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Safety of Sports for Athletes With Implantable Cardioverter-Defibrillators

Results of a Prospective, Multinational Registry

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Background**—**The risks of sports participation for implantable cardioverter-defibrillator (ICD) patients are unknown.

Methods and Results**—**Athletes with ICDs (age, 10–60 years) participating in organized (n=328) or high-risk (n=44) sports were recruited. Sports-related and clinical data were obtained by phone interview and medical records. Follow-up occurred every 6 months. ICD shock data and clinical outcomes were adjudicated by 2 electrophysiologists. Median age was 33 years (89 subjects <20 years of age); 33% were female. Sixty were competitive athletes (varsity/junior varsity/traveling team). A pre-ICD history of ventricular arrhythmia was present in 42%. Running, basketball, and soccer were the most common sports. Over a median 31-month (interquartile range, 21–46 months) follow-up, there were no occurrences of either primary end point—death or resuscitated arrest or arrhythmia- or shock-related injury—during sports. There were 49 shocks in 37 participants (10% of study population) during competition/practice, 39 shocks in 29 participants (8%) during other physical activity, and 33 shocks in 24 participants (6%) at rest. In 8 ventricular arrhythmia episodes (device defined), multiple shocks were received: 1 at rest, 4 during competition/practice, and 3 during other physical activity. Ultimately, the ICD terminated all episodes. Freedom from lead malfunction was 97% at 5 years (from implantation) and 90% at 10 years.

Conclusions**—**Many athletes with ICDs can engage in vigorous and competitive sports without physical injury or failure to terminate the arrhythmia despite the occurrence of both inappropriate and appropriate shocks. These data provide a basis for more informed physician and patient decision making in terms of sports participation for athletes with ICDs. **(*Circulation*. 2013;127:2021-2030.)**

Key Words: defibrillators, implantable ■ sports

Consensus statements from the American College of Cardiology and European Society for Cardiology[1–3] advise against sports participation more vigorous than bowling or golf for patients with implantable cardioverter-defibrillators (ICDs). The bases for these recommendations are postulated risks of failure to defibrillate, injury resulting from loss of control caused by arrhythmia-related syncope or shock, and damage to the ICD system. However, the frequency with which these adverse events might occur has not been investigated.

Clinical Perspective on p 2030

In a 2006 retrospective survey of Heart Rhythm Society physician members,[4] >40% reported having at least 1 ICD patient in their practice participating in vigorous or competitive sports despite existing recommendations. No serious adverse events related to sports participation were reported. Although limited by its retrospective design and possible selection and recall biases, these results suggested that a prospective registry of athletes with ICDs was feasible, ethical, and necessary.

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The ICD Sports Safety Registry, a multinational, prospective, observational registry, was established to identify and quantify risks associated with sports participation for ICD patients. These data will assist physicians and ICD patients in making informed decisions regarding sports participation.

Methods

Participants and Recruitment

Patients with ICDs who were 10 to 60 years of age and participating in organized sports, involving regular practice and regularly scheduled competition with static and dynamic components greater than those traditionally classified as IA (more vigorous than golf or bowling), were eligible to participate.[1] Only patients already participating in sports were included, and the consent process emphasized that registry participation did not imply endorsement of the participant's sports participation. Participants in potentially high-risk sports, defined as those in which a brief loss of control could result in injury (eg, skiing or surfing), were also enrolled.

Patients were enrolled starting December 2006 by participating sites (41 North American, 18 European; n=211 patients; see the online-only Data Supplement for a list of sites) or by contacting the central site (Yale) directly (self-enrollment; North America only; n=161). Information was disseminated via mailings to physicians and by direct communication with patients via patient group Internet sites and mailing lists. This study was approved by the Yale Human Investigation Committee and by the institutional review boards of participating sites. All patients provided signed informed consent. For self-enrolled patients, consent and medical release forms and procedures as needed were discussed by phone, and signed copies were returned by fax/email.

Study Design

Data were collected and entered into a secure Web-based database by Yale or University Hospitals, Leuven, Belgium, personnel. Patients were contacted by phone to obtain information on sports participation, and medical records were obtained for clinical information.

