408 to 1:111,418		1:1,050,143 to 1:326,987	1:471,026 to 1:263,581	1:461,995 to 1:209,257	1:639,096 to 1:269,999
Adjusted <sup>a</sup> incidence rate difference		1:131,890	1:1,443,174	1:1,436,397			1:924,815	1:668,395	1:1,470,749
–95% CI		1:251,468 to 1:89,386	–1:1,351,849 to 1:470,464	–1:409,514 to 1:260,804			–1:3,290,070 to 1:405,426	–1:9,304,811 to 1:322,610	–1:1,335,178 to 1:474,200
Adjusted <sup>a</sup> incidence rate ratio		5.24	1.39	1.39			1.60	1.84	1.38
–95% CI		1.88 to 13.64	0.67 to 2.98	0.15 to 6.14			0.85 to 3.22	0.92 to 3.88	0.67 to 2.97
p-value	NA	<0.001	0.34	0.66	NA	Reference	0.13	0.07	0.35

I to III represent increasing static components of sports; A to C represent increasing dynamic components of sports.

<sup>a</sup>Adjustment of SrSCD ( $\times 2.1$ ) based on average autopsy rate in Switzerland (47.5%).<sup>13</sup>  
SrSCD: sports-related sudden cardiac death; CI: confidence interval; NA: not applicable.

## Discussion

To our knowledge, this is the first study focusing on the incidence and distribution of SrSCDs according to dynamic and static components of sports activities as defined by the 36th Bethesda Conference Task Force 8 in a population with selective PPS, including ECG.<sup>7,8</sup>

### Incidences

The analysis of SrSCDs in Switzerland with a PPS for elite athletes only and PPS on a voluntary basis for all

other athletes showed a relatively low incidence of SrSCDs, with a significantly higher incidence of SrSCDs in COMP compared to REC. By contrast, the data from Denmark showed no significant differences in COMP versus REC (0.47 versus 0.43/100,000 athlete person-years); however, their definition of REC athletes differed from ours. They defined REC with a higher threshold regarding training load; hence, absolute numbers of SrSCDs in REC were very low in their study, and this methodological difference makes comparison difficult between the two studies.<sup>18</sup> Our SrSCD incidence was similar to that found in a prospective

III. High (>50% MVC)	Gymnastics = 2 Sport climbing = 6 Weight lifting = 3 Total = 11 (15.9%)  <i>Incidence*:</i> 0.25/100'000 (95% CI: 0.16 - 0.37)	Downhill skiing = 3 Wrestling = 3 Total = 6 (8.7%)  <i>Incidence*:</i> 0.18/100'000 (95% CI: 0.10 - 0.31)	Cycling = 9 Rowing = 2 Total = 11 (15.9%)  <i>Incidence*:</i> 0.25/100'000 (95% CI: 0.16 - 0.37)
	Auto racing = 1 Diving = 2 Equestrian = 1 Total = 4 (5.8%)  <i>Incidence*:</i> 0.94/100'000 (95% CI: 0.41 - 1.84)	Total = 0 (0%)  <i>Incidence*:</i> N/A	Basketball = 1 Ice hockey = 2 Cross-country skiing = 1 Swimming = 7 Team handball = 2 Total = 13 (18.8%)  <i>Incidence*:</i> 0.33/100'000 (95% CI: 0.22 - 0.48)
	Total = 0 (0%)  <i>Incidence*:</i> N/A	Volleyball = 1 Total = 1 (1.5%)  <i>Incidence*:</i> 0.25/100'000 (95% CI: 0.03 - 0.90)	Race walking = 2 Racequetball/squash = 1 Running = 9 Soccer = 11 Total = 23 (33.3%)  <i>Incidence*:</i> 0.29/100'000 (95% CI: 0.21 - 0.34)
I. Low (<20% MVC)	(A) (<40% MaxO <sub>2</sub> ) I. Low	(B) (40%–70% MaxO <sub>2</sub> ) II. Moderate	(C) (>70% MaxO <sub>2</sub> ) III. High

**Figure 3.** Numbers and incidences of sports-related sudden cardiac deaths in different sport categories. Classification of sports-related sudden cardiac deaths in recreational sport and competitive sport athletes based on peak static (isometric) and dynamic (isotonic) components according to the Task Force 8 of the American College of Cardiology.<sup>7</sup> I to III represent increasing static components of sports; A to C represent increasing dynamic components of sports.

\*Incidences are shown in “athlete person-years” and calculated based on the average autopsy rate in Switzerland (47.5%)<sup>13</sup> and adjusted ( $\times 2.1$ ) sports-related sudden cardiac death numbers.

Max O<sub>2</sub>: maximal oxygen uptake; MVC: maximal voluntary contraction; CI: confidence interval.

study in France<sup>19</sup> with a similar PPS practice, as well as similar to retrospective studies from the USA with 2/100,000 athlete person-years<sup>20,21</sup> and to data from Norway with 0.9/100,000 athlete person-years.<sup>22</sup> A study from Italy, a nation that maintains a strict PPS practice, has also shown similar incidences since the implementation of its systematic PPS program.<sup>4,23</sup> Whether our SrSCD athletes underwent a PPS is unknown; however, it has been suggested that only 9% of non-elite COMP athletes in Switzerland undergo a PPS.<sup>24</sup>

The clear male predominance in our study population supports the findings of many previous studies. The higher training loads and intensities of males during competitive sports, higher participation rates and also a predisposition for premature CAD could be explanations for this observation.<sup>21,25</sup>

