Epidemiology of sport-related traumatic dental injury among United States High School Athletes

Raquel T. Capote

A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Public Health

University of Washington

2015

Reading Committee:

Stephen Hawes, Chair

Anne-Marie Bollen

Program Authorized to Offer Degree:

Epidemiology

University of Washington

Abstract

Epidemiology of sport-related traumatic dental injury
Among United States High School Athletes

Raquel T. Capote

Chair of the Supervisory Committee:
Associate Professor Stephen Hawes
Epidemiology

Background: Participation in high school athletics is steadily increasing thus placing more youth at risk for traumatic dental injuries (TDIs). TDI is an important public health problem due to its high prevalence, challenging management, economic burden, and potential for long-lasting detrimental effects. Although TDIs cannot be completely eliminated, injury rates and severity have the potential to be reduced.

Objectives: To describe dental injuries and examine the protective effect of mouthguards in sport-related dental injuries in high school athletes.

Methods: National High School Sports-Related Surveillance Study data (2005/2006−2013/2014) were analyzed. Certified athletic trainers from a national sample of participating high schools prospectively record injury incidence and athlete exposure (AE)

information for high school athletes participating in 20 sports. A case-control design was used to evaluate the effectiveness of mouthguards. Cases were all reportable dental injuries in the surveillance system during the study period. Four different control groups were used: oral soft-tissue injuries, ankle injuries, eye & nose injuries, and non-head/non-face injuries.

Results: The incidence rate for dental injuries was 0.63 per 100,000 AE; student-athletes required surgery with greater frequency for dental injuries (32%) as compared to oral soft-tissue, ankle, nose & eye, and non-head/non-face injury groups examined. When comparing dental injuries to the oral soft-tissue injuries, there was a persistent, though statistically non-significant, trend toward protection of mouthguard wear by approximately 20% after adjustment for athlete's sex, level of exposure, and sport [OR=0.80, 95% CI: 0.23-2.83]; using ankle injuries and non-head/face injuries control groups, mouthguard wear was significantly associated with lower odds of dental injury after adjustment for athlete's sex and level of exposure [OR=0.35; 95% CI: 0.22−0.55] and [OR=0.25, 95% CI: 0.16−0.39], respectively; using an eye & nose injury control group, mouthguard wear was associated with increased odds of dental injury, although the associate was not statistically significant [OR=1.56, 95% CI: 0.96-2.54].

Conclusions: We found that sport-related dental injuries were rarely reported yet often severe. The majority of players complied with the mandatory mouthguard equipment policy and there was some evidence of mouthguard protection against dental injuries.

TABLE OF CONTENTS

List of Tables

Introduction

Engaging in high school athletics has many health benefits but it also involves risk of injury, including dental trauma. As many as one third of all dental injuries are sports related.[1] Traumatic dental injury (TDI) is a common occurrence in the pediatric population and considered an important public health problem due to its high prevalence, challenging management, economic burden, and potential for long-lasting detrimental effects. Approximately 20% of children and adolescents have sustained trauma to a permanent tooth and it is estimated that 71-92% of all TDIs sustained in a lifetime occur before the age of 19 years.[2] Dental trauma can result in esthetic defects (i.e. crown fractures, discoloration), functional alterations (i.e. mobility, pain), and quality of life (QoL) impairment (i.e. avoids smiling, speaking, or laughing, exhibits a negative self-image, or has poor social interactions).[3,4] On average, children with an untreated TDI are 20 times more likely to report an impact on QoL because of injury as compared to children without dental trauma.[5] However, even with treatment, recent studies of adolescents with an uncomplicated crown fracture show that the impact of trauma on daily life is not eliminated.[6] These treated individuals still suffer from reduced quality of life compared with adolescents with no history of trauma.

TDIs can be particularly devastating because the majority of dental injuries affect the anterior teeth and are generally irreversible, involving long-term sequelae and care that will likely continue over a patient's lifetime.[7] TDIs are also more time-consuming and costly to treat than many other outpatient injuries.[8] The average number of ambulatory treatment visits in the immediate 12-month period following dental trauma to a permanent tooth has been shown to

range from 1.9−9.1, compared to an average of 1.5 visits for other similar bodily injuries.[9] Treatment time for traumas to permanent teeth is dominated by follow-ups irrespective of the complication status while the extent and cost of treatment depends on the degree of complication. In the U.S., the replacement cost for a single avulsed tooth ranges from $20,000−$35,000.[10] Furthermore, in an assessment of the socioeconomic burden of treating dental avulsions 90% of patients and 86% of parents reported that school and work time was lost as well.[11] Estimates from Sweden suggest the annual direct plus indirect costs of dental trauma to be 3.3−4.4 million USD per million individuals in patients up to 19 years of age.[7] However, much of the expensive treatment involves specialists in several disciplines with full repair carried out in the adult years. In a Danish study in which adults were included, the cost of treatment including only acute trauma service, follow-up and subsequent restoration, ranged from 2−5 million USD per million inhabitants per year.[12] The economic burden is substantial despite the reality that many TDIs are left untreated.[13]

Although traumatic dental injuries cannot be completely eliminated, injury rates and severity have the potential to be reduced. Athletic mouthguards are commonly regarded as protective devices against dental and oral soft tissue injuries. They are believed to reduce "absorbing energy imparted at the site of impact and by dissipating the remaining energy" which otherwise would be transferred directly to the underlying dentition.[14] Before the development of orofacial protectors such as helmets, face shields, and mouthguards, it was estimated that half of all football injuries occurred in and around the oral cavity,[15] and that most of those injuries could have been prevented by the use of athletic protective equipment during play.[16] Since 1962 all U.S. high school football players participating under the regulations of the National Federation

of State High School Athletic Associations (NFHS) have been required to wear mouthguards during games,[17] and it was subsequently stated that facial and dental injuries sustained on the football field were reduced by 48%.[18]

The National Federation of State High School Associations is committed to establishing standards to ensure the safety and general welfare of the millions of students who participate annually in organized high school sports. Currently the NFHS mandates mouthguards for football, field hockey, ice hockey, lacrosse and wrestling (for wrestlers wearing braces). Contact sports such as football and ice hockey have traditionally been profiled as high-risk activities for dental trauma, yet many other sports including basketball, baseball, and soccer have also been implicated in dental injury.[19] The American Dental Association (ADA) Council on Access, Prevention and Interprofessional Relations and the Council on Scientific Affairs recommend the use of a properly fitted mouthguard in any sporting or recreational activity that may pose a risk of injury.[20] The ADA lists 29 sports/exercise activities. However, there are limitations in the available evidence that athletic mouthguards are effective in reducing risk of dental and oral soft-tissue injury. U.S. government reports fail to make recommendations about the mandatory use of mouthguards because of the lack of quality research on their effectiveness.

The bulk of published research on mouthguards has focused on the physical properties of various materials used to make the guard rather than true effectiveness of protection *in vivo*. Few studies have attempted to investigate prospectively whether athletes who are wearing mouthguards sustain significantly fewer and/or less severe dental injuries as compared to those who do not. Many reports have been based primarily on questionnaires or subjective opinions among athletes

without statistical analysis or a control group. Moreover, prior studies have been limited by low sample size, both with respect to number of injuries and/or low numbers of participants.

Participation in high school athletics is steadily increasing, thus placing more youth at risk for TDI. Nearly 7.8 million students participated in high school athletics during the 2013-14 school year, representing an estimated 50% of all enrolled U.S. high school students.[21] Because of the serious consequences of traumatic dental injuries, there is overwhelming need to analyze risk and protective factor data of such injuries within the high school population. The Reporting Information Online (RIO) system is currently the only sports injury surveillance system of a national sample of U.S. high school athletic teams. The RIO system prospectively records injury surveillance data each year for high school athletes and is closely modeled after the National Collegiate Athletic Association Injury Surveillance System, which has successfully collected quality data on injuries, athletic exposures, and risk factors since 1982. RIO data has been used successfully in several projects but has not been applied to investigate dental injuries and the effectiveness of athletic mouthguards. This study aimed to use this database to (1) describe the epidemiology (including risk factors such as age, sex, sport and level of competition) of sports-related traumatic dental injury in U.S. High School athletes and (2) examine the protective effect of mouthguards in sport-related dental injuries from 2004/2005-2013/2014 academic year using a case-control study design.

