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Altitude Modulates Concussion Incidence

Implications for Optimizing Brain Compliance to Prevent Brain Injury in Athletes

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Investigation performed at Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

Background: Recent research indicates that the volume and/or pressure of intracranial fluid, a physiology affected by one's altitude (ie, elevation above sea level), may be associated with the likelihood and/or severity of a concussion. The objective was to employ an epidemiological field investigation to evaluate the relationship between altitude and concussion rate in high school sports.

Hypothesis: Because of the physiologies that occur during acclimatization, including a decline in intracranial compliance (a ''tighter fit''), increased altitude may be related to a reduction in concussion rates in high school athletes.

Study Design: Cohort study; Level of evidence, 3.

Methods: Data on concussions and athlete exposures (AEs) between 2005-2006 and 2011-2012 were obtained from a large national sample of high schools (National High School Sports-Related Injury Surveillance System [High School RIO]) and were used to calculate total, competition, and practice concussion rates for aggregated sports and for football only.

Results: Altitude of participating schools ranged from 7 to 6903 ft (median, 600 ft), and a total of 5936 concussions occurred in 20,618,915 exposures (2.88 per 10,000 AEs). When concussion rates were dichotomized by altitude using the median, elevated altitude was associated with a reduction in concussion rates overall (rate ratio [RR], 1.31; $P < .001$), in competition (RR, 1.31; $P < .001$), and in practice (RR, 1.29; $P < .001$). Specifically, high school sports played at higher altitude demonstrated a 31% reduction (95% confidence interval [CI], 25%-38%) in the incidence of total reported concussions. Likewise, concussion rates at increased altitude were reduced 30% for overall exposures, 27% for competition exposures, and 28% for practice exposures in football players ($P < .001$).

Conclusion: The results of this epidemiological investigation indicate increased physiological responses to altitude may be associated with a reduction in sports-related concussion rates, especially in collision sports. Future research that focuses on the potential prophylactic effect of optimizing outflow impedance and thus reduction of intracranial compliance (a ''tighter fit'') in humans is warranted to determine the most effective approaches to mitigate sport-related concussion, especially in football players.

Keywords: concussion; athletes; sports-related concussion; prevention; football; elevation; *Slosh* theory

As the most common form of traumatic brain injury (TBI) in the United States, mild traumatic brain injury (mTBI) results in a substantial public health burden, causing an estimated 75% to 90% of traumatic brain injury–related morbidity, hospitalizations, and emergency department visits each year.[16] The Centers for Disease Control and Prevention estimates that the yearly incidence of sports- and recreation-related TBIs in the United States is between 1.6 and 3.8 million, many of which remain undiagnosed or do not result in doctor or hospital visits.[16] In a recent 10-year period, there has been a 100% increase among 8- to 13-year-olds and a 200% increase in sports-related emergency room visits for concussion among 14- to 19-year-olds.[1] Previous research has indicated that concussions represent from 5.5% to 22% of all high school athletic injuries.[8,18] Athletes who sustain a concussion may demonstrate impaired executive function, poorer processing function, decreased attention span, somatic symptoms, and, in younger populations, educational difficulties and behavioral changes.[6,29] These athletes are also at risk of a second concussion or "second impact syndrome," where a

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subsequent hit can have magnified effects compared to the first.

