Neurochemical Aftermath of Amateur Boxing

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Background: Little solid information is available on the possible risks for neuronal injury in amateur boxing.

Objective: To determine whether amateur boxing and severity of hits are associated with elevated levels of biochemical markers for neuronal injury in cerebrospinal fluid.

Design: Longitudinal study.

Setting: Referral center specializing in evaluation of neurodegenerative disorders.

Participants: Fourteen amateur boxers (11 men and 3 women) and 10 healthy male nonathletic control subjects.

Interventions: The boxers underwent lumbar puncture 7 to 10 days and 3 months after a bout. The control subjects underwent LP once.

Main Outcome Measures: Neurofilament light protein, total tau, glial fibrillary acidic protein, phosphorylated tau, and β-amyloid protein 1-40 (Aβ1-40) and 1-42 (Aβ1-42) concentrations in cerebrospinal fluid were measured.

Results: Increased levels after a bout compared with after 3 months of rest from boxing were found for 2 markers for neuronal and axonal injury, neurofilament light protein (mean±SD, 845±1140 ng/L vs 208±108 ng/L; \( P = .008 \)) and total tau (mean±SD, 449±176 ng/L vs 306±78 ng/L; \( P = .006 \)), and for the astroglial injury marker glial fibrillary acidic protein (mean±SD, 541±199 ng/L vs 405±138 ng/L; \( P = .003 \)). The increase was significantly higher among boxers who had received many hits (>15) or high-impact hits to the head compared with boxers who reported few hits. In the boxers, concentrations of neurofilament light protein and glial fibrillary acidic protein, but not total tau, were significantly elevated after a bout compared with the nonathletic control subjects. With the exception of neurofilament light protein, there were no significant differences between boxers after 3 months of rest from boxing and the nonathletic control subjects.

Conclusions: Amateur boxing is associated with acute neuronal and astroglial injury. If verified in longitudinal studies with extensive follow-up regarding the clinical outcome, analyses of cerebrospinal fluid may provide a scientific basis for medical counseling of athletes after boxing or head injury.

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comparison of long-term biochemical evidence for neuronal impairment in amateur boxers.

**METHODS**

Fourteen Swedish amateur boxers (11 men and 3 women; age [mean ± SD], 22 ± 3.8 years) were enrolled in the study. Ten healthy male nonboxers with no known history of head trauma (age [mean±SD], 30±6.3 years) were included as control subjects. The study was approved by the Ethics Committee for Medical Research at Go¨teborg University, Go¨teborg, Sweden, and written informed consent was obtained from all participants. Cerebrospinal fluid was collected in polypropylene tubes by lumbar puncture (LP) through the L3-4 or L4-5 interspace. In boxers, LP was performed both 7 to 10 days after boxing and after a 3-month period of rest from boxing. One boxer refused the second LP. Only 1 LP was performed in each of the healthy control subjects. Seven to 10 days was chosen as the optimal length of time for detection of a change in biomarker levels as a result of a bout on the basis of CSF biomarker kinetics in a study of stroke.7 All CSF samples were stored at −80°C pending analysis. The participants were examined physically and neurologically before LP. All were healthy and showed no signs of focal neurologic injury. The number and severity of hits to the head were assessed by interviewing the boxers when examined 7 to 10 days after a bout. Because a score in amateur boxing is counted for hits to any part of the front or sides of the head or body, it was impossible to use the total score of the opponent as a measure of hits to the head. The severity of hits was divided into 2 categories: more than 15 hits to the head or groginess during or after a bout, and 15 or fewer hits to the head and no groginess during or after the bout. None of the boxers received a knockout hit.

Cerebrospinal fluid total tau (T-tau) concentration was determined using a sandwich enzyme-linked immunosorbent assay (ELISA) (Innotest hTAU-Ag; Innogenetics, Gent, Belgium) specifically constructed to measure all tau isoforms irrespective of phosphorylation status, as previously described.8 Phosphorylated tau in CSF was determined using a sandwich ELISA specific for tau phosphorylated at threonine 181.9 Cerebrospinal fluid concentrations of neurofilament light protein (NFL) and glial fibrillary acidic protein (GFAP) were analyzed using previously described ELISA methods.10,11 The detection limit for the NFL ELISA was 125 ng/L. β-Amyloid proteins 1-40 ($\text{A}_\text{β}$1-40) and 1-42 ($\text{A}_\text{β}$1-42) concentrations were determined by ELISA as previously described.12,13 Albumin levels in CSF were measured by immunonephelometry on an Immage immunochemistry system (Beckman Coulter Inc, Fullerton, Calif).

<table>
<thead>
<tr>
<th>Biomarker</th>
<th>Boxers After a Bouta (n = 14)</th>
<th>Boxers After Absence From Boxingb (n = 13)</th>
<th>Control Subjectsc (n = 10)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFL</td>
<td>845 (1140)</td>
<td>208 (108)</td>
<td>≤125</td>
<td>.008</td>
</tr>
<tr>
<td>T-tau</td>
<td>449 (176)</td>
<td>306 (78.1)</td>
<td>325 (97.7)</td>
<td>.006</td>
</tr>
<tr>
<td>GFAP</td>
<td>541 (199)</td>
<td>405 (138)</td>
<td>402 (88.8)</td>
<td>.003</td>
</tr>
<tr>
<td>P-tau</td>
<td>37.9 (10.2)</td>
<td>37.8 (9.30)</td>
<td>46.4 (14.5)</td>
<td>.67</td>
</tr>
<tr>
<td>$\text{A}_\text{β}$1-40</td>
<td>19,300 (2740)</td>
<td>19,500 (3990)</td>
<td>19,400 (5050)</td>
<td>.70</td>
</tr>
<tr>
<td>$\text{A}_\text{β}$1-42</td>
<td>858 (128)</td>
<td>796 (133)</td>
<td>773 (114)</td>
<td>.15</td>
</tr>
</tbody>
</table>

Abbreviations: $\text{A}_\text{β}$1-40 and $\text{A}_\text{β}$1-42, β-amyloid proteins 1-40 and 1-42, respectively; GFAP, glial fibrillary acidic protein; NFL, neurofilament light protein; P-tau, phosphorylated tau; T-tau, total tau.

