Commentary: Applications of Functional Neuroimaging to Civil Litigation of Mild Traumatic Brain Injury

Robert P. Granacher, Jr, MD, MBA

The current definition of mild traumatic brain injury (MTBI) is in flux. Presently, there are at least three working definitions of this disorder in the United States, with no clear consensus. Functional neuroimaging, such as single photon emission computed tomography (SPECT) and positron emission tomography (PET), initially showed promise in their ability to improve the diagnostic credibility of MTBI. Over the past decade, that promise has not been fulfilled and there is a paucity of quality studies or standards for the application of functional neuroimaging to traumatic brain injury, particularly in litigation. The legal profession is ahead of the science in this matter. The emergence of neurolaw is driving a growing use of functional neuroimaging, as a sole imaging modality, used by lawyers in an attempt to prove MTBI at trial. The medical literature on functional neuroimaging and its applications to MTBI is weak scientifically, sparse in quality publications, lacking in well-designed controlled studies, and currently does not meet the complete standards of *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, for introduction of scientific evidence at trial. At the present time, there is a clear lack of clinical correlation between functional neuroimaging of MTBI and behavioral, neuropsychological, or structural neuroimaging deficits. The use of SPECT or PET, without concurrent clinical correlation with structural neuroimaging (CT or MRI), is not recommended to be offered as evidence of MTBI in litigation.

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The article by Wortzel *et al.*[1] is timely and accurate, based on my experience. They contribute important information to the controversies that exist in the application of functional neuroimaging to mild traumatic brain injury cases in civil litigation. They point out that single photon emission computed tomography (SPECT) is relatively sensitive to the metabolic changes produced by traumatic brain injury (TBI). They argue that such changes are not specific to TBI in general, and the presence of detectable changes on cerebral SPECT imaging does not confirm a diagnosis of mild TBI (MTBI). Moreover, they point out that the absence of findings on cerebral SPECT in cases of TBI may be of prognostic value. The review of literature by Wortzel *et al.* confirms a lack of consistent relationships between SPECT neuroimaging and concurrent neuropsychological testing or the expression of neuropsychiatric symptoms in MTBI. They provide further convincing arguments based on *Daubert v. Merrell Dow Pharmaceuticals, Inc.*,[2] that SPECT neuroimaging should not be admitted in court as a stand-alone diagnostic test in an effort to prove or disprove the existence of MTBI.

The overselling of SPECT or positron emission tomography (PET) neuroimaging by lawyers is a serious potential evidentiary concern in the civil litigation of MTBI. As Wortzel *et al.* note, the *New York Times Magazine*, in a March 11, 2007, feature story, chronicled the rapidly emerging field of neurolaw.[3] I performed a Google search on the topic, SPECT neuroimaging in traumatic brain injury, and the search returned almost as many Web sites and citations by legal firms as in articles or books covering the science of SPECT.[4] I also served as an expert witness in a recent trial, wherein the attorney who lost the verdict polled the jury after the case had closed. It was discovered from several jurors that the lawyer was

Dr. Granacher is President, Lexington Forensic Neuropsychiatry and Clinical Professor of Psychiatry, University of Kentucky College of Medicine, Lexington, KY. Address correspondence to: Robert P. Granacher, Jr, MD, MBA, Lexington Forensic Neuropsychiatry, 1401 Harrodsburg Road, Lexington, KY 40504. E-mail: rgranacher@aol.com

perceived as boring, and he was criticized for not using visual aids or PowerPoint slides. Television shows such as "CSI" have raised juries' expectations and have had a negative impact on the lawyers whose presentations at trial involve traditional means of communication.[5] There are several concerns directly related to MTBI and the use of functional neuroimaging at trial that should give all expert witnesses pause.

Controversies Regarding Mild Traumatic Brain Injury

There is no universally agreed upon definition of MTBI. There are three definitions currently in use, and there is significant variation among them. These include the definition of the American Congress of Rehabilitation Medicine (ACRM),[6] the National Center for Injury Prevention and Control Conceptual Definition of MTBI,[7] and the Centers for Disease Control Working Group Limited Criteria for Identifying MTBI.[7] The World Health Organization recently provided a comprehensive review of methodologic problems in MTBI research and gave recommendations for improving research efforts in MTBI.[8] Wortzel *et al.*[1] have delineated some of these definitions.

