

Causes of Sudden Death During Sports Activities in Spain

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Introduction and objectives. Sudden death during sports activities has a profound impact on relatives, society, and athletes. Medical screening programs usually fail to prevent sudden death. We report the characteristics of a series of sudden deaths that occurred during sports in Spain.

Methods. We reviewed cases of sudden death that occurred during sports activities from 1995 to 2001 in the registries of the Institute of Toxicology of Madrid, Spain (Ministry of Justice).

Results. The series included 61 cases ranging in age from 11 to 65 years (average 31.9 ± 14.2), 59 males and 2 females. The sports most frequently involved were cycling (21), football (13), and gymnastics (5). The causes of death were atheromatous coronary disease: 25 (40.9%) (23 over 30 years); arrhythmogenic cardiomyopathy: 10 (16.3%) (7 under 30 years); hypertrophic cardiomyopathy: 4 (6.5%); idiopathic left ventricular hypertrophy: 3 (4.9%); postmyocarditis myocardial fibrosis: 2 (3.2%); dilated cardiomyopathy: 1 (1.6%); congenital anomalies in the origin of the coronary arteries: 2 (3.2%); aortic valve disease: 2 (3.2%); and others: 2 (3.2%). In 10 cases (16.3%) (all under 30), the cause of death was undetermined. In 16 cases (26.2%) there was a known pathological antecedent. The disease responsible for death had been diagnosed in only three cases.

Conclusions. Arrhythmogenic cardiomyopathy and severe left ventricular hypertrophy were the most common causes of sports-related death in persons under the age of 30. In 30% the cause of death was undetermined. Atheromatous coronary disease was prevalent over the age of 30 years and associated with cycling. Medical screening programs actually in use fail to detect a significant proportion of athletes at risk for sudden death.

Key words: Sudden death. Causes. Sports.

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Causas de muerte súbita asociada al deporte en España

Introducción y objetivos. La muerte súbita durante la práctica deportiva produce un gran impacto familiar, social y deportivo, siendo los reconocimientos médicos frecuentemente ineficaces para su prevención. Presentamos las características de una serie española de muerte súbita asociada al deporte.

Métodos. Revisamos los casos de muerte súbita durante la actividad deportiva estudiados entre 1995 y 2001 en el Instituto de Toxicología de Madrid (Ministerio de Justicia).

Resultados. Encontramos 61 casos entre 11 y 65 años ($31,9 \pm 14,2$), 59 varones y 2 mujeres. Los deportes más frecuentemente implicados fueron: ciclismo (21), fútbol (13) y gimnasia (5). Las causas de muerte fueron: enfermedad ateromatosa coronaria en 25 casos (40,9%) (23 pacientes > 30 años); miocardiopatía arritmogénica en 10 (16,3%) (7 pacientes < 30 años); miocardiopatía hipertrofica en 4 (6,5%); hipertrofia ventricular izquierda idiopática en 3 (4,9%); fibrosis miocárdica posmiocarditis en 2 (3,2%); miocardiopatía dilatada en 1 (1,6%); anomalías en el origen de las arterias coronarias en 2 (3,2%); valvulopatía aórtica en 2 (3,2%) y otras patologías en dos (3,2%). En 10 casos (16,3%) (todos menores de 30 años) el origen de la muerte fue indeterminado. En 16 casos (26,2%) existían antecedentes patológicos y en tres se había diagnosticado la enfermedad responsable de la muerte.

Conclusiones. Las principales causas identificables de muerte súbita en deportistas menores de 30 años son la miocardiopatía arritmogénica y la hipertrofia ventricular izquierda severa. Un 30% son inexplicadas. La enfermedad ateromatosa coronaria asociada al ciclismo fue predominante en mayores de 30 años. Los reconocimientos médicos que se realizan habitualmente a deportistas pueden ser insuficientes para detectar muchos de estos procesos.

Palabras clave: Muerte súbita. Causas. Deporte.

INTRODUCTION

The sudden death of a young and apparently healthy person has a dramatic social and familial impact, particularly if it takes place while practicing sports. In Spain, the communications media headlined the deaths

ABBREVIATIONS

CAD: coronary atheromatous disease
ACM: arrhythmogenic cardiomyopathy
DCM: dilated cardiomyopathy
HCM: hypertrophic cardiomyopathy
LVH: idiopathic left ventricular hypertrophy

last year of 2 adolescents, a young man playing soccer and a young woman playing badminton, as well as a professional marathon runner during a training session. These deaths stimulate debate as to what medical examinations should be carried out in persons participating in sports, either professionally or as a hobby.

Cardiovascular pathology is the most frequent cause of death, as is also the case in sudden death not associated with sports activities. In older athletes, coronary atheromatous disease (CAD) predominates, whereas in younger athletes congenital diseases are prominent.^{1,2} In the bibliography various series of sudden deaths associated with sports activities have been published that differ with respect to the study population and method of study. In American athletes, the primary cause of death is hypertrophic cardiomyopathy (HCM),^{1,3,4} whereas in athletes from northern Italy the predominant pathology is arrhythmogenic cardiomyopathy (ACM).⁵ In series published in specialized forensic journals, the population studied is usually recreational athletes, who are generally older and have a clear predominance of CAD.^{6,7}

Nevertheless, many of these diagnoses are based only on gross examinations, which often are made by different investigators, as occurs in the series of Maron et al.³ and van Camp et al.,⁴ so the diagnostic criteria cannot be homogeneous. In addition, these series include cases collected from the press. In the series of Ragosta et al.,⁶ of Rhode Island, which includes 81 cases, post mortem studies were made in only 29 cases (36%). In the other 52 cases, the cause of death was established using the medical history and symptoms. In 15% of the cases collected in the series of van Camp et al.,⁴ the results of the post mortem studies were either unknown or these studies were not made.

We present a Spanish series of sudden deaths occurring during athletic activities that were examined by forensic pathologists, with detailed gross and microscopic post mortem studies carried out by the authors.

