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ORIGINAL RESEARCH

Neuroimaging in professional combat sports: consensus statement from the association of ringside physicians

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ABSTRACT

Professional boxing, kickboxing, and mixed martial arts (MMA) are popular sports with substantial risk for both acute and chronic traumatic brain injury (TBI). Although rare, combat sports athletes have died in the ring or soon after the completion of a bout. Deaths in these instances are usually the result of an acute catastrophic neurological event such as an acute subdural hematoma (SDH). Other causes may include acute epidural hematoma (EDH), subarachnoid hemorrhage (SAH), intraparenchymal hemorrhage (IPH), or a controversial, rare, and still disputed clinical entity called second-impact syndrome (SIS). Neuroimaging or brain imaging is currently included in the process of registering for a license to compete in combat sports in some jurisdictions of the United States of America and around the world. However, the required imaging specifics and frequency vary with no consensus guidelines. The Association of Ringside Physicians (an international, nonprofit organization dedicated to the health and safety of the combat sports athlete) sets forth this consensus statement to establish neuroimaging guidelines in combat sports. Commissions, ringside physicians, combat sports athletes, trainers, promoters, sanctioning bodies, and other healthcare professionals can use this statement for risk stratification of a professional combat sports athlete prior to licensure, identifying high-risk athletes and for prognostication of the brain health of these athletes over the course of their career. Guidelines are also put forth regarding neuroimaging requirements in the immediate aftermath of a bout.

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Boxing; mixed martial arts; combat sports; brain imaging; safety

Preamble: development of these consensus guidelines

These consensus guidelines express a collaborative effort among the Association of Ringside Physicians (ARP) board, emeritus board, and ARP subject matter expert members. An extensive literature search including but not restricted to MEDLINE (http://www.ncbi.nlm.nih.gov/pubmed/), Cochrane Reviews (http://www.cochrane.org/reviews/) and non-indexed peer-reviewed articles published in online medical journals was performed to answer the research questions what are the neuroimaging requirements in combat sports at the time of initial licensure and in the immediate aftermath of a bout? Primary keywords used for the search strategy included combat sports, boxing, mixed martial arts, traumatic brain injury, head injury, subdural hematoma, epidural hematoma, intracranial hemorrhage, chronic traumatic encephalopathy, dementia pugilistica, punch drunk, mortality, CT scan head, MRI brain, fMRI, MEG, MRS, DTI, ASL, PET, vascular malformations, aneurysm, cavernous malformation, arachnoid cyst, and venous malformation. Unfortunately, significant studies/articles/information specifically detailing neuroimaging requirements in combat sports are lacking in the published literature. However multiple studies were identified detailing neuroimaging techniques in traumatic brain injury. These included the use of CT scan head, MRI brain and advanced MRI imaging techniques such as diffusion tensor imaging. Publications from the ongoing longitudinal cohort study of combat sport athletes (professional fighters brain health study) were reviewed to develop guidelines intended to protect brain health of combatants. These studies (listed under references) were reviewed to extrapolate information about sensitivity and specificity of neuroimaging modalities with relevance to combat sports. The collective medical expertise and clinical ringside experience of the authors were used to then frame consensus guidelines that are practical and easy to implement across different commissions and different combat sports event settings. The primary author (NS), a neurologist, was delegated the task to compose the first draft of the accompanying guidelines. Parts of the manuscript are reproduced verbatim and with permission from an article which NS published in 2017 in the South African Journal of Sports Medicine [1]. Once the first draft was completed, the second author (JN), who sub-specializes in sports medicine, edited the document. The final draft of the manuscript was e-mailed to the entire ARP board for review. While we did not employ Delphi methodology to establish level of consensus among different board members on each guideline, pertinent suggestions were incorporated; disagreements if any were resolved by discussions conducted via group e-mails or telephone and after an informal consensus was obtained via e-mail the manuscript was formally approved by both authors and the entire ARP board.

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Utility of neuroimaging in professional combat sports

Neuroimaging serves three distinct roles in the individualized care of the combat sports athlete.

