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Prevalence of Cerebral Microbleeds in Active Amateur Boxers: A 3T Susceptibility-Weighted Imaging Study

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ABSTRACT

Introduction: To estimate the prevalence of cerebral microbleeds (CMBs) on 3T susceptibility-weighted imaging (SWI) in active amateur boxers and compare findings with healthy controls.

Methods: Thirty active male amateur boxers and 30 healthy male volunteers (18-29 years) underwent brain magnetic resonance imaging including SWI on a 3T system. Boxing exposure variables (age, boxing duration, self-reported number of matches, knockouts, and history of concussion) were recorded via structured interviews. Two experienced neuroradiologists, blinded to group allocation, independently reviewed SWI datasets for CMBs using magnitude and phase information to confirm susceptibility and exclude mimics. Group differences in CMB prevalence were assessed using Fisher's exact test. For zero-event data, 95% confidence intervals (CIs) for prevalence were reported.

Results: Boxers had a mean boxing career duration of 6.04 years, with a total of 1,152 self-reported matches (38.4 per boxer), 47 knockouts, and 8 traumatic concussions. No CMBs were observed on SWI in either the boxer or control group (0/30 vs. 0/30; Fisher's exact test, p=1.00). For each group, the two-sided 95% CI for CMB prevalence was 0% to 11.6%. Inter-reader agreement was complete.

Conclusion: No CMBs were observed on 3T SWI in this cohort of young active amateur boxers. However, given the sample size and zero-event outcome, clinically relevant low prevalences cannot be excluded; larger studies enriched for higher cumulative head-impact exposure are needed to provide tighter prevalence estimates and clarify clinical significance.

Keywords: Amateur boxing, cerebral microbleeds, susceptibility weighted imaging (SWI)

Introduction

Trauma-related brain injury has become a major global public health problem, disproportionately affecting young and economically productive individuals and leading to substantial disability and mortality (1). Common causes of traumatic brain injury (TBI) include traffic and occupational accidents, sports-related trauma, falls from height, and physical violence. TBI-related disturbances are typically categorized as primary and secondary (2). Primary injury refers to damage occurring at the moment of impact, including hemorrhage, vascular injury, cranial fractures, and diffuse axonal injury (DAI). Secondary injury encompasses biochemical, physiological, and vascular processes that develop minutes to days after trauma as a consequence of homeostatic disruption.

Interest and participation in close-contact combat sports such as boxing have increased at both amateur and professional levels, accompanied by a rise in sports-related head injuries (3). Because the head is a frequent target in boxing, repetitive impacts are thought to contribute to both acute and chronic brain injury. Acute injuries span a wide clinical spectrum, ranging from concussion and intracranial hemorrhage to cerebral white matter axonal damage. Behavioral disturbances and later-life motor and cognitive impairments have been reported after athletic careers end (4). The delayed and cumulative neural effects of repetitive blows may become more apparent after retirement from boxing.

Brain computed tomography (CT) and conventional magnetic resonance imaging (MRI) are widely used to evaluate athletes with suspected mild TBI (mTBI). However, these examinations frequently yield normal or non-specific findings, limiting their sensitivity for detecting subtle injury (5). This limitation has motivated increased interest in advanced neuroimaging techniques to better characterize TBI mechanisms and identify brain changes that may precede overt clinical findings, potentially enabling earlier risk stratification and preventive interventions.

Susceptibility-weighted imaging (SWI) is an advanced MRI technique first described for clinical implementation by Haacke et al. (6) in 2004. SWI leverages the magnetic susceptibility effects of blood products (e.g., deoxyhemoglobin, intracellular hemoglobin, and hemosiderin) and

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minerals such as iron and calcium by combining magnitude and phase information to enhance the detection of small hemorrhagic lesions, including cerebral microbleeds (CMBs). Given the established sensitivity of SWI for microhemorrhagic foci and the relevance of repetitive head trauma in boxing, this technique represents a particularly suitable tool for investigating subclinical brain injury in this population.

The aim of this study was to evaluate the presence and prevalence of CMBs on SWI in active amateur boxers exposed to repetitive head impacts, by comparing findings with those of healthy controls.

Methods

Study Design and Ethical Approval

This study was conducted between September 2021 and September 2022, after approval was obtained from the Selçuk University Ethics Committee (approval number: 2020/103, date: 04.03.2020). MRI-related costs were supported by Selçuk University's Scientific Research Projects Unit. Written informed consent was obtained from all participants before enrollment. All participants were informed of the study procedures, potential risks and benefits, the confidentiality of personal data, and their right to withdraw at any time without consequences. The consent process complied with the principles of the Declaration of Helsinki.