METHODS

The Institute of Toxicology is a center affiliated

with the Ministry of Justice that is responsible for carrying out complementary analyses for post mortem studies by forensic pathologists. The Madrid department is the reference center for the communities of Galicia, Asturias, Cantabria, Castilla y León, Castilla-La Mancha, La Rioja, and Madrid (only certain post mortem studies). The Histopathology Section of this institute studies organs sent by forensic doctors after performing a judicial post mortem study.

We reviewed our archives from 1995 to June 2001 and selected cases of sudden death that took place during, or within one hour of concluding, athletic activities,⁸ which had a complete post mortem study (with opening of the three cavities) and a negative toxicological analysis for alcohol and substances of abuse.

CAD was established as the cause of sudden death in cases in which at least some of the following lesions existed: more than 75% reduction of the lumen by an atheroma plaque in at least one of the main epicardial coronary arteries, extensive infarction scars, acute myocardial infarction, or coronary thrombosis.⁹ The diagnosis of ACM was established in cases of myocardial substitution by fibroadipose tissue in the right ventricle (subendocardial, subepicardial, or transmural distribution), left ventricle (subepicardial), or both, in the presence of normal coronary arteries.¹⁰ HCM was diagnosed in hearts of high weight and/or extensive areas of disorganization of the myocardial fibers, frequently associated with patches of fibrosis and dysplasia of the intramural arteries.¹¹ In the absence of arterial hypertension, valvular, ischemic or congenital heart disease, ventricular dilation or myofibrillar disorganization, the diagnosis of idiopathic left ventricular hypertrophy (LVH) was established in hearts that exceeded by 20-30% the established maximum weight for the patient's body weight.^{11,12} In all cases in which the cause of death was not found, the cardiac conduction system was studied using the simplified method published previously.¹³

The statistical method used was the χ^2 test to compare qualitative variables, with the Yates correction for contingency tables of low frequencies. A value of $P < .05$ was considered significant statistically.

RESULTS

We found 61 cases of sudden death that occurred during athletic activities between 1995 and June 2001 in athletes ranging in age from 11 to 65 years (31.9 ± 14.2). The causes and characteristics of these sudden deaths are summarized in Table 1. All, except two, were men and no death of extracardiac origin was found. All died while practicing athletic activities. The sport associated with the greatest number of cases of

TABLE 1. Sudden death during athletic activities (1995-2001)

	No. of cases	Age (years)	Sex	Pathology	Sport
Total	61	11-65 (31.9±14.2)	59 M 2 W		Cycling (21), soccer (13), gymnastics (5), jogging (4), paddle/fronton (4), basketball (2), other (12),
CAD	25 (40.9%)	28-65 (44.4±9.4)	25 M	Atheroma (88%) Scars (56%) AMI (8%) Thrombosis (28%)	Cycling (11), Soccer (4), Gymnastics (2), Fronton (2), jogging (2) paddle, mountain climbing marching, other (4)
ACM	10 (16.3%)	13-39 (25.5±8.3)	10 M	Biventricular (4) RV (2) LV (2)	Cycling, Fronton, tennis, Gymnastics, marathon (5), soccer (3) other sport (2)
HCM	4 (6.5%)	11 30 44 45	M M M W	Heart: 252 g (symmetrical) Heart: 405 g (asymmetrical) Heart: 478 g (asymmetrical) Heart: 401 g (symmetrical)	Gymnastics Cycling Cycling Jogging
LVH	3 (4.9%)	28 20 18	M M M	Heart: 512 g (?) Heart: 528 g (↑34%) Heart: 459 g (↑20%)	Other sport Basketball Soccer
Myocardial fibrosis	2 (3.2%)	20 17	M M	LV subepicardial fibrosis LV/RV fibrosis	Basketball Cycling
DCM	1 (1.6%)	14	M	DCM (Heart: 550 g)	Soccer
Coronary anomalies	2 (3.2%)	22 16	M M	LC in right sinus RC between aorta and pulmonary Posterior LV fibrosis	Cycling Soccer
Aortic valve disease	2 (3.2%)	12 15	M M	Supravalvular AS Complicated bicuspid valve	Gymnastics Other sport
ASD	1 (1.6%)	17	M	ASD 9 × 10 mm RV hypertrophy	Cycling
Flecainide	1 (1.6%)	51	M	Heart: 464 g	Cycling
Indeterminate	10 (16.3%)	15-29 (20.2±5.3)	9 M 1 W	No significant changes	Cycling (3), soccer (3), jogging (1), badminton (1), other sport (2),

RC indicates right coronary; ASD, atrial septal defect; IHD, left coronary; CAD, coronary atheromatous disease; AS, aortic stenosis; LVH, idiopathic left ventricular hypertrophy; AMI, acute myocardial infarction; ACM, arrhythmogenic cardiomyopathy; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; LV, left ventricle; RV, right ventricle.

sudden death was cycling, with 21 subjects (34.4%), mean age 36.5±14.4 years (range 15 to 65 years). The second most frequent sport was soccer, with 13 cases (21.3%), mean age 24±8.8 years (range 14 to 42 years). Only two athletes were professionals (a basketball player and a marathon runner).

Causes of death

The predominant pathology was CAD, with 25 cases (40.9%) and a mean age of 44 years. In 11, death was associated with cycling and in 4, soccer. The most frequent lesion in this group was significant chronic stenosis of the coronary arteries. In 22 cases (88%) of coronary involvement, one vessel was

involved in 9 hearts (36%), two vessels in 10 (40%), and three vessels in 3 (12%). The second most frequent lesions were scars from previous infarction, which occurred in 14 cases (56%). Acute infarctions were observed in 2 cases (8%) and coronary thromboses in 7 (28%).