(1) Neuroimaging prior to licensure helps to identify and/or exclude coincidental or clinically suspected brain lesions which may pose a risk for rupture, bleeding, or other catastrophic brain injury during a bout/training, representing a step toward personalized medicine and individual risk stratification of a combat sports athlete.
(2) Neuroimaging in the immediate aftermath of a bout primarily serves to rule out acute life-threatening traumatic brain injury such as SDH and other significant acute injury such as skull fracture.
(3) Neuroimaging may also be conducted to assess for evidence of prior structural brain injury associated with brain trauma. Prevailing hypothesis is that this makes a combat sports athlete more likely to express late life neuropsychologic sequelae such as chronic traumatic encephalopathy (CTE), or dementia pugilistica/punch drunk syndrome. Serial neuroimaging could help identify these at-risk athletes if progressive structural and functional changes are present over time. In these athletes, structural and functional neuroimaging could play a prognostic role and aid in determining whether the combatant should be allowed to continue to participate in future bouts.

The risks for both acute and chronic traumatic brain injury are high in contact sports such as professional boxing, kickboxing, and MMA [2,3]. Currently there are no consensus neuroimaging guidelines for combat sports. Standardizing neuroimaging guidelines for licensure, with the goal of screening for both acute and chronic traumatic brain injury, could assist in protecting the combat sport athlete's health and safety, both in the ring/cage, and after their professional careers have ended.

Neuroimaging prior to licensure

Neuroimaging prior to licensure aids the clinical judgment of supervisory personnel (ringside physicians and commission officials) regarding whether the combat sports athlete should be allowed to participate in a future bout [1,4,5]. It also helps identify and/or exclude coincidental or clinically suspected brain lesions that may pose a risk for rupture, bleeding, or other catastrophic injuries to the brain should a combat sports athlete participate in future bouts including identifying signs of increased intracranial pressure [1]. These structural lesions include but are not limited to cerebral aneurysms, arteriovenous malformations, cavernous angiomas, mixed malformations, vein of Galen malformations, venous malformations, large arachnoid cysts, pituitary macroadenomas, and other space-occupying lesions or tumors [1]. It is important to emphasize that the above represent a heterogeneous group of cerebral and cerebrovascular lesions, which have different natural histories and propensities to bleed [1]. A less urgent but equally significant role of neuroimaging prior to licensure is to identify evidence of prior structural injury associated with brain trauma. While definitive evidence is lacking, it is reasonable hypothesis that such injury predisposes a combat sports athlete to express late-life neuropsychiatric sequelae such as chronic traumatic encephalopathy (CTE), dementia pugilistica, chronic post-concussion syndrome, post-traumatic dementia, post-traumatic cognitive impairment, post-traumatic Parkinsonism, and chronic posttraumatic headache [1]. This information aids the physician in prognosticating for the risk of future neurologic sequelae particularly when the athlete's clinical history is ambiguous [1].

Either a computed tomography (CT) or magnetic resonance imaging (MRI) of the brain is currently included in the process of registering for a license to compete in combat sports in some jurisdictions in the United States of America and around the world (Table 1). The imaging specifics and frequency vary widely, with some commissions requiring MRI brain scan every 1–5 years and others only once, i.e. at the time of licensure. Some commissions do not require any imaging prior to licensure. Other commissions only require imaging if a combat sports athlete is of a certain age or deemed 'high-risk.' Classification of what makes a combat sports athlete 'high-risk' also varies from commission to commission, but usually is related to age (usually >40 years), period of inactivity (usually >1 year), and/or recent loss/multiple losses (usually >10). Some commissions detail the required MRI imaging sequences and specifically request sequences such as susceptibility weighted imaging (SWI) and gradient echo imaging (GEI). Some commissions require that all combat sports athletes undergo a magnetic resonance angiogram (MRA) of the brain in addition to MRI of the brain at the start of their professional career (time of licensure) to primarily exclude any incidental vascular malformations of the brain.

Sensitivity and specificity of different neuroimaging modalities

The CT is extremely sensitive in detecting the stigmata of acute TBI such as bleeding and bone pathology (craniofacial fractures, fractures of the orbits). It has the added advantage of widespread availability, short scan time, and low cost. The MRI is superior to a CT for detecting the stigmata of chronic TBI [1,6]. The ability of the MRI to detect hematomas improves over time as the composition of the blood changes [1,6]. The overwhelming majority of patients with mild brain injury frequently show no parenchymal abnormality on MRI [1,6]. However, coincidental structural brain abnormalities are found in about 2–3% of all studies, including meningiomas, coincidental, and non-pathologic anomalies, and small often unruptured cerebral aneurysms [1]. Small circle of Willis cerebral aneurysms are better visualized with CT or MR angiography. Large arteriovenous malformations (AVMs) can be readily identified on CT and MRI [7]. With reference to contact sports, relevant abnormalities include hemorrhagic cortical contusions, petechiae, or foci of altered signal that represent white matter shear injury (diffuse axonal injury) [1,5,6]. When petechiae resolve, they can leave a permanent hemosiderin deposition on the MRI [1]. While the MRI is superior to a CT in the detection of axonal injury, it is insensitive in detecting

Table 1. Neuroimaging requirements for combat sports licensure in different Commissions around the world.

