

Clinical Profile and Spectrum of Commotio Cordis

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SUDDEN AND UNEXPECTED DEATHS of young individuals are highly visible and emotionally charged events.¹⁻³ These deaths are frequently the consequence of unsuspected congenital cardiovascular diseases³⁻⁶ in trained athletes. However, organized sports are subject to another risk for sudden death (ie, blunt, nonpenetrating, and usually innocent-appearing chest blows, *commotio cordis*).⁷⁻¹² However, the spectrum of *commotio cordis* is diverse, and the risks considerably more pervasive. In this study we characterize more completely the evolving and heterogeneous clinical profile of chest blows causing sudden death.

METHODS

The 128 cases consecutively entered into the US *Commotio Cordis* Registry, Minneapolis, Minn, as of September 1, 2001, constitute the present series. Fourteen (11%) of these cases were identified from news media and Internet accounts, 46 (36%) from records of the US Consumer Product Safety Commission, and 68 (53%) from direct submission to the registry by medical examiners, other medical or sports-related sources, and interested nonmedical parties.

Each case fulfilled the following inclusion criteria: (1) a witnessed event of a blunt, nonpenetrating blow to the chest immediately preceded cardiovascular collapse; (2) detailed documentation of the circumstances from available newspa-

Context Although blunt, nonpenetrating chest blows causing sudden cardiac death (*commotio cordis*) are often associated with competitive sports, dangers implicit in such blows can extend into many other life activities.

Objective To describe the comprehensive spectrum of *commotio cordis* events.

Design and Setting Analysis of confirmed cases from the general community assembled in the US *Commotio Cordis* Registry occurring up to September 1, 2001.

Main Outcome Measure *Commotio cordis* event.

Results Of 128 confirmed cases, 122 (95%) were in males and the mean (SD) age was 13.6 (8.2) years (median, 14 years; range, 3 months to 45 years); only 28 (22%) cases were aged 18 years or older. *Commotio cordis* events occurred most commonly during organized sporting events (79 [62%]), such as baseball, but 49 (38%) occurred as part of daily routine and recreational activities. Fatal blows were inflicted with a wide range of velocities but often occurred inadvertently and under circumstances not usually associated with risk for sudden death in informal settings near the home or playground. Twenty-two (28%) participants were wearing commercially available chest barriers, including 7 in whom the projectile made direct contact with protective padding (baseball catchers and lacrosse/hockey goalies), and 2 in whom the projectile was a baseball specifically designed to reduce risk. Only 21 (16%) individuals survived their event, with particularly prompt cardiopulmonary resuscitation/defibrillation (most commonly reversing ventricular fibrillation) the only identifiable factor associated with a favorable outcome.

Conclusions The expanded spectrum of *commotio cordis* illustrates the potential dangers implicit in striking the chest, regardless of the intent or force of the blow. These findings also suggest that the safety of young athletes will be enhanced by developing more effective preventive strategies (such as chest wall barriers) to achieve protection from ventricular fibrillation following precordial blows.

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per articles, police reports, and telephone interviews with family members or other witnesses; (3) absence of structural damage to the sternum, ribs, and heart itself; and (4) absence of any underlying cardiovascular abnormalities.

Autopsies were performed in 82 of the 107 fatal cases; 23 of the other 25 cases occurred in ball sports (baseball, softball, cricket, hockey, and lacrosse) in circumstances similar or identical to other registry cases for which autopsy data were available. In 3 cases, real-time videotape of the event was available for analysis. Of the 128 cases, 65 (51%) occurred from 1995 through 2001, 28 (22%) from 1985

through 1994, and 35 (27%) prior to 1985. Selected data from 70 cases have been included in prior reports.^{7,13}

RESULTS

Demographics

Ages of the 128 cases ranged from 3 months to 45 years (mean [SD], 13.6

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[8.2] years; median, 14 years); 56 (44%) were 12 years or younger while only 28 (22%) were 18 years or older (FIGURE 1); 122 (95%) were male.

Event Setting

Competitive Sports. At the time of their commotio cordis event, 79 participants (62%) were engaged in organized competitive sports at the youth (n=37), high school or junior high school (n=30), college (n=7), and professional (n=5) levels (FIGURE 2). Although 11 sports are represented, 46 (58%) of these commotio cordis events occurred during either baseball or softball games and 13 (16%) at ice hockey games (Figure 2).