The weakness of all current definitions of mild traumatic brain injury is that the expression of this disorder is primarily subjective. There are few observable biological markers for this condition. MTBI is similar to back pain or headache; it does not allow for the use of any unequivocal metrics to detect it. This lack of metric support provides an opportunity in litigation to present very subjective data based primarily on symptoms and allows the case to rest almost entirely on a nonobjective and immeasurable presentation. Thus, MTBI is easy to obfuscate and difficult to detect. For many plaintiffs' lawyers, this becomes an advantage at trial. Moreover, a review of recent world literature on MTBI demonstrates that at this point in medical history, despite decades of research, claims of incomplete recovery from MTBI are poorly understood. On the other hand, the data demonstrate that for a substantial majority of people, MTBI is self-limiting and generally follows a predictable course of improvement. Permanent cognitive, psychological, or psychosocial problems due to the biological effects of this injury are relatively uncommon in trauma patients and rare in athletes.[9–11] There is now a substantial body of evidence in the medical literature that reports that persons in litigation after MTBI have a high likelihood of magnifying symptoms or prolonging symptoms merely for compensation.[12–19] The base rate of malingering MTBI in more than 30,000 neuropsychology examinations was recently reported to be 39 percent.[20] Neuropsychological examinations are highly effort-dependent. As a result, those providing examinations for forensic purposes to persons with claims of MTBI must honestly explore litigation issues, and, without question, must examine carefully for symptom validity in any person presenting for neuropsychiatric examination with a complaint of MTBI within a legal context.

Potential Pitfalls in the Forensic Application of Functional Neuroimaging to Traumatic Brain Injury

SPECT has several sources of potential measurement error that can produce unreliable data for use in forensic settings. Unlike PET, SPECT imaging requires that regional radiation counts be normalized to a brain area that is theoretically free of injury. This comparison sets a standard of relative flow values in SPECT. Nuclear medicine physicians often base these relative values on a region such as the thalamus or cerebellum, which is assumed to be uninjured. These assumptions may be valid in some populations with focal lesions such as in stroke, but they may not be valid in populations wherein the neuropathology is much more diffuse, such as occurs in TBI.[21] As Wortzel *et al.*[1] point out, use of an abnormal SPECT scan for prognosis is not recommended at this time.[22] The studies published to date on SPECT in TBI are sparse and inadequate. These studies have not been shown to correlate clearly with behavior changes or neuropsychological deficits at a level that one could testify to within reasonable medical probability or certainty. Discrimination of neural or anatomic detail is not possible, even when SPECT is paired or fused with CT or MRI. The American College of Radiology (ACR) published revised head trauma guidelines in 2006.[23] SPECT appropriateness criteria are 1/9 for mild or minor acute closed head injury (GCS $\geq$ 13), without risk factors or neurologic deficit (where 1 is least appropriate and 9 is most appropriate). Table 1 outlines the current appropriateness criteria for Variant 1 of head trauma published by the American College of Radiology for Neuroimaging used in minor or mild acute closed

Table 1 Variant 1: Minor or Mild Acute Closed Head Injury (GCS ≥ 13), Without Risk Factors or Neurologic Deficit*

Radiologic Exam Procedure	Appropriateness Rating	Comments
CT, head, without contrast	7	Known to be low-yield
X-ray and/or CT, cervical spine	5	
MRI, head, without contrast	4	
CT, head, without and with contrast	3	
CTA, head and neck	3	Rarely indicated with mild trauma
CT, head, without and with contrast	2	
INV, cerebral angiography	1	
NUC, SPECT	1	
PET	1	
CT, head, xenon-enhanced	1	
US, transcranial Doppler	1	

Appropriateness Criteria Scale: 1 = least appropriate; 9 = most appropriate. CT, computed tomography; MRI, magnetic resonance imaging; CTA, computed tomographic angiography; SPECT, single photon emission computed tomography; PET, positron emission tomography; US, ultrasound; MRA, magnetic resonance angiography; INV, invasive; fMRI, functional magnetic resonance imaging.
*Head Trauma: American College of Radiology Appropriateness Criteria for Neuroimaging.[23]

head injury. Variant 2 covers those cases in which a minor or mild acute closed head injury has occurred but focal neurologic deficits are found after injury and/or risk factors are present. Table 2 outlines the current neuroimaging criteria for Variant 2 of head trauma published by the ACR. As can be noted in that table, SPECT has an appropriateness rating of 1/9 for Variant 2, where 1 is least appropriate and 9 is most appropriate.[23]