Commission	Imaging Requirements for Combat Sports Licensure
UNITED STATES OF AMERICA	
ALABAMA ATHLETIC COMMISSION	None
ARIZONA BOXING & MMA COMMISSION	MRI if 40+ 'if reccomended' by the examining physician
CALIFORNIA STATE ATHLETIC COMMISSION	MRI every 5 years for all, also need MRA if 40+
COLORADO STATE BOXING COMMISSION	None
CONNECTICUT DEPT. OF EMERGENCY SERVICES & PUBLIC PROTECTION – BOXING AND MMA REGULATION	'May include' MRI/CT
FLORIDA STATE BOXING COMMISSION	MRI every year if 40+
GEORGIA ATHLETIC AND ENTERTAINMENT COMMISSION	None
IDAHO STATE ATHLETIC COMMISSION	None
ILLONOIS STATE ATHLETIC COMMISSION	MRI/CT for all every 5 years
INDIANA GAMING COMMISSION	None
KANSAS ATHLETIC COMMISSION	None
KENTUCKY BOXING & WRESTLING COMMISSION	None
LOUISIANA BOXING & WRESTLING COMMISSION	MRA if 40+
COMBATIVE SPORTS AUTHORITY OF MAINE	None
MARYLAND STATE ATHLETIC COMMISSION	None
MASSACHUSETTS STATE ATHLETIC COMMISSION	MRI/CT for all every 5 years
MICHIGAN UNARMED COMBAT COMMISSION	None
MINNESOTA OFFICE OF COMBATIVE SPORTS	None
MISSISSIPPI ATHLETIC COMMISSION	None
MISSOURI OFFICE OF ATHLETICS	None
NEBRASKA ATHLETIC COMMISSION	None
NEVADA ATHLETIC COMMISSION	MRI every 5 years for all, also need MRA once
NEW HAMPSHIRE BOXING/WRESTLING COMMISSION	None
NEW JERSEY ATHLETIC CONTROL BOARD	MRI/CT for all, also need MRA if 40+
NEW YORK STATE ATHLETIC COMMISSION	MRI every 3 years for all, also need MRA if 40+
NORTH CAROLINA BOXING AUTHORITY	MRI if 40+ or 'high risk'
OHIO ATHLETIC COMMISSION	MRI if 35+ or 'high risk'
OKLAHOMA STATE ATHLETIC COMMISSION	MRI if 40+ or 'high risk'
OREGON STATE ATHLETIC COMMISSION	None
PENNSYLVANIA ATHLETIC COMMISSION	None
RHODE ISLAND LICENSING AND REGULATION	MRI/CT every 3 years for all, also need MRA if 40+
SOUTH CAROLINA ATHLETIC COMMISSION	None
SOUTH DAKOTA ATHLETIC COMMISSION	None
TENNESSEE ATHLETIC COMMISSION	None
TEXAS COMBATIVE SPORTS PROGRAM	None
PETE SUAZO UTAH ATHLETIC COMMISSION	None
VERMONT BOXING COMMISSION	None
VIRGINIA BOXING AND WRESTLING	CT if lost last bout via TKO/KO
WASHINGTON STATE DEPARTMENT OF LICENSING	MRI if 37+ or if combat sports athlete has had 6 or more losses in a row
WEST VIRGINIA ATHLETIC COMMISSION	MRI & MRA if 40+
WISCONSIN DEPARTMENT OF SAFETY AND PROFESSIONAL SERVICES	MRI/MRA if 40+
WYOMING STATE BOARD OF MIXED MARTIAL ARTS	None
CANADA	
EDMONTON COMBATIVE SPORTS COMMISSION (ALBERTA)	Baseline MRI/CT for all, MRI every year if 40+
LETHBRIDGE COMBATIVE SPORTS COMMISSION (ALBERTA)	MRI if 40+
BRITISH COLUMBIA ATHLETIC COMMISSION	None
MINISTRY OF TOURISM, CULTURE & SPORT	None
MANITOBA COMBATIVE SPORTS COMMISSION	None
NEW BRUNSWICK COMBAT SPORTS COMMISSION	MRI if 40+
NOVA SCOTIA BOXING AUTHORITY	None
OFFICE OF THE ONTARIO ATHLETICS COMMISSIONER	MRI/CT every 2 years for all
QUEBEC BOXING COMMISSION	CT scan
ATHLETICS COMMISSION OF SASKATCHEWAN	None
SOUTH AMERICA	
BRAZILIAN MMA ATHLETIC COMMISSION (CABMMA)	MRI every 3 years for all, also MRA every 3 years for all
EUROPE	
BRITISH BOXING BOARD OF CONTROL	MRI or MRA every year for all
BRITISH & IRISH BOXING AUTHORITY	MRI or MRA every year for all
BOXING UNION OF IRELAND	MRI every year for all, also need MRA once if younger than 40, MRA every year if 40+
SUOMEN AMMATTINYRKKEILYLIITTO (FINNISH PROFESSIONAL BOXING FEDERATION)	MRI every year for all
SUOMEN VAPAAOTTELUIITTO (FINNISH MIXED MARTIAL ARTS FEDERATION)	MRI every 2 years for all, also need MRA once in beginning of career
FFBOXE FéDERATION FRANçAISE DE BOXE (FRANCE)	MRI or MRA if requested by the federation ringside physician
FEDERAZIONE PUGILISTICA ITALIANA (ITALY)	MRI or MRA every year for all
MALTA BOXING COMMISSION	MRI or MRA every year for all
SWISSBOXING	MRI or MRA every year for all