Recent research indicates that altering the cerebral outflow impedance and thus optimizing the compliance (eg, cradling the brain to prevent excess movement) of the intracranial fluid space may be associated with the likelihood and/or severity of a concussion.[32] Although the skull, blood, and brain are almost incompressible, the vasculature tree of the cerebrum is reactive and compressible.[7] It is well known that hypercarbia can increase the cerebral blood flow and blood volume by up to 40%.[14] What may make the human brain vulnerable to a blast wave is the propensity to oscillate in the skull following a rapid acceleration or deceleration, commonly referred to as *Slosh* dynamics. The oscillation in the skull is permitted because the cerebrospinal fluid (CSF) is free-flowing and the brain effectively "floats" somewhat unrestrained in the CSF. According to the National Aeronautics and Space Administration (NASA), "Liquid *Slosh* in the fuel tanks of a spacecraft has been a long-standing concern for space missions" (Schlee K, Gangadharan S, Ristow J, Sudermann J, Walker C, Hubert C. "Modeling and Parameter Estimation of Spacecraft Fuel Slosh Mode." Proceedings of the 2005 Winter Simulation Conference). "The oscillation of a fluid caused by external force, called *Slosh*ing, occurs in moving vehicles containing liquid masses, such as trucks, railroad cars, aircraft, and liquid-fueled rockets. This *Slosh*ing effect could be a severe problem in vehicle stability and control."[15] The brain, essentially a moving vehicle containing liquid masses, faces levels of *Slosh* peril during external force impartation. During rapid acceleration/deceleration of the skull, such as that which exists during an impact, there is likely a concomitant deformation of brain matter, which is the proposed mechanism of concussion and brain injury.[2] Rapid deformation of the brain can lead to increased shear when tissues of differing mass decelerate at different rates. If one reduces the compliance of the cranial space upon impact, differing tissue densities will likely accelerate or decelerate at the same rate, similar to having an airbag deploy or "bubble wrap" inflate and thus prevent damage to structures within a container (the brain in this example). In concussion, rapid deformation of brain tissue is thought to cause "diffuse mechanically induced depolarization of cortical neurons."[2,31] One hypothesized mechanism of this relationship between volume of intracranial fluid and concussion risk is that a decrease in intracranial fluid results in a relative increase in the amount of space through which the brain travels in the cranium upon impact, resulting in enhanced acceleration/deceleration of both linear and rotational injury inputs to the brain.

Ross[28] accounted for the "random nature of cerebral mountain sickness" during ascent to altitude by suggesting that individuals with more compliant systems (more atrophic brains and larger ventricles) could accommodate more hypoxic cerebral swelling, and hence, would be more protected from a subsequent increase in intracranial pressure (ICP). Those at increased altitude, and specifically more prone to hypoxemia, would presumably experience greater hypoxic cerebral swelling as a result of vasogenic edema.[12] The "tight fit" hypothesis and subsequent current understanding of altitude, specifically acute mountain sickness (AMS), is that individuals with less compliant CSF systems (smaller ventricles and CSF spaces) have a greater increase in ICP for a given increase in brain volume as a result of hypoxic cerebral edema.[39] The authors contend that this loss of compliance at altitude (tight fit) might actually protect against concussion by optimizing the actions of fluids inside moving containers (hydrodynamics = *Slosh*).

Ascent to high altitude results in a fall in barometric pressure and corresponding fall in the inspired partial pressure of oxygen, leading to arterial hypoxemia.[27] This hypobaric hypoxia may drive increases in cerebral blood flow (CBF) and hence, in ICP, an effect that may contribute to the occurrence of high-altitude headache (HAH).[37] This same physiology should occur upon chronic adaptation to increased altitude. Although less likely etiologies, chronic adaptations to altitude also include hormonal alterations in erythropoietin (Epo), polycythemia, increased hemoglobin, changes in cell water content, decreased plasma volume, and increased 2,3-diphosphoglycerate (2,3-DPG). These metabolic responses may have unintended consequences, some of which may impact acute injury responses. Restated, individuals may be at higher risk of concussion rate or severity based on differences in absorption of energies into the brain space based on excess intracranial compliance (redundant space). In those having more tightly compacted tissues, axons and cells would be more likely to avoid the *Slosh*ing of tissues with resultant strain and shear.[32] However, the effect of implementing *Slosh* mitigation strategies on concussion incidence in humans has not been investigated in an epidemiologic study to date.

