Multimodal Advanced Imaging for Concussion

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KEYWORDS

• Concussion • Multimodal imaging • Traumatic brain injury (TBI) • Quantitative MR imaging • Cortical thickness • Diffusion tensor imaging (DTI) • Kurtosis • Intravoxel incoherent motion (IVIM)

KEY POINTS

- The potential utility of multimodal imaging is not limited to diagnosis: It can also be beneficial in predicting the clinical course of concussion, monitoring recovery, and assessing the efficacy of existing and developing therapies.
- The pathologic hallmarks of primary and secondary injuries may not be directly measured by conventional clinical protocols, which may contribute to our current problems predicting clinical outcomes. Advanced imaging models of the underlying biochemical mechanisms may be needed.
- The authors emphasize the value of using multimodal and multidimensional quantitative MR imaging methods to improve pathologic specificity and potential in predicting clinical outcomes.

INTRODUCTION

Overall, the yearly worldwide incidence of traumatic brain injury (TBI) is estimated to be around 10 million (Murray 1996). Motor vehicle accidents (MVA), sporting events, falls, violence, war, and other unintentional injuries have been postulated as the most common causes of TBI in the literature. The highest rates of TBI due to MVAs are in the Latin American and Caribbean region, whereas India has the greatest rate of TBI-related injuries due to falls.[1] In the United States alone, more than 1.4 million people have a TBI every year, whereas annual estimates of sports-related concussions range from 1.6 to 3.8 million.[2] Concussion is defined as transient and immediate alteration in brain function, including alteration of mental status and level of consciousness, caused by a blow to the head.[3] In a broader sense, The American Academy of Neurology defines concussion as "a pathophysiologic disturbance in neurologic function characterized by clinical symptoms induced by biomechanical forces."[4] However, the definition of concussion still remains

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controversial; it is sometimes applied differently in sports-related, emergency department, and military environments; and the terms *mild TBI* (mTBI) and *concussion* are often used interchangeably.[5]

The burden of mortality and morbidity associated with head trauma makes TBI a pressing public health and medical problem. Public health concerns about head trauma also relate to repeated impact to the head in recreational and professional sports, including ice hockey, soccer, football, martial arts, boxing, and other sports that may affect the normal development of the brain, especially in children, adolescents, and young adults. Repeated sports-related concussions (SRCs) at a young age may affect normal brain development and prevent recovery in some cases.[6] Although most patients who sustain SRCs recover quickly and are asymptomatic within a short amount of time, a notable minority of patients experience persistent symptoms after concussion, sometimes referred to as postconcussion syndrome.[7] SRCs have been associated with an increased risk for depression and memory problems,[8] chronic traumatic encephalopathy (CTE),[9] Alzheimer dementia,[10–12] Parkinson disease,[13] and cerebrovascular diseases, which may occur through decreases in cerebral blood flow and cerebral vascular reactivity[14] as well as other patho-mechanisms.

MECHANISMS OF INJURY

TBI-induced damage can be divided into injuries at macroscopic and microscopic levels (**Fig. 1**). Macroscopic injuries can be divided into primary

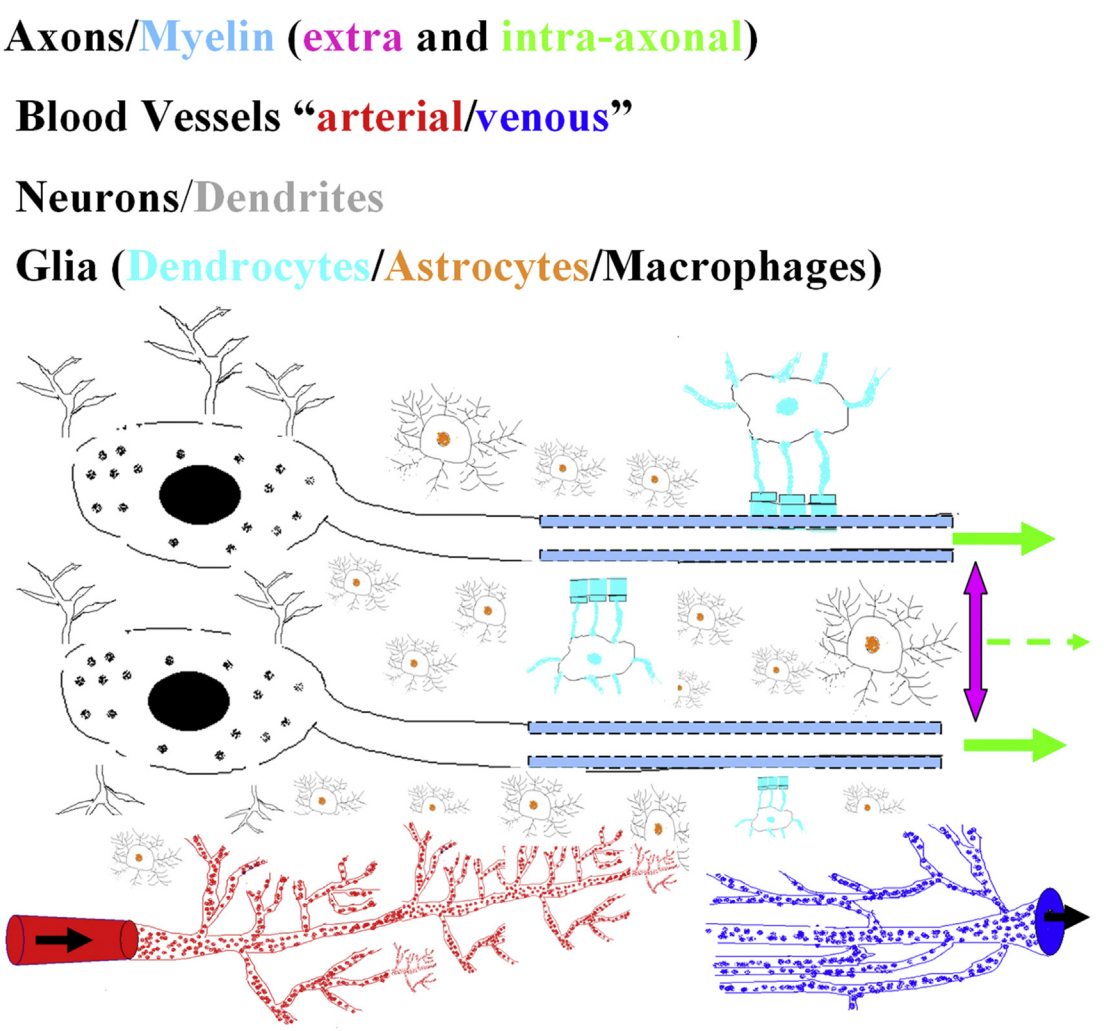

Fig. 1. Common injury mechanisms in TBI. Secondary to injury, glial activation takes place to further exacerbate the axonal, neuronal, and myelin injury, including the arterial and venous system.

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