Participants

A total of 60 individuals were included: 30 active amateur boxers and 30 healthy male volunteers. The control group was recruited from the same age range as the boxer group and matched to the boxer group for age and sex. No significant difference in age was observed between the two groups (boxer group: median age 23 years, range 18-29 years; control group: median age 23 years, range 18-29 years; $p>0.05$). All participants were male. For the boxer group, the following variables were recorded via structured interviews: age, duration of boxing career, total number of matches, mean number of matches per boxer, total number of knockouts, and number of prior traumatic concussions.

Exclusion Criteria

Participants were excluded if they had any of the following: a known neurological disease; a history of head trauma (except boxing-related trauma in the boxer group); epilepsy; metabolic disorders; perinatal asphyxia; active or prior central nervous system disease; a history of drug or substance use; or hypertension.

Clinical Assessment

All participants underwent a standardized neurological examination. The neurological evaluation assessed the presence of focal neurological deficits, tremor, nystagmus, speech disturbances, and subjective memory complaints. Data were collected using standardized forms and predefined evaluation protocols throughout the study period.

MRI Acquisition

MRI examinations were performed using a 3-Tesla scanner (Magnetom Aera, Siemens Healthcare, Erlangen, Germany) with a dedicated head coil. Initial sagittal localizer images were obtained. SWI was acquired with the following parameters: repetition time, 49 ms; echo time, 40 ms; in-plane resolution, 0.9 × 0.9 mm; section thickness, 1.6 mm; base resolution, 320; flip angle, 15°; phase field of view, 75%; image matrix, 247 × 320 (Figure 1). SWI images were reviewed for artifacts; no participant was excluded due to imaging artifacts.

Image Analysis

All images were evaluated independently by two academic radiologists with 10 and 12 years of neuroradiology experience, respectively. Readers were blinded to participant group and to each other's assessments. SWI magnitude images were reviewed together with corrected phase images to confirm susceptibility effects and to help exclude mimics. CMBs were defined as small, rounded or ovoid hypointense foci on SWI magnitude images (typically within the microbleed size range) that showed corresponding susceptibility on phase images and were not attributable to venous structures, calcifications, or artifacts. Microbleeds were recorded as present or absent. If present, the number of foci was counted. Any potential disagreements would be resolved by consensus; however, no disagreements occurred.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23 (IBM Corp., Armonk, NY, USA). The prevalence of

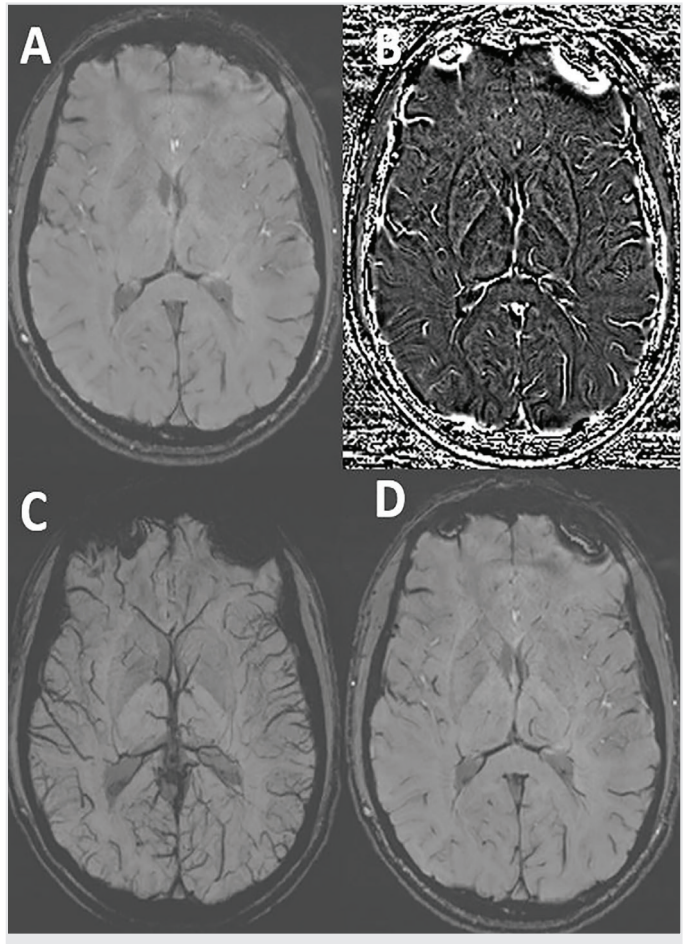

Figure 1. SWI examples: (A) magnitude image; (B) filtered phase image; (C) minIP image; (D) processed SWI image. SWI: Susceptibility-weighted imaging

microbleeds was compared between groups using Fisher's exact test. Age, as a demographic variable, was compared between groups using the Mann–Whitney U test. A two-sided p value of <0.05 was considered statistically significant. For each group, two-sided 95% confidence intervals (CIs) for microbleed prevalence were calculated. When the event count was zero, the upper bound of the CI was derived using the exact binomial (Clopper–Pearson) method.