Because of the physiologies that occur during acclimatization, including a decline in intracranial compliance (a tighter fit), it was hypothesized that increased altitude (ie, elevation above sea level) acclimatization likely affects *Slosh* of the brain during competitive sports.[12,37,39] Our purpose was to conduct an epidemiological field investigation to examine the relationship between altitude and concussion rate in high school sports using data from a large national sample of US high schools. Because of the mild increase in hypoxic vasogenic edema leading to a decrease in compliance (a tight fit) at higher altitudes, we hypothesized that raised altitude would be related to reduced concussion rates in high school athletes.

METHODS

Data were obtained from the National High School Sports-Related Injury Surveillance System, High School Reporting Information Online (High School RIO; http://www.ucdenver.edu/academics/colleges/PublicHealth/research/ResearchProjects/piper/projects/RIO/Pages/default.aspx), an Internet-based sports Information surveillance system that has been described previously.[8,24] US high schools with 1 or more National Athletic Trainers Association–affiliated certified athletic trainer (AT) with a valid e-mail address were invited to participate. Responding high schools were categorized into 8 strata based on school population ($\leq$1000 and >1000) and US Census geographic regions.[35] The High

School RIO system has 2 panels for data collection. The first is a stratified random sample of high schools, originally established in 2005-2006 with 9 sports to provide national estimates. A second convenience sample of high schools with an additional 11 sports was added since 2008-2009 to enable comparisons of injury rates, risks, and circumstances across sports but without generating national estimates. All surveillance methods were approved by the institutional review board.

For the 9 sports included in the study since 2005-2006 (boys': football, soccer, basketball, wrestling, and baseball; girls': soccer, volleyball, basketball, and softball), 100 high schools were randomly chosen to participate (12 or 13 from each of 8 strata). If a school dropped out of the study, a replacement from the same stratum was randomly selected to maintain the annual 100-school study population. For the 9 sports added to the study in 2008-2009 (boys': ice hockey, lacrosse, swimming & diving, and track & field and girls': gymnastics, field hockey, lacrosse, swimming & diving, and track & field) and the 2 added in 2009-2010 (boys' volleyball and cheerleading [boys and girls]), not enough schools from the 8 strata volunteered annually to make it possible to produce a randomly selected sample. Thus, exposure and injury data for these sports were collected from a convenience sample of schools. If an AT from a convenience sample school also reported information for athletes in 1 of the original 9 sports, these data were included in the overall convenience sample data set.

ATs from participating high schools logged onto the study website weekly throughout each academic year to report injury incidence, including incidence of concussion, and athlete exposure (AE, with 1 athlete participating in 1 practice or competition representing 1 AE) information. This research project used all concussion incidence and AE data from all schools participating in either study sample during the 7-year sports injury surveillance study. School addresses were then used to record the elevation of each reporting school to examine the relationship between altitude and concussion rates.

Statistical Analysis

In this study, the median, 25th percentile, and 75th percentile cutoff points for elevation of the study schools were used to analyze altitude as both a dichotomous variable and as a quartiled categorical variable. To explore the effect of altitude on concussion rate in this sample, we calculated concussion rates by dividing the summed concussion incidence by the summed AEs in high- versus low-elevation schools for the dichotomized sample and for schools in each category of the quartiled sample. Rate ratios (RRs) and 95% confidence intervals (CIs) were calculated using χ^2 tests, with the highest elevation category used as the referent category. Data were analyzed using SAS/STAT software (version 9.3; SAS Institute, Chicago, Illinois, USA). Statistical significance was defined as $P \leq .05$. We evaluated the association between altitude and concussion rate for all data reported to High School RIO for all 20 sports overall, in competition only, and in practice only. Additionally, because football annually has the highest incidence and highest rate of concussion among the 20 sports, we replicated the evaluation of dichotomized elevation in football overall, in competition, and in practice. Given the size of the sample, we did not have statistical power to conduct similar analyses in each of the other 19 sports.

