Letters to the Editor

NEUROSURGICAL FORUM

Pediatric sports-related concussions

TO THE EDITOR: The paper by Ellis et al.[1] in the September issue (Ellis MJ, Leiter J, Hall T, et al: Neuroimaging findings in pediatric sports-related concussion. *J Neurosurg Pediatr 16:*241–247, September 2015) serves to illustrate the need for "updating" our physician and athletic management community, including the families and individuals with concussion/mild traumatic brain injury (mTBI), on the newer objective radiological brain injury evaluations available today. The retrospective chart review, diagnostic conclusions, and follow-up by a single neurosurgeon appear to have reflected out-of-date evaluative procedures. Ellis et al. reviewed data acquired in 36 patients (2% of 151 patients diagnosed with sports-related concussions [SRCs]) who underwent neuroimaging before referral to a specialty clinic. MR images were obtained in patients with focal neurological findings or symptoms or symptoms lasting more than 1 or 2 months, and those with abnormal CT findings. The abnormal CT findings included skull fractures, intracranial hemorrhage, arachnoid cyst, and suspected hemorrhage into an arachnoid cyst. MRI revealed intraparenchymal hemorrhage, sylvian fissure arachnoid hemorrhage, nonhemorrhagic contusion, demyelinating disease, posterior fossa arachnoid cyst, cerebellar volume loss, and nonspecific white matter changes.

The authors correctly concluded that CT scans yielded no signs of traumatic injury to structures of the brain in most cases of SRC, and that CT should be limited to patients whose symptoms suggest possibility of skull fracture or intracranial hemorrhage. These notions are correct and point primarily to structural bony or skull lesions, lesions of supportive structures of the brain, vascular injuries, or bleeds. For these other-than-brain-tissue injuries, CT and MRI are and were appropriate. However, the authors wrote that no positive findings were found, that no actual brain damage or injury was documented, and that CT and regular MRI scans ordered to study an injured brain from an SRC are of no value except to find the structural defects and bleeds as mentioned in the study. One may question if these studies are of no value in actual brain tissue injury, and are they ordered only to show other structural lesions potentially accompanying mTBI/concussion since actual brain lesions are not found by plain CT and MRI? If these non–brain tissue injuries are present (or not!), then the next logical step is to order a study that will show actual accompanying brain tissue damage in order to make the injury "visible."

In order to meet the urgent improvement need in treatment and evaluation of concussion/mTBI, we, as care providers, must leave behind the inappropriate practice and mindset that concussion/mTBI represents a symptom-only diagnosis and a symptom-only treatment. We must help others overcome the same struggle! The standard appears to be that "if there are symptoms, then treat, and if the symptoms are resolved, then the individuals can return to their respective activity." This, my dear colleagues, is wrong and offers a lower standard of care than, for example, stroke, which is also a brain injury, although sometimes potentially more serious than concussion/mTBI. Nonetheless concussion/mTBI treatment offers a lesser standard of care than for stroke! Stroke standard-of-care therapy involves the acquisition of many scans, serially, until the lesion is resolved, with potential physical and cognitive losses as sequelae, as are potential in mTBI/concussion.

As said, the study provides support to consider a different modality to make the actual brain injury more knowable. Greenwald et al.[2] found that, even in the absence of symptoms and with patient nonreporting of symptoms, with more thorough cognitive testing the symptoms can be made more visible, and any re-injury or the extension of a current injury is obviated by more rest. In this instance, more thorough psychological testing is appropriate and potentially "brain saving." Furthermore, comprehensive psychological testing is Step 1 in making the injury more visible, despite the absence or disappearance of symptoms or patient nonreporting. However, psychological testing, no matter how thorough or prolonged, may only make concussion/mTBI symptoms apparent. How do we make the injury more visible after we are eventually unable to show it through psychological testing? Psychological testing does not provide objective proof that the injured brain is healed; it merely shows symptoms.

It is an absolute fact that if/when there are symptoms after concussion/mTBI, then there is an organic brain injury. However, we as physicians and other caregivers also know that when the symptoms of an injury or illness are gone, injury or disease may still be present. This is the likely case in concussion/mTBI. And so it becomes a task for all in the chain of evaluation and care of concussed patients of all ages to seek and demand a higher standard of care than simply resolution of symptoms.

This potential is available today but sadly not often used. It appears that some physicians are not aware of the current literature on how to make brain injuries other than stroke or structural/skull injuries more visible. Diffusion tensor imaging (DTI) is an objective radiological modality