*Data are given as mean (SD) in nanograms per liter.

Figure 1. Individual cerebrospinal fluid biomarker values in boxers after a bout and after a period of rest from boxing. Cerebrospinal fluid levels of the neuronal and astrogial markers neurofilament light protein (A), total tau (B), and glial fibrillary acidic protein (C) after a bout are related to the number of hits to the head. Red squares indicate boxers who received many hits (>15) or high-impact hits to the head; blue circles, boxers who received few hits to the head. Each boxer underwent lumbar puncture twice, 7 to 10 days after a bout and after 3 months of rest from boxing.
After a bout, there was a marked increase (4.1-fold) in the CSF levels of NFL compared with levels detected in the same individuals after a 3-month rest from boxing (Table 1 and Figure 1). The CSF levels of T-tau and GFAP also were significantly increased after a bout compared with after a 3-month rest from boxing (1.5-fold and 1.3-fold, respectively; Table 1 and Figure 1). The changes in NFL, T-tau, and GFAP concentrations were higher in boxers who had received many hits (>15) or high-impact hits to the head compared with boxers who reported few hits (Table 2 and Figure 1). With the exception of NFL, boxers who received few hits had biomarker levels statistically indistinguishable from those in control subjects (Table 2). Levels of phosphorylated tau and Aβ1-40 and Aβ1-42, markers that reflect molecular changes in Alzheimer disease, were not significantly altered in boxers after a bout compared with after rest or levels detected in the nonathletic control subjects. No significant differences in CSF albumin concentrations were detected, indicating that amateur boxing does not significantly impair the blood-brain barrier function (data not shown).

The current study contributes new information about brain injury risks in amateur boxing. Data suggest that participation in an amateur boxing bout is directly associated with neuronal and astroglial damage, as ref-
lected by the increase in NFL, T-tau, and GFAP concentrations in CSF. The findings that the increase in these CSF biomarkers is most pronounced in boxers who receive many hits or high-impact hits to the head and that the CSF levels show normalization after 3 months of rest from boxing indicate that the changes are directly related to brain trauma inflicted by hits to the head. The high correlation between biomarker changes in individual boxers supports this interpretation.

The most pronounced change was a marked increase in CSF NFL after a bout that also correlated with the severity of received hits, while a similar but less pronounced increase was found for CSF T-tau. Both NFL and tau are important constituents of neuronal axons.\textsuperscript{14,15} The CSF levels of these proteins increase in disorders with neuronal and axonal degeneration and damage,\textsuperscript{16-19} and the increase is known to correlate with the size of the brain lesion.\textsuperscript{7,10} When applied to the results of this study, the increases in NFL and T-tau probably reflect damage to neuronal axons from hits to the head during a bout. An increase after a bout was also found for CSF GFAP, which is an intermediate filament protein mainly expressed in astrocytes, for which it constitutes a selective marker.\textsuperscript{11} This finding suggests that there is also astroglial damage caused by amateur boxing. Similarly, in acute brain trauma, a marked increase in serum GFAP concentration was recently found.\textsuperscript{20} This increase also correlated with clinical outcome.

A large body of evidence supports the belief that professional boxers who have been exposed to repetitive head trauma are at increased risk for developing Alzheimer-like pathologic findings, with hyperphosphorylation of tau and formation of tangles and deposition of Aβ into plaques.\textsuperscript{21-23} We, therefore, tested whether amateur boxing results in any changes in CSF biomarkers reflecting these pathogenic processes, that is, elevated phosphorylated tau concentration and decreased Aβ\textsubscript{1-42} concentration and the ratio of Aβ\textsubscript{1-42} to Aβ\textsubscript{1-40}.\textsuperscript{11,24} No significant changes were detected; hence, our data provide no evidence for any acute disturbances in these systems in amateur boxers. In conclusion, our study results suggest that amateur boxing impairs axonal and astroglial integrity. The molecular changes detected are likely to be even more pronounced in professional boxers and in boxers who have received a knockout punch.

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Author Contributions: Drs Zetterberg, Hietala, Blennow, and Wallin had full access to all 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: Zetterberg, Andreasen, Edman, Popa, Ransludza, Rosengren, Blennow, and Wallin. Acquisition of data: Zetterberg, Jonsson, Andreasen, Styrd, Karlsson, Edman, Popa, Rasulzada, Wahlund, Mehta, Rosengren, Blennow, and Wallin. Analysis and interpretation of data: Zetterberg, Hietala, Andreasen, Popa, Ransludza, Wahlund, Mehta, Rosengren, Blennow, and Wallin. Drafting of the manuscript: Zetterberg, Hietala, Andreasen, Styrd, Edman, Wahlund, and Blennow. Critical revision of the manuscript for important intellectual content: Zetterberg, Hietala, Jonsson, Karlsson, Popa, Rasulzada, Mehta, Rosengren, Blennow, and Wallin. Statistical analysis: Zetterberg and Hietala. Administrative, technical, or material support: Zetterberg, Styrd, Popa, Rasulzada, Wahlund, Mehta, Rosengren, Blennow, and Wallin. Study supervision: Andreasen, Rosengren, Blennow, and Wallin.

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REFERENCES