The second most frequent pathology was ACM, with 10 cases, which represents 16.3% (most of these cases have been published previously¹⁰). In 4 cases the involvement was biventricular (Figure 1) in 4, only the right ventricle was affected, and in 2, only the left ventricle. Various sports were associated with death due to this condition (Table 1). One death occurred in a professional marathon runner. None of the conditions had been diagnosed in life.

In 7 patients (11.4%), severe left ventricular



Fig. 1. Biventricular arrhythmogenic cardiomyopathy. Dilation of the right ventricle with visible transmural fat infiltration. Brownish-gray circumferential subepicardial band in the left ventricle. The microscopic study demonstrated myocardial substitution by fibroadipose tissue with permeable coronary arteries, which established the diagnosis.



Fig. 2. Hypertrophic cardiomyopathy. Biventricular cross-section of the heart of a 30 year-old man who died while cycling. His heart weighed 405 g and presented asymmetrical septal hypertrophy that practically occluded the ventricular lumen, with whitish patches of fibrosis.

hypertrophy was detected in the anatomopathological study, 4 with HCM, and 3 with LVH without changes in myocardial fiber structure. The 4 athletes with HCM ranged in age from 11 to 45 years, and one was a woman. Two were asymmetrical septal forms (Figure 2) and the other two were symmetrical HCM. In all the cases there was extensive fiber disorganization (Figure 3).

In the 3 athletes with LVH, heart weight was more than 20% over the estimated maximum heart weight for body weight, with a mean of 500 ± 36 g. In the first case, the body weight was unknown, but the heart weighed so much (512 g) that we considered it

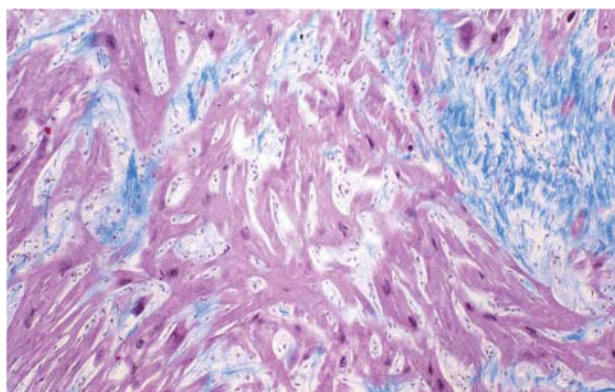


Fig. 3. Disorganized appearance of myocardial fibers with whorled images and patches of fibrosis characteristic of hypertrophic cardiomyopathy. Masson trichrome stain, OM $\times 10$.



Fig. 4. Anomalous origin of the left coronary artery in the right sinus of Valsalva. Initial section embedded in the wall of the aorta (arrow).

pathological. A 20 year-old athlete was professional basketball player and an 18 year-old male athlete showed signs of asthmatic bronchitis with scant intrabronchial mucus plugs were found, in addition to cardiac hypertrophy, that were insufficient to explain death.

In another 2 hearts pertaining to 2 men, age 20 and 17 years, respectively, extensive subepicardial scarring of the left ventricular free wall was found in one case, and biventricular scarring in the other one (Table 1). Coronary arteries were permeable. The second athlete had undergone a medical check-up shortly before his death, in which nothing pathological was detected. A 14 year-old male who died while playing soccer presented dilated cardiomyopathy (DCM), a probable sequela of myocarditis in childhood, with biventricular hypertrophy and dilation.

In 2 men, age 22 and 16 years, respectively, anomalies in the origin of the coronary arteries were found. The first athlete died after a 30-km ride on his bicycle. In his heart, the left coronary ostium was located in the right Valsalva sinus and the left coronary

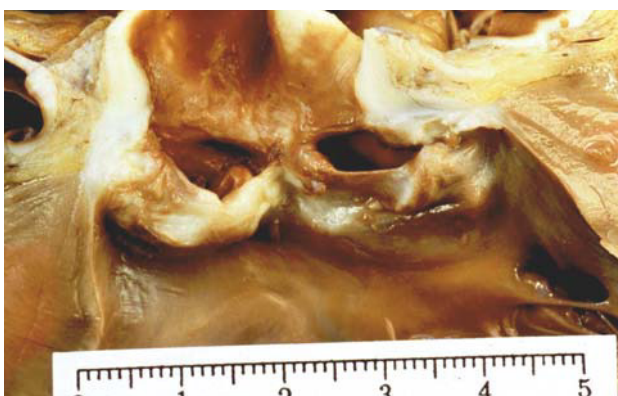


Fig. 5. Bicuspid aortic valve with supralvalvular stenosis and hourglass morphology.

artery lay in the aortic adventitia (Figure 4) to the point where it divided into the anterior descending coronary and circumflex artery. In the second athlete, the right coronary ostium was located on the commissure between the right and left Valsalva sinuses, with a segment of about 5 mm between the aortic and pulmonary arteries. The posterior wall of the left ventricle showed subendocardial fibrosis.

In another 2 cases, aortic valve disease was found. A 12 year-old male who died in gymnastics class had supralvalvular stenosis with an hourglass morphology, associated with the bicuspid valve (Figure 5) and cardiac weight of 396 g. Another 15 year-old male, who was diagnosed as having a double aortic lesion, had a bicuspid valve with fibrous thickening of the leaflets and a cardiac weight of 527 g.

A 17 year-old male with interatrial septal defect who had surgical correction scheduled in two months died during cycling practice. His heart weighed 411 g

and the tricuspid valve annulus (13.3-cm perimeter) and right ventricle (5-cm diameter) were dilated. The thickness of the right ventricle was 4 mm and the thickness of the left ventricle and interventricular septum was 10 mm. The athlete had an *ostium secundum* type interatrial septal defect, of 9×10 mm and focal pulmonary lymphangiectasia. There were no morphological signs of pulmonary hypertension.

A 51 year-old man with a history of arrhythmia (type not specified) also died while cycling. His heart weight was 464 g and 3.85 µg/ml of flecainide (toxic range) was detected in blood.