currently available to study actual organic brain injury after a concussion/mTBI, and it is fairly easily performed by radiologists, if only asked for by you, my dear colleagues! The literature on DTI in brain injury and axonal tractography is robust, and many papers support its use.[3,4] Narayana et al.[5] have suggested that after 90 days postinjury DTI can detect no further brain damage in white matter tracts. What is the average waiting time for symptomatic or asymptomatic concussed/mTBI patients to return to prior activities? Niogi and Mukherjee[6] have written that "unlike computed tomography or conventional magnetic resonance imaging, DTI is sensitive to microstructural axonal injury, the neuropathology that is thought to be the most responsible for the persistent cognitive and behavioral impairments that often occur after mTBI." In the excellent review of mTBI and the use of DTI by Shenton et al.,[7] the authors used the term "post-concussive syndrome" instead of "chronic mTBI" and this seems appropriate. The point is that the more often DTI (or any other potential objective radiological study) is demanded by those in the treatment chain (ER docs, sports docs, primary care docs, orthopods, internists in the ICU, neurologists, neurosurgeons, etc.), the better and more technologically sophisticated DTI and these studies will become, or they could even morph into an entirely different technology. However, DTI is what we have now, today, and its effectiveness in detecting an injury in patients with concussion/mTBI is robustly supported in the literature, as underscored here by just a few examples drawn from supportive literature. There are likely a few naysayers, but the need to use this tool and make it part of an improved and expected standard-of-care protocol far outweighs any specious or scientifically unfounded objection to it. Our athletes (young and old, professional and amateur), our soldiers, our first responders, those with accidental concussions of all types, must be helped by our making the injured brain more visible, with and without presence of symptoms. DTI ought to be a part of the standard of care, to be performed serially, just as scanning is for stroke. Many concussion/mTBI patients sustain multiple brain injuries in their activities and have been given symptomatic to symptom-free care, which is not an acceptable standard of care or treatment end point.

I have a concern that the title of this paper may mislead many physicians and others in the chain of care to believe that no neuroimaging modalities are of use in concussion/mTBI. This is simply not the case, given the availability and relative ease of specialized MRI (i.e., DTI) and potentially other objective tests. Ellis and colleagues reviewed a series of patients and offered a hugely impactful and influential result based on seeing inappropriate and outdated radiological modalities that have allowed an unacceptable standard of care. Their results must be a beginning of turning to objective testing to show that the injured/concussed brain is healed, and not just merely symptom free. The paper gives welcome support to other evaluative methods than regular CT and regular MRI for mTBI/concussion in a pediatric population.

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Disclosures

The author reports no conflict of interest.

Response

We thank Dr. Griffin for his letter, which provides a review of our recent article and highlights a number of important issues and knowledge gaps in the field of concussion and mTBI.

As you are aware, the field of concussion has long held the notion that SRC is a functional injury and not associated with any structural injury to the brain. As such, most consensus position statements suggest that conventional neuroimaging studies such as CT and MRI show normal findings and thus offer little value to the evaluation and management of individuals who have sustained a concussion or mTBI. Unfortunately there is little empirical evidence to support these conclusions. While our preliminary study detected traumatic abnormalities in a small proportion (11%) of pediatric SRC patients who underwent imaging, it is misleading to assume that because the majority of these studies were normal that they did not provide clinical value to the treating physician and the patient. As illustrated in the study, children and adolescents who present with prolonged or worsening neurological symptoms following head injuries may also harbor other neurological conditions that, in many cases, can only be detected and appropriately managed following the judicious use of structural neuroimaging.

We agree that we have an obligation to our patients to look beyond treating individual symptoms and offer a more comprehensive, multidisciplinary approach to concussion and TBI. Thankfully, the appropriate use of physical examination tools and graded aerobic treadmill testing has increasingly permitted us to classify patients with acute SRC[2] and post-concussion syndrome (PCS)[4,6] and direct them toward emerging evidence-based therapies that target the pathophysiological mechanisms gov-

erning individual symptoms.[7,12] In view of the fact that concussion is, as Dr. Griffin correctly points out, an "organic brain injury," it is incumbent on leaders in the field to continue to promote the value of comprehensive care by a multidisciplinary team of TBI experts working within their scope of practice and training. We agree that these teams should always include clinical neuropsychologists, the only professionals with optimal training in the administration and interpretation of neuropsychological testing that can assist in confirming complete neurocognitive recovery in concussion patients.[1,11]

We also agree that there remains an urgent and persistent need for neuroimaging assessment tools that can make concussion "more visible" and provide valuable biomarkers that impact the clinical management of individual concussion patients. While there has been an explosion of neuroimaging studies in SRCs utilizing advanced techniques such as DTI, task-based and resting-state functional MRI, and resting cerebral blood flow, none of these technologies have advanced beyond experimental use.[13] As Dr. Griffin points out, alterations in white matter integrity have been demonstrated in groups of patients with mTBI,[10] but they have also been observed in those who have sustained subconcussive head impacts,[8] and in some cases DTI indices have failed to discriminate between subject groups with and without PCS.[5] While we hope that future technical refinements will help clarify inconsistencies observed among DTI studies in SRC and mTBI, at present the failure of this modality to provide reliable and consistent quantitative biomarkers that can be used to diagnose, classify, prognosticate, or confirm recovery in individual concussion patients leads the authors to question how routine use of this technology would impact clinical decision-making in our patients.[3] On the other hand, emerging work suggests that MRI-based cerebrovascular reactivity mapping may hold promise to help visualize and quantify the functional alterations that mediate PCS symptoms in individual patients,[9] but more work remains to be completed to validate this technique, especially in adolescents.

Lastly, we acknowledge the reader's concerns regarding the title of our recent article, the conclusion, and the current standard of concussion care. As we indicated, the decision to order neuroimaging studies, and include certain sequences, is impacted not only by patient factors, but also by the clinical judgment and experience of the multidisciplinary team, which undoubtedly contributes to wide variability in the standard of care across centers and health care providers. Nonetheless, we believe the findings of this preliminary study clearly support the conclusion that currently validated clinical neuroimaging studies are normal in the majority of pediatric SRC patients imaged, but in selected cases these studies can provide clinically valuable information that impacts the management of children and adolescents presenting with neurological symptoms following concussion and TBI.

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