***Although listed as none, some commissions state that additional medical test may be necessary based on the past or present medical condition

acute hemorrhage (oxy-Hgb and deoxy-Hgb) within 48–72 h after injury; emphasizing the value of CT without contrast in rapid triage of patients with acute TBI.

Stigmata of old TBI on an MRI also include chronic SDHs and areas of encephalomalacia and gliosis, particularly in areas prone to coup-contrecoup forces, such as the frontal lobe (anterior as well as inferior margin along the cribriform plate), anterior temporal lobe, and the occipital pole [1,6]. The MRI is also superior to a CT at imaging the brainstem, basal ganglia, and thalami [1,5,6]. Fluid-attenuated inversion recovery (FLAIR) MRI, a sequence that suppresses the high signal from cerebrospinal fluid (CSF) by using a long inversion time (T1), has been found to be more sensitive in detecting traumatic lesions and hematomas [1,8,9]. White matter abnormalities may be seen on an MRI in patients with mild TBI [1,10]. However, it should be remembered that white matter changes are also found in a sizable percentage of healthy middle-aged individuals, middle-aged persons with chronic vascular risk factors including hypertension and diabetes, as well as younger patients with migraines, cerebrovascular disease, and Lyme disease [1,10–12].

Newer MRI technology and acquisition sequences have improved the sensitivity of the MRI for detecting the stigmata of TBI, but not all sequences are routinely adopted or performed in clinical contexts, and some are presently strictly related to research due to high rates of false positives and false negatives. Among these is diffusion tensor imaging (DTI). Traumatic axonal injury is characterized by a reduction in fractional anisotropy (FA) on DTI. Magnetization transfer imaging (MTI), which applies radio frequency power only to the protons in the macromolecules of tissues rather than the protons in water, can add sensitivity to an MRI [1,8,9]. Magnetic source imaging (MSI), using a combination of MRI and magnetoencephalography (MEG), was found to be superior to using only an MRI in the detection of TBI [1,8,9]. Proton magnetic resonance spectroscopic imaging (1 H-MRSI) has been found to be a sensitive tool in detecting axonal injury in the corpus callosum of TBI patients [1,8,9]. Susceptibility-weighted imaging (SWI) and functional MRI (fMRI) techniques including arterial spin labeling (ASL) which can demonstrate changes in regional brain activation are newer MRI methods for better detection of TBI and microhemorrhages [8,9].