Routine Daily and Recreational Sporting Activities. Forty-nine other commotio cordis events (38%) occurred during a variety of innocent-appearing and recreational activities in informal and largely unstructured settings, such as in the backyard, playground, or neighborhood school yard or while participating in a variety of daily activities and circumstances unrelated to sports and often under other extraordinary circumstances (TABLE).

Eighteen of the 49 events involved either bodily contact or contact with implements regarded as toys (and were not athletic equipment), such as a hollow plastic bat a 13-year-old boy flung 15 feet that inadvertently struck the chest of his 2-year-old sister. A 5-year-old boy died instantaneously after being struck in the chest by a circular plastic sledding saucer. Two adolescent boys died suddenly after receiving sharp but light chest blows from friends during a playful “shadow” boxing match that involved a closed or open fist (ie, with a jab or push). In 2 other unusual cases, a 23-year-old man fatally struck his friend in the chest with a closed fist, as a mutually agreed on remedy for hiccups, and a 2-year-old girl was incidentally struck in the chest by the head of her pet dog. The oldest victim in this series was a 44-year-old teacher, who died when she was inadvertently struck in the chest by an elbow while intervening during a scuffle between 2 teen-aged female students.

In 8 of these 18 cases, relatively modest chest blows caused death when an adult struck either a child as part of parent-child discipline (ages 3 months to 11 years) or an adult struck another adult in gang-related rituals. Seven of these 8 cases triggered a homicide investigation with charges of first-degree murder (1 prosecutor sought the death penalty); each perpetrator was convicted of murder, manslaughter, or reckless homicide.¹⁴

Profile and Implements of Sports-Related Chest Blows

Projectiles. Of 107 commotio cordis events that were regarded as part of competitive or other sporting activities, 87 (81%) involved a blunt precordial blow from a projectile (which served as a standard implement of the game), or another object propelled against a stationary chest wall, resulting in relatively localized contact, during organized or recreational play (Table). Projectiles were most commonly baseballs (n=53), including 50 of apparent regulation design, 1 hard rubber ball, and 2 others marketed commercially as reduced-injury, softer-than-normal (so-called safety or training) balls, made largely of rubber of various textures contained in a synthetic covering.

Other projectiles included 14 softballs, as well as 10 hockey pucks and 5 lacrosse balls, both of which are made of hard rubber. With the exception of 1 air-filled soccer ball, each projectile that resulted in commotio cordis had

a hard solid core. Six of these 87 cases were innocent bystanders inadvertently struck in the chest by a thrown or batted ball, including spectators or players observing the game from the dug-out or bull pen.

Scenarios Involving Projectiles. Individuals struck in the chest by baseballs (including T-balls) or softballs were involved in a variety of scenarios. In 23 instances, balls struck young children in the chest at relatively close range, either batted or thrown by friends, parents, or siblings at speeds not unusual for the circumstances. For example, 1 fatal incident occurred on a family outing, when a soft baseball gently tossed underhand by a father to 6-year-old son deflected off the heel of his glove striking the child’s chest.

In competitive circumstances, 13 cases were batters (or in 1 case an umpire without a chest protector) who were struck by a pitched ball; body size

Figure 1. Age at Time of Commotio Cordis Event

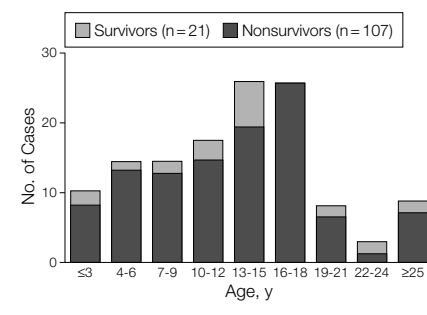
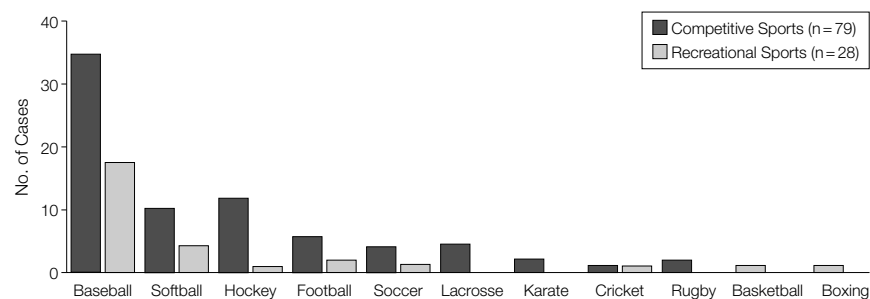