Patients were asked to call the central site if they received an ICD shock and were queried about preceding activity and any sequelae. Preshock activity was categorized as competition/practice/postcompetition or practice (within 2 hours), other physical activity (recreational activity or other exertion, eg, running for a bus), or rest. Patients were also contacted every 6 months about shocks received and any change in sports participation, health or ICD status, or injuries received. Overall compliance with scheduled every-6-month interviews was 84%. If interviews were missed, information for the missed 6-month period was obtained at the next call. Medical records were obtained from sites or patients' treating physicians or facilities and were reviewed by study personnel for any shock or changes in health or ICD status (eg, lead replacement, death). Stored ICD electrograms and event detail data were reviewed for rhythm diagnosis and shock outcome by 2 electrophysiologists (R.L., B.O., H.H.), as were clinical data on system malfunction (R.L., H.H.). If the stored electrogram was not saved and could not be retrieved and thus was not available to the study team, the diagnosis of the treating ICD physician was reported (n=18). Vital status was determined for patients lost to follow-up (n=9) through contact with their treating physician (n=6) or device company (n=3). The database was closed on January 12, 2012.

End Points

The primary predetermined end point was a serious adverse event during or up to 2 hours after sports defined as (1) tachyarrhythmic death or externally resuscitated tachyarrhythmia caused by shock failure, incessant ventricular arrhythmia, or postshock pulseless electric activity or (2) severe injury, defined as requiring hospitalization, resulting from shock or syncopal arrhythmia.

Secondary end points included (1) numbers of appropriate (for ventricular tachyarrhythmia) and inappropriate shock episodes (both defined as a device-counted episode); (2) multiple shocks within 1 appropriate shock episode (ie, failure of first maximum-energy shock or recurrent arrhythmia); (3) moderate injury (requiring emergency room visit) associated with a shock; (4) ICD lead/system damage, including definite lead malfunction, defined as change in pacing function with documented noise on electrogram or visible lead abnormality, or probable malfunction, change in pacing function only. Site-reported lead malfunctions for which no clinical data could be obtained were also classified as probable (n=4). All end points were reviewed periodically by the Data Safety Monitoring Board (see the online-only Data Supplement for a list).

Statistical Analysis

Descriptive statistics were used to summarize patient characteristics, sports participation, and shock episodes. The binomial 95% confidence interval for adverse event was estimated with the exact method. The Fisher exact test was performed to compare the frequency of multiple shocks across activity categories and to compare the incidence of sports-related shocks for demographic and clinical variables. The McNemar test was performed to compare in a pairwise fashion the fraction of people shocked during competition with those receiving shocks during other physical activity versus or at rest.

Survival analysis was performed for time to lead malfunction by the Kaplan–Meier method based on date of lead implantation. All analyses were performed (by J.D. and F.L.) with SAS version 9.2 (SAS Institute Inc, Cary, NC).

A subgroup analysis was done of the most competitive participants, defined as varsity, junior varsity, or traveling team competition and meeting the Bethesda Conference definition[1] of "…regular competition against others as a central component, places a high premium on excellence and achievement, and requires some form of systematic (and usually intense) training."

Results

Patient Characteristics

Of the 413 patients consented, 30 were later determined ineligible (not participating in organized or high-risk sports) and 11 did not complete the enrollment interview. Of the 372 participants, 328 were participating in organized sports and 44 were participating in high-risk sports.

Demographic and clinical characteristics are shown in Table 1. The most common diagnoses were long-QT syndrome (n=73), hypertrophic cardiomyopathy (n=63), and arrhythmogenic right ventricular cardiomyopathy (n=55). Of the 155 subjects with a preimplantation history of ventricular fibrillation (VF) or tachycardia (VT), the arrhythmia occurred in 42 during sports participation. Sixty-two percent of the overall group were treated with β-blockers. Median time since implantation was 27 months (interquartile range [IQR], 12–59 months), with 100 subjects enrolled within 1 year of implantation. The lowest zone for treatment of arrhythmia was set at a median of 200 bpm (IQR, 188–215 bpm) and for the competitive subgroup was 217 bpm (IQR, 210–222 bpm).

The most common organized sports were running, basketball, and soccer, and most common high-risk sport was skiing (Table 2). There were 60 participants engaged in varsity/junior varsity/traveling team competition (10 on college-level teams, 47 on high school varsity/junior varsity–level teams; and 3 on pre–high-school traveling teams) and 72 postgraduate athletes participating at the national or international level. Subjects spent a median of 5.1 h/wk (IQR, 2.8–9.3 h/wk) participating in practice or competition during the relevant season, with those in the competitive subgroup spending a median of 13 hours (IQR, 7–19 hours).