Finally, in 10 cases (16.3%) no pathology was found to explain the death. These athletes included 9 men and 1 woman, mean age 20±5.3 years.

In view of our experience with sudden death, which shows that ischemic heart disease is predominant over the age of 30 years, we divided the series into two groups, over 30 and under 30 years age (Table 2). The predominant pathology in athletes over 30 years was CAD, which was present in 79.3% versus only 6.2% in younger athletes; this difference was statistically significant ($P<.00001$). In young people, the predominant pathology was ACM, with 21.8% of cases, followed by LVH, myocardial fibrosis (including DCM), anomalies in the origin of the coronary arteries, and aortic valve pathology, although it did not reach statistical significance. There was a statistically significant difference ($P<.001$) in the group of the deaths of indeterminate origin. In the older group, the cause of death was found in every case, but in the group under 30 years, the cause of death could not be established in more than 30% (Table 2).

In our archives we also reviewed sudden deaths not associated with sports in persons ≤ 30 years of age,

TABLE 2. Sudden death during athletic activities, by age (1995-2001)

	No. of cases	CAD	HCM	ACM	LVH	Fibrosis/DCM	Coronary anomalies	Aortic valve disease	Others	Indeterminate
≤ 30 years	32	2 (6.2%)	2 (6.2%)	7 (21.8%)	3 (9.3%)	3 (9.3%)	2 (6.2%)	2 (6.2%)	1 (3.1%)	10 (31.2%)
> 30 years	29	23 (79.3%)	2 (6.8%)	3 (10.3%)	—	—	—	—	1 (3.4%)	—
<i>P</i>		<.00001	NS	NS	NS	NS	NS	NS	NS	<.001

CAD indicates coronary atheromatous disease; LVH, idiopathic left ventricular hypertrophy; ACM, arrhythmogenic cardiomyopathy; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; NS, non-significant.

TABLE 3. Sudden death associated and not associated with athletic activities in subjects ≤ 30 years

	N/mean age	CAD	HCM	ACM	LVH	Fibrosis/DCM	Myocarditis	Coronary anomalies	Aortic valve disease	CS	Others	Indeterminate
Sports	32/20.2 ± 5.7	2 (6.2%)	2 (6.2%)	7 (21.8%)	3 (9.3%)	3 (9.3%)	—	2 (6.2%)	2 (6.2%)	—	1 (3.1%)	10 (31.2%)
Non-sports	81/19.2 ± 7	9 (11%)	4 (5%)	3 (3.7%)	—	—	5 (6%)	4 (5%)	—	3 (3.7%)	10 (12.3%)	38 (47%)
<i>P</i>		NS	NS	<.01	<.05	<.05	NS	NS	NS	NS	NS	NS

CAD indicates coronary atheromatous disease; LVH, idiopathic left ventricular hypertrophy; ACM, arrhythmogenic cardiomyopathy; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; CS, conduction system; NS, non-significant.

TABLE 4. Cases of sudden death associated with athletic activities in presence of a medical history

	Age/sex	History	Cause of death	Sport
1.	41/M	Pain in chest and left arm days earlier. Treated by masseuse	Chronic CAD	Cycling
2.	39/M	Wolff-Parkinson-White syndrome	Chronic CAD	Cycling
3.	55/M	Syncopes related with exercise	Chronic CAD	Mountain-climbing
4.	55/M	Two previous infarctions	Chronic CAD	Paddle
5.	22/M	Grade IV malignant ventricular arrhythmia. Father and uncle died suddenly.	ACM	Cycling
6.	35/M	Non-specific arrhythmia	ACM	Other sport
7.	13/M	Syncope one year ago. Fatigue.	ACM	Other sport
8.	44/M	Palpitations one year ago. Seen by cardiologist	HCM	Cycling
9.	14/M	Childhood myocarditis	DCM	Soccer
10.	15/M	Double aortic lesion	Complicated bicuspid valve	Other sport
11.	18/M	Asthma	Idiopathic LVH	Soccer
12.	51/M	Arrhythmias	Flecainide in toxic range	Cycling
13.	17/M	Scheduled for surgery 2 months late	ASD	Cycling
14.	29/M	Precordial pain for the last 6 months	Indeterminate	Soccer
15.	15/M	Tachycardia at age 1 month	Indeterminate	Cycling
16.	19/M	In treatment with ventolin on demand	Indeterminate	Indoor soccer

ASD: atrial septal defect; CAD, coronary atheromatous disease; LVH, idiopathic left ventricular hypertrophy; ACM, arrhythmogenic cardiomyopathy; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy.

and made a comparative study with sudden deaths associated with sports among persons of the same age (Table 3). The incidence of ACM was 21.8% in the cases of sudden death during athletic activities and only 3.7% in sudden deaths not associated with sports; this difference was statistically significant ($P<.01$). No case of LVH or DCM/myocardial fibrosis (probable sequela of myocarditis) was observed among the sudden deaths not associated with sports, whereas 3 cases were observed in the group of athletes, each with one of these injuries. This difference also was statistically significant ($P<.05$). With regard to other pathologies, acute myocarditis and conduction system anomalies were diagnosed only in sudden deaths not associated with sports, but the difference was not significant. In both groups, the percentage of unexplained deaths was high, 31.2% in deaths associated with sports and 47% in deaths not associated with sports.

Pathological background

In 16 of 61 cases (26.2%) a pathological antecedent was known (Table 4), but in 3 cases only the disease that produced death had been diagnosed: CAD in a 55 year-old man with two previous infarctions (case 4), a bicuspid valve with fibrosis of the leaflets was observed in a 15 year-old male with a diagnosis of double aortic lesion (case 10), and interatrial septal defect in a 17 year-old male who was scheduled for surgery (case 13).