Methods

Data source

Data for the present study were collected as part of the National High School Sports-Related Surveillance Study and obtained from Dr. R. Dawn Comstock, principal investigator of High School RIO™. The surveillance system has been described previously.[22,23,24] In the current study, National High School Sports-Related Surveillance Study data (2005/2006−2013/2014) were analyzed.

The surveillance system consists of a sample of high schools with 1 or more National Athletic Trainers' Association–affiliated certified athletic trainers with valid e-mail addresses. Since it began in the 2005/2006 school year, sport injury surveillance has expanded from 9 sports to a comprehensive report of 20 sports. High School RIO™ has 2 data collection panels (Table 1): (i) a random sample of 100 schools recruited annually since 2005/2006 that report data for 9 sports; and (ii) an average of 84 schools recruited annually since 2008/2009 that report data for 11 additional sports of interest. For the first panel, high schools were recruited into 8 strata based on school population (enrollment ≤1000, or >1000) and US Census geographic region (Northeast, Midwest, South, or West). If a school dropped out of the surveillance study, a replacement school from the same sampling stratum was enrolled. Because of strong regional variations in sport sponsorship (i.e. boys' ice hockey, girls' field hockey, boys' and girls lacrosse) it was impossible to approximate a random sample for the second panel. As a result, exposure and injury data for the schools in the second panel represent a convenience sample of US high schools.

Table 1: The two data collection panels of High School RIO ™

(i) First panel: since 2005/2006	(ii) Second panel: since 2008/2009
Representative sample of 100 US high schools	Same reporting mechanism but different sampling methodology Convenience sample Attempt to enroll 100 schools reporting for each sport
9 sports: Boys' football, soccer, basketball, wrestling, and baseball Girls' volleyball, soccer, basketball, and softball	11 sports*: Boys' lacrosse, ice hockey, swimming & diving, and track & field Girls' lacrosse, field hockey, gymnastics, swimming & diving, and track & field *2009/2010 expansion included cheerleading and boys' volleyball.

Data from both panels were used in this study.

Data Collection

Modeled after the National Collegiate Athletic Association (NCAA) Injury Surveillance Program, High School RIO™ relies on weekly reports from National Athletic Trainers' Association-affiliated certified athletic trainers across the country to prospectively record injury surveillance data for high school athletes. Certified athletic trainers (ATs) from participating high schools reported injury incidence and athlete exposure information throughout the academic year by using a secure website. After each adverse event, the AT completed a detailed injury report on the injured athlete (e.g., age, sex, height, weight, year in school), the injury (e.g., principal body site, diagnosis, severity), and the injury event (e.g., activity, mechanism, player position, level of play, protective equipment). Athletic trainers were only required to indicate whether the student-athlete was wearing a mouthguard at the time of injury if the principal site of the reported injury was oral. If a mouthguard had been worn, ATs were then to specify the type of mouthguard in use i.e. self-fitted "boil and bite" vs. professionally-fitted custom appliance. For all injuries, ATs were asked whether they believed the addition of protective equipment or

the more appropriate use of equipment would have been beneficial and to describe. ATs also reported whether injured players had previously sustained the specific injury (i.e., injury recurrence). Throughout the study, participating ATs were able to view and update previously submitted reports as needed with new information (e.g., need for surgery, "time loss" or number of days until athlete return to play). Data capture occurred weekly throughout the academic year. Reporters who repeatedly failed to complete the weekly exposure and injury reports or who had errors with their reporting were contacted by the RIO system staff and either reminded to report, asked to correct errors, or assessed for their willingness to continue participating in the study.

Definitions

A reportable injury in the RIO surveillance system was initially defined as one that (1) occurred as a result of an organized high school athletic practice or competition, (2) required medical attention by a certified athletic trainer or physician, and (3) resulted in restriction of the athlete's participation for 1 or more days beyond the day of injury. The definition expanded slightly in the 2007/2008 school year to include all brain concussions, fractures, and dental injuries resulting from participation in a high school-sanctioned practice or competition, regardless of whether it resulted in a restriction of the student-athlete's participation. In the case of multiple concurrent injuries, the certified athletic trainer determined and reported the most severe injury.

Injuries were categorized into oral injuries and non-oral injuries.[25] Oral injuries comprised of dental and soft-tissue injuries. Dental injuries included hard tissue injuries or fractures to the tooth, alveolus, and jaw as well as supporting periodontal injury classified as concussion, subluxation, dislocation, and avulsion injuries.[26] Soft-tissue injuries encompassed oral

lacerations, contusions, abrasions, as well as ligament sprain and muscle strain of the temporomandibular complex. All other injuries were defined as non-oral injuries.

An athlete-exposure (AE) was defined as 1 athlete participating in a whole, or any part of, a team athletic practice or competition. Only athletes with actual playing time, regardless of the time associated with that participation, were counted as having exposures. This method provides a more accurate estimate of injury risk than the standard practice of using the total number of players as the denominator.

Selection of cases and controls

Cases were defined as all reportable dental injuries in the RIO surveillance system during the study period (2005/2006−2013/2014 school years). For all analyses conducted, four different control groups were used, each recognized according to the principal injury identified on the AT injury report. The first control group consisted on all reportable oral soft-tissue injuries. The latter three control groups were of student-athletes who sustained non-oral injuries: ankle injuries; eye & nose injuries; non-head/non-face injuries. Ankles injuries were retained in the fourth control group.

Measure of mouthguard exposure

Exposure to mouthguard wear was determined using two methods: (i) measured directly for only oral injuries in the athletic trainer report and (ii) applied NFHS mandate which requires mouthguards in football, field hockey, ice hockey, lacrosse and wrestling (for wrestlers wearing braces). For other sports, mouthguard use was optional.

ATs were required to indicate whether the student-athlete was wearing a mouthguard during the injury event for only oral injuries. When missing in the AT oral injury report, data was imputed to absence of mouthguard using the AT's response that the addition of a mouthguard would have been beneficial.

The athletic trainer did not record mouthguard wear for the latter three control groups (non-oral injuries). As a surrogate for mouthguard wear, we assumed regulatory compliance. In other words, we considered an athlete was wearing a mouthguard if it was required for all players in the sport.

Statistics

All analyses were performed using Stata12 software (Stata Statistical Software: Release 12; StataCorp LP, College Station, TX). Descriptive statistics were calculated, including frequency and percent for categorical variables and mean and standard deviations for quantitative variables. We also calculated the incidence rate (IR) per 100,000 AE for injuries. The total number of AEs during the study period was determined by selecting for sports in which dental and soft-tissue injuries were reported. Seven sports were excluded because they were without registered dental and oral soft-tissue injuries: boys' and girls' volleyball, boys' and girls' swimming and diving, boys' and girls' track and field, and girls' gymnastics.

Kappa and Kendall's correlation coefficient was used in attribute agreement analysis for mouthguard exposure ascertained from AT report and mouthguard exposure determined by

NFHS sport rule. For each comparison group in the case-control analysis, we ran separate logistic regression models with mouthguard wear (yes/no) as the exposure and dental injury (yes/no) as the outcome. Associations were measured using odds ratios, with 95% confidence intervals. A factor was considered a confounder after consideration of its relationship to the exposure and outcome and if its adjusted and crude OR differed by more than 10%. Potential confounders/effect modifiers included athlete's sex, sport, and level of exposure (competition vs. practice). The possible confounding effects of these variables were evaluated by comparing crude and adjusted ORs.

Because all data were de-identified the University of Washington institutional review board provided the determination of nonhuman subjects research and considered this research to be exempt from review.

Results

A total of 300 reportable oral injuries were identified through the RIO surveillance system during the 9-year study period. These injuries comprised of nearly equal number of traumatic dental injuries (N=149) and soft-tissue injuries (N=151) (Table 2). Tooth fractures accounted for half of all reported dental injuries. In addition, 19 tooth avulsions were registered by ATs, which represented 13% of the reported dental injuries. The majority (71%) of oral soft-tissue injuries were lacerations, mainly of the lip.

