RESEARCH LETTER

Risk of Concussion for Athletes in Contact Sports at Higher Altitude vs at Sea Level: A Meta-analysis

It has been postulated that a higher altitude increases cerebral blood flow, which causes venous blood engorgement, increases intracranial pressure, and creates subsequent slight brain swelling and a tighter fit between the brain and the skull to decrease brain sloshing and reduce concussive events.1,2 The prospect of protecting the brain from within seems novel and exciting, but the proposed physiologic basis for this mechanism is not scientifically sound.3 Recent studies show conflicting data on whether the incidence of sports-related concussions is associated with altitude.1,2,4,5 Thus, we sought to determine whether the incidence of concussions from contact sports is different when the sport is played at sea level vs at a higher altitude.

Methods | We conducted a systematic review of the published literature using the US National Library of Medicine database (PubMed.gov) on June 20, 2016. The search terms were (altitude OR elevation) AND (concussion OR concussions). Concussion incidence was defined as the number of adverse events per athlete exposure (1 game). Sea level was defined as an elevation less than 195 m. Higher altitude was defined as an elevation of approximately 200 m to 300 m above sea level, based on the available literature. MedCalc Statistical Software version 16.4.3 (MedCalc) was used, with the meta-analysis relative risk option selected. A random effects model was used if there was heterogeneity between studies.

Results | Search results revealed 59 publications, but only 4 examined altitude and sport-related concussions.1,2,4,5 One study looked at Division I football concussion injuries in the regular season and postseason using data obtained from the National Collegiate Athletic Association Injury Surveillance Program from 2009 to 2014.4 Two studies looked at concussion injuries in National Football League players from the 2012 and 2013 regular seasons, with data obtained from each team’s official website and from the PBS Frontline Concussion Watch web-based resource.1,5 A fourth study looked at concussion rates in adolescents participating in 9 high school sports between 2005 and 2012, with data obtained from the National High School Sports Related Injury Surveillance System.2

Because 2 studies used similar data on football players from similar years in the National Football League,1,5 we decided to use the study that published actual concussion rates.1 The 2 non-National Football League studies used different databases, so there was no overlap of injury rates.2,4 Thus, 3 studies were included in this meta-analysis.1,2,4 The Table demonstrates that the number of adverse events per athlete exposure (1 game) at sea level ranged from approximately 0.07% to 0.45%, which is similar to the rate at higher altitudes (approximately 0.06% to 0.50%). There was heterogeneity between studies, so a random effects model was used. There was no difference in the relative risk of concussion at sea level compared with at higher altitude (Table; Figure). There was no publication bias evident.

Discussion | The link between on-field collisions and chronic traumatic encephalopathy6 suggests that there are long-term health risks for athletes in contact sports, especially football. However, there is no physiologic basis for an altitude less than approximately 2200 m influencing concussion risk,3 and this meta-analysis of nearly 5 million data points demonstrates that there is no clinically relevant association between altitude and concussion risk. Even if altitude protected athletes from concussion, altitude is not a factor that can be readily altered and is of little value from a public health standpoint. Likewise, sports protective equipment meant to replicate the effects of altitude are not scientifically justified. As such, we firmly believe epidemiologic data are already sufficient to indicate that this is an issue that should not be examined further. Further research on this issue will simply divert resources from more clinically effective research aimed at identifying modifiable risk factors for concussion, developing scientifically sound technologies that improve athlete safety, and improving acute and long-term management of sports-related head injuries.

Table. Meta-analysis of the Relative Risk of Concussions in Contact Sports at Higher Altitude vs at Sea Level

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of Adverse Events/No. of Athlete Exposures (%)</th>
<th>Slightly Above Sea Level (200 m to 300 m)</th>
<th>At Sea Level (≤195 m)</th>
<th>Relative Risk (95% CI)</th>
<th>z Score</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynall et al.,4 NCAA Division 1 football</td>
<td>71/14 159 (0.50)</td>
<td>76/26 795 (0.28)</td>
<td>1.77 (1.28-2.45)</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Myer et al.,1 NFL</td>
<td>842/725 995 (0.12)</td>
<td>52/11 483 (0.45)</td>
<td>0.26 (0.19-0.34)</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Smith et al.,2 high school athletics</td>
<td>1306/2 248 360 (0.06)</td>
<td>1461/1 971 496 (0.07)</td>
<td>0.78 (0.73-0.84)</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Total (random effects model)</td>
<td>2219/2 988 514 (0.07)</td>
<td>1589/2 009 774 (0.08)</td>
<td>0.71 (0.31-1.64)</td>
<td>-0.81</td>
<td>.42</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: NCAA, National Collegiate Athletics Association; NFL, National Football League; NA, not applicable.

