NeuroRehabilitation 31 (2012) 223–226
DOI 10.3233/NRE-2012-0792
IOS Press

Introduction

Neuroimaging in Neurorehabilitation

Elisabeth A. Wilde[a,b,c,d,*], Jill V. Hunter[a,c,e] and Erin D. Bigler[f,g,h,i]
[a]*Department of Physical Medicine and Rehabilitation, Baylor College of Medicine, Houston, TX, USA*
[b]*Department of Neurology, Baylor College Medicine, Houston, TX, USA*
[c]*Department of Radiology, Baylor College Medicine, Houston, TX, USA*
[d]*Michael E. DeBakey Veterans Affairs Medical Center, Houston, TX, USA*
[e]*Department of Pediatric Radiology, Texas Children's Hospital, Houston, TX, USA*
[f]*Department of Psychology, Brigham Young University, Provo, UT, USA*
[g]*Neuroscience Center, Brigham Young University, Provo, UT, USA*
[h]*The Brain Institute, University of Utah, Salt Lake City, UT, USA*
[i]*Department of Psychiatry, University of Utah, Salt Lake City, UT, USA*

Abstract. Tremendous advances in neuroimaging methods and analytic techniques hold great promise in providing the rehabilitation clinician with a much greater understanding of brain pathology and its potential influence on rehabilitation outcome. This special issues of *NeuroRehabilitation* overviews the field. Contemporary neuroimaging methods are reviewed specifically in traumatic brain injury (TBI), anoxic brain injury (ABI) and stroke. Innovative methods combined with standard quantitative metrics and traditional clinical assessment provide the rehabilitation clinician with multiple methods to best understand the nature and extent on underlying neuropathology and how to use this information in guiding rehabilitation therapies and predicting outcome.

Keywords: Neuroimaging, neurorehabilitation, diffusion tensor imaging (DTI), magnetic resonance imaging (MRI), computed tomography (CT), children

Since the advent of computed tomography (CT) in the early 1970s, the capabilities of neuroimaging to capture structural and functional neuropathology following the onset of some type of neurological disorder has exponentially improved. In the beginning, neuroimaging was used primarily in a descriptive manner – to identify the presence or absence of an abnormality and its general location. Neuroimaging distinctly improved early diagnosis of stroke and traumatic brain injury (TBI), leading to a greater number of individuals surviving these neurological events and consequently, an increased number of individuals in need of neurorehabilitation.

However, the diagnostic and descriptive utilization of neuroimaging to identify abnormalities did not necessarily change how neurorehabilitation therapies were implemented. In the early days of neuroimaging, the main focus was still upon lesion localization [1]. This was partly because there were no real quantitative methods for "measuring" brain pathology other than coarse linear measurements, such as width and length of a lesion, and these techniques had to be implemented by hand [2]. The practice of neuroradiology was mostly descriptive, and while it was certainly beneficial to know that a stroke or old contusion, as examples, were "large" or "small" and where they were located, this information was not necessarily directly applicable to the kinds of therapeutic interventions that might be recommended during rehabilitation.

As neuroimaging technology evolved coincident with more powerful computers and better software programs, investigators began to look at basic 3D metrics such as the volume of a lesion and correlate this with clinical outcomes, e.g., an infarct and its relationship to stroke outcome [3,4] or the size and depth of traumatic

*Corresponding author: Elisabeth A. Wilde, Ph.D., Cognitive Neuroscience Laboratory, Baylor College of Medicine, Houston, TX 77030, USA. Tel.: +1 713 798 7331; Fax: +1 713 798 6898; E-mail: ewilde@bcm.edu.