Table 2: Characteristics of Oral Injuries Among High School Athletes, RIO Surveillance Study, United States, 2005/2006 – 2013/20014 School Years

ORAL INJURIES	N	(%)
DENTAL INJURIES	149	100
Tooth Concussion	4	3
Tooth Subluxation	21	14
Tooth Luxation with displacement	23	15
Complete Tooth Avulsion	19	13
Nerve Damage	3	2
Tooth Fracture	74	50
Alveolar Fracture	2	1
Jaw Fracture	2	1
Tooth, not otherwise specified	1	1
SOFT-TISSUE INJURIES	151	100
Oral laceration	107	71
Oral contusion	31	21
Oral abrasion	3	2
Muscle strain/Ligament sprain of TMJ	10	7

Most of the TDIs sustained by student-athletes occurred during regular season play (77%), and nearly all (97%) were new injuries as opposed to recurrences or complications from previous injuries (Table 3).

Table 3: Demographic characteristics of dental injury cases and controls in U.S. high school student athletes, High School Sports-Related Injury Surveillance Study, United States, 2005/2006 - 2013/2014 School Years

CHARACTERISTICS		PRINCIPAL INJURY REPORTED									
		ORAL INJURIES				NON-ORAL INJURIES					
		Cases		Control 1		Control 2		Control 3		Control 4	
		DENTAL		ORAL SOFT-TISSUE		ANKLE		EYE & NOSE		NON-HEAD/NON-FACE	
		(N=149)		(N=151)		(N=9,741)		(N=642)		(N=46,323)	
Age (years)	Mean± (SD)	15.9	±1.3	16.0	±1.1	16	±1.3	16	±1.2	15.9	±1.3
	Unknown N (%)	34.0	(23)	29.0	(19)	1,613	(17)	116	(18)	7,694	(17)
		N	(%)	N	(%)	N	(%)	N	(%)	N	(%)
Sex	Male	107	(72)	98	(65)	5,998	(62)	395	(62)	32,983	(71)
	Female	42	(28)	53	(35)	3,743	(38)	247	(38)	13,340	(29)
Year in High School	Freshman	34	(23)	25	(17)	2,036	(21)	116	(18)	10,013	(22)
	Sophmore	38	(26)	37	(25)	2,395	(25)	191	(30)	11,238	(25)
	Junior	35	(24)	53	(36)	2,435	(25)	178	(28)	11,764	(26)
	Senior	40	(27)	33	(22)	2,735	(28)	147	(23)	12,645	(28)
	Unknown	2	(1)	3	(2)	140	(1)	10	(2)	663	(1)
Play Level	Varsity	86	(66)	91	(62)	5,394	(61)	354	(62)	26,169	(62)
	Junior Varsity	34	(26)	43	(29)	2,179	(25)	167	(29)	10,092	(24)
	Freshman	5	(4)	8	(5)	812	(9)	40	(7)	3,993	(9)
	Sophmore	1	(1)	0	(0)	42	(0)	0	(0)	162	(0)
	Other	4	(3)	5	(3)	345	(4)	14	(2)	1,863	(4)
	Unknown	19	(13)	4	(3)	969	(10)	67	(10)	4,044	(9)
Sport [a]	Boys' football	16	(11)	24	(16)	3,015	(31)	58	(9)	18,717	(40)
	Boys' ice hockey	2	(1)	1	(1)	32	(0)	3	(0)	547	(1)
	Girls' field hockey	8	(5)	15	(10)	106	(1)	24	(4)	697	(2)
	Boys' lacrosse	5	(3)	1	(1)	145	(1)	4	(1)	1,026	(2)
	Girls' lacrosse	3	(2)	1	(1)	133	(1)	5	(1)	490	(1)
	Boys' soccer	10	(7)	14	(9)	743	(8)	62	(10)	3,171	(7)
	Girls' soccer	6	(4)	13	(9)	991	(10)	47	(7)	3,481	(8)
	Boys' basketball	39	(26)	30	(20)	1,425	(15)	135	(21)	3,349	(7)
	Girls' basketball	11	(7)	11	(7)	1,147	(12)	71	(11)	3,147	(7)
	Boys' baseball	21	(14)	18	(12)	216	(2)	78	(12)	1,637	(4)
	Girls' softball	10	(7)	11	(7)	288	(3)	56	(9)	1,449	(3)
	Boys' wrestling	12	(8)	9	(6)	296	(3)	58	(9)	3,327	(7)
	Cheerleading	5	(3)	1	(1)	93	(1)	28	(4)	479	(1)
	Boys' volleyball	0	(0)	0	(0)	21	(0)	0	(0)	37	(0)
	Girls' volleyball	1	(1)	0	(0)	800	(8)	10	(2)	1,966	(4)
	Boys' swimming and diving	0	(0)	1	(1)	0	(0)	0	(0)	98	(0)
	Girls' swimming and diving	0	(0)	0	(0)	6	(0)	2	(0)	171	(0)
	Boys' track and field	0	(0)	1	(1)	101	(1)	0	(0)	1,124	(2)
	Girls' track and field	0	(0)	0	(0)	145	(1)	1	(0)	1,265	(3)
	Girls' gymnastics	0	(0)	0	(0)	38	(0)	0	(0)	145	(0)
Type of Exposure	Competition	87	(58)	85	(56)	5,082	(52)	367	(57)	23,148	(50)
	Practice	62	(42)	66	(44)	4,659	(48)	275	(43)	23,175	(50)
Time in Season	Pre-Season	25	(17)	25	(17)	2,148	(22)	86	(14)	11,246	(24)
	Regular Season	114	(77)	115	(77)	7,217	(75)	523	(82)	33,278	(72)
	Post-Season	10	(7)	9	(6)	317	(3)	27	(4)	1,535	(3)
	Unknown	0	(0)	2	(1)	59	(1)	6	(1)	264	(1)
School Year [a, b]	2005-2006	18	(12)	3	(2)	907	(9)	58	(9)	3,783	(8)
	2006-2007	14	(9)	15	(10)	883	(9)	66	(10)	3,989	(9)
	2007-2008	12	(8)	13	(9)	852	(9)	61	(10)	4,096	(9)
	2008-2009	18	(12)	24	(16)	1,179	(12)	94	(15)	6,031	(13)
	2009-2010	18	(12)	20	(13)	1,173	(12)	66	(10)	5,880	(13)
	2010-2011	16	(11)	11	(7)	1,059	(11)	74	(12)	4,969	(11)
	2011-2012	19	(13)	15	(10)	998	(10)	56	(9)	4,832	(10)
	2012-2013	18	(12)	20	(13)	1,256	(13)	82	(13)	5,964	(13)
	2013-2014	16	(11)	30	(20)	1,434	(15)	85	(13)	6,779	(15)

[a] Data reported on 9 sports in 2005/2006 School Year; High School RIO™ expanded to include 9 additional sports of interest in 2008/2009 and added 2 sport in 2009/2010 school year

[b] Definition of reportable injury expanded in 2007/2008 school year to include all brain concussions, fractures, and dental injuries resulting from participation in a high school-sanctioned practice or competition, regardless of whether it resulted in a restriction of the student-athlete's participation.