Figure 2. Sports Participated in at the Time of Commotio Cordis Events



Data are shown separately for competitive and organized recreational athletic activities. Four T-ball-related events are included in the baseball category.

Table. Characteristics of Chest Blows in 128 Commotio Cordis Events

Implements/Circumstances	No. of Events
Sports equipment	
Baseballs*	53
Softballs	14
Hockey pucks	10
Lacrosse balls	5
Cricket balls	2
Soccer ball	1
Hockey stick	1
Tennis ball (filled with coins)†	1
Bodily collisions in sports‡	
Knee or foot	5
Elbow or forearm	5
Shoulder	4
Fist§	2
Head (football helmet)	2
Goalpost	1
Daily and recreational activities	
Playful ("shadow") boxing	6
Parent-to-child discipline	5
Gang rituals	3
Scuffle	1
Plastic sledding saucer (diameter, 91.44 cm [36 in])	1
Plastic (hollow) toy bat	1
Snowball	1
Playground swing carriage	1
Pet (collie) dog head	1
Hiccups remedy (by friend)	1
Fall on playground apparatus ("monkey bars")	1

*Includes 4 T-balls.

†Training device for baseball pitchers.

‡Baseball, football, karate, soccer, basketball, and hockey.

§Closed or open fist (including jab, push, slap).

and athletic ability of the pitcher and the speed of the ball were considered unremarkable for the game and only 1 pitcher was an adult. Velocities of the pitched ball were estimated to be 48 to 80 km/h (30-50 mph) from distances of about 12 to 18 m (40-60 ft). Eleven other baseball players were pitchers struck in the chest by batted balls over similar distances. Twenty other players, including base runners and catchers, were hit in the chest at distances of up to 30 m (100 ft) by batted or thrown balls.

Ten ice hockey-related events resulted from chest blows inflicted by a high-velocity slap-shot at relatively close range, involving players stationed in defensive positions, including 1 goalie. Five other events occurring during a lacrosse match, included 3 goalies who were struck by high-velocity shots and 2 others by errant field passes.

Nonprojectile Blows. During competitive or other sporting activities, 20

individuals (19%) received chest blows delivered by physical contact with another person—ie, by a fist, shoulder, forearm, elbow, knee, foot, or head or by the heel of an ice hockey stick (Table). Examples included bodily collisions in rugby, hockey, and soccer; between baseball players in pursuit of a batted ball; blocking and tackling in football; or from karate blows.

Resuscitation

Of the 128 individuals experiencing commotio cordis, 107 (84%) died as a consequence of their event, and 21 (16%) have survived as of April 2001 over a follow-up period of 1 to 20 years (mean [SD], 7 [5] years). Fifteen survivors achieved complete physical recovery, and 6 have mild to moderate residual neurologic disability or cardiac impairment (manifested by reduced left ventricular ejection fraction). Of the 21 survivors, 19 had resuscitative measures instituted for cardiac arrest, including 2 particularly fortuitous baseball-related events in which a 13-year-old batter and a 38-year-old umpire who was not wearing a chest protector were each struck in the chest by a pitched ball and had ventricular fibrillation terminated by an automated external defibrillator. The 2 others collapsed with apnea, loss of consciousness, and cyanosis but responded spontaneously without resuscitation, including a hockey player struck by a slap-shot during the Stanley Cup playoffs; these events were judged likely to be examples of aborted commotio cordis.

Cardiopulmonary resuscitation was known to have been performed by bystanders in cases of 106 individuals, including defibrillation in 41; most of these events involved trained personnel such as nurses, fire-fighters, physicians, or emergency medical technicians. Of 68 events for which resuscitative measures were known to have been instituted in a timely fashion (estimated <3 minutes), 17 (25%) survived. In contrast, of the other 38 cases in which resuscitation was substantially delayed (>3 minutes), there was only 1 survivor (3%, $P = .007$ by χ^2 test).