Another 6 patients presented symptoms that could be related to the cause of death: two who died of CAD (cases 1 and 3) and three who died of ACM, in which there was a history of arrhythmias and syncope (cases

5, 6, and 7). A 44 year-old man who died of HCM had been seen by a cardiologist for palpitations (case 8). A 14 year-old male died of DCM, probably secondary to a myocarditis that he suffered during childhood (case 9). A man (case 12) with a history of nonspecific arrhythmia probably died as a result of elevated flecainide levels.

In case 2, a person with a history of Wolff-Parkinson-White syndrome, the finding of a reduction of more than 90% in the lumen of the anterior descending coronary artery and of 50-75% in the right coronary induced us to think that CAD was the most probable cause of death during cycling, instead of tachyarrhythmia associated with the pre-excitation syndrome.

DISCUSSION

Incidence

The incidence of sudden death during athletic activities is low. In the Irish series of Quigley et al⁷ the incidence was 1 case per 600 000 inhabitants; in the series of Tabib et al, of Lyon and Saint-Etienne,¹⁴ the incidence was 0.26 casos/100 000 inhabitants/year; in the series of amateur athletes studied by Ragosta et al of Rhode Island,⁶ the incidence is 0.36/100 000 inhabitants/year for persons under 30 years, and 4.46 and 0.05/100,000 inhabitants/year for men and women, respectively, over 30 years of age. The incidence in competitive athletes of American high schools is considered to be about 1/200 000/year.¹⁵ In marathon runners, the incidence is 1/50 000¹⁶ and in joggers, 1/15 000/year.¹⁷ In the Veneto region, the incidence among athletes is 1.6/100 000/year.⁵

In Spain, it is calculated that there are more than 6 000 000 federated athletes and that more than 12 million people practice sports.⁸ We do not know the prevalence of sudden death associated with sports in our country. According to data of the Mutualidad General Deportiva (an insurance fund for athletes), from 1994 to 1997 there were 191 deaths among athletes, most of traumatic origin and only 21 (10.9%) of cardiac origin.⁸ The figures reported in this study (61 cases in 7 years) lack epidemiological value because we do not know how many people practice sports in our area of influence. Moreover, the Institute of Toxicology studies only cases referred by courtrooms, and those in which a forensic doctor has requested complementary studies. It is possible that pathologies that are clearly visible on gross inspection (for example, aortic rupture, chronic ischemic heart disease, or very severe cardiac hypertrophy) do not reach our department. Currently, the Spanish Federation of Sports Medicine is designing a National Registry of Accidental and Sudden Death in Athletes (ASDS) that will undoubtedly be of extraordinary value for knowing the incidence and true causes of this process in the athletes of Spain.

Sport

The sports most closely related with sudden death vary in different countries. Among American athletes,^{3,4} the sports most often associated with sudden death are basketball and football, which represent 68% and 76% of cases, respectively. In forensic series from Ireland⁷ and Rhode Island,⁶ the sport that produces more cases of sudden death is golf, with 31.3% and 23.4% of the cases, respectively, followed by cricket in Ireland (21.5%) and jogging in Rhode Island (20%).

In the Italian study by Corrado et al,⁵ with 49 cases of sudden death in persons under 35 years, the sport most frequently involved was soccer, with 22 cases (44.8%), followed at a distance by basketball (5 cases) (10.2%), swimming (4 cases) (8%), and cycling (3 cases) (6%).

In our series, soccer was associated with a large number of sudden deaths (21.3% of the total and 33.3% of athletes under 35 years), but the sport most closely associated with sudden death was cycling, which was responsible for 34.4% of cases. Although the age range of the athletes in this group was 15 to 65 years (mean 36 years), when we considered athletes under 35 years (for comparison with the Italian series), cycling caused 24% of deaths in this age group.

Although CAD is considered the cause of 78% of deaths associated with jogging or marathon training,¹¹ in our series, 11 of 25 subjects who died of CAD were cycling, and only two were running and one marching

(Table 1).

Mitchell et al¹⁸ proposed a classification of sports in relation to cardiovascular risk and sudden death, depending on their static and dynamic components. Dynamic exercises produce intense oxygen consumption and volume overload. In contrast, what is most characteristic about static exercises is the large increase in blood pressure and pressure overload in the heart. Most sports associated with sudden death have a large dynamic component and high or moderate static component.

Causes of death

In Table 5 are listed the causes of sudden death associated with sports in the most important series published as compared with our series. The causes of death are similar in all of them, but the incidence of pathological processes varies in relation to several factors. In the first place, there are differences in the type of population and geographic region. In competitive American athletes, the most frequent cause of death was HCM, with an incidence of 36-42%,^{1,3,4} whereas in athletes from northern Italy (Veneto region), the predominant pathology was ACM (22.4%).⁵

In series of forensic origin, CAD is the most frequent cause in the U.S.^{6,9,11} and in Europe.⁷ In our series, this was absolutely the first cause of death, with 25 cases (40.9%) (Tables 1 and 5).

In the forensic series of Burke et al,⁹ the incidence of HCM was also important (24%), probably because mean age was only 26 years. In the series of Virmani et al,¹¹ the second most relevant pathology in frequency was LVH. In our series, ACM occupied second place (16.3%) (Table 5).

The second factor to consider in the different series is age. In Table 6 a comparative study is made of the deaths associated with sports in athletes older and younger than 30-35 years, depending on the series. This table shows a greater incidence of CAD in older athletes. In our series this difference was significant (Table 2). The predominant pathology in younger athletes was HCM and LVH in the American series of Virmani et al,¹¹ whereas in the French series of Tabib et al,¹⁴ HCM and ACM were frequent. In our series, ACM was predominant (22%), but not statistically significant.