CHARACTERISTICS		PRINCIPAL INJURY REPORTED									
		ORAL INJURIES				NON-ORAL INJURIES					
		Cases		Control 1		Control 2		Control 3		Control 4	
		DENTAL		ORAL SOFT-TISSUE		ANKLE		EYE & NOSE		NON-HEAD/NON-FACE	
		(N=149)		(N=151)		(N=9,741)		(N=642)		(N=46,323)	
		N	(%)	N	(%)	N	(%)	N	(%)	N	(%)
Mechanism of Injury	Contact with another person	94	(63)	88	(59)	4,008	(42)	405	(64)	19,139	(42)
	Contact with playing surface	8	(5)	6	(4)	2,347	(24)	13	(2)	8,187	(18)
	Contact with playing apparatus	45	(30)	51	(34)	414	(4)	205	(32)	3,229	(7)
	Contact with out of bounds object	0	(0)	1	(1)	5	(0)	0	(0)	34	(0)
	No contact (e.g. pulled muscle, overuse/chronic)	0	(0)	1	(1)	2,741	(29)	0	(0)	14,485	(32)
	Other	2	(1)	3	(2)	87	(1)	9	(1)	662	(1)
	Unknown	0	(0)	1	(1)	139	(1)	10	(2)	587	(1)
New or Recurrence											
	New injury	144	(97)	146	(99)	8,243	(85)	618	(97)	40,780	(89)
	Recurrence	5	(3)	2	(1)	1,406	(15)	19	(3)	5,015	(11)
	Unknown	0	(0)	3	(2)	92	(1)	5	(1)	528	(1)
Time Loss [b]	<1wk	96	(68)	117	(82)	4,373	(50)	367	(62)	20,668	(51)
	1-3wks	26	(18)	23	(16)	3,661	(41)	169	(29)	13,368	(33)
	>3wks	10	(7)	2	(1)	546	(6)	26	(4)	3,713	(9)
	Season ending	9	(6)	1	(1)	247	(3)	30	(5)	3,106	(8)
	Unknown	8	(5)	8	(5)	914	(9)	50	(8)	5,468	(12)
Do you (athletic trainer) believe the addition of protective equipment or the more appropriate use of equipment would have been beneficial?											
	Yes	90	(60)	60	(41)	2,910	(30)	118	(19)	5,841	(13)
	No	54	(36)	81	(55)	5,809	(60)	472	(75)	37,088	(81)
	Unknown	5	(3)	7	(5)	925	(10)	42	(7)	3,001	(7)
	Missing	0	(0)	3	(2)	97	(1)	10	(2)	393	(1)
Required Surgery	Yes	47	(32)	15	(10)	155	(2)	126	(20)	3,336	(7)
	Unknown	4	(3)	1	(1)	153	(2)	17	(3)	1,067	(2)
Has player had unrelated injury reported this season?											
	Yes	24	(16)	15	(10)	1,080	(11)	86	(14)	5,912	(13)
	No	123	(84)	133	(90)	8,531	(89)	547	(86)	39,869	(87)
	Missing	2	(1)	3	(2)	130	(1)	9	(1)	542	(1)

[b] Definition of reportable injury expanded in 2007/2008 school year to include all brain concussions, fractures, and dental injuries resulting from participation in a high school-sanctioned practice or competition, regardless of whether it resulted in a restriction of the student-athlete's participation.

Although these injuries largely (68%) resulted in a time loss from sport participation of less than 7 days, student-athletes required surgery (47 of 139 or 32%) with greater frequency for dental injuries as compared to other injuries examined in the study (Table 3). For the majority of injuries (60%) certified athletic trainers indicated that they believed the addition of protective equipment or more appropriate use would have been beneficial.

Direct player contact was the predominant mechanism of injury for dental, oral soft-tissue, ankle, eye and nose, and non-head/non-face injuries. This was followed by contact with a playing apparatus (i.e. contact with a baseball) for dental, oral soft-tissue and eye & nose injuries. In contrast, the second most common mechanism of injury resulting in ankle or non-head/non-face

injuries was no contact (e.g. pulled muscle, overuse/chronic).

Similar to other injuries examined, the majority (66%) of dental injuries occurred at the varsity level of play and during competition. No dental injuries were reported for boys' or girls' swimming and diving, boys' or girls' track and field, boys' volleyball, and girls' gymnastics. Excluding sports for which dental and soft-tissue injuries were not reported, there were 23,612,426 AEs resulting in a dental injury rate of 0.63 per 100,000 AEs (Table 4).

Table 4: Injury Rates per 100 000 Athlete-Exposures by Sex, Sport, Level of Exposure, and Mouthguard Regulation for Select High School Sports*, High School Sports-Related Injury Surveillance Study, United States, 2005/2006 - 2013/2014 School Years

	Athlete-Exposures	Dental Injuries		Oral Soft-Tissue Injuries		All Oral Injuries		Ankle Injury		Eye & Nose Injury		Non-Head/Non-Face Injury	
		N	Injury Rate	N	Injury Rate	N	Injury Rate	N	Injury Rate	N	Injury Rate	N	Injury Rate
Overall*	23,612,426	148	0.63	149	0.63	297	1.26	8,630	36.55	629	2.66	41,517	175.83
by Sex [a]													
Boys' sports	15,867,971	105	0.66	97	0.61	202	1.27	5,872	37.01	398	2.51	31,774	200.24
Girls' sports	7,744,455	43	0.56	52	0.67	95	1.23	2,758	35.61	231	2.98	9,743	125.81
by Sport													
Boys' football [d]	5,929,294	16	0.27	24	0.40	40	0.67	3,015	50.85	58	0.98	18,717	315.67
Boys' ice hockey [b,d]	356,997	2	0.56	1	0.28	3	0.84	32	8.96	3	0.84	547	153.22
Girls' field hockey [b,d]	569,551	8	1.40	15	2.63	23	4.04	106	18.61	24	4.21	697	122.38
Boys' lacrosse [b,d]	662,960	5	0.75	1	0.15	6	0.91	145	21.87	4	0.60	1,026	154.76
Girls' lacrosse [b,d]	481,687	3	0.62	1	0.21	4	0.83	133	27.61	5	1.04	490	101.73
Boys' soccer	2,225,836	10	0.45	14	0.63	24	1.08	743	33.38	62	2.79	3,171	142.46
Girls' soccer	1,900,452	6	0.32	13	0.68	19	1.00	991	52.15	47	2.47	3,481	183.17
Boys' basketball	2,680,389	39	1.46	30	1.12	69	2.57	1,425	53.16	135	5.04	3,349	124.94
Girls' basketball	2,160,536	11	0.51	11	0.51	22	1.02	1,147	53.09	71	3.29	3,147	145.66
Boys' baseball	2,041,045	21	1.03	18	0.88	39	1.91	216	10.58	78	3.82	1,637	80.20
Girls' softball	1,522,740	10	0.66	11	0.72	21	1.38	288	18.91	56	3.68	1,449	95.16
Boys' wrestling	1,971,450	12	0.61	9	0.46	21	1.07	296	15.01	58	2.94	3,327	168.76
Cheerleading [c]	1,109,489	5	0.45	1	0.09	6	0.54	93	8.38	28	2.52	479	43.17
by Level of Exposure													
Competition	6,401,111	86	1.34	85	1.33	171	2.67	4,693	73.32	360	5.62	21,652	338.25
Practice	17,211,315	62	0.36	64	0.37	126	0.73	3,937	22.87	269	1.56	19,865	115.42
by Mouthguard Regulation [e]													
Yes	8,000,489	34	0.42	42	0.52	76	0.95	3,431	42.88	94	1.17	21,477	268.45
No	15,611,937	114	0.73	107	0.69	221	1.42	5,199	33.30	535	3.43	20,040	128.36

* 7 sports without injuries registered for dental and oral soft-tissue were excluded. These sports were boys' and girls' volleyball, boys' and girls' swimming and diving, boys' and girls' track and field, and girls' gymnastics

[a] We attributed A-E for cheerleading to female participation because according to a 2013-14 High School Athletic Participation Survey conducted by the NHFS,

[b] Reported since 2008/2009 school year

[c] Reported since 2009/2010 school year

[d] Sports requiring mouthguard wear according to NFHS mandate

[e] Applied NFHS mandate (sport rule)

Greater numbers of the dental injuries were registered for boys' sports. Boys' basketball and baseball were responsible for 39 (26%) and 21 (14%) of the dental injuries captured in High School RIO^{TM} respectively. However, these apparent sex differences become less pronounced when calculating injury rates using athlete-exposure (IR= 0.66 vs. 0.55). The highest rate of injury per 100,000 AE occurred in boys' basketball (1.46), followed by girls' field hockey (1.40), then boys' baseball (1.03). Notably, the overall rate of oral injury in girls' field hockey exceeded all other boys' sports and girls' sports. The injury rates were higher in competition than practice for both oral and non-oral injuries. In contrast to ankle and non-head/non-face IRs by mouthguard regulation, injury rates of dental, oral-soft tissue and eye-nose were higher in sports not requiring mouthguard use than for those in which mouthguard wear was compulsory (Table 4).