Results

Study Population

A total of 60 male participants were included in the study: 30 active amateur boxers and 30 healthy controls. The overall age range was 18-29 years, and the median age in both groups was 23 years. No statistically significant difference in age was found between the boxer and control groups (p>0.05).

Boxing Exposure Characteristics

In the boxer group, the mean duration of boxing participation was 6.04 years. The total number of matches was 1,152, corresponding to a mean of 38.4 matches per boxer. There were 47 knockouts and 8 documented traumatic concussions. Systematic data on sparring frequency and training-related head impacts were not collected as part of the structured interview; this represents a recognized limitation of the exposure assessment, as discussed below.

SWI Findings

All SWI datasets were considered diagnostically adequate. SWI magnitude and corrected phase images generated through post-processing were independently evaluated by two academic radiologists with 10 and 12 years of neuroradiology experience. Both readers were blinded to the participant group and to each other's assessments.

Neither reader identified lesions suggestive of microbleeds in any participant in either group. Accordingly, the observed prevalence of SWI-detected microbleeds was 0/30 (0%) in the boxer group and 0/30 (0%) in the control group (Fisher's exact test, p=1.00). For each group, the two-sided 95% CI for microbleed prevalence was 0% to 11.6%.

Inter-reader Agreement

Inter-reader agreement was complete, with 100% concordance between the two radiologists regarding the presence or absence of microbleeds.

Discussion

Repetitive head impacts in boxing have been associated with a broad spectrum of TBI-related findings, including cerebral and cerebellar atrophy, ventricular enlargement, post-traumatic cysts, contusions, intraparenchymal and extra-axial hematomas, axonal injury, and white matter microhemorrhages. TBI may manifest as focal lesions or DAI. Importantly, microhemorrhages related to mTBI and DAI are most frequently located in deep subcortical white matter and the brainstem, and they may remain occult on cranial CT and conventional MRI sequences (7). Because the number, size, and anatomical distribution of microhemorrhages can correlate with clinical severity and may inform prognosis, reliable detection of these lesions is clinically meaningful in populations exposed to repetitive head trauma (8).

SWI leverages magnetic susceptibility differences to enhance the conspicuity of venous structures and blood products. In SWI processing, phase information is filtered and combined with magnitude data to generate images with increased contrast for susceptibility effects, thereby improving the visualization of hemorrhagic foci and certain mineral deposits compared with conventional MRI (6). Prior work has demonstrated the added value of SWI in a variety of intracranial pathologies. For example, İkizceli and Mutlu Değer (9) evaluated SWI on a 1.5-T system across a heterogeneous cohort and reported that SWI increased lesion conspicuity and facilitated detection of micro- and macrohemorrhages, venous malformations, and mineral accumulation relative to conventional sequences. Similarly, in a large cohort study comparing T2* and SWI at 1.5 T, SWI was reported to be highly sensitive for slow-flow vascular lesions, hemorrhagic foci, mineral deposition, internal characteristics of cerebral masses, and hemorrhagic transformation in ischemic stroke, while preserving anatomic detail (10).

Earlier imaging studies of boxers using CT and lower-field MRI frequently reported normal findings or only subtle abnormalities, likely reflecting limited sensitivity and technical constraints. In a CT-based study of 338 active professional boxers, 93% had normal findings, while borderline atrophy was identified in 6% (7). In an MRI study including 12 active and 40 retired boxers, mild cerebral atrophy was reported in eight cases, and reduced size of the mammillary bodies and optic chiasm was described in 30 cases (11). However, early MRI studies often used low-field systems and thick slices, which likely limited detection of small lesions and constrained the interpretation of negative results. Consistent with this, a 1992 MRI study of 13 amateur boxers acquired on a 0.5-T system with 10-mm slice thickness reported no abnormalities and no cerebral microhemorrhages (12).

In contrast to these earlier reports, the present study employed SWI to investigate microbleeds potentially related to repetitive head trauma in active amateur boxers. We also recorded exposure-related variables that may influence injury burden (e.g., number of matches, knockouts, and documented concussions). Despite these measures, no SWI-detected microbleeds were observed in either the boxer group or the control group, and inter-reader agreement was complete.