The low incidence of HCM in northern Italy can be attributed to the medical examination that athletes undergo before practicing athletic activities, including echocardiography. This examination enables the early diagnosis of this condition and separation of the athlete from competition.^{5,19} Racial and genetic factors are also involved. The number of black athletes who died of HCM was significantly higher than that of

TABLE 5. Causas de muerte súbita en relación con el deporte

Authors	Years	N.º of cases	Age (years)	Population	CAD	HCM	ACM	LVH	Coronary anomalies	Mycocarditis	Valvular AS/MVP	CS	Aortic rupture	Other cardiac	Non cardiac	Indeterminate
Maron et al. ¹	1950-1979	29	13-30	Athletes	3 (10.3%)	14 (48.2%)	-	5* (17.2%)	4 (13.7%)	-	-	Non-routine	2 (6.9%)	-	-	1 (3.4%)
Van Camp et al. ⁴	1983-1993	136	13-24	Athletes	3 (2.2%)	51 (37.5%)	1 (0.7%)	5* (3.6%)	16 (11.7%)	7 (5.14%)	6/1 (5.14%)	Not studied	2 (1.4%)	9 (6.6%)	32 (23.5%)	7 (5.14%)
Maron et al. ³	1985-1995	158	12-40	Athletes	3 (2%)	48 (36%)	4 (3%)	14* (10%)	31 (23%)	4 (3%)	5/3 (6%)	Non-routine	6 (5%)	13 (9.7%)	24 (15%)	3 (2%)
Corrado et al. ⁵	1979-1996	49	<35	Athletes	9 (18.3%)	1 (2%)	11 (22.4%)	-	8 (16%)	3 (6.12%)	0/5 (10.2%)	4	1 (2%)	6 (12.2%)	1 (2%)	-
Regosta et al. ⁶	1975-1982	81	23±70	Veneto	71 (87.6%)	1 (1.2%)	-	1 (1.2%)	1 (1.2%)	-	-	Not studied	1 (1.2%)	3 (3.7%)	3 (3.7%)	-
Burke et al. ⁹	1981-1988	34	26 media	Forensic	9 (26%)	8 (24%)	1 (3%)	3 (9%)	4 (12%)	2 (6%)	-	Non-routine	-	1 (3%)	-	6 (18%)
Virmani et al. ¹¹	1989-1996	62	10-65	Maryland	11 (18%)	5 (8%)	4 (6%)	8 (13%)	(?)	(?)	(?)	Non-routine	(?)	21** (34%)	-	13 (21%)
Quigley, ⁷	1987-1996	51	28±13	Maryland	42 (82.3%)	1 (1.9%)	-	-	1 (1.9%)	1 (1.9%)	2/0 (3.9%)	Not studied	-	4 (7.8%)	-	-
2000	1995-2001	61	48	Ireland	25 (40.9%)	4 (6.5%)	10 (16.3%)	3 (4.9%)	2 (3.2%)	-	2/0 (3.2%)	-	-	5 (8.1%)	-	10 (16.3%)
Suárez-Mier et al			31.9±14.0	Spain												

*Maron et al and Van Camp et al consider LVH as «probable HCM». ** In their series of 62 cases, Virmani et al (1997) do not specify how many have each pathology, as indicated by () and they are included in «Other cardiac.» CAD indicates coronary atheromatous disease; AS, aortic stenosis; LVH, idiopathic left ventricular hypertrophy; ACM, arrhythmogenic cardiomyopathy; HCM, hypertrophic cardiomyopathy; MVP, mitral valve prolapse; CS, conduction system.

TABLE A 6. Causes of sudden death during athletic activities, by age

Authors	Years	Edad (years)	N.º of cases	Population	CAD	HCM	ACM	LVH	Coronary anomalies	Mycarditis	Valvular AoS	CS	Aortic rupture	Other cardiac	Indeterminate
Virmani et al ¹¹	1989-1996	10-32	48	Forensic	4 (8.3%)	5 (10.4%)	4 (8.3%)	7 (14.5%)	(?)	(?)	(?)	Non-routine	(?)	15 (31.2%)	13 (27%)
1997		22±6		Maryland	7 (50%)	-	-	1 (7%)	(?)	(?)	(?)	Non-routine	(?)	6 (42.8%)	-
Tabib et al ¹⁴	1980-1995	<30	27	Forensic	3.7%	29.6%	25.9%	-	14.8%	-	7.4%	3.7%	-	15%	-
1999		46±9		France	49%	24%	3.7%	-	1.8%	-	-	7.4%	-	14%	-
Quigley, ⁷	1987-1996	<35	11	Forensic	3 (27.2%)	1 (9%)	-	-	1 (9%)	-	2 (18%)	Non studied	-	4 (36.3%)	-
2000		>35	40	Ireland	39 (97.5%)	-	-	-	-	1 (2.5%)	-	Non studied	-	-	-
Suárez-Mier, et al	1995-2001	≤30	32	Forensic	2 (6.2%)	2 (6.2%)	7 (21.8%)	3 (9.3%)	2 (6.2%)	-	2 (6.2%)	-	-	4 (12.5%)	10 (31.2%)
		>30	29	Spain	23 (79.3%)	2 (6.8%)	3 (10.3%)	-	-	-	-	-	-	1 (3.4%)	-

*In their series of 62 cases, Virmani et al (1997) do not specify how many pertain to each pathology, as indicated (?) and they are included in «Other cardiac.» CAD indicates coronary atheromatous disease; AS, aortic stenosis; LVH, idiopathic left ventricular hypertrophy; ACM,

white athletes in the series of Maron et al.³ HCM is associated with mutations in the proteins of the cardiac sarcomere, which also condition the risk of sudden death.²⁰ For ACM, mutations in several chromosomes have also been identified, although the genetic defect is unknown in most of them.²¹⁻²³ This could explain the predilection of HCM for North America and ACM in Italy and Spain.

Diagnostic criteria must also be considered. In the American series of Ragosta et al.,⁶ CAD is considered the cause of death in the case of reductions of only 50% of the coronary lumen, which may explain the high incidence of deaths due to this process. On the other hand, Maron et al.^{1,3} established the diagnosis of HCM in the presence of hearts weighing more than 500 g with a familial history of HCM or premature sudden death, even in the absence of the typical histological condition of extensive fiber disorganization and frequent dysplasia of intramural arteries, which we and other authors¹¹ usually require. Moreover, the groups of Maron and van Camp^{1,3,4} consider LVH to be «probable HCM».

