Evaluation of the brain after traumatic brain injury (TBI) with advanced magnetic resonance imaging: the LSU approach

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Introduction

Standard computed tomography and magnetic resonance (MR) findings cannot explain the cognitive, behavioral