Athletic trainers completed 300 injury reports for student-athletes who sustained an oral injury; 56 of these reports failed to indicate whether a mouthguard was being by athlete at the time injury (Table 5). Thus, 244 oral injuries were included in these analyses representing various sports. For 122 of the dental cases, mouthguard wear was reported by the athletic trainer. The remaining 27 were missing mouthguard wear and were excluded from all analyses. Similarly, for the 151 oral soft-tissue injuries, the athletic trainer recorded mouthguard wear for 122, and 29 were excluded from the analysis.

Table 5: Regulatory compliance: A comparison of athletic trainer observed mouthguard use among student-athletes with oral injuries and the NFHS's mandatory mouthguard equipment policy by sport.

	MOUTHGUARD USE BY ATHLETIC TRAINER REPORT			
SPORT RULE	Yes	No	unknown	Total
NFHS Mandates Mouthguard Wear				
Boys' football	26	7	7	40
Boys' ice hockey	2	0	1	3
Girls' field hockey	16	4	3	23
Boy's lacrosse	5	0	1	6
Girls' lacrosse	4	0	0	4
Not Compulsory to Wear				
Boys' soccer	1	19	4	24
Girls' soccer	0	9	10	19
Boys' basketball	0	58	11	69
Girls' basketball	0	18	4	22
Boys' baseball	0	30	9	39
Girls' softball	1	16	4	21
Boys' wrestling	0	19	2	21
Cheerleading	0	6	0	6
Girls' volleyball	0	1	0	1
Boys' swimming and diving	0	1	0	1
Boys' track and field	0	1	0	1
TOTAL	55	189	56	300

	All Oral Injuries	
NFHS Sport Rule	AT reported use	AT reported non-use
Wear Required	53	11
Wear NOT Required	2	178

kappa	0.8558	*very good aggreement between sport rule and AT report*
kendall's tau-b	0.8601	*sport rule and AT report are highly correlated*

Overall, there was very good agreement between athletic trainer reporting and NFHS's mandatory mouthguard equipment policy (Kappa=0.86). Among those with oral injuries (n=64) playing in sports with a mandatory mouthguard policy, 11 student athletes (17%) did not adhere to NFHS's sport regulations on mandatory mouthguard wear.

Table 6: Odds Ratios of the Association Between Use of Athletic Mouthguard at Time of Sports-Related Trauma and Dental Injuries Among U.S. High School Athletes, High School Sports-Related Surveillance Study, United States, 2005/2006 - 2013/2014 School Years

	ORAL INJURIES						NON-ORAL INJURIES					
	CASES	**Control 1**					**Control 2**		**Control 3**		**Control 4**	
MOUTHGUARD WEAR	**Dental injuries**	**Oral soft-tissue injuries**	OR (95% CI)	Adjusted OR* (95% CI)	Adjusted OR** (95% CI)	Adjusted OR*** (95% CI)	**Ankle injuries**	Adjusted OR** (95% CI)	**Eye & Nose injuries**	Adjusted OR** (95% CI)	**Non-head/ Non-face injuries**	Adjusted OR** (95% CI)
	N=122	N=122					N=9,741		N=642		N=46,323	
By Athletic Trainer report for Oral injuries and By Sport rule for Non-Oral injuries [a]	26 (21.3%)	29 (23.8%)	0.87 (0.48–1.58)	0.89 (0.49–1.64)	0.86 (0.47–1.57)	0.80 (0.23–2.83)	3,431 (35.2%)	0.35 (0.22–0.55)	94 (14.6%)	1.56 (0.96–2.54)	21,477 (46.4%)	0.25 (0.16–0.39)
	N=149	N=151					N=9,741		N=642		N=46,323	
By Athletic Trainer report <u>with</u> Sport rule imputed for 56 oral injuries missing AT mouthguard report [b]	30 (20.1%)	37 (24.5%)	0.78 (0.45–1.34)	0.79 (0.46–1.36)	0.77 (0.23–2.55)	0.68 (0.20–2.33)	-	-	-	-	-	-
By Sport rule exclusively	34 (22.8%)	42 (27.8%)	0.77 (0.45–1.29)	0.78 (0.46–1.32)	0.78 (0.46–1.32)	-	3,431 (35.2%)	0.39 (0.26–0.59)	94 (14.6%)	1.69 (1.09–2.63)	21,477 (46.4%)	0.28 (0.19–0.42)

Case-control analysis with No. (%), Odds Ratio (95% CI), and Adjusted OR (95% CI)

[a] For 244 Oral Injuries, AT injury report was used to determine student-athlete mouthguard use at time of injury. Recategorized 9 missing responses to not mouthguard absent based AT indication that the addition of a mouthguard would have been beneficial

[b] For remaining 56 Oral Injuries without an AT report on mouthguard use or nonuse, sport rule was use to categorize wear (N=300)

* Adjusted for sex
** Adjusted for sex and level of exposure (competition vs. practice)
*** Adjusted for sex, level of exposure (competition vs. practice), and sport

A series of case control analyses were performed to describe the association between mouthguard wear and dental injuries (Table 6). Four separate control groups were used: oral soft-tissue injuries, ankle injuries, eye & nose injuries, and non-head/non-face injuries. For all comparisons except vs. eye & nose injuries, mouthguard wear was associated with lower odds of dental injury, supporting the hypothesized protective effect of mouthguard wear against dental injury. We adjusted for confounding variables, sex, level of exposure (completion vs. practice), and sport when comparing dental injuries to the oral soft-tissue injuries. There was a non-significant association between mouthguard wear reported by athletic trainer and dental injuries adjusted for sex and level of exposure when oral-soft tissue injuries were used as the control group. This association persisted, although remained statistically non-significant, after additional adjustment for sport [OR=0.80; 95% CI: 0.23−2.83].

Using non-oral injury categories as control groups, there were significant associations between mouthguard wear and dental injuries. For ankle injuries and non-head/face injuries, mouthguard wear was significantly associated with lower odds of dental injury adjusted for sex and level of exposure [OR=0.35; 95% CI: 0.22−0.55] and [OR=0.25, 95% CI: 0.16−0.39], respectively. When compared to the eye & nose control group, mouthguard wear was associated with increased odds of dental injury, although the association was not statistically significant [OR=1.56; 95% CI: 0.96−2.54]. Notably, for the comparison of dental injuries to the eye & nose controls (and other non-oral injury controls), we could not control for sport.

Using alternate definitions of mouthguard exposure for oral injuries (i.e. measured by AT report, determined by NFHS protective equipment sport regulation, or defined as a combination) did not

produce qualitatively different results for any comparison. However, when using sport rule to define mouthguard wear among dental injuries, mouthguard wear was significantly associated with increased odds of dental injury [OR=1.69; 95% CI: 1.09−2.63], or said another way, mouthguard use was associated with lower risk of eye & nose injury.

Discussion

Our study evaluated oral injury data captured by the National High School Sports-Related Injury Surveillance System for 20 different sports over a 9-year period (2005-2014). A key finding was that sport-related dental injuries were rarely reported (0.63 per 100,000 AE) yet often severe. Student-athletes required surgery with greater frequency for dental injuries (32%) as compared to ankle, nose & eye, and non-head/non-face injury groups examined. A previous study that included all body site fractures resulting from participation in high school sports found "mouth/teeth" second only to "thigh/upper leg" as a site where fracture was frequently a surgery-requiring diagnosis.[27] In our study, tooth fractures accounted for half of all registered dental injuries. This is consistent with previous reports on trauma to the permanent dentition.[28,29,30] In addition, 13% of the TDIs recorded in High School RIO™ were avulsions of permanent teeth, which is similar to that reported in retrospective audits of emergency presentations for dental trauma at hospitals.[28,29] Separation of a permanent tooth from the socket is a serious injury and requires urgent care. Prognosis depends largely on the length of time the tooth is outside the socket so very effort should be made to replant the tooth within the first 15–20 minutes.[31] The International Association of Dental Traumatology recommends replantation at most within 1 hour of the trauma or the long-term prognosis is not favorable.[32] Timely care often relies on the

person(s) present at the site of the injury event to reimplant and/or reposition luxated teeth prior to the initial dental contact. Multiple studies report that parents and teachers, including physical education teacher,[33] have inadequate knowledge to appropriately manage dental injuries. [34,35,36] To our knowledge, the competency of National Athletic Trainers' Association-affiliated certified athletic trainers in dealing with the initial management dental trauma has not been assessed.