We can show that sports with a high dynamic (e.g. running), static (e.g. weight lifting) or dynamic and static component (e.g. cycling and rowing) were associated with high numbers of SrSCDs. Notably, these

are also the types of sports with a high participation rate within the general Swiss population.<sup>16</sup> There were no significant differences between the sports categories with regards to SrSCD incidence, apart from sports category IIA, which significantly differed from IIIB. Only four SrSCD cases were observed in the IIA sports category, and this higher incidence was driven by the low participation rate in this sports category. Our findings of similar incidences between sports categories are in contrast to the study of Harmon et al., who showed in National Collegiate Athletic Association athletes in the USA that athletes engaged in “stop-and-go” sports such as basketball (high dynamic/moderate static) were at highest risk for SrSCD.<sup>11</sup> However, their finding was largely due to SrSCDs in black college athletes, who were not represented in our study.<sup>11</sup> Similarly to our findings, in the Venetian population, SrSCDs occurred mostly in soccer players, followed by basketball players and swimmers, with no differences in incidences between these sports.<sup>3</sup> In contrast to our study, participation

rates were not known in the studies from the Norwegian and French databases, which showed most SrSCDs in high-dynamic/low-moderate-static sports.<sup>19,22</sup>

### Underlying causes of SrSCD

Interestingly, CAD with and without MI was the most common underlying cause of SrSCD in this study cohort of young athletes. The CAD proportion was similarly high in both groups at 38% in COMP and 25% in REC ( $p=0.27$ ). CAD was also found to be the main reason for SrSCD in older athletes,<sup>26</sup> whereas in younger athletes, hereditary cardiac diseases were found to be the main underlying conditions.<sup>3,9,19,27</sup> This is in contrast to our study, in which CAD was the predominant cause of SrSCD, even in our younger athletes ( $\leq 35$  years of age). The fact that CAD was the leading cause of SrSCD can be interpreted in different ways. As PPS by ECG cannot detect premature CAD, but may detect cardiomyopathies or channelopathies, selection bias might be part of the explanation. Notably, in all three elite athletes who underwent a mandatory PPS, the underlying cause of death was MI. Interestingly, similar results were found in the Norwegian study with 48% of young athletes suffering from SrSCD related to MI,<sup>22</sup> and 66% of SrSCDs in Turkish football players were related to CAD.<sup>28</sup> CAD was also the main cause of non-sports-associated cardiac arrests in 43% of individuals aged 25–35 years in the USA.<sup>21</sup> Similarly, CAD was the underlying cause of sudden cardiac death in 30% of young non-athletes in French-speaking parts of Switzerland (5–39 years of age).<sup>13</sup> Furthermore, in a large prospective study from France, SrSCDs mainly occurred in REC and in a large proportion were due to underlying CAD.<sup>10</sup> Similarly, in a recently published study from Germany, SrSCDs in older athletes ( $>35$  years of age) were mainly triggered by premature CAD. In the same study, however, CAD was also the underlying cause of SrSCD in a high number of younger athletes ( $<35$  years of age).<sup>29</sup> In summary, it seems that there may be regional differences with regards to CAD-associated SrSCD,<sup>3,25,27</sup> which might be represented in our Swiss cohort, with less frequent cardiomyopathies than premature CAD. Interestingly, familial hypercholesterolaemia is highly prevalent in Europe (1:500) and also in Switzerland.<sup>30</sup> In most countries, familial hypercholesterolaemia is largely underdiagnosed (e.g. 13% in Switzerland and  $<1\%$  in both Italy and France)<sup>31</sup> and linked to SrSCD in young adults.<sup>32</sup> There is also evidence that “maturity-onset diabetes of the young” is underdiagnosed.<sup>33</sup> However, whether cardiovascular risk factors are underdiagnosed in asymptomatic athletes is unclear.

### Limitations

An important limitation is that personal motivation of the athlete and exertion with exercise is not reflected in the classification based on dynamic and static components. A further limitation is the heterogeneity of the forensic reports from the different institutes, which may have led to an underestimation of the true SrSCD incidence. The number of events is small and statistical power is therefore rather low, especially in the low-moderate-static/dynamic sports. Moreover, the assumed autopsy rate of approximately 47.5% for SrSCD in Switzerland<sup>13</sup> may have under- or over-estimated the true number. However, it might be hypothesised that the calculated SrSCDs multiplied by 2.1 reflects the “highest possible” incidence rate. A selection bias regarding age, gender, sports category and diagnosis at autopsy is unknown; nevertheless, this cannot be excluded. Another issue is possible misclassification of the underlying causes (e.g. lack of molecular autopsy in cases with otherwise unremarkable autopsy findings or SrSCDs being classified as CAD, where CAD was possibly an uninvolved coincidental autopsy finding). This fact of coincidental findings might also be applicable to other cases (e.g. sarcoidosis). Further, the distinction between REC and COMP reflected the physical activity at the time of SrSCD, regardless of the fitness and training history of the person, and may have led to misclassification of athletes.<sup>34</sup>

### Conclusion

In this Swiss cohort with a selective PPS, the incidence of SrSCD in young athletes ( $\leq 39$  years of age) was very low, but higher in COMP compared to REC. Absolute numbers of SrSCDs were higher in sports with high-dynamic and/or -static components. However, since these sports were also the most popular, we found no relevant differences in the incidences of SrSCDs between sports categories. CAD proved to be the most common underlying cause of SrSCD in COMP and REC, and also in athletes who were younger or older than 35 years of age.

### Declaration of conflicting interests

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