Since there are currently no good biomarkers (biofluids such as blood and cerebrospinal fluid or imaging) for chronic TBI and its reported link with chronic traumatic encephalopathy (CTE); serial multimodal imaging techniques may help to enhance the yield of detection and characterization of stigmata of prior TBI such as cerebral microhemorrhages also at times referred to as cerebral microbleeds (CMBs) [1,11]. One of the reasons CMBs are detected now with increasing frequency in professional combatants is because some Commissions require MRI scans to be done on a 1.5 T or 3 T magnet (high magnetic field strength) with SWI and GEI sequences. At present, the clinical significance of incidentally detected CMBs in MR scans of young asymptomatic combatants is unclear. Along with neuropsychological testing, imaging methods such as DTI and positron emission tomography (PET) may help in the prediction of brain health of athletes who partake in contact sports by providing information of neural networks that subserve cognition and affective function [1]. It is hoped that advances in neuroimaging and the development of sensitive and specific imaging and biofluid biomarkers for TBI and neurodegenerative disorders will lead to the development of rational and evidence-based medicine approaches to the management and risk stratification of combat sports athletes who demonstrate evidence of prior TBI on their MRI scans [1].

Association of ringside physicians consensus guidelines regarding neuroimaging requirements for professional licensure in combat sports

- A brain MRI (1.5 Tesla minimum or 3 Tesla magnet strength) is the recommended imaging modality of choice to assess for any structural pathology and to establish a baseline at the time of initial licensure.
- When a brain MRI is not feasible, either due to its non-availability, or a combat sports athlete has an absolute contraindication to an MRI scan, a CT of the brain with and without intravenous contrast may suffice with the knowledge of the limitations of CT scan technology. It is recommended that such combat sports athletes also undergo a comprehensive neurological exam at the time of initial licensure.
- Any combatant with an aneurysm or arteriovenous malformation (AVM) should be denied professional licensure in combat sports. Cavernous malformations range in size from less than one-quarter inch to 3–4 inches and have a lower risk of bleeding as compared to aneurysms and AVMs. At present there is no consensus on an acceptable size of cavernous malformation with respect to combat sports. Combatants with cavernous malformations in the brain MRI need further evaluation and clearance from a neurologist or a neurosurgeon prior to licensure. Preferably this clearance should be obtained from a physician with experience in management of cerebral vascular malformations.
- Combatants with venous anomalies on brain MRI may be allowed licensure on a case-by-case basis after clearance from a neurologist or neurosurgeon. Preferably this clearance should be obtained from a physician with experience in management of cerebral vascular malformations.
- At present there is no consensus on acceptable size of other structural lesions such as arachnoid cysts. Combatants with large arachnoid cysts should be denied licensure. Combatants with small-sized arachnoid cysts may be granted licensure after clearance from a neurologist or neurosurgeon. Preferably this clearance should be obtained from a physician with experience in management of these cysts.
- Repeat brain MRI should be considered if there is neurological/neurocognitive decline from baseline.
- Repeat brain MRI should also be performed prior to the next bout if a combat sports athlete sustained a significant head impact exposure (in competition/training) that poses a risk for TBI. When repeat brain MRI is not feasible, either due to its non-availability, or a combat sports athlete has an absolute contraindication to an MRI scan, a CT of the brain with and without contrast may suffice with the knowledge of limitations

of CT technology and balancing cumulative radiation exposure against clinical utility.

- Regardless of suspected neurological decline or history of significant injury, repeat brain MRI should be performed at a minimum every 3 years provided initial/previous imaging had no abnormalities. If previous brain MRI has shown an abnormality, more frequent repeat imaging is indicated. All repeat imaging should be compared to baseline/previous imaging. When repeat brain MRI is not feasible, either due to its non-availability, or a combat sports athlete has an absolute contraindication to an MRI scan, a CT of the brain with and without contrast may suffice with the knowledge of limitations of CT technology and balancing cumulative radiation exposure against clinical utility.
- A CTA or MRA of the brain is recommended in addition to an MRI of the brain at the time of initial licensure for all combat sports athletes 40 years or older.
- The decision to medically clear a combat sports athlete to compete when imaging suggests evidence of an abnormality, prior/chronic TBI, or change from baseline, should be made on a case-by-case basis after careful consideration and review of the combat sports athlete's medical and family history, age, fight record, neurological examination, and neurocognitive assessment.
- The role of more advanced neuroimaging techniques such as DTI, ASL, fMRI, MTI, MSI, and MEG in risk stratification and prognostication needs further study and should be considered on a case-by-case basis.