The present study also reaffirms that injury rates vary depending on the sport while providing new information on the great risk of oral injuries in US high school girls' field hockey. High school boys' basketball followed by boys' baseball, were the sports with the largest total numbers of registered dental injuries. This finding is echoed in the literature on dental trauma[37,38,39] and recognized in the American Academy of Pediatric Dentistry's published Policy on Prevention of Sports-related Orofacial Injuries,[40] although neither high school basketball nor high school baseball are included in NFHS's position statement on sports for which mouthguard use is mandatory. Because the mechanisms responsible for dental injuries differ by sport the character and nature of the particular game should be considered. In basketball, the relatively small court, close proximity of players, and speed of the game increases the potential for possible oral trauma. The predominant mechanism of injury was direct player contact often by hand or elbow to the face or by collision. In contrast the majority of dental injuries sustained in boys' baseball were attributed to direct impact with the ball, primarily when fielding a hit or thrown baseball. Player positions found most at risk were pitchers, infielders, and batters. These findings within baseball are in agreement with earlier epidemiologic studies analyzing the High School RIO^{TM} database[37,41] as well as a 12-year retrospective review of facial fractures sustained in baseball or softball using the medical records patient database at Strong Memorial Hospital,

Rochester, NY.[42] Bak et al. reported that 68% of fractures were caused by impact with a ball, the most common of which were midface factures.[42]

Basketball and baseball were also found to be the sports most frequently associated with dental injuries in girls. However, dental injury rates per 100,000 AE for girls' field hockey exceeded rates calculated for all girl sports (girls' field hockey IR=1.40; softball IR=0.66; IR basketball=0.51) thus demonstrating the value in having athletic trainers collect data on athlete-exposure (opportunities for the possibility of athletic injury). Girls' field hockey has largely been overlooked in the sports-injury research field probably due to its relatively low participation. According to the 2013-14 NFHS High School Athletics Participation Survey, field hockey is played by 61,471 girls in 1,795 programs nationwide. This is about 1/7th of the number of females who engaged in high school girls' basketball during that year.[21] To our knowledge, this present study is the first to document the overall high rate of oral injuries, both dental and soft-tissue, associated with girls' field hockey (IR=4.04). This rate exceeds the oral injury rates found in any boys' or girls' high school sport captured by RIO^{TM}.

Similar to girls' softball and boys' baseball, dental injuries for girls' field hockey are predominately attributed to direct impact with a playing apparatus, most commonly the ball, next was the stick. Advances in stick construction and new reinforcement materials that allow players to hit the ball with greater velocity, elimination of the offside rule, and alterations to the substitution guidelines to allow the prompt and frequent interchange of players are changes that promote fast-paced, continuous play but may increase risk of injury. For example, a strategy that has been adopted by teams since the elimination of the offside rule is filling the striking circle

with as many defenders as possible. This tactic crowds the goal area and may increase the risk of injury to players. Despite the NFHS rules for girls' field hockey that require all field players to wear shin guards, mouthguards, and as of April 2011, eye protection that meets the current American Society for Testing and Materials (ASTM) standard for field hockey, those who play remain at risk of injury to the mouth, eyes and nose from lofted shots, rebounds off sticks, and the backward swing of the stick when making a chase tackle from the rear of a player about to strike a ball. These findings suggestion that a helmet with a full-face shield should be considered when playing high school girls' field hockey as this orofacial protective equipment is required in ice hockey.

The rules of play are the foundation of safe conduct in sports because they set expectations for behavior and define infractions. The NFHS currently requires mouthguards for football, field hockey, ice hockey, lacrosse and wrestling (for wrestlers wearing braces). In the current study, the presence of a mouthguard worn at the time of trauma was recorded for players with oral injuries. According to athletic trainer report, the majority of the injured student-athletes in our study complied with NFHS's mandatory mouthguard equipment policy. This seems plausible due to greater enforcement and/or supervision at the high school level. Hawn et al.,[43] reported on ATs estimates of mouthguard wear in NCAA men's collegiate ice hockey competition and found a higher overall level of enforcement at the combined Division II and III levels (82%) than at the combined Division I and independent levels (65%). In addition, Hawn reported that both the AT and coach were more likely to encourage mouthguard use at the Division II and III levels and found that this heightened level of enforcement corresponded with significantly higher athlete compliance at Division II and III levels (72%) than at Division I and independent levels

(52%). Our study demonstrates that NFHS's mandatory safety equipment standards as pertaining to mouthguard wear appear to be upheld. A finding of equal interest is the virtual absence of mouthguard use (n=2) among injured high school athletes participating in sports for which mouthguard wear was optional. Cronwell et al.,[44] in a study to measure mouthguard wear by basketball players in Victoria, Australia, documented that the most frequent reason given by youth and adult athletes for never wearing a mouthguard during basketball play was that they had 'never thought about it.' This finding highlights the influence of sport regulations and brings to mention the commonly cited player objections to mouthguard wear in the literature which include the appliance being uncomfortable or impacting perceived or real athletic performance such as creating difficulty speaking or breathing.[44,45] Finally, with respect to the accuracy of recorded mouthguard wear, we consider the athletic trainer an appropriate source for this information because they are not responsible for players being properly equipped with a mouthguard for play nor are they penalized for lack of compliance; whereas the coach or student-athlete may receive a misconduct penalty and thus bring to question the potential for bias. Nonetheless, if there were mouthguard use misclassification by athletic trainers it would likely be nondifferential and bias our results toward the null, reducing the apparent protective effect of mouthguard exposure on dental injuries.

For the majority (60%) of registered oral injuries, athletic trainers responded "yes" when asked whether they believed the addition of protective equipment or the more appropriate use of equipment would have been beneficial, an indication that they believed mouthguards play a role in oral injury prevention. Specific objectives mentioned in the literature for the use of "properly fitted mouthguards" as protective devices in sports have included: reduce the potential chipping

of tooth enamel surfaces and reduce fractures of teeth, roots or bones; protect the lip and cheek tissues from being impacted and lacerated against tooth edges; reduce the incidence of a fractured jaw caused by a blow delivered to the chin or head; provide protection to toothless spaces, so support is given to the missing dentition of the student-athlete.[40]

We performed a series of case control analyses to examine the protective effect of mouthguards in sport-related dental injuries. The three major findings of this case-control study are: (1) when comparing dental injuries to the oral soft-tissue injuries, there was a persistent, though statistically non-significant, trend toward protection by approximately 20% after adjustment for athlete's sex, level of exposure, and sport; (2) compared to the control group of those with ankle and non-head/face injuries, mouthguard wear was significantly associated with lower odds of dental injury after adjustment for athlete's sex and level of exposure; and lastly (3) using an eye & nose injury control group, mouthguard wear was associated with increased odds of dental injury, although the associate was not statistically significant. However, when using sport rule to define mouthguard exposure for dental injuries, mouthguard wear was significantly associated with increased odds of dental injury, or said another way, mouthguards were associated with lower risk of eye & nose injury. We question the latter and offer an explanation for this apparent contradictory finding by identifying concurrent use of other NFHS required types of orofacial protective equipment (e.g. full facemask, eye protection) in sports requiring mouthguards. For example, NFHS requires facemasks and helmets with a secured chin strap and properly fitted intra-oral mouthpieces for football. Compulsory use of mouthguards is collinear or clustered with other required orofacial protective equipment. This is especially true in our study population of high school student-athletes who demonstrated very limited wear of mouthguards

(n=2) in sports not requiring their use.