Table 1. Demographic and Clinical Characteristics

	Entire Cohort (n=372)	Competitive Subgroup (Varsity/Junior Varsity/Traveling Teams; n=60)
Age, n (%)		
10–19 y	89 (24)	55 (92)
20–29 y	70 (19)	5 (8)*
30–39 y	66 (18)	
40–49 y	72 (19)	
50–60 y	75 (20)	
Male, n (%)	249 (67)	33 (55)
Race, n (%)		
White	349 (94)	56 (93)
Black	12 (3)	3 (5)
Other/unknown	11 (3)	1 (2)
Cardiac diagnosis, n (%)		
Long-QT syndrome	73 (20)	28 (47)
Hypertrophic CM	65 (17)	13 (22)
Arrhythmogenic right ventricular dysplasia	53 (14)	3 (5)
Coronary artery disease	41 (11)	0
Idiopathic VT/VF (normal heart)	40 (11)	2 (3)
Dilated cardiomyopathy	31 (8)	0
Congenital heart disease	30 (8)	6 (10)
Catecholaminergic polymorphic VT	10 (3)	3 (5)
Brugada syndrome	7 (2)	1 (2)
Valvular heart disease	6 (2)	0
Left ventricular noncompaction	5 (1)	1 (2)
None, family history	5 (1)	1 (2)
Other	6 (2)	2 (4)
ICD indication		
Ventricular fibrillation/cardiac arrest, n (%)	102 (27)	15 (25)
Sustained VT, n (%)	53 (14)	1 (2)
Syncope, n (%)	99 (27)	25 (42)
Prophylactic–CAD/CM, n (%)†	32 (9)	0
Prophylactic–other, n (%)	65 (17)	17 (29)
Positive electrophysiology study, n (%)	21 (6)	2 (3)
Time since initial ICD implantation, mo	27 (12–59)	16 (8–28)
ICD rate cutoff, bpm‡	200 (188–215)	217 (210–222)
Primary prevention, bpm	201 (188–219)	
Secondary prevention, bpm	200 (187–210)	
Ejection fraction, %	60 (50–66)	67 (60–72)
Taking β-blocking agents, n (%)	229 (62)	40 (67)

CAD indicates coronary artery disease; CM, cardiomyopathy; ICD, implantable cardioverter-defibrillator; VF, ventricular fibrillation; and VT, ventricular tachycardia. Values are either number (percent) or median (interquartile range) as appropriate.

*All ≤ 21 years of age.

†As defined by the Sudden Cardiac Death in Heart Failure Trial,[5] Multicenter Unsustained Tachycardia Trial,[6] or Multicenter Automatic Defibrillator Implantation Trial II.[7]

‡Lowest zone with treatment programmed, secondary prevention, VT or VF, primary prevention, other diagnoses.

Median follow-up was 31 months (IQR, 21–46 months) for the group and 30 months (IQR, 23–43 months) for those enrolled within 1 year of implantation. Twenty-one patients did not complete the study. Nine were lost to follow-up (all confirmed alive), 6 withdrew, 4 developed worsening cardiac or medical conditions that decreased their ability to exercise, and 2 died. One 52-year-old cyclist with coronary artery disease died after receiving multiple shocks at work (desk job); no postmortem ICD interrogation was performed. One 34-year-old volleyball and softball player with familial dilated cardiomyopathy died while hospitalized for congestive heart failure.

Table 2. Sports Participation

Sports	Total, n	Pre–High School, n	High School, n	College, n	Postgraduate, n	Competitive Subgroup* (Varsity/Junior Varsity/ Traveling Teams), n
Baseball	18	6	8	3	1	11
Basketball	56	7	15	14	20	23
Cycling	39			2	37	1
Equestrian	3		1		2	1
Field hockey	1		1			1
Football, flag	13		3	6	4	5
Football, tackle	6		3	1	2	2
Hockey	6				6	
Lacrosse	4		2	2		4
Racquetball	5				5	
Rock climbing	7		1	1	5	
Running						
Track/field	12	1	11			12
Cross-country	4		2	1	1	2
Marathon	19				19	
Running (other)	71		1	5	65	5
Skiing	71	1	4	2	64	1
Snowboarding	15		2	7	6	2
Soccer	69	6	13	11	39	19
Softball	34		4	5	25	6
Squash	6				6	
Surfing	13		1	2	10	2
Swimming	10		3		7	4
Tennis	39		7	2	30	7
Triathlons	24			2	22	2
Ultimate Frisbee	3			2	1	1
Volleyball	27	2	6	7	12	11
Wrestling	1		1			1
Other	72	1	13	6	52	14
Total	648	24	102	81	441	137

Some subjects participated in >1 sport. All sports meeting criteria for enrollment were tabulated.
*Defined in text.