For 1 survivor, the time interval from collapse to resuscitation could not be determined. Fifty-one of the 68 who received apparently prompt resuscitation nevertheless died.

Arrhythmias

Data from the initial electrocardiogram conducted after collapse (recorded in the emergency department or by emergency medical technicians) could be analyzed in 82 cases. The arrhythmias included 33 with ventricular fibrillation (VF), 3 with ventricular tachycardia, 3 with bradyarrhythmias, 2 with idioventricular rhythm, 1 with complete heart block, and 40 with asystole, which was unlikely to be the initial rhythm after impact. These rhythms were recorded at the scene of the event in 42 cases, and in the other 29 cases, they were recorded in the emergency department. Eleven cases could not be resolved with certainty. Ventricular tachycardia/fibrillation were identified in 26 non-survivors and 10 survivors.

Chest Wall Protection

Of the 79 individuals participating in organized, competitive athletic activities, 22 (28%) were wearing standard, commercially available chest barriers, generally regarded as providing protection to the chest wall against the consequences of direct blows. These included 12 hockey (including 2 goalies), 5 football, 3 lacrosse (all goalies during 2000 and 2001), and 2 baseball (both catchers) players.

Analysis of the hockey-related events suggests a scenario for 8 cases in which it is likely that the puck probably struck the chest wall directly due to the angle of the shot, which appeared to circumvent the position of the standard shoulder-chest protector. Alternatively, when the defensive player instinctively raised (or extended) his arms to obstruct a slap-shot, the chest barrier probably migrated cephalad, thereby allowing the puck to directly strike the unprotected precordium.⁷ Similarly, for each of the 5 football players wearing standard equipment, design of the chest-shoulder padding was judged unlikely

to have protected the precordium from the blow.

In 7 other athletes with commotio cordis (3 lacrosse goalies, 2 baseball catchers, 2 hockey goalies), all of whom were equipped with commercially available chest barriers of standard design, the projectiles that caused the commotio cordis event were judged to have probably struck the chest protector directly (but not the chest), nevertheless resulting in a commotio cordis event. Each chest barrier was made largely from rubberlike closed or open-cell polymer foam covered by fabric or hard shell.

COMMENT

Blunt, nonpenetrating chest blows, often innocent in appearance and causing virtually instantaneous sudden death (commotio cordis) most commonly in young males, have been the subject of increasing attention.^{7-9,14} Although earlier reports were limited largely to organized and competitive sports, particularly baseball,^{7,10,15,16} our continued interest in this devastating phenomenon with its increased visibility and public exposure during the past 6 years has permitted the systematic assembly of a large cohort. Even though the data from this registry do not allow determination of the prevalence or incidence of commotio cordis, the cases included demonstrate a diverse spectrum of events, including many occurring in the broader context of daily life unrelated to sports. Indeed, many cases of commotio cordis resulted from innocent and often unintentional chest blows occurring at home or at school, including several under particularly unusual circumstances that could not be regarded (even remotely) as life-threatening.

Some such examples include chest blows delivered by punitive parent-child interaction; as an ill-advised effort to terminate hiccups; and from the head of a pet dog as it greeted a small child, a snowball, a rebound motion of a playground swing carriage, and a hollow plastic toy bat flung during a child's game; or a blow during a friendly shadow-boxing match. Such

examples underscore the critical message that any chest blow, even when modest or innocent and delivered unintentionally, can be life-threatening.

The uncommon occurrence of commotio cordis is largely explained by its mechanism, which requires the exquisite confluence of several determinants such as location of the blow directly over the heart^{7,17} and precise timing to the vulnerable phase of repolarization (just prior to T-wave peak).¹⁷⁻²⁰ Young children with narrow and underdeveloped chest cages also appear most susceptible to commotio cordis, as evidenced by the average age of 14 years in this cohort (one third of whom were 10 years or younger), although adults comprised almost one fourth of the study group.

Commotio cordis impacts are typically of low-energy and velocity^{7,13,17-20} although the wide range of velocities is evidenced by some hockey puck and lacrosse ball blows with estimated speeds up to 144 km/h (90 mph). Solid core projectiles appear much more likely to trigger commotio cordis since only 1 registry case involved an air-filled ball (ie, soccer). It is likely that projectiles with a non-solid core are capable of absorbing much more of the impact energy by their own collapse without transmitting that momentum to the chest wall.