In general, the results of the present study are in accordance with a recent meta-analysis by Knapik et al. [46] and earlier work by Labella et al.[47] The meta-analysis of studies comparing mouthguard users and nonusers showed that the overall risk of orofacial injury is 1.6 to 1.9 times greater when a mouthguard is not worn than when a mouthguard is worn.[46] In a prospective cohort study of men's NCAA Division I college basketball players that included 70,936 athlete exposures, Labella and colleagues compared custom-fitted mouthguard users and nonusers and found that custom-fitted mouthguards can significantly reduce the risk of dental injuries (0.12 vs. 0.67 injuries per 1,000 AE) but not oral soft-tissue injuries (0.69 vs. 1.06 injuries per 1,000 AE).[47]

An important finding is that TDIs can still occur with a mouthguard in place. In other words, mouthguards offer some protection but they are not 100% effective. The type of mouthguard appears to influence effectiveness. There are three broad categories of mouthguards: stock, boil-and-bite, and custom-fitted. Stock mouthguards come ready to wear without modification. Boil-and-bite self-fit mouthguards are made of a thermoplastic material that is softened in boiling water and then formed to fit over the teeth as it cools. Both stock and boil-and-bite mouthguards are relatively inexpensive and may be purchased at sporting goods outlets. Custom-fitted mouthguards are typically made by a dental professional. They are more expensive, but these mouthguards offer the best fit because they are made using a mold of the athlete's mouth. The majority of all mouthguards worn by nonprofessional/noncollegiate athletes are of the boil-and-bite type.[44] In the present study, all but two of the mouthguards worn by high school student-

athletes were reported by ATs as self-fitted "boil and bite" appliances (96%). Labella documented a single dental injury among custom-fitted mouthguard users in men's Division 1 college basketball while in our population of high-school student athletes 26 dental injuries were among mouthguard users. All types of mouthguards comply with the NFHS rules. However, some research indicates that custom-fitted mouthguards are better for preventing dental and maxillofacial injuries than are other types of mouthguards.[48,49,50]

The strengths of the present study include the use of a large national sample of injured high school athletes in 20 sports over a 9-year period (2005/2006-2013/2014). The National High School Sports-Related Injury Surveillance System relies on active participation of National Athletic Trainers' Association–affiliated certified athletic trainers. Data were collected prospectively, as the injury events occur, so there is minimal risk of recall bias. Injury and exposure data were collected. However, athlete exposure, a unit of susceptibility to injury defined as one athlete participating in one game or practice in which he/she is exposed to the possibility of athletic injury, was not collected separately for mouthguard users and for non-user. Therefore, a case control study was well suited to evaluate mouthguard wear as an intervention to prevent TDIs in high school student-athletes. Dental injury is a rare outcome which makes cohort or interrupted time series designs difficult.

A limitation of the present study was the likely underreporting of dental injuries. Dental injuries may be particularly prone to underreporting because of the lack of relative importance given to non-time loss injuries. As a result, the sample of dental injuries in this study most likely reflects more severe injury types. Therefore, the conclusions regarding the relative injury rates and

severity by injury site and sport are potentially influenced by the relative proportion and severity of dental injuries compared to other types of injuries reported to and by athletic trainers.

The RIO surveillance system initially captured only injuries that resulted in time-loss from sport participation. In the 2007/2008 school year, the definition of a reportable injury expanded slightly for only dental, brain concussion, and fractures to include injuries regardless of whether the injury resulted in restriction of the athlete's play for 1 or more days beyond the day of injury. The NCAA also requires all dental injuries to be reported regardless of time loss yet Labella et al. found that the dental injury rate reported by the NCAA was significantly lower than that reported in her study in NCAA Division I men's college basketball.[47] The authors speculated that athletic trainers might overlook this exception to the NCAA general reporting requirements. The RIO surveillance system does not capture concurrent injuries and therefore in the case of multiple concomitant injuries the certified athletic trainer determined and reported the most severe injury. The site of injury reported may reflect a priority of importance bias. Furthermore, only U.S. high schools whose athletes had access to care from an AT affiliated with NATA were eligible and only injuries that came to the attention of AT were included. Injuries treated in a dental office, emergency department, or urgent-care facility and not reported to an AT were not captured. These factors suggest that the current RIO surveillance data may be an underestimate of the true incidence of dental injuries in US high school student-athletes and may not be representative of all high school dental injuries. Another important limitation of the present study was the lack of AT ascertainment of mouthguard use in non-oral injury controls. Based on the very good agreement seen between athletic trainer reporting and NFHS's mandatory mouthguard equipment policy (Kappa=0.86) for oral injuries and that we had no reason to

believe that the observed pattern of mouthguard usage would differ for non-oral injury control groups, we consider NFHS's mouthguard policy an acceptable surrogate when mouthguard use was not measured. The assumption of adherence with NFHS's regulations for players sustaining non-oral injuries was conservative in that it might result in an underestimation of the protective effect of mouthguards. The requirement of other orofacial protective equipment in sports for which NFHS mandates mouthguard wear was problematic to calculating protection attributable to mouthguards in the present study. It was unfortunate that our study demonstrated the virtual absence of mouthguard use among injured high school athletes participating in sports for which mouthguard wear was optional. Higher usage of mouthguards for sports or in player positions for which use of other orofacial protective equipment is not compulsory (i.e. basketball, soccer, and baseball players positioned in the infield) would have been helpful in examining the isolated beneficial effect of mouthguards. Lastly, mouthguard fit was not assessed and oral predisposing factors were not measured. Increased overjet with protrusion, inadequate lip coverage, and prior history of dental trauma are considered the most significant oral factors predisposing to dental trauma.

In conclusion, the present study was the first to evaluate oral injury data captured by the National High School Sports-Related Injury Surveillance System to measure the prevention effectiveness of athletic mouthguards in high school student athletes. We found that (1) sport-related dental injuries were rarely reported yet often severe, (2) the majority of the injured student-athletes in our study complied with NFHS's mandatory mouthguard equipment policy, and (3) there was a trend toward mouthguard protection for oral injuries which was most apparent when compared to ankle and nonhead/nonface injuries. These findings are meaningful in view of that these dental

injuries occurred to high school student-athletes during organized and supervised sport activity. Prognosis of traumatized teeth depends on prompt and appropriate treatment. Training and resources need to be in place for coaches, athletic trainers, and student-players. Although appropriate and timely dental treatment is essential, preventing dental injuries is of the utmost importance. Greater enforcement of mouthguard wear is needed. Also the financial and human costs associated with dental injury indicate the need to target mouthguard wear promotion to high school student-athletes most at risk for sports-related dental injuries (i.e. basketball players and student-athletes with oral factors predisposing them to dental trauma).

References

1. Billings RJ, Berkowitz RJ, Watson G. Teeth. *Pediatrics.* 2004;113(4Suppl):1120-1127.
2. Glendor U. Epidemiology of traumatic dental injuries- a 12 year review of the literature. *Dental Traumatology*. 2008;24(6):603-611.
3. Soriano EP, Caldas Jr AF, Carvalho MVD, Amorim Filho HA. Prevalence and risk factors related to traumatic dental injuries in Brazilian schoolchildren. *Dental Traumatology*. 2007; 23(4):232–240
4. Bendo CB, Paiva SM, Torres CS, Oliveira AC, Goursand D, Pordeus IA, Vale MP. Association between treated/untreated traumatic dental injuries and impact on quality of life of Brazilian schoolchildren. *Health Qual Life Outcomes*. 2010;8:114.
5. Cortes M, Marcenes W, Sheiham A. Impact of traumatic injuries to the permanent teeth on the oral health-related quality of life in 12-14-year old children. *Community Dent Oral Epidemiology*. 2002;30:193-198.
6. Ramos-Jorge M, Bosco V, Peres M, Nunes A. The impact of treatment of dental trauma on the quality of life of adolescents- a case-control study in southern Brazil. *Dental Traumatology*. 2007;23:114-119.
7. Glendor U, Jonsson D, Halling A, Lindqvist K. Direct and indirect costs of dental trauma in Sweden: a 2-year prospective study of children and adolescents. *Community Dent Oral Epidemiology*. 2001;29:150-160.
8. Glendor U, Halling A, Andersson L, Andreasen J, Klitz I. Type of treatment and estimation of time spent on dental trauma- a longitudinal and retrospective study. *Swedish Dental Journal.* 1998;22:27-60.
9. Glendor U. On dental trauma in children and adolescents. *Swedish Dental Journal.* 2000;140:1-52.
10. Gustafson D, McTigue D, Thikkurissy S, Casamassimo P, Nusstein J. Continued care of children seen in an emergency department for dental trauma. *Pediatric Dentistry*. 2011;33(5):426-430.
11. Nguyen PM, Kenny DJ, Barrett EJ. Socioeconomic burden of permanent incisor replantation on children and parents. *Dental Traumatology*. 2004;20:123-133.
12. Borum MK, Andreasen JO. Therapeutic and economic implications of traumatic dental injuries in Denmark: an estimate based on 7549 patients treated at a major trauma center. *International Journal of Paediatric Dentistry.* 2001;11(4):249-258.
13. Lacerda JTD, Ribeiro JD, Ribeiro DM, Traebert J. Prevalence of orofacial pain and its impact on the oral health-related quality of life of textile industries workers of Laguna, SC, Brazil. *Ciência & Saúde Coletiva*. 2011;16(10):4275-4282.
14. McClelland C, Kinirons M, Geary L. A preliminary study of patient comfort associated with customized mouthguards. *British Journal of Sports Medicine*. 1999;33(3):186-189.
15. Heintz WD. Mouth protectors: a progress report. *Journal of the American Dental Association.* 1968;77(3):632-636.
16. Joint Commission on Mouth Protectors of American Association of Health, Physical Education and Recreation and the American Dental Association. Report of the Joint Commission on Mouth Protectors of the American Association of Health, Physical Education and Recreation and the American Dental Association. Chicago: American Dental Association;1960.