Primary End Point

There were no occurrences of the primary end point (tachyarrhythmic death or externally resuscitated tachyarrhythmia during or after sports participation or severe injury resulting from arrhythmia-related syncope or shock during sports). The 95% confidence interval for the occurrence of an adverse event at 1 year, based on the 315 participants followed up for at least 1 year, was 0% to 1.2%; for 2 years, based on the 243 participants followed up for at least 2 years, the 95% confidence interval was 0% to 1.5%.

Secondary End Point: Shock Episodes and Multiple Shock Episodes

Overall, 77 individuals (21% of the study population) experienced 121 shock episodes. Forty-eight participants (13%) received at least 1 appropriate shock, and 40 (11%) received at least 1 inappropriate shock (Table 3). ICD-stored electrograms and event details were available for 103 episodes; in 18, the diagnosis of treating ICD physician was used. Overall, 36 individuals (10% of the study population) experienced shocks during competition or practice (47 total shocks), 29 individuals (8% of the study population) experienced shocks during other physical activity (39 total shocks), and 23 individuals (6% of the study population) experienced shocks (33 total shocks) during rest. Statistically more individuals received shocks during either competition/practice or physical activity than during rest (16% versus 6%; $P<0.0001$), but there was no difference between the proportion receiving a shock during competition/practice and those receiving a shock during other physical activity (10% versus 8%; $P=0.34$). Similarly, the proportion receiving appropriate shocks during either competition/practice or other physical activity was greater than the proportion receiving appropriate shocks during rest (8% versus 3%; $P=0.006$), but there was

Table 3. Number of Shock Events and of Individuals Receiving Shocks, Total Cohort

Rhythm	Competition Related, n*	Physical Activity Related, n†	Other, n	Total, n (%)
Ventricular tachycardia	22/16	14/11	11/8	47/35 (9)
Ventricular fibrillation	8/6	3/3	10/5	21/14 (4)
Sinus tachycardia	7/6	6/3	1/1	14/10 (3)
Atrial fibrillation	5/3	10/6	3/3	18/12 (3)
Other supraventricular tachycardia	2/2	2/2	0/0	4/4 (1)
Noise	0/0	2/2	6/5	8/7 (2)
T-wave oversensing	2/2	1/1	1/1	4/4 (1)
Other	3/2	1/1	1/1	5/4 (1)
Total, n (%)	49/36 (10)	39/29 (8)	33/23 (6)	121/77 (21)

Values refer to number of events/number of unique individuals. Percents refer to percent of the study population. Eighteen shocks did not have available implantable cardioverter-defibrillator–stored data, so the diagnosis is based on that of the treating physician. Of these, 4 were ventricular arrhythmia, 2 were supraventricular, 7 were noise, and 5 were other.

*Includes competition, postcompetition, or practice for competition.

†Includes physical activity and post–physical activity.

no difference between competition/practice and other physical activity (6% versus 4%; P=0.18).

Twenty-one individuals received appropriate shocks during competition/practice. Individuals ≥20 years of age were more likely to receive appropriate shocks during competition/practice. Those with arrhythmogenic right ventricular dysplasia or idiopathic VF were more likely than those with hypertrophic cardiomyopathy (P<0.05 for each) or with long-QT syndrome (P<0.05 and P=0.07, respectively) to receive appropriate shocks during competition/practice (Table 4). Other demographic or clinical characteristics were not associated with receipt of appropriate shocks during competition/practice.

Table 4. Bivariate Association of Clinical Characteristics and Appropriate Shocks During Sports

	Total, n	VT/VF Shock During Competition/Practice (n= 21), n (%)	*P* Value
Age, 10–19 y	89	1 (1)	0.03
20–60 y	283	20 (7)	
Competitive subgroup	60	1 (2)	0.22
Others	312	20 (6)	
Indication			
Secondary prevention	155	10 (6)	0.65
Primary prevention	217	11 (5)	
Cardiac diagnosis			
Idiopathic VT/VF (normal heart)	33	4 (12)	<0.01
CAD	39	3 (8)	
ARVD	53	8 (15)	
HCM	65	1 (2)	
LQTS	73	2 (3)	
Others	109	3 (3)	
Sex			
Female	123	10 (8)	0.16
Male	249	11 (4)	
β-Blocker			
Yes	229	14 (6)	1.00
No	115	7 (6)	

ARVD indicates arrhythmogenic right ventricular dysplasia; CAD, coronary artery disease; HCM, hypertrophic cardiomyopathy; LQTS, long-QT syndrome; VF, ventricular fibrillation; and VT, ventricular tachycardia.