RESULTS

Data from 497 schools were utilized in the analysis of total concussion rates for all sports, with the altitudes of these schools ranging from 7 to 6903 ft (median, 600 ft; interquartile range, 200-935 ft; 1 ft ≈ 0.305 m). ATs at these schools reported a total of 5936 concussions that occurred during 20,618,915 AEs (2.88 per 10,000 AEs). Concussion rates for all sports combined are presented by dichotomized and quartiled elevation categories in Table 1. When the sample of schools was dichotomized above and below 600 ft, concussion rates were reduced at increased altitudes overall, in competition, and in practice ($P < .001$). Specifically, high school sports played at higher topographical altitude demonstrated a 31% decrease (95% CI, 25% to 38%) in the incidence of total reported concussions ($P < .001$). When the data were assessed in altitude quartiles, a similar trend was noted, although not all comparisons reached statistical significance (Table 1).

The authors acknowledge that in the high school population, football statistics are most often higher than those in other sports. Therefore, we undertook analyses focused in football athletes to further evaluate these associations of altitude on a specific collision sport. This confirmatory analysis in only football players indicates a similar pattern to the overall sport analysis. Specifically, concussion rates at increased altitude were reduced 30% for overall exposures, 27% for competition exposures, and 28% for practice exposures in football players ($P < .001$) (Table 2).

DISCUSSION

Recent research provides evidence for a simple and efficacious method to alter the impedance of the outflow vessels in rats, thereby altering the compliance of the cranial contents prior to a concussive event and reducing concussive injuries by 83%.[10,32] The results of this first evaluation of the association between altitude and reported concussion supports our a priori hypothesis that exposure to increased altitude would also alter the compliance of the cranium of athletes prior to concussions and may be related to a mitigation of concussion injury. The authors acknowledge that the enhanced resistance to the concussive event could also stem from a number of metabolic adaptations that occur at higher altitudes. Stated more simply, the findings of this study indicate that athletes living above 600 feet in altitude experience fewer concussion symptoms than those living at lower elevations. Such speculation begs the question, why would there be fewer concussions elicited and reported at higher altitude?

Cerebral blood flow rises in response to hypoxemia, including hypoxic changes associated with increased elevations.[38]

TABLE 1
Association Between Altitude and Concussions Among All United States High School Sports Combined[a]

	Dichotomous Altitude, ft		Altitude in Quartiles, ft			
	0-600	≥601	0-200	201-600	601-935	≥936
Total						
No. of concussions	3207	2729	1673	1534	1407	1322
No. of AEs	9,748,551	10,870,364	5,658,239	4,090,312	5,476,019	5,394,345
Rate per 10,000 AEs	3.29	2.51	2.96	3.75	2.57	2.45
RR	1.31	Referent category	1.21	1.53	1.05	Referent category
95% CI	1.25-1.38		1.12-1.30	1.42-1.65	0.97-1.13	
P value	<.001		<.001	<.001	.22	
Competition						
No. of concussions	2110	1781	1121	989	919	862
No. of AEs	2,588,783	2,868,496	1,466,303	1,122,481	1,444,549	1,423,947
Rate per 10,000 AEs	8.15	6.21	7.65	8.81	6.36	6.05
RR	1.31	Referent	1.26	1.46	1.05	Referent
95% CI	1.23-1.40		1.16-1.38	1.33-1.59	0.96-1.15	
P value	<.001		<.001	<.001	.29	
Practice						
No. of concussions	1097	948	552	545	488	460
No. of AEs	7,159,767	8,001,868	4,191,936	2,967,831	4,031,470	3,970,398
Rate per 10,000 AEs	1.53	1.18	1.32	1.84	1.21	1.16
RR	1.29	Referent	1.14	1.59	1.04	Referent
95% CI	1.19-1.41		1.00-1.29	1.40-1.79	0.92-1.19	
P value	<.001		.04	<.001	.50	

[a]From the National High School Sports-Related Injury Surveillance System, United States, 2005-2006 through 2011-2012. AE, athlete exposure; CI, confidence interval; RR, rate ratio.

