Imaging of Concussion in Young Athletes

Jeffrey P. Guenette, MD[a,b], Martha E. Shenton, PhD[a,b,c,d], Inga K. Koerte, MD[b,d,e,*]

KEYWORDS

• Concussion • Mild traumatic brain injury • Head trauma • Sports • Pediatrics • MR imaging • Diffusion tensor imaging • Susceptibility-weighted imaging

KEY POINTS

- Routine clinical imaging is typically not indicated in sports-related concussion.
- Per the American Association of Neurology and the American Medical Society of Sports Medicine guidelines, in concussion, imaging should only be performed if there are concerns regarding skull fracture, intracranial hemorrhage, or other intracranial disorders based on clinical examination.
- There are many studies that may lead to important diagnostic and prognostic neuroimaging biomarkers that will assist in the diagnosis of brain alterations associated with concussion and that indicate those who are most at risk for adverse outcomes. This information will become available clinically over the next decade.
- Screening for clinical neuroimaging biomarkers will likely become important in ensuring adequate positive and negative predictive values and to maintain cost-effectiveness.
- Although some neuroimaging examinations may be appropriate in the acute phase of injury, many are likely to be more appropriate in the subacute or chronic phases, and the timing of examinations depends on clinical presentation.

INTRODUCTION

Concussion, also known as mild traumatic brain injury (mTBI), is a clinical syndrome characterized by an immediate but transient alteration in brain function, generally caused by a blunt force. In young athletes, the cause is typically a direct blow to the head. The American Academy of Neurology and the American Medical Society for Sports Medicine guidelines currently indicate that there is no role for routine clinical imaging in sports-related concussion given that the findings are typically negative.[1,2] However, many new and emerging imaging techniques show potential diagnostic and prognostic value.

EPIDEMIOLOGY

Half of pediatric emergency department visits for concussion are sports related.[3] Specifically, more than 170,000 children aged 19 years or younger are seen annually for sports and recreation–related traumatic brain injury in the United States.[4] Further, more than 62,000 cases of concussion occur annually in high school varsity athletes, 60% of which occur in football players.[5]

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[a] Department of Radiology, Brigham and Women's Hospital, Harvard Medical School, 75 Francis Street, Boston, MA 02115, USA; [b] Psychiatry Neuroimaging Laboratory, Department of Psychiatry, Brigham and Women's Hospital, Harvard Medical School, 1249 Boylston Street, Boston, MA 02215, USA; [c] VA Boston Healthcare System, Brockton Division, 940 Belmont Street, Brockton, MA 02301, USA; [d] Department of Psychiatry, Massachusetts General Hospital, Harvard Medical School, 55 Fruit Street, Boston, MA 02114, USA; [e] Department of Child and Adolescent Psychiatry, Psychosomatic, and Psychotherapy, Ludwig-Maximilian-Universität, Nußbaumstr 5a, Munich 80336, Germany

* Corresponding author. Psychiatry Neuroimaging Laboratory, 1249 Boylston Street, Boston, MA 02215.
E-mail address: ikoerte@bwh.harvard.edu

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Moreover, concussion comprises nearly 9% of reported high school athletic injuries and 6% of collegiate athletic injuries,[6] and there is evidence that sports-related concussion is substantially underreported. For example, amateur male hockey players report approximately 14 times more concussions than official reports of such injury suggest.[7] The most common symptom of concussion is headache, which occurs in 93.4% of concussed high school athletes, whereas loss of consciousness occurs 4.6% of the time.[8]

Reported rates of concussion in high school sports increased 4.2-fold between 1997 to 1998 and 2007 to 2008,[9] and this increase corresponds with a similar increased rate of concussion-related emergency department visits, which has doubled in children 8 to 13 years old and tripled in children 14 to 19 years old in the United States over this same time period. Of note, this increase is despite an overall decline in participation in organized team sports.[3] A similar rate of increase in emergency department visits for concussion has also been reported by the US Centers for Disease Control and Prevention for the years 2001 to 2009.[4] The activities most associated with youth emergency department visits for concussion are bicycling, football, playground activities, basketball, and soccer.[4] In addition, more than 10% of youth emergency department visits for concussion are related to horseback riding, ice skating, golfing, all-terrain vehicle riding, and tobogganing/sledding.[4]

SEX DIFFERENCES IN CONCUSSION

Although more than 70% of emergency department patients with sports and recreation–related concussion visits are male,[4] high school girls experience twice the rate of concussion as boys participating in similar sports.[9] Even more concerning is that female high school and collegiate athletes who sustain a concussion experience more frequent cognitive impairment, greater declines in simple and complex reaction times relative to preseason baseline levels, and also more postconcussion symptoms compared with male athletes.[10] A study of children hospitalized after concussion also reports more severe symptoms in girls than in boys at presentation.[11] Similar findings have been identified in a study of female soccer players who performed worse on computer-based neuropsychiatric testing after concussion than did male players,[12] and in a neuroimaging study of female athletes who had more severe white matter abnormalities at 6 months postconcussion than did male athletes.[13]

CONSIDERATIONS REGARDING TIMING OF IMAGING

Based on physical examination, clinical anatomic imaging is performed in the acute setting if skull fracture or hemorrhage is suspected. Although cognitive function typically returns to baseline in 5 to 7 days,[14] in one study of 416 children and adolescents with concussion, 29.3% had postconcussion symptoms at 3 months, and missed more than 1 week of school on average.[15] Similarly, in another study of 190 children, almost 25% experienced headache, 20% fatigue, and 20% longer thinking times at 1 month, with average sleep disturbances lasting 16 days.[16] Given that these symptoms are measured on a timeline of weeks to months, it is important to develop imaging biomarkers to identify the acute or subacute phase to determine whether or not this information will have value in predicting outcome (prognosis). Thus imaging examinations performed in the chronic phase at 1 month to 3 months are more likely to reveal alterations in the brain that may be useful in predicting which patients are most likely to have prolonged postconcussive symptoms or even permanent cognitive deficits.

OBJECTIVE OF THIS ARTICLE

Research on neuroimaging of concussion in young athletes is currently focused on identifying highly sensitive and quantitative measures of early concussion diagnosis and on accurate prognosis. The goal of these efforts is to identify imaging markers that can be used as biomarkers that provide important clinical information, including an individual's risk for prolonged postconcussive symptoms, risk for long-term cognitive deficits, and an appropriate time interval before return to play. This article discusses the results of advanced imaging techniques that are currently being used in neuroimaging research in youth concussion, with an emphasis on those techniques that may soon be incorporated into the clinical evaluation of concussed young athletes.

Normal Anatomy and Imaging Technique

Traditional clinical anatomic imaging

The American Academy of Neurology guidelines recommend conventional clinical neuroimaging in the setting of suspected concussion in those patients who have loss of consciousness, posttraumatic amnesia, persistent Glasgow Coma Scale score less than 15, focal neurologic deficit, evidence of skull fracture on examination, or signs of clinical deterioration.[1] Neuroimaging in this