Among the 37 individuals who received any shocks during sports, 4 terminated participation in all sports, and 7 terminated participation in 1 or some sports (ie, 30% of those who received shocks during sports, totaling 3% of the study population, stopped at least 1 sport.) Five other patients stopped at least 1 sport as a result of shocks received unrelated to sports.

Among the 64 appropriate shock episodes, 8 episodes in 7 individuals (2% of study population) required >1 high-energy shock for arrhythmia termination (Table 5): 4 were related to competition/practice; 3 were related to other physical activity, and 1 occurred at rest. Among all appropriate shock episodes occurring during competition or practice, 14% required multiple shocks for termination compared with 20% of those occurring during other physical activity and 5% of those at rest (P=0.26 for percent requiring multiple shocks during either competition/other physical activity versus at rest). Among the 7 participants experiencing multiple shock episodes, 3 had coronary artery disease, 1 had catecholaminergic polymorphic VT (CPVT), 2 had idiopathic VF, and 1 had hypertrophic cardiomyopathy (who received multiple shocks at rest).

Two participants had VT below the programmed rate cutoff of the ICD and were externally cardioverted. One patient with CPVT and a history of VT developed heart racing while jogging and was found to be in VT at 190 bpm; the device was set at 231 bpm. The other, with repaired congenital heart disease and a history of VT, was awakened from sleep, also with heart racing, and was found to be in VT at 200 bpm; the device was set at 222 bpm. Both were on β-blockers, and neither took other antiarrhythmic medications

There was 1 proarrhythmic event in which antitachycardia pacing delivered during sinus tachycardia (unrelated to sports) induced VT that was terminated by 1 shock.

Table 5. Events/Individuals Requiring >1 Shock for Termination to Sinus Rhythm

Sex	Age, y	Cardiac Diagnosis	Primary Sport	Activity	Activity Type	Shocks, n
M	28	Idiopathic VF	Ultimate Frisbee	Ultimate Frisbee	Competition	5
F	47	Idiopathic VF	Cycling	Cycling	Practice	4
M	44	CAD	Running	Running	Practice	2
M	50	CAD	Cycling	Cycling	Practice	6
M	57	CAD	Tennis, basketball	Walking	Physical Activity	6
F	16	CPVT	Lacrosse field hockey	Running	Post–physical activity	3
				Running	Post–physical activity	4
M	15	HCM	Baseball	Socializing	Other	2

CAD indicates coronary artery disease; CPVT, catecholaminergic polymorphic ventricular tachycardia; HCM, hypertrophic cardiomyopathy; and VF, ventricular fibrillation.

Secondary End Point: Moderate Injury

There were no moderate injuries related to arrhythmias or shocks received during sports.

Secondary End Point: System Malfunction

There were 13 definite and 14 possible lead malfunctions. The estimated lead survival free of definite malfunction (from implantation date) was 97% at 5 years and 90% at 10 years; the rate of survival free of definite plus possible malfunction was 93% at 5 years and 84% at 10 years (Figure [A and B]). There were no generator malfunctions.

Competitive (Varsity/Junior Varsity/Traveling Team) Subgroup

There were 60 individuals participating in sports on varsity, junior varsity, or traveling teams, all ≤21 years of age (all were North American; Table 1). Cardiac diagnoses and ICD indications were similar to those of the overall group except for coronary artery disease. Specific sports are listed in Table 2. There were no primary end points as above.

Seventeen individuals (28% of the subgroup) experienced a total of 25 shocks (Table 6). Twelve shocks were appropriate, 2 of which occurred during competition or practice (same individual) and 6 during other physical activity. The percentage of individuals in the competitive subgroup receiving appropriate shocks during competition/practice (1%) was not different from the percentage of those not in the competitive subgroup (7%; Table 4). Among the 5 individuals who received shocks during competition/practice, 1 stopped all sports on the direction of his physician, and 1 stopped 1 sport (40% of shock recipients and 3% total of the competitive subgroup).

Discussion

Challenging conventional wisdom, this prospective study is the first to show that many athletes with ICDs can engage in sports without physical injury or failure to terminate the arrhythmia. Although ICD shocks occurred during and after sports or practice, there were no tachyarrhythmic deaths, resuscitated cardiac arrests, or injuries related to shocks resulting from sports participation.