There are diagnostic discrepancies for ACM from a morphological point of view. In northern Italy^{21,23,24} and in other series like the French series of Tabib et al.,¹⁴ a form of pure fatty ACM is recognized, whereas other authors, like the Virmani group^{11,25,26} and us,¹⁰ demand the presence of fibroadipose tissue for diagnosis. These differences of criterion, as well as the need for a microscopic study of the myocardium for diagnosis, can be partly responsible for differences in incidence between one series and another.

Coronary anomalies were the second most frequent cause of death among American athletes,^{1,3,4} with an incidence of 11%-23%, and the third most frequent cause in Italian athletes, with 16.3%. The most frequent condition is the anomalous origin of the left coronary on the right sinus of Valsalva,^{1-3,11,15,27,28} as in the case presented in Figure 4. Nevertheless, the functional meaning of the intramyocardial segment of anterior descending coronary artery is debated. For some authors,^{29,30} it is a frequent finding in normal human hearts (present in 30%), whereas American series^{3,4} considered this anomaly to be a cause of sudden death, which may mean that the coronary anomalies, as a whole, are more common in American series.

Myocarditis is not a frequent cause of sudden death among athletes, probably because physical exercise is contraindicated in this disease, due to the known risk of potentially malignant arrhythmias.³¹ The incidence of this process ranges from 2% to 6% (Table 5), according to the series. We found no case of acute myocarditis. Nevertheless, a 14 year-old male died from DCM (Table 1), probably a sequela of childhood myocarditis. The finding of extensive scars devoid of adipose tissue that could correspond to chronic forms

of myocarditis in the hearts of two athletes, 17 and 20 years-old, respectively, was interesting.^{2,32,33}

Aortic stenosis is a well-known cause of sudden death. In athletes the incidence ranges from 3% to 4.5%.^{3,4,7} It is more frequent in sudden deaths not associated with athletic activity,⁹ and no case has been diagnosed in the series of Corrado et al.⁵ (Table 7). This is probably because it is a pathology that is easily detectable in life and leads to the restriction of physical exercise in these patients, which excludes them from competitive sports.^{2,34} Cases of sudden death due to aortic stenosis in athletes usually occur in persons under 30-35 years (Table 6). We found it in only 2 men (Table 1).

The disorders observed in the cardiac conduction system are a topic of discussion since they constitute a cause of sudden death for some authors^{35,36} whereas others consider them to be anatomical variations.^{13,37,38} We did not observe any case of significant stenosis of the artery that irrigates the atrioventricular node in this series of athletes. This lesion is observed in 2.8% of cases of sudden death in persons under 40 years.³⁹

In our series we found no case of aortic rupture, which is present in other series (Table 5), probably because it is an unequivocal cause of death that is easily diagnosed in the post mortem study, so such cases may not be referred to our center.

Since the causes of sudden death during athletic activities are the same as those that produce sudden death in non-athletes, the comparative study of the causes of sudden death in one set of circumstances or the other is interesting. In Table 7 are summarized the findings in three series (including our series) of sudden death in young persons. In the American series of Burke et al.,⁹ CAD was more frequent among non-athletes and HCM among athletes.

In the Italian series of Corrado et al.,⁵ there were no major differences in CAD, but the incidence of ACM with respect to non-athletes was significant. In our cases, ACM was also much more frequent among athletes, reaching statistical significance (Table 3). In a previously published study of 21 cases of ACM,¹⁰ 11 athletes (52.3%) died during athletic practice and 8 (35%) presented symptoms in relation to sports. These findings support the idea that athletic activity is a clear risk factor for sudden death in patients with this disease. In our series they also emphasized LVH without structural fiber disorganization, and post-myocarditis myocardial fibrosis (including DCM).

Other observed causes of death in our series were interatrial septal defect and a possible overdose of flecainide. With respect to the interatrial septal defect, found in 17 year-old male, the absence of clinical data precludes our assessment of its hemodynamic repercussions. Since this patient was scheduled for surgery, there was probably increased pulmonic pressure compatible with right ventricular hypertrophy

TABLE 7. Causes of sudden death associated and not associated with athletic activity

Authors	Years	Circumstances (no. of cases)	Mean age	Population	CAD	HCM	ACM	LVH	Coronary anomalies	Myocarditis	Valvular AS/MVP
Burke et al ⁹ , 1991	1981-1988	Sports (34)	26	Forensic	9 (26%)	8 (24%)	1 (3%)	3 (9%)	4 (12%)	2 (6%)	-
		Non-sports (656)	32	Maryland	307 (47%)	20 (3%)	-	42 (6.4%)	8 (1.2%)	31 (4.5%)	12/11 (3.5%)
Corrado et al ⁵ , 1998	1979-1996	Athletes (49)	23±7	Veneto	9 (18.3%)	1 (2%)	11 (22.4%)	-	8 (16.3%)	3 (6.12%)	0/5 (10.2%)
		Non-athletes (220)	<35	Italy	36 (16.4%)	16 (7.3%)	18 (8.2%)	-	1 (0.5%)	19 (8.6%)	0/21 (9.5%)
Suárez-Mier et al	1995-2001	Sports (32)	≤30	Forensic Spain	2 (6.2%)	2 (6.2%)	7 (21.8%)	3 (9.3%)	2 (6.2%)	-	2/0 (6.2%)
			20.2±5.7								
		Non-sports (81)	≤30	9 (11%)	4 (5%)	3 (3.7%)	-	4 (5%)	5 (6%)	5/0 (6%)	
			19.2±7.5								

CAD indicates coronary atheromatous disease; AS, aortic stenosis; LVH, idiopathic left ventricular hypertrophy; ACM, arrhythmogenic cardiomyopathy; HCM,

and dilation observed in the heart. The association of this heart disease with a sport that has a major static and dynamic component, such as cycling,¹⁸ could determine death. Flecainide is an antiarrhythmic drug pertaining to class 1C. Intoxication with these drugs, if not immediately treated, causes a mortality of 22%.⁴⁰ The cardiac symptoms associated with intoxication include bradycardia and, less frequently, tachyarrhythmias, which appear 30 min to 2 h after administration. Death can occur as a result of conduction disorders that progress to electromechanical dissociation and asystole.⁴⁰ The flecainide levels found in the cyclist in our series were lower than in other cases of fatal intoxication,⁴¹⁻⁴³ but higher than therapeutic levels. Since ventricular arrhythmias can be triggered by exercise in flecainide users,⁴⁴ we thought that this death was related to the drug.