The forensic psychiatrist will generally see head trauma cases in the subacute or chronic phase. In those instances, the SPECT scan is accepted by the ACR as having slightly higher appropriateness. Table 3 lists Variant 5 for head trauma from the ACR appropriateness criteria for neuroimaging head trauma with subacute or chronic cognitive and neurologic deficits. SPECT is listed as 4/9 for appropriateness but this is for selected cases only and not for all cases.[23]

At present, there are few consistent data regarding validity and reliability of SPECT techniques in clinical cases of TBI. In a review of the literature, almost all data that have been applied are single case studies or small group studies. No studies of a large nature with appropriate clinical controls exist. Thus, the forensic examiner should be very careful when reporting SPECT studies as a sole measure of MTBI in a legal case. There is no particular SPECT profile that is pathognomonic for any level of TBI or MTBI, and false-positive results are high.[24–26]

For functional neuroimaging, and in particular for SPECT or PET, there are no published atlases demonstrating pathognomonic or characteristic lesions following TBI or MTBI. This should cause substantial concern in legal settings, particularly from the standpoint of applying *Daubert* criteria. For instance, with MRI or CT, it is very easy to find pathognomonic lesions in published brain atlases for trau-

Table 2 Variant 2: Minor or Mild Acute Closed Head Injury, Focal Neurologic Deficit and/or Risk Factors*

Radiologic Exam Procedure	Appropriateness Rating	Comments
CT, head, without contrast	9	
MRI, head, without contrast	6	For problem solving
X-ray and/or CT, cervical spine	6	
MRA, head and neck	5	If vascular injury is suspected; for problem solving
CTA, head and neck	5	If vascular injury is suspected; for problem solving
MRI, head, without and with contrast	3	
CT, head, without and with contrast	2	
INV, cerebral angiograph	1	
NUC, SPECT	1	
PET	1	
CT, head, xenon-enhanced	1	
US, transcranial Doppler	1	
X-ray, skull	1	

Appropriateness Criteria Scale: 1 = least appropriate; 9 = most appropriate. Abbreviations are as defined in Table 1.
*Head Trauma: American College of Radiology Appropriateness Criteria for Neuroimaging.[23]

Table 3 Variant 5: Subacute or Chronic Closed Head Injury With Cognitive and/or Neurologic Deficit(s)*

Radiologic Exam Procedure	Appropriateness Rating	Comments
MRI, head, without contrast	8	
CT, head, without contrast	6	
MRA, head and neck	4	For selected cases
CTA, head and neck	4	For selected cases
NUC, SPECT	4	For selected cases
PET	4	For selected cases
MRI, head, without and with contrast	3	
fMRI, head	2	
X-ray, skull	2	
X-ray and/or CT, cervical spine	2	Assuming there are no spinal neurologic deficits
CT, head, without and with contrast	2	
INV, cerebral angiography	1	
CT, head, xenon-enhanced	1	
US, transcranial Doppler	1	

Appropriateness Criteria Scale: 1 = least appropriate; 9 = most appropriate. Abbreviations are as defined in Table 1.
*Head Trauma: American College of Radiology Appropriateness Criteria for Neuroimaging.[23]

ma-induced subarachnoid hemorrhage, subdural hematoma, parenchymal contusions, epidural hematoma, brainstem contusions, mass effects, intraventricular hemorrhage, and shift of intracranial contents.[27–29] There are no SPECT or PET atlases with corresponding pathognomonic features of classic brain injury patterns.