More shocks occurred during physical activity than at other times. However, there was no difference in the percentages of patients receiving shocks during competition/practice and those receiving shocks during other physical activities such as recreational activity or other activities. Athletic participation becomes an issue of quality of life. Although ICD shocks can decrease quality of life,[8] so can sports restriction. Healthy college athletes have higher physical, emotional, and social functioning and quality-of-life scores than nonathletes, yet athletes sidelined with an injury score lower in all of these domains than both active athletes and nonathletes.[9] Many adolescents with ICDs[10] and their physicians[11] report restriction from sports and the resultant feeling of not being normal[10] as one of the most important negative aspects of their device. The basic principle of patient-centered care is that only the patient can determine what brings quality to his/her life.[12] Although formal quality of life was not measured, the majority of athletes who received shocks during sports chose to continue playing, suggesting that the negative impact of shocks was outweighed by the benefits of continued sports participation for those individuals. The interaction of sports participation, shocks, and quality of life is an important subject of ongoing research.

Current recommendations restricting vigorous, competitive sports are based on the concern that the ICD will not be effective during the autonomic, metabolic,[13] and potentially ischemic changes that may occur during sports.[1,2] The ICD effectively treats life-threatening arrhythmias in patients with hypertrophic cardiomyopathy,[14,15] arrhythmogenic right ventricular cardiomyopathy,[16] and the long-QT syndrome under nonexercise conditions.[17] Laboratory studies are contradictory on the impact of intravenous catecholamines on defibrillation, with some showing an increased[18] and others showing a decreased[19] shock efficacy. However, just 2 cases of shock failure during exercise in ICD patients have been reported. One patient, who died during a treadmill test,[20] had an ethmozine-induced increase in defibrillation threshold noted previously. In the second, exercise followed heavy alcohol ingestion.[21] Successful conversions during competitive sports have been reported.[15] In the present study, there were no failures of the ICD to convert ventricular arrhythmia.

Ventricular arrhythmias requiring multiple shocks occurred during 8 episodes in 7 individuals, 2% of the study population. Although the frequency of this phenomenon in

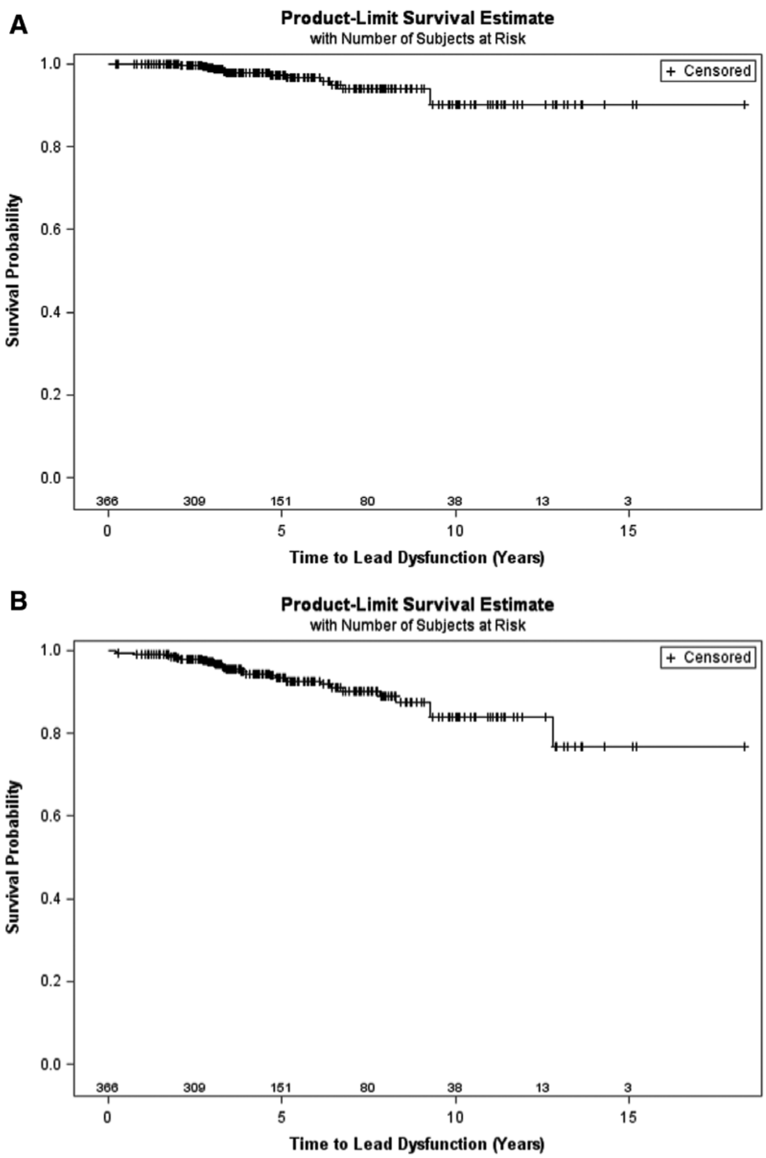

Figure. Lead survival based on time since lead implantation. **A**, Kaplan–Meier curve of freedom from definite lead malfunction (n=13 of 366). **B**, Kaplan–Meier curve of freedom from definite or possible lead malfunction (n=27 of 366).