* We used a random effects model because there was heterogeneity between studies (Cochran Q, 85.6; df, 2; P, 97.7%; P < .001).

The link between on-field collisions and chronic traumatic encephalopathy suggests that there are long-term health risks for athletes in contact sports, especially football. However, there is no physiologic basis for an altitude less than approximately 2200 m influencing concussion risk, and this meta-analysis of nearly 5 million data points demonstrates that there is no clinically relevant association between altitude and concussion risk. Even if altitude protected athletes from concussion, altitude is not a factor that can be readily altered and is of little value from a public health standpoint. Likewise, sports protective equipment meant to replicate the effects of altitude are not scientifically justified. As such, we firmly believe epidemiologic data are already sufficient to indicate that this is an issue that should not be examined further. Further research on this issue will simply divert resources from more clinically effective research aimed at identifying modifiable risk factors for concussion, developing scientifically sound technologies that improve athlete safety, and improving acute and long-term management of sports-related head injuries.
Conclusions | Based on several million athlete exposures, this meta-analysis found no association between concussion incidence at mild altitude compared with altitude at sea level. The myth that higher altitude reduces concussion incidence in athletes is not supported.

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Published Online: September 6, 2016. doi:10.1001/jamaneurol.2016.0795

Author Contributions: Drs Zavorsky and Smoliga had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: All authors.

Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: All authors.

Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: All authors.

Administrative, technical, or material support: Zavorsky.

Study supervision: Zavorsky.

Conflict of Interest Disclosures: None reported.


Chronic Subthreshold Cortical Stimulation to Treat Focal Epilepsy

Approximately 1 to 3 in 1000 people have drug-resistant focal epilepsy.1 Resective surgical procedures are the most effective treatments for patients with epilepsy but are not feasible when seizures originate from critical cortical areas, i.e., the eloquent cortex. Despite evidence for efficacy, current approaches to focal brain stimulation rarely yield seizure-free outcomes.2 We report on 13 patients treated with continuous subthreshold electrical cortical stimulation, which led to the suppression of interictal epileptiform discharges (IEDs) and improvement in clinical seizures (i.e., reduced frequency, with some experiencing reduced intensity and duration).

Methods | The Mayo Clinic Institutional Review Board approved this study, and informed consent was waived, as data were obtained through a deidentified database. Thirteen patients with drug-resistant focal epilepsy were deemed unsuitable for resective surgical procedures following intracranial electroencephalography monitoring with surgically implanted subdural grid and depth electrodes (Figure, A). To accurately estimate the seizure focus, prestimulation monitoring was typically several days, as clinically determined. If they were not a surgical candidate, patients were offered a therapeutic trial of continuous cortical stimulation (biphasic; frequency, 2-100 Hz; pulse width, 90-450 μs; amplitude, 1-6 V in voltage mode) via adjacent strip and occasional depth electrodes in the region of seizure onset. Permanent stimulation hardware (16-contact Medtronic PrimeAdvanced Neurostimulator with Medtronic 6-mm2 platinum-iridium 2×8 surgical leads or Medtronic DBS electrodes [model 3387, 3389, or 3391]) was implanted when intracranial electroencephalography electrodes were explanted.

Data were analyzed retrospectively. Rates of IED were quantified for 6 patients who underwent stimulation at 2 Hz and had 24 hours of pre- and poststimulation intracranial electroencephalography data available for analysis; the 7 patients who were stimulated at greater than 2 Hz were excluded from IED rate analysis because of stimulation artifact. Six 15-minute blocks from a 24-hour period of 500-Hz sampled data were analyzed before and during stimulation. Interictal epileptiform discharges were automatically detected in 5 electrodes per patient (electrode with the highest IED rate and 4 background electrodes) using a previously validated method3 (Figure, B). Within a 4 millisecond window, spikes that occurred at a frequency of 2, 1, or 0.5 Hz were excluded to account for stimulation artifact. Results from IED rates calculated via manual detection for 3 patients using 1 hour of data were similar. Assessments of epilepsy severity and life satisfaction (on a scale from 1 to 10) as well as frequency of disabling seizures were based on retrospective patient report. Statistical significance was set at P < .05.

Results | Ten of the 13 patients (76.9%) reported improvement for both epilepsy severity and life satisfaction following chronic stimulation (Table). According to patient self-report, the mean...