The situation is no better for PET vis-à-vis applications in forensic settings of TBI. In fact, one of the world's standard textbooks on PET, published in 2003, demonstrates not a single chapter on PET use in brain trauma.[30] Tables 1 to 3 indicate that PET fares no better than SPECT for appropriateness using the criteria of the American College of Radiology for head trauma neuroimaging. For minor or mild acute closed head injury, PET is ranked 1/9 for appropriateness, and for subacute or chronic closed head injury with cognitive and/or neurologic deficits, PET appropriateness is 4/9.[23] PET is also subject to significant error when applied forensically to MTBI cases. Most of the studies from neuropsychological and other psychological assessments have been obtained at points in time that were quite disparate from the time at which the PET imaging occurred.[31] Even though there are some findings in the literature that correlate PET somewhat with symptomatic TBI or MTBI patients, there are no systematic, long-term, large-scale studies of PET imaging in patients with TBI that would allow a forensic examiner to develop standards for the interpretation of PET when used during examination of MTBI symptoms without also obtaining concurrent structural imaging.[21] As noted for the SPECT scan, there are also no pathognomonic features on PET imaging that are specific for TBI or MTBI. The same difficulty with false-positives in SPECT imaging applies to PET imaging. Multiple neurological, psychiatric, metabolic, and medical causes are known for altered brain metabolism, which may confound the interpretation or clinical correlation of PET imaging after MTBI.

Summary

The present article by Wortzel *et al.*[1] delineates well the current controversies in the forensic applications of cerebral SPECT in MTBI. Moreover, their conclusions about SPECT just as easily apply to the use of PET neuroimaging or functional magnetic resonance imaging (fMRI) in the forensic analysis of mild traumatic brain injury. While SPECT and PET have general sensitivity in the detection of cerebral blood flow or metabolic changes following MTBI, they lack significant discriminate specificity in their ability to delineate MTBI and clinically to correlate functional neuroimaging lesions with neuroanatomical or neuropsychological data. At the present time, the reliability of SPECT and PET, when applied forensically to MTBI or TBI cases, will not meet all *Daubert* criteria. This is particularly true in cases of MTBI as these have their own lack of diagnostic precision. As Wortzel *et al.*[1] point out, even with the noted limitations, cerebral SPECT and PET probably meet the *Daubert* criterion as to whether the theories behind and the techniques related to the performance of cerebral SPECT and PET can be, or have been tested. The second *Daubert* criterion also is probably met, in that both SPECT and PET stud-

ies have been subjected to peer review and publication. However, the use of small samples in studies, anecdotal reports, single case studies, and lack of controlled parameters, may allow functional neuroimaging in MTBI to have clinical usefulness but its application in the legal arena is very questionable.

In particular, the third criterion of *Daubert* regarding known or potential error rates is particularly problematic when functional neuroimaging is applied as a sole indicator or marker for evidence of MTBI in litigation. Here, the ability to determine a causal relationship between a lesion on SPECT or PET and a putative MTBI lacks scientific validity. These potential errors and lack of discriminate specificity have both been mentioned by Wortzel and colleagues and in this article. Comorbidities, medications, substance abuse, pre-existing psychiatric illness, prior head trauma, and even mental activity can generate false positives in either SPECT or PET neuroimaging, which cannot be distinguished from those produced by mild TBI. For instance, as noted earlier, Iverson *et al.*[18] could not distinguish traumatic brain injury from substance abuse by the use of functional neuroimaging. There is no generally accepted standard for the diagnosis of mild TBI and there are no published standards for pathognomonic lesion determination using PET or SPECT after MTBI. While the American College of Radiology has published appropriateness criteria for the use of neuroimaging in head trauma,[23] those appropriateness criteria do not allow a precise determination of exactly which cases are appropriate for functional neuroimaging without the concurrent use of structural neuroimaging.

The last criterion in *Daubert* regards general acceptance of the theory and technique within the relevant scientific community. Analysis of the world literature on SPECT or PET and the American College of Radiology guidelines,[23] as well as the Society of Nuclear Medicine Procedure Guidelines for Single Photon Emission Computed Tomography,[32] indicate that general acceptance has not been achieved. At present, the availability of research studies and published data on both SPECT and PET is consistent with the conclusion that these neuroimaging techniques do not provide objective evidence of MTBI, and they will not meet, to a satisfactory degree, *Daubert* criteria when functional neuroimaging data are presented in a legal forum. At this time in scientific medicine, the use of SPECT and PET as evidence of mild TBI, without structural neuroimaging clinical correlation, cannot be supported in a legal forum. The evidentiary usefulness of functional neuroimaging to prove mild TBI in a court of law lacks a sufficient scientific database and lacks sufficient scientific standards. Thus, experts are not able to present sound opinions to a trier of fact. In particular, the ethics guidelines stated by Wortzel *et al.*[1] for testimony about cerebral SPECT imaging in mild TBI should be followed.

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