ICD patients is not described, electrical storm occurs in 4% to 20% of adult[22,23] and 5% of pediatric[24] device patients. Prudence suggests that an individual experiencing multiple shocks for ventricular arrhythmias should refrain from exercise until further evaluation and treatment. This phenomenon was limited to patients with CPVT, idiopathic VF, and coronary artery disease. Although the CPVT patients did not suffer failure of shocks, 1 in 10 required multiple shocks on 2 occasions. Prior case reports have described CPVT patients experiencing proarrhythmic effects of ICD shocks,[25,26] which increase catecholamines,[27] and lethal VT refractory to ICD shocks. Whether CPVT patients are at higher risk, at least pending more effective therapies, is unknown. Athletes presenting with idiopathic VF should undergo careful evaluation for CPVT. Ischemia can increase the defibrillation threshold and the frequency of reinitiation of VF after shock.[28] More aggressive or frequent stress testing in coronary artery disease patients wishing to exercise vigorously may also be warranted.

Whereas more inappropriate and appropriate shocks occurred during physical activity (although not differing between competition/practice and other physical activity), overall rates of individuals receiving shocks in this population are similar to those reported for less active, more typical ICD populations, both adult and pediatric.[24,29] Exercise exacerbates arrhythmias in apparently healthy individuals,[30] in multiple disorders,[31–33] and in ICD patients.[34] The paradox of exercise is well described[35]: Although exercise can immediately trigger life-threatening ventricular arrhythmias, even in the physically fit, the better conditioned the individual, the less likely overall he or she is to die suddenly. Whether a similar phenomenon exists in younger patients with arrhythmogenic conditions is unknown, and whether shocks would have been less or more common in these relatively healthier patients had they abandoned vigorous physical activity cannot be determined.

Another rationale for recommending against sports participation for individuals with ICDs is concern that loss of control caused by syncopal arrhythmia or shock could result in injury.[1,2] In this study, shocks occurring during competition or practice did not result in injury. The possibility of damage to leads or generator has been stated[1] as another theoretical reason to recommend against sports participation. Lead

Table 6. Number of Shock Events and of Individuals Receiving Shocks, Competitive Subgroup (Varsity/Junior Varsity/Traveling Team)

Rhythm	Competition Related, n (%)*	Physical Activity Related, n (%)†	Other, n (%)	Total, n (%)
Ventricular tachycardia	0/0	4/2 (3)	2/1 (2)	6/3 (5)
Ventricular fibrillation	2/1 (2)	2/2 (3)	2/1 (2)	6/4 (7)
Sinus tachycardia	0/0	0/0	0/0	0/0
Atrial fibrillation	1/1 (2)	2/2 (3)	0/0	3/3 (5)
Other supraventricular tachycardia	1/1 (2)	1/1 (2)	0/0	2/2 (3)
Noise	0/0	1/1 (2)	2/2 (3)	3/3 (5)
T-wave oversensing	1/1 (2)	1/1 (2)	1/1 (2)	3/3 (5)
Other	1/1 (2)	1/1 (2)	0/0	2/2 (3)
Total	6/5 (8)	12/10 (17)	7/5 (8)	25/17 (28)

Values refer to number of events/number of unique individuals. Percents refer to percent of subgroup. Five shocks did not have available implantable cardioverter-defibrillator–stored data, so the diagnosis is based on that of the treating physician. Of these, 2 were noise, 1 was ventricular fibrillation, 1 was T-wave oversensing, and 1 was other.

*Includes competition, postcompetition, or practice for competition.

†Includes physical activity and post–physical activity.

survival rates in this study were similar to the previously described rates of 85% to 98% at 5 years in more typical ICD populations.[36]

These data suggest that a blanket recommendation against competitive sports for all patients with ICDs is not warranted. There are risks and benefits of sports participation. However, neither do these data suggest that all sports are safe for all patients. How best to evaluate individual risk is an important avenue of future research. Stress testing is important to evaluate for the propensity of frequent exercise-induced ventricular arrhythmias, as well as for CPVT or ischemia, as clinically relevant. In addition, for patients with arrhythmogenic right ventricular cardiomyopathy, preliminary data[37–39] suggest that exercise could accelerate the progression of the underlying disease. How physical activity might affect the phenotype in other cardiomyopathies such as hypertrophic cardiomyopathy has not been studied.