Association of ringside physicians consensus guidelines regarding neuroimaging requirement after a bout

- An urgent CT scan of the head without contrast is recommended if the combat sports athlete demonstrates any of the 'red flag' during the bout or in the immediate aftermath of the bout (Table 2).
- A combat sports athlete who demonstrates any of the 'red flag' signs and symptoms should be transported immediately via on-site ambulance to a designated trauma center for evaluation. Transport to a Level I trauma center with 24 h in-house coverage by neurosurgery and neurology is recommended.
- Clinical decision regarding the need for cervical spine imaging should be made on a case-by-case basis determined by the mechanism of injury, presence or absence of numbness and tingling in the extremities, neck pain, midline tenderness, and neurological deficit.

Table 2. Signs and symptoms concerning for acute traumatic brain injury.

'Red Flag' Signs and Symptoms of Serious Brain Injury
Glasgow Coma Scale (GCS) <15
Suspected open, depressed or basal skull fracture
Cerebrospinal fluid (CSF) coming out of nose or ears
Post-traumatic seizure
Focal neurological deficit
>1 episode of vomiting since the head injury
Pupillary abnormality
Progressive increase of headache, nausea/vomiting, light/ noise sensitivity and vision problems
Deterioration of mental status/overall condition

Discussion of guidelines

Because scientific studies and articles regarding neuroimaging in combat sports are sorely lacking, the Association of Ringside Physicians created these consensus guidelines based on the collective expertise/experience of the authors who are all experienced ringside physicians. Numerous publications from the ongoing Professional Fighters Brain Health Study and previous studies have demonstrated an association between increased changes of the brain on imaging and increased cognitive impairment with higher levels of fight exposure (frequency of competing and duration of career) in combat sports athletes [13–22]. Increased exposure to sparring has also been associated with increased cognitive and balance dysfunction [23]. For that reason, ARP recommends that all potential professional combat sports athletes obtain a 'baseline' MRI of the brain prior to obtaining initial professional licensure. Baseline imaging can be valuable to clinicians in determining brain changes over time and assess potential development of the stigmata of chronic TBI. If MRI of the brain is regionally unavailable or a combat sports athlete has an absolute contraindication to MRI scan such as metal shrapnel embedded in the head and face area or metallic foreign bodies in the globe, a CT of the brain with and without contrast may suffice with the knowledge of the limitations of CT scan technology as documented above.

Baseline imaging can also be important to identify incidental brain abnormalities that are not related to head trauma but could potentially cause significant morbidity/mortality with exposure to head trauma and/or sports. Specifically, arachnoid cysts have a rare but well-known propensity to hemorrhage or rupture because of trauma and are found in 1% of the general population [24]. There have been multiple published case reports of arachnoid cysts bleeding in non-combat sports, resulting in the development of subdural hematomas [25–30]. Additional publications recommend that people with subtypes of Arnold Chiari Malformation such as Type II, a sometime silent congenital disorder of the brain, refrain from contact sports [31]. Cerebral aneurysm is another potentially silent life threating intra-cranial condition with a lifetime risk of rupture of 3–5% in the American population [32]. Risk factors for cerebral aneurysm include but are not limited to age over 40 years old, family history of aneurysms and history of trauma. Exercise has been shown to be a trigger factor that may cause an aneurysm to rupture [33,34]. Based on this current information, there appears to be an increased risk for these silent brain conditions to degenerate in the face of non-combat sports. It is reasonable to assume that there is even greater risk of rupture of these brain lesions when exposed to combat sports. Therefore, ARP believes that it would be wise for an athlete to obtain MRI of the brain at the time of initial combat sports professional licensure. Potentially life-threatening silent brain lesions can be detected so that an informed decision can be made to pursue combat sports or

not. There is an increased risk of the development of cerebral aneurysm after the age of 40 [32]. For that reason, ARP also recommends that a CTA or MRA of the brain be performed on those combat sports athletes who are pursuing licensure at 40 years old or older (high-risk athletes).

Repeat brain MRI should be considered if there is neurological/neurocognitive decline from baseline. Combat sports athletes with deterioration of athletic skills or multiple recent losses may reflect neurological compromise. Repeat brain MRI should be performed prior to the next bout if a combat sports athlete sustained a significant injury (in competition/training) that poses a risk for TBI. Regardless of suspected neurological decline or history of significant injury, repeat brain MRI should be performed at a minimum of every 3 years provided initial/previous imaging had no abnormalities. The average competitive combat sports athlete has a professional career that spans approximately 10 years. This frequency of imaging shall ensure that he/she gets imaged at least twice during the years of active competition in addition to imaging at the time of initial licensure. If previous brain imaging has shown an abnormality such as an arachnoid cyst, a small cavernoma or a venous malformation, more frequent repeat imaging may be needed to monitor that aberrancy more closely over time.