ISSN 1053-8135/12/$27.50

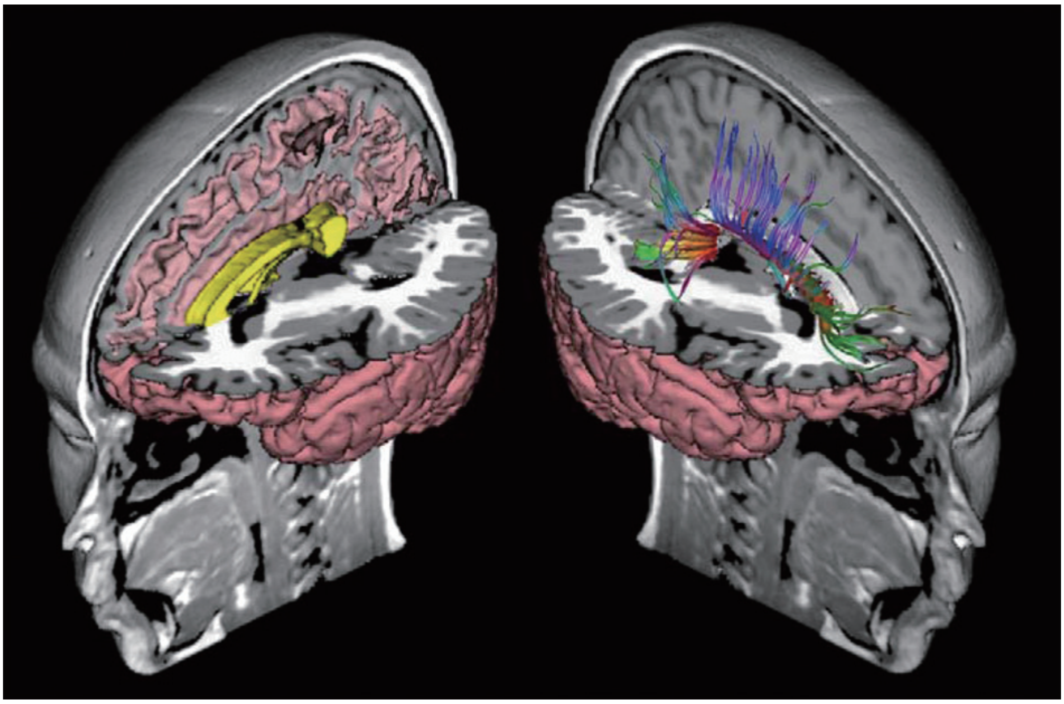

Fig. 1.

lesions in relation to injury severity or outcome [5]. However, at best, these measurements were still restricted to a static, purely anatomic description of the brain pathology.

Before the end of the 20th century, a variety of improvements in image acquisition techniques, resolution, sensitivity to pathology, and methods to quantify normal as well as pathological neuroanatomy rapidly became available, allowing inroads into the understanding of some of the underlying pathophysiology. As shown in Fig. 1, contemporary methods of image analysis and display using magnetic resonance imaging (MRI), which will be the focus of this special issue, provide exquisite anatomical detail. For example, in yellow the corpus callosum is highlighted, and with contemporary techniques it can be isolated, its surface area or volume calculated, common regions of interest identified, and its shape and contour measured (i.e., regions such as the genu and splenium); additionally, the impact of focal pathology can also be appreciated (e.g., note the dark area at the posterior segment of the isthmus, as it represents a shear lesion from TBI). Basic anatomy can be taken to the next level where not only can these morphometric measurements be obtained and compared to a large normative sample, but the actual connectivity of structures like the corpus callosum can be identified using advanced techniques such as diffusion tensor imaging (DTI; as shown in the image on the right) and resting state functional MRI. The basic methods for acquisition and analysis that are now available for neuroimaging studies of patients receiving neurorehabilitation services including image quantification, functional and structural neuroimaging in rehabilitation outcome is outlined in Wilde et al. [6].

Voelbel et al. [7] review DTI applications in neurorehabilitation and Strangman et al. [8] demonstrate the actual use of DTI findings in predicting memory rehabilitation. Benson and colleagues address the use of DTI in assessing and planning treatment mild TBI. These reviews emphasize the potential utilization of DTI to inform the neurorehabilitation clinician about pathway integrity. As discussed by Wilde and colleagues [9], in their article on neuroimaging in pediatric neurorehabilitation, advances in knowledge of connectivity are central to understanding injury related neuromotor, neurosensory, neurocognitive and neurobehavioral consequences.