Clinical management of ICD patients participating in sports remains to be defined, such as how best to prevent shocks in athletes, which may include stress testing and appropriate ICD programming.[40,41] Half of the athletes in this study had rate cutoffs higher than that documented to be safe in unselected populations.[41] However, although 2 participants had VT below the rate cutoffs, they were minimally symptomatic. It is possible that VT may be better tolerated given the preserved ejection fractions of these athletes. The optimum programming of ICDs in patients participating in sports is an important avenue of future research. Increased frequency of interrogation (in person or remotely) may detect early warning of changes in lead performance. β-Blocker use was not associated with decreased likelihood of appropriate shocks during competition/practice. However, because use of β-blockers was not randomized, their impact cannot be determined. β-Blockers may also protect against shocks for sinus tachycardia.

Decisions on if and when athletes with cardiac conditions should return to play have been difficult because there are few large prospective studies. This registry, in which individuals who had made the decision to participate in organized sports were identified and followed up prospectively, without encouragement of activities with unknown risk, may also provide a paradigm to assess return-to-play decisions for other cardiac conditions. Critical to this paradigm was collaboration with Internet-based patient advocacy groups (see Acknowledgments) in publicizing this study. This collaboration led to enrollment of more than half of the North American participants, demonstrating the power and increasing importance of community-based participatory research,[42] which was invaluable to this study.

Limitations included the fact that study participants were self-selected; whether they are representative of all ICD patients participating in sports is unknown. Participants may have been assessed by their physicians as being at lower arrhythmic risk. Most subjects had excellent ejection fractions, and these data cannot be extrapolated to those with depressed ejection fraction. In addition, for the self-enrolled participants, shocks were self-reported either at the time of shock or during questioning at the time of the every-6-month telephone follow-up. It is possible that the number of reported shocks underestimated the true frequency. Although there were many athletes participating in sports with moderate contact such as basketball and soccer, very few were participating in aggressive contact sports (tackle football, ice hockey), and it is possible that injury or ICD system damage could be higher in these sports. In addition, because antitachycardia pacing is asymptomatic, we could not evaluate whether ATP-terminated VT was common during sports; however, if so, it did not result in arrhythmia-related injury or failure to terminate an arrhythmia. Finally, because patients could enroll at any time after implantation (median, ≈2 years), we cannot exclude the possibility of survival or selection bias, ie, that those who had been participating uneventfully before the initiation of this study continued, whereas those who had suffered adverse events did not. However, there were no primary end points in any of the athletes, including the quarter of the group enrolled early after implantation. Longer-term follow-up is needed.

Conclusion

Many athletes with ICDs can engage in vigorous competitive sports without physical injury or failure to terminate the arrhythmia despite the occurrence of both inappropriate and appropriate shocks in a small number. These data provide a basis for more informed physician and patient decision making on sports participation for athletes with ICDs.

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CLINICAL PERSPECTIVE

Although current recommendations restrict sports participation for patients with an implantable cardioverter-defibrillator (ICD), the risks are unknown. In this study, athletes with ICDs (age, 10–60 years) participating in organized (n=328) or high-risk (n=44) sports were followed up prospectively for median of 30 months, with sports-related and clinical data obtained by phone interview and medical records at baseline, if a shock occurred, and every 6 months. Median age was 33 years (89 subjects <20 years of age); 33% were female; and 42% had a pre-ICD history of ventricular arrhythmia. Sixty subjects were competitive athletes (varsity/junior varsity/traveling team). Running, basketball, and soccer were the most common sports. There were no occurrences of either primary end point—death or resuscitated arrest or arrhythmia- or shock-related injury—during sports. Shocks were not uncommon; there were 49 shocks in 37 participants (10% of study population) during competition/practice, 39 shocks in 29 participants (8%) during other physical activity, and 33 shocks in 24 participants (6%) at rest. In 8 ventricular arrhythmia episodes (device defined), multiple shocks were received: 1 at rest, 4 during competition/practice, and 3 during other physical activity. The ICD terminated all episodes. Freedom from lead malfunction was 97% at 5 years (from implantation) and 90% at 10 years, similar to that reported in unselected populations. In summary, many athletes with ICDs can engage in vigorous and competitive sports without physical injury or failure to terminate the arrhythmia, despite the occurrence of both inappropriate and appropriate shocks. These data provide a basis for more informed physician and patient decision making in terms of sports participation for athletes with ICDs.