Sports-related commotio cordis deaths have triggered considerable interest in chest barriers to protect young sports participants from catastrophic precordial blows. Indeed, these registry data provide an opportunity to gain insights into the adequacy of chest barriers by analyzing a subset of 22 cases for whom chest protectors failed to prevent VF. In many ice hockey and football-related deaths, it was unlikely that commercially available chest or shoulder padding had actually covered the precordium at the time of impact. For example, standard gear in football does not extend inferiorly to cover most of the chest cage; shoulder and chest padding in hockey may cover the precordium but can move upward when the arms are raised, thereby leaving the

critical central area of the anterior chest unprotected and vulnerable.⁷

Of note, in 7 cases reported herein, it appeared that a projectile struck the chest protector directly. These cases included baseball catchers and lacrosse goalies, suggesting that the standard commercially available chest barriers, made from relatively soft foam padding, may have been inadequate to abort or blunt sufficiently the instantaneous transmission of mechanical energy to the heart that occurs in commotio cordis; this may have occurred due to local absorption rather than the distribution of force.¹⁷⁻²⁰ Indeed, because of the current level of uncertainty regarding the material composition of chest barriers that would be truly protective against chest blow-induced VF, the American Academy of Pediatrics has not recommended routine use of chest protectors for youth baseball players other than catchers.²¹

We have previously demonstrated in an experimental model of commotio cordis that reduced injury (safety) baseballs decreased (but did not abolish) risk for VF with 48 km/h (30 mph) precordial impacts.¹⁸ However, 2 of the deaths discussed herein were associated with balls specifically marketed for their safety design as softer-than-normal; much of the core was made from rubber of varying hardness, in contrast to the tightly-wound nylon or wool yarn and cork (or rubber) that constitutes a regulation baseball. Therefore, when cases in this series that are associated with chest barriers that proved to be inadequate are combined with those involving reduced-risk balls, 24 children in this registry died despite the perception that they were probably protected from serious injury by commercially available safety products. Although chest barriers and safety balls may reduce risk, it is apparent that these devices do not achieve absolute protection from commotio cordis and may only provide a false sense of security. This emphasizes the necessity of designing chest protectors that reliably cover the precordium under all circumstances and have

a high level of efficacy for preventing VF following a precordial blow.

Only about 15% of commotio cordis cases in this series survived their events^{22,23} with most achieving normal neurologic and cardiac function. These data suggest that particularly prompt cardiopulmonary resuscitation or defibrillation is a major determinant of surviving a commotio cordis event. Resuscitation efforts in 2 survivors demonstrated the importance of defibrillation (with automated external defibrillators) in terminating potentially lethal ventricular tachyarrhythmias and restoring sinus rhythm at the scene.

For cases in which electrocardiographic data were available, ventricular tachyarrhythmia was the substrate most commonly responsible for chest blow-induced sudden death, as previously demonstrated in our experimental animal model.^{17-20,24} Such ventricular tachyarrhythmias were commonly

identified at the scene and in the emergency department and were also the shockable rhythms in those cases in which survival was due to the availability and use of an automated external defibrillator. On the other hand, when cardiopulmonary support was substantially delayed, often due to the failure of bystanders to fully appreciate the nature of the collapse, survival rarely occurred. Nevertheless, prompt resuscitation for commotio cordis did not guarantee survival, underscoring the serious nature of chest impact-induced VF, even in the absence of underlying structural heart disease.

In conclusion, commotio cordis occurs in the setting of sporting events as well as in a variety of circumstances that are part of daily living and unrelated to athletic activities. Our observations emphasize the dangers implicit in striking the chest sharply under any condition, including light or inadvertent blows. Prevention of these catastro-

phes will be enhanced by greater education and awareness about commotio cordis and its pathophysiology, within both the lay and medical communities. Continued reports of these tragic events during sports emphasize the importance of more timely resuscitative efforts, including access to automated external defibrillators,²⁴ as well as developing preventive strategies including the design of effective chest barriers.

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Statistical expertise: Gohman.

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