An example of disrupted connectivity and its importance for neurorehabilitation is presented in Fig. 2. Based on MRI findings, standard structural imaging does not reveal much in the way of any abnormality in the corpus callosum of the individual depicted in Fig. 2 who sustained a TBI, as shown on the right and compared to an age- and sex-matched normal con-

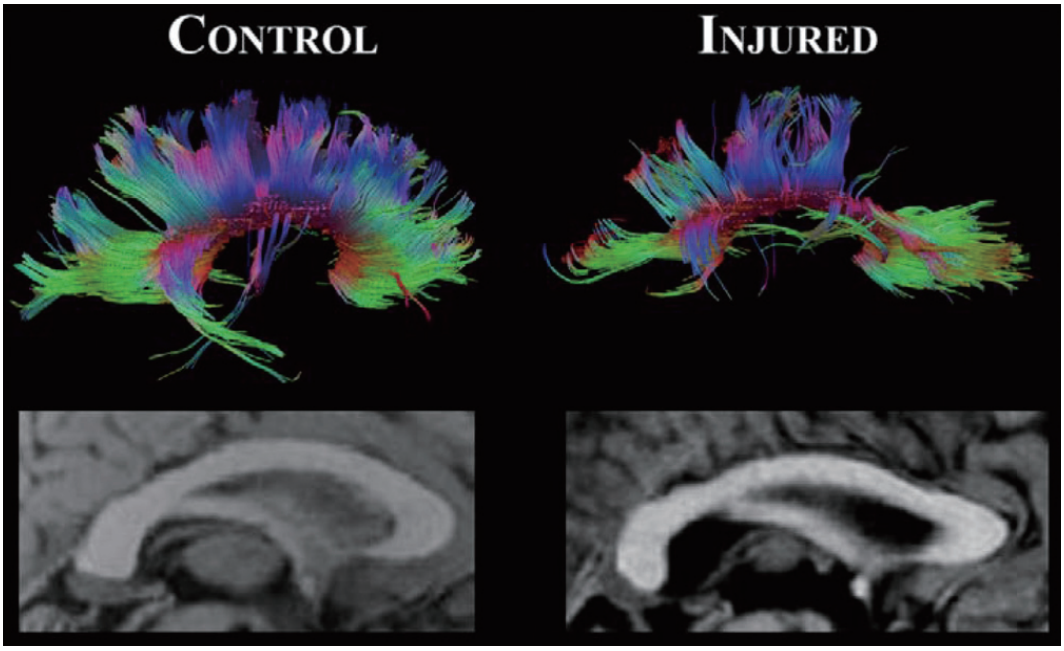

Fig. 2.

trol on the left. However, the integrity of the tracts as reflected in what is referred to as DTI tractography, shows that projections from the anterior aspect of the corpus callosum to the frontal lobes are distinctly abnormal. Clinically, this implies that this patient has significantly diminished bihemispheric frontal lobe integration, which likely relates to diminished speed of processing, executive functioning and emotional control, which were all deficits noted following this brain injury. Although an over simplification, this illustration demonstrates the problems with past neuroimaging that focused just on the appearance and/or simple size or volume measurements. Based solely on those aspects of image analysis, minimal to no relationship might be observed between corpus callosum surface area and cognitive variable [10]. However, as shown by Benson et al., Strangman et al. and Voelbel et al., DTI provides a new dimension in understanding connectivity, and for the subject in Fig. 2, had the neurorehabilitation clinician or treatment team not requested a DTI sequence, rehabilitation decisions would be based on a rather normal appearing brain, with no specific "lesion" within the corpus callosum to suggest any abnormality of connectivity, except for a few hemosiderin deposits.