In 10 cases (16.3%) we did not find any structural pathology that explained the death, in spite of a systematic study of the cardiac conduction system. These figures are similar to those reported in other series. In the series of Burke et al⁹ the figure is 18%, and in the series of Virmani et al,¹¹ it reaches 21% (Table 5). When we examined sudden death in young people, the figures were still higher: 27% in the series of Virmani et al¹¹ and 31.2% in ours (Table 6). In our series, all the deaths of indeterminate cause took place in persons under the age of 30 years, a significant difference (Table 2).

It should be kept in mind that the series of the Virmani group and our series are based fundamentally on the anatomopathological study. It is known that the discovery of the cause of the death requires a combined assessment of the morphological findings, medical history, place and circumstances of death. In this section, the arrhythmias that can produce sudden death have special relevance and course with microscopically and grossly normal hearts, the anomalies being molecular: Brugada syndrome,^{45,46} long QT syndrome, idiopathic ventricular fibrillation,² and pre-excitation syndromes (associated with anomalous pathways, generally located in the valvular

annuli, outside the nodofascicular axis and, therefore, outside the area examined in microscopic studies of the conduction system). Unfortunately, in this group of patients sudden death can be the first manifestation of the disease and there is almost never a previous electrocardiogram.

Precise knowledge of the circumstances of death is determinant in establishing the cause of death in many cases. Consequently, as can be seen in Table 5, which includes death by *commotio cordis*,³ heat shock,^{3,4} status asthmaticus, anaphylaxis associated with exercise, or electrocution.⁴

Cardiological examination in athletes

The recommendations of the American Heart Association with respect to the recommended medical examination before athletic activities include: review of family history (especially with regard to sudden death or heart diseases), personal history (murmurs, systemic hypertension, fatigue, syncope, and dyspnea or thoracic pain associated with exercise), and a physical examination (murmurs, femoral pulses, characteristics of Marfan's syndrome and measurement of blood pressure).⁴⁷

Using this protocol, some of the athletes in our series might have been advised to avoid athletic activity until a more exhaustive study had been made, especially persons with a history of arrhythmia, syncope, palpitations, or chest pain (Table 4).

Others consider that a basic cardiological examination must include, in addition, a 12-lead resting electrocardiogram and a submaximal exercise stress test.³¹ The fact that CAD is the first cause of sudden death in athletes supports this view. In addition, the electrocardiogram can be useful for detecting HCM, coronary anomalies, long QT syndrome, Wolff-Parkinson-White, Brugada, etc.³¹ As remarked, if an electrocardiogram had been made before death, a cause of sudden death might have been found for some of the indeterminate deaths in the series.

The addition of echocardiography to the medical history and electrocardiogram allows the correct

CS	Aortic rupture	Other cardiac	Indeterminate
Non-routine	–	1 (3%)	6 (18%)
Non-routine	17 (2.6%)	104 (16%)	104 (16%)
4 (8%)	1 (2%)	6 (12.2%)	–
20 (9%)	11 (5%)	78 (35.4%)	–
–	–	4 (12.5%)	10 (31.2%)
3 (3.7%)	–	10 (12.3%)	38 (47%)

hypertrophic cardiomyopathy; MVP, mitral valve prolapse; conduction system.

diagnosis of most patients with HCM. False positives can occur (athlete's heart) in competitive athletes that practice cycling or rowing (in which the most severe hypertrophies occur), as well as false negatives (there are forms of HCM that are not detectable until adolescence and there are forms of HCM without hypertrophy),^{48,49} but electrocardiograms are usually abnormal in such patients. With respect to ACM, when right ventricular dilation is absent or the left ventricle is involved, no echocardiographic disturbances are observed and electrocardiography is fundamental. Magnetic resonance imaging has been considered to be one of the best diagnostic tools,⁵⁰ but its elevated cost and the existence of false positives and false negatives mean that its performance is not high.

To prevent sudden death in sports enthusiasts, it might be useful to organize awareness-raising campaigns targeting the community so that athletes will undergo specific medical examinations before practicing sports, especially cycling.

Study limitations

In the first place, the series presented here has limited value from the statistical and epidemiological point of view. As noted, this study does not include all cases of sudden death associated with sports in the geographic zone of influence of the Institute of Toxicology. In addition, we do not know how many recreational or competition athletes there are. In second place, the clinical history of the subject is exiguous because the data were provided by forensic doctors, often after collecting it at the time of the post mortem study and probably not in the best conditions for interviewing family members.

CONCLUSIONS

1. In this series, coronary atheromatous disease was the most frequent cause of sudden death in relation to exercise in athletes over 30 years, particularly in association with cycling.

2. The main identifiable causes of sudden death in

athletes under the age of 30 years were arrhythmogenic cardiomyopathy and severe left ventricular hypertrophy (HCM and idiopathic LVH).

3. Myocardial fibrosis (possible sequela of myocarditis) was also significant in young athletes who died suddenly during athletic activities.

4. More than 30% of the sudden deaths in athletes under the age of 30 years were of indeterminate origin.

5. The medical examinations usually made in athletes can be insufficient for diagnosing the pathological processes that can cause sudden death. Cycling enthusiasts deserve special attention.

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