If the recommended imaging shows evidence that suggests a brain abnormality, evidence of prior/chronic TBI or change from baseline, the decision to medically clear a combat sports athlete to compete should be made on a case-by-case basis. Ringside physicians/commissions may request additional neuroimaging (as detailed above) and a formal neurocognitive evaluation of the combat sports athlete. Specific neuroimaging consideration needs to be given to the development or progression of cavum septum pellucidum and cavum vergae. The ongoing Professional Fighters Brain Health Study has demonstrated an association between these two findings and decreased cognitive performance [35]. Risk stratification is the process of identifying the individual risk of a combat sports athlete suffering from a particular condition after careful review of history, laboratory, and clinical tests. Some combat sports athletes may warrant disqualification and denial of license to compete, and others may be medically cleared to compete after careful review of all relevant history, neurocognitive examination, and imaging findings.

To ensure the health and safety of all combat sports participants, it is recommended that the above-mentioned consensus neuroimaging guidelines prior to licensure be standardized across different commissions and sport's governing bodies in all countries. Standardization of neuroimaging requirements shall allow the physician and combat sports athlete to make measured decisions about the combat sport athlete's future health and brain fitness to begin or continue to compete. It is recommended that the various commissions and sport's governing bodies coordinate to assist with the setting up of an online central neuroimaging database so that neuroimaging data can be shared in the different countries where the combat sports athlete may compete.

The prime need for neuroimaging after a bout is to ascertain acute TBI. A CT scan of the head without contrast is the recommended imaging modality due to its high sensitivity and specificity for identifying the presence of blood and bone fracture in the acute setting, its widespread availability and short acquisition time. Based on the assessment by the ringside physician(s) after the post-fight physical examination, a combat sports athlete who is suspected of having sustained a TBI should be transported immediately by ambulance to the designated trauma center for an emergency assessment of possible TBI, an urgent CT scan of the head, and further care as deemed necessary by the trauma center physicians. Trauma center designation is a process outlined and developed at a state or local level and the ARP recommends that combat sports athletes in whom acute TBI is suspected be transported to a trauma center with access to specialist neurology and neurosurgery care. Concern for TBI is raised if the combat sports athlete manifests or reports 'red flag' signs and symptoms (Table 2) [36]. Such athlete should be urgently transported to the designated trauma center via an onsite ambulance for a CT scan of the head (as per National Institutes of Health and Care Excellence (NICE) guidelines for determining the need for an acute CT scan of the head in adults following a traumatic head injury) [37–39].

Qualifying statement

These guidelines are recommendations designed to assist ringside physicians, combat sports athletes, trainers, promoters, sanctioning bodies, governmental bodies, and others in decision making. These recommendations may be adopted, modified, or rejected according to clinical needs and constraints and are not intended to replace local commission laws, regulations, or policies. We understand that the above guidelines have limited involvement from various stakeholders such as combat sports athletes and their coaches, the sport's governing bodies and individual national and international commissions. Future versions of the consensus statement should take the above parties views and preferences into consideration. We hope that these guidelines will serve to augment locally agreed policies already in place. The guidelines developed by the ARP are not intended as standards or absolute requirements, and their use cannot guarantee any specific outcome. They provide basic recommendations that are supported by synthesis and analysis of the current literature, expert and practitioner opinion, commentary, and clinical feasibility. Guidelines are subject to revision as warranted by the evolution of medical knowledge, technology, and practice. It is the ARP recommendation and intention to revisit and revise the above guidelines as and when more evidence based scientific data and studies become available. It is important to emphasize that the role of neuropsychological testing in return to play decision making, prognostication of the brain health of the combat sport athlete and how it can complement information obtained from neuroimaging needs further elucidation. It is recommended that the above consensus guidelines be debated vigorously by ringside physicians and the larger scientific community in conjunction with professional combat sport's governing bodies. The observance of these guidelines will go a long way to ensuring the health and safety of professional combat sports athletes.

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Contributorship statement

NKS conceived, drafted and edited the manuscript. JN helped draft and edit the manuscript.

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