Our findings align with studies using contemporary MRI approaches in boxing populations, suggesting low rates of detectable microbleeds in amateur cohorts. In one study of 24 professional boxers using current MRI techniques, diffusion values did not differ significantly between boxers and controls (13). In another study of 49 professional boxers, conventional MRI was normal in 42 participants; the remaining seven showed non-specific white matter lesions. Notably, diffusion tensor metrics differed between boxers and controls, findings interpreted as potential preclinical indicators of brain injury (14). Neither of these diffusion-focused studies specifically assessed microbleed burden. In a 3-T MRI study of 42 male amateur boxers and 37 healthy male controls, microhemorrhages were more frequent in boxers, but the difference did not reach statistical significance (15). Similarly, in a 1.5-T study including 21 amateur boxers and 21 controls, microhemorrhage was identified in 2 of 21 boxers, and these foci were not seen on conventional sequences (16).

Several factors may explain the absence of microbleeds in our boxer cohort. First, participants were young, active amateurs rather than long-retired athletes with decades of exposure, which may have reduced the cumulative risk of detectable hemorrhagic sequelae. Second, the observed burden of severe events (e.g., knockouts and documented concussions) may have been insufficient to yield SWI-visible lesions in this sample. Third, depending on the timing and biological evolution of microbleeds, some lesions may become less conspicuous over time. Finally, improvements in protective equipment, medical supervision, and stricter enforcement of safety regulations in boxing may have contributed to lower rates of microhemorrhagic injury in contemporary amateur athletes (17).

An important interpretive caveat must be emphasized: the absence of SWI-detected microbleeds does not exclude the presence of subtle microstructural or functional brain alterations in this cohort. SWI is specifically sensitive to blood products and susceptibility effects; it is not designed to detect DAI, white matter microstructural changes, or functional connectivity alterations. Advanced neuroimaging techniques such as diffusion tensor imaging, functional MRI, and magnetic resonance spectroscopy may reveal abnormalities in athletes with repetitive head trauma even when SWI findings are negative (13,14). Furthermore, the 95% CI for microbleed prevalence in the boxer group extended as high as 11.6%, indicating that a low but potentially clinically relevant prevalence cannot be excluded on the basis of this study alone. These considerations underscore the need for multimodal imaging approaches in future research, and caution against interpreting a negative SWI result as evidence of the absence of brain injury.

Study Limitations

This study has limitations that warrant careful consideration. First, the sample size was modest (n=30 per group), which substantially limits statistical power for detecting rare outcomes; with 0/30 observed microbleeds, the 95% CI upper bound was 11.6%, indicating that a low but potentially clinically relevant prevalence cannot be excluded. The small sample size is, therefore, a critical constraint on interpreting the negative finding; future studies with larger cohorts are needed to provide more definitive estimates. Second, the lack of longitudinal follow-up means that the temporal evolution of potential microstructural changes cannot be assessed; cross-sectional imaging at a single time point may miss lesions that develop or become more conspicuous with continued exposure. Third, although match exposure was recorded, unmeasured sparring and training-related head impacts may have led to exposure misclassification and underestimation of cumulative trauma—sparring sessions in particular, can involve substantial repetitive subconcussive impacts that are not captured by official match statistics. Fourth, SWI is sensitive to blood products, but very small or remote chronic foci may become less conspicuous over time due to resorption and tissue remodeling. Fifth, findings from a young amateur cohort may not generalize to professional or high-risk subgroups, particularly athletes with repeated knockouts or suspected chronic traumatic encephalopathy.

Conclusion

SWI is a robust method for detecting CMBs, an imaging correlate of TBI. In this study, however, SWI did not show an increased prevalence of microbleeds in active amateur boxers compared with healthy controls. Importantly, this negative finding should not be interpreted as evidence of the absence of brain injury; SWI does not capture the full spectrum of brain changes related to repetitive head trauma, and the upper bound of the 95% CI (11.6%) indicates that a clinically relevant prevalence of microbleeds cannot be definitively excluded. Larger prospective studies—ideally enriched for higher cumulative head-impact exposure, with longitudinal follow-up and integration of clinical outcomes and advanced microstructural imaging metrics—are needed to define the role of SWI in monitoring repetitive head trauma and to identify athletes at risk for long-term neurological sequelae.

Ethics

Ethics Committee Approval: This study was conducted between September 2021 and September 2022, after approval was obtained from the Selçuk University Ethics Committee (approval number: 2020/103, date: 04.03.2020).

Informed Consent: The written informed consent was obtained from all participants before enrollment.

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Footnotes

Authorship Contributions: Concept - M.Ö., H.C., Design - M.Ö., A.B., O.Ç., K.D., H.C.; Data Collection or Processing - M.Ö., A.B., O.Ç., K.D., H.C.; Analysis or Interpretation - A.B., O.Ç., H.C.; Literature Search - A.B., H.C.; Writing - M.Ö.

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