17. American Dental Association. Bureau of Dental Health Education. Mouth protectors for football players: the dentist's role. *Journal of the American Dental Association.* 1962;64(3):419-421.
18. Sigurdsson A. Evidence-based review of prevention of dental injuries. *Pediatric Dentistry*. 2013;*35*(2):184-190.
19. Newsome P, Tran D, Cooke, M. The role of the mouthguard in the prevention of sports-related dental injuries: a review. *International Journal of Paediatric Dentistry*. 2001;11(6):396-404.
20. American Dental Association. The importance of using mouthguards: tips for keeping your smile safe. *Journal of the American Dental Association.* 2004;135:1061.
21. National Federation of State High School Associations. 2013-2014 high school athletics participation survey. http://www.nfhs.org/ParticipationStatics/PDF/2013 14_Participation_Survey_PDF.pdf. *Accessed January 20, 2014.*
22. Centers for Disease Control and Prevention. Sports-related injuries among high school athletes--United States, 2005-06 school year. *MMWR: Morbidity and Mortality Weekly Report.* 2006;55(38):1037-1040.
23. Rechel JA, Yard EE, Comstock RD. An epidemiologic comparison of high school sports injuries sustained in practice and competition. *Journal of Athletic Training*. 2008;43(2):197-204.
24. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions Among United States High School and Collegiate Athletes. *Journal of Athletic Training*. 2007;42(4):495 503.
25. Petersson EE, Andersson L, Sorensen S. Traumatic oral vs. non-oral injuries: an epidemiologic study during one year in a Swedish county. *Swedish Dental Journal.* 1997;21:55-68.
26. Andreasen JO, Lauridsen E, Gerds TA, Ahrensburg SS. Dental Trauma Guide: A source of evidence-based treatment guidelines for dental trauma. *Dental Traumatology*, 2012;28(5):345-350.
27. Swenson DM, Henke NM, Collins CL, Fields SK, Comstock RD. Epidemiology of United States high school sports-related fractures, 2008-09 to 2010-11. *American Journal of Sports Medicine*. 2012;40(9):2078-2084.
28. Dang KM, Day PF, Calache H, Tham R, Parashos P. Reporting dental trauma and its inclusion in an injury surveillance system in Victoria, Australia. *Australian Dental Journal*. 2015;60(1):88-95.
29. Lombardi S, Sheller B, Williams BJ. Diagnosis and treatment of dental trauma in a children's hospital. *Pediatric Dentistry* 1997;20(2):112-120.
30. Borssen E, Holm AK. Traumatic dental injuries in a cohort of 16-year-olds in north Sweden. *Dental Traumatology*. 1997;13:276-280.
31. Trope M. Clinical management of the avulsed tooth: present strategies and future directions. *Dental Traumatology*. 2002;*18*(1):1-11.
32. Flores MT, Andersson L, Andreasen JO, Bakland LK, Malmgren B, Barnett F, et al. Guidelines for the management of traumatic dental injuries. II Avulsion of permanent teeth. *Dental Traumatology*. 2007;23(3):130-136.

33. Holan G. Cohenca N, Brin I, Sgan‐Cohen H. An oral health promotion program for the prevention of complications following avulsion: the effect on knowledge of physical education teachers. *Dental Traumatology*. 2006;22(6):323-327.
34. Vergotine RJ, Koerber A. The relationship of dental visits to parental knowledge of management of dental trauma. *Pediatric Dentistry*. 2010;*32*(4):329-332.
35. Sae‐Lim V, Chulaluk K, Lim LP. Patient and parental awareness of the importance of immediate management of traumatized teeth. *Dental Traumatology*. 1999;15(1):37-41.
36. Panzarini SR, Pedrini D, Brandini DA, Poi WR, Santos MF, Correa JPT et al. Physical education undergraduates and dental trauma knowledge. *Dental Traumatology*. 2005;21(6):324–328.
37. Stewart GB, Shields BJ, Fields S, Comstock RD, Smith GA. Consumer products and activities associated with dental injuries to children treated in United States emergency departments, 1990–2003. *Dental Traumatology*. 2009;25(4), 399-405.
38. Huffman EA, Yard EE, Fields SK, Collins CL, Comstock RD. Epidemiology of rare injuries and conditions among United States high school athletes during the 2005–2006 and 2006–2007 school years. *Journal of Athletic Training*, 2008;43(6):624-630.
39. Cohenca N, Roges RA, Roges R. The incidence and severity of dental trauma in intercollegiate athletes. *Journal of the American Dental Association*. 2007;138(8):1121-1126.
40. American Academy of Pediatric Dentistry Clinical Affairs Committee, & American Academy of Pediatric Dentistry Council on Clinical Affairs. Policy on prevention of sports-related orofacial injuries. *Pediatric Dentistry*. 2005;*27*(7 Suppl), 45.
41. Collins CL, Comstock RD. Epidemiological Features of High School Baseball Injuries in the United States, 2005-2007. *Pediatrics*. 2008;121:1181-1187.
42. Bak MJ, Doerr TD. Craniomaxillofacial fractures during recreational baseball and softball. *Journal of Oral and Maxillofacial Surgery.* 2004;62(10):1209-1212.
43. Hawn KL, Visser MF, Sexton PJ. Enforcement of Mouthguard Use and Athlete Compliance in National Collegiate Athletic Association Men's Collegiate Ice Hockey Competition. *Journal of Athletic Training.* 2002;37(2):204–208.
44. Cornwell H, Messer LB, Speed H. Use of mouthguards by basketball players in Victoria, Australia. *Dental Traumatology.* 2003;19(4):193-203.
45. Berry DC, Miller MG, Leow W. Attitudes of Central Collegiate Hockey Association Ice Hockey Players Toward Athletic Mouthguard Usage. *Journal of Public Health Dentistry* 2005;65(2)71-75.
46. Knapik JJ, Marshall SW, Lee RB, Darakjy SS, Jones SB, Mitchener TA, et al. Mouthguards in sport activities: history, physical properties and injury prevention effectiveness. *Sports Medicine*. 2007;37(2):117-144.
47. Labella CR, Smith BW, Sigurdsson A. Effect of mouthguards on dental injuries and concussions in college basketball. *Medicine and Science in Sports and Exercise*. 2002;34(1):41-44.
48. Bemelmanns P, Pfeiffer P. Shock absorption capabilities of mouthguards in different types and thicknesses. *International Journal of Sports Medicine.* 2001;22(2):149–153.
49. Hoffmann J, Alfter G, Rudolph NK, Goz G. Experimental comparative study of various mouthguards. *Endodontics and Dental Traumatology*. 1999;15(4):157–163.

50. Finch C, Braham R, McIntosh A, McCrory P, Wolfe R. Should football players wear custom fitted mouthguards? Results from a group randomized controlled trial. *Injury Prevention*. 2005;11(4):242–246.