Hopkins and Jackson [11] show that just the issue of critical illness alone, separate from a specific neurological event, has the potential to result in neurological compromise, detectable by neuroimaging. Many patients who have some type of primary brain injury initially receive critical care early in their hospitalization. Part of what may be influencing this compromise associated with having critical illness or injury may be related to hypoxia, but hypoxic/anoxic injury is also a primary etiology in brain injuries that ultimately require neurorehabilitation. Hopkins and Bigler [12] review how anoxic brain injury may be assessed using contemporary neuroimaging methods and the relevance of such findings to neurorehabilitation.

Finally, cerebral vascular accidents represent another common disorder that requires neurorehabilitation and Gale and Pearson review the current role of neuroimaging [13]. In stroke, like TBI, there is typically a baseline scan, when change over time and the application of new image analysis techniques provide improved insight into the extent of vascular-related neuropathology.

What will be evident when completing the review of these articles in this special issue of NeuroRehabilitation is that despite unprecedented improvements in neuroimaging technology, there is actually very little systematic research that has addressed the potential uses of advanced neuroimaging technology in a neurorehabilitation setting [14]. Applications of imaging tools that could be utilized to probe functional brain changes (e.g., functional task-related and resting state connectivity MRI, magnetic source imaging, positron emission tomography, etc.) in the rehabilitation setting remain in their infancy yet hold enormous promise in better understanding disruption and recovery of neural networks in future work. Nonetheless, the articles within this special edition provide an overview of what is currently available and a glimpse into future applications.

References

[1] Kertesz, A., *Localization and neuroimaging in neuropsychology* 1994, San Diego: Academic Press.
[2] Bigler, E.D., Turkheimer, E and Yeo, R.A., Neuropsychological function and brain imaging, 1989, Plenum: New York.
[3] Beloosesky, Y., et al., The importance of brain infarct size and location in predicting outcome after stroke. Age and ageing, 1995. **24**(6): p. 515-8.
[4] Turkheimer, E., R.A. Yeo, and E.D. Bigler, Basic relations among lesion laterality, lesion volume and neuropsychological performance. Neuropsychologia, 1990. **28**(10): p. 1011-9.
[5] Levin, H.S., et al., Magnetic resonance imaging in relation to functional outcome of pediatric closed head injury: A test of the Ommaya-Gennarelli model. Neurosurgery, 1997. **40**(3): p. 432-40; discussion 440-1.
[6] Wilde, E.A., Hunter, J.V. and Bigler E.D., *Neuroimaging; Primer for Neurorehabilitation.* NeurorRehabilitation, 2012.
[7] Voelbel, G.T., Genova, H.M., Chiaravalotti, N.D. and Hoptman, M., *Diffusion Tensor Imaging of Traumatic Brain Injury Review: Implications for Neurorehabilitation.* NeuroRehabilitation, 2012.
[8] Strangman, G.E., O'Neil-Pirozzi, T.M., Supelana, C. Goldstein, R., Katz, D.I. and Glenn, MB, Fractional anisotropy helps predicts memory rehabilitation outcome after traumatic brain injury. NeuroRehabilitation, 2012.
[9] Wilde, E.A., Hunter, J.V. and Bigler, E.D., *Pediatric Traumatic Brain Injury: Neuroimaging and Neurorehabilitation Outcome* NeuroRehabilitation, 2012.
[10] Johnson, S.C., Bigler, E.D.,Burr, R.B., and Blatter, D.D. (1994), White matter atrophy, ventricular dilation, and intellectual functioning following traumatic brain injury. Neuropsychology, 1994. **8**(307-315).
[11] Hopkins, R.O.J., J.C., *Neuroimaging Findings in Survivors of Critical Illness.* NeuroRehabilitation, 2012. in press.
[12] Hopkins, R.O.B., E.D, Neuroimaging of anoxic injury: Implications for neurorehabilitation. NeuroRehabilitation, 2012. in press.
[13] Gale, S.D.P., C.M., *Neuroimaging predictors of stroke outcome: Implications for neurorehabilitation.* Neurorehabilitation, 2012. in press.
[14] Bigler, E.D. and E.A. Wilde, Quantitative neuroimaging and the prediction of rehabilitation outcome following traumatic brain injury. Frontiers in human neuroscience, 2010. **4**: p. 228.