TABLE 2
Association Between Altitude and Concussions in United States High School Football[a]

	Low Altitude (0-644 ft)			High Altitude (≥645 ft)		
	Practice	Competition	Total	Practice	Competition	Total
No. of concussions	585	876	1461	511	795	1306
No. of AEs	1,641,185	330,311	1,971,496	1,867,735	380,625	2,248,360
Rate per 10,000 AEs	3.56	26.52	7.41	2.74	20.89	5.81
RR	1.30	1.27	1.28	Referent	Referent	Referent
95% CI	1.16-1.47	1.15-1.40	1.18-1.37			
P value	<.001	<.001	<.001			

[a]From the National High School Sports-Related Injury Surveillance System, 2005-2006 through 2011-2012. Compiled data, as well as separate practice and competition analyses, show that there is a significant reduction in the rate of concussions per 10,000 exposures with altitude ≥645 ft ($P < .001$). AE, athlete exposure; CI, confidence interval; RR, rate ratio.

Restricted venous drainage in the face of this increased cerebral blood flow would result in venous engorgement and a subsequent rise in ICP when the limits of cerebral compliance are reached.[37] The relationship between increased altitude adaptation and mitigating concussive symptoms is unclear. It may be that some of the adaptive effects of the body to higher altitude may impart some protection against concussive symptoms. Because it is unknown if the athletes in this cohort were experiencing chronic or acute adaptations, we will discuss the putative protective effects as they relate to mitigating symptoms evoked by concussive impacts. Even small changes in altitude seem to afford alterations in physiology or advantages, as evidenced by the 2007 banning of soccer competition at high altitude (≥2500 m) by the Federation of International Football Association (FIFA).[22] The effect of altitude difference on the probability of winning and on the number of goals scored was recently reported.[22] Even though the ban was at altitude greater than 2500 m, the advantage was seen at altitudes as low as 152.4 m (500 ft). We should note that ambient oxygen levels are known to be different at what the literature calls "low altitude"; for example, oxygen levels at 1000 ft are slightly lower at 20.1% rather than 20.9% at sea level.[13] One would intuitively think that altitudes of merely 600 to 2000 ft would not impart alterations in the physiology of the body, yet many differences in physiologies are noted at these minor altitudes. As you move to higher altitudes, air pressure decreases significantly—approximately 3% for every 1000 feet of elevation. In this scenario, a moving baseball is exposed to up to 16% less drag at the 5000-foot elevation of Denver's Coors Field than at Boston's Fenway Park, a stadium at sea level.[36] Again, physical parameters are seen to be altered at even relatively low altitudes and, at least in reference to decreasing air density, would be thought to *increase* the speed of a concussive object moving toward (and thus higher concussive rates), yet our results paradoxically show a protective effect of altitude.

Yet another parameter that alters with altitude, the atmospheric lapse rate defines the relationship of altitude and temperature. Although the actual atmospheric lapse rate varies, under normal atmospheric conditions, the average atmospheric lapse rate results in a temperature decrease of 3.5°F/1000 ft (6.4°C/km) of altitude.[9] Humidity is not directly affected by altitude. However, humidity is affected by air density and temperature. At high altitudes, the air is usually much thinner (lower pressure) and often the temperature is lower. At low temperatures and low pressures, air cannot hold as much water. Thus, the humidity is necessarily low when the air is thin and cold. So it would appear that many alterations exist in the physical parameters experienced by high school athletes at even mild altitudes of 600 to 2000 feet.

In the chronic phase of adaptation at altitude, erythropoietin stimulates increased blood synthesis with further polycythemia. Initially, hemoglobin and hematocrit rise and blood volume declines, but as acclimatization occurs, an increase in erythrocyte volume is manifested.[40] In long-term acclimatization, increased arterial oxygen content is sustained by expansion of erythrocyte volume.[40] Vasogenic edema in the brain leads to increased extravascular water. These 2 adaptations would also lead to tighter packaging of the brain (less compliance = tight fit) with increased blood cell content surrounding the brain. It has been noted that cerebral volume must rise by only 3 to 4 mL before pressure starts to rise and take up the compliance with brain tissues.[17,26] Figure 1 presents this continuum and a potential mechanistic model that may be associated with the reduced rate of concussion observed at higher altitude in this study.[17] The primary pathophysiological response of cerebral concussion is felt to be due to the movement of the intracranial contents inside the skull, leading to the potential for both cellular and microstructural brain injury. The concept of *Slosh* has emerged as a descriptive and physiological mechanism whereby there is differential motion between the skull and brain.[10,32] The notion that mild internal jugular vein compression can cause an immediate increase in intracranial blood volume and protect the brain from concussion is an emerging theory that has been demonstrated in a standard rodent mTBI model.[10,32] In rat models (during a 900-*g* impact, per Marmarou protocol[19]), findings of increased brain pressure and volume were thought to reduce intracranial *Slosh* effects and were associated with mitigated traumatic axonal injury.[10,32] The differences between just the supine and upright postures include a 1.8-fold increase in the intracranial volume, a 2.4-fold reduction in the cerebrospinal fluid oscillatory volume, and a 2.8-fold increase in the intracranial compliance index with a corresponding decrease in pressure.[23] These orthostatic changes are likely associated with intracranial hydrodynamic changes. Therefore, it is reasonable to suppose that such changes in volume, pressure, and compliance could occur with increases in elevation similar to those seen with orthostatic dynamics. The noted physiological responses to increased altitude may influence a similar reduction in potential brain *Slosh* leading to a decreased risk of concussion at increased altitudes.

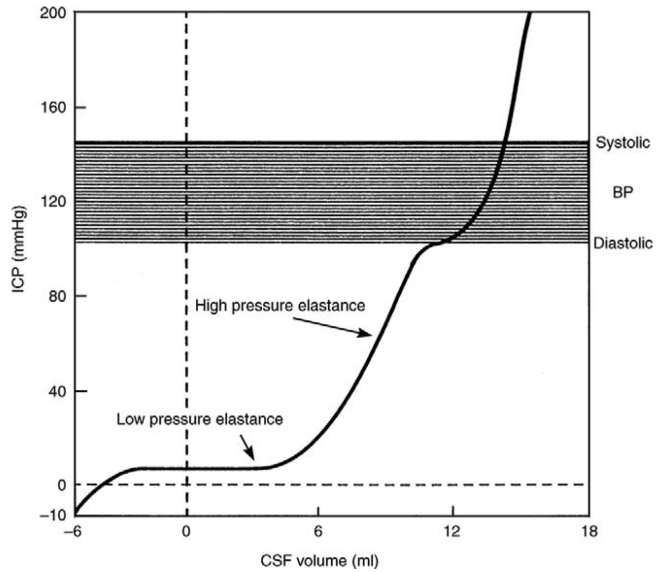

Figure 1. Cerebral volume must rise by 3 to 4 mL before pressure starts to rise. (Reprinted with permission from Löfgren J, Zwetnow NN. Cranial and spinal components of the cerebrospinal fluid pressure–volume curve. *Acta Neurol Scand*. 1973;49:575-585. ©1973, Wiley.)

To be thorough, a less likely alternative explanation could be offered that at the intracellular level, increased 2,3-DPG enhances the oxygen dissociation curve, promoting liberation of oxygen at the tissue and promoting the T-state of hemoglobin. Note that the "T" refers to the "tense" state of hemoglobin, which would be expected to reduce the compliance of the hemoglobin and cell itself during impacts. In a study to determine the cell wall effects of 2,3-DPG, "treatment with 2,3-DPG resulted in membranes with decreased deformity (less *Slosh*). 2,3-DPG-treated RBC required 1.8 times the shear stress than normal membranes to reach equivalent deformation."[5] 2,3-DPG has 4 negative charges and can act as a cross-linking molecule. Cross linking results in decreased molecular mobility of proteins and membranes.[30,33] Thus, the brain, hemoglobin, and blood cells may all be packaged somewhat tighter or better at higher altitudes.

Since 2009 and the passing of the Lystedt Law (House Bill 1824) in Washington state, 48 more states, including Washington, DC, have passed laws protecting student athletes from returning to play too soon after sustaining a concussion.[11] Currently all states but Mississippi have passed such legislation. As severity of head injury has been reported to be increased in younger athletes relative to older participants in similar sports, further research effort into prevention is warranted in high school athletics.[25] A summary statement of international meetings purported that more research was needed to understand the differences between older and younger athletes regarding recovery from TBI.[20,21] Intracranial compliance is greatest in the 0- to 20-year age group,[4] which is the same group that is reported to be most susceptible to mTBI. "*Slosh* theory" might offer a mechanism as "elastin loses its functionality in cerebral arteries with aging, leading to stiffer, less compliant arteries." This aging effect of the cerebral vascular tree would necessarily protect against *Slosh*-mediated injury, thus leaving the younger age groups potentially more at risk for mTBI.[3] As noted by the results of the current investigation, a better understanding of the potential *Slosh* effects on brain injury mitigation during concussive blows across athletes of different age groups may provide direction to injury prevention strategies of the future.

Limitations

Although this study utilized a data set of nearly 6000 concussions reported by ATs from a large national sample of US high schools ranging in altitude from nearly sea level to nearly 7000 ft, there were limitations. One limitation to our study was that we did not have a direct measure of athlete hydration or intracranial compliance or volume. It is possible that athletes accustomed to living at higher altitudes might have adapted to one of these conditions, maintaining appropriate levels of hydration, which may negate the proposed difference of concussion risk due to differences in intracranial fluid. Additionally, because high school sports teams—unlike their collegiate and professional counterparts—rarely travel through large differences in altitude for competitive opportunities, we were unable to further evaluate our theory by analyzing data from a subgroup of sports teams that have traveled from a higher altitude to a lower altitude for a competition. Future prospective investigations may consider attempting to identify ways to objectively capture and control for such potential confounding factors to further delineate their influence relative to the observed association between altitude and concussion rates. Because there is no reason to believe there are differences in concussion diagnosis or reporting patterns by ATs working at different altitudes or differences in athletes' approaches to sports participation at different altitudes (eg, athletes at lower elevations do not hit harder or more frequently) as there have been no published reports of such differences to date, we speculate that this observed relationship between elevation and concussion rate may reflect some protective effect afforded by increased intracranial pressure, volume, or some cellular or humeral alteration at higher altitudes. The large quantity of concussion data captured from a national sample of athletes playing sports at a wide range of altitudes provided us with the first opportunity to evaluate the potential association between elevation and concussion risk. However, the authors acknowledge that further research is warranted to confirm our findings and to delineate the mechanisms that underlie the observed reduction in concussion rates at higher altitudes.

CONCLUSION

The *Slosh* energy management model predicts reduced concussion rates at higher altitudes due to modified physiologies resulting from acclimatization to altitude. Increased DPG, red cell mass, intracranial volume, and decreased compliance (a "tight fit"), or a combination thereof, will mitigate *Slosh*, and the current study's results confirm this conclusion. Specifically, the current study utilized a data set of nearly 6000 concussions reported by athletic trainers from a large national sample of US high schools to evaluate altitude from nearly sea level to nearly 7000 ft and found that increased altitude was associated with a reduced concussion rate in high school athletes. Recent research that utilized a brain impact protocol in rats at 900-*g* impacts (note, football concussive blows occur at 25-*g* to 50-*g* range) reduced brain injury by as much as 83%—a feat accomplished merely through an innovative technology of jugular pressure to optimize brain fluid dynamics.[32,34] Future research is warranted to test the hypothesis that mitigating *Slosh* in the human cranium via mild jugular vein compression will prevent or diminish severity of concussion. Specifically, research that is focused on the potential prophylactic effect of optimizing outflow impedance and thus reduction of intracranial compliance in humans is warranted to determine the most effective approaches to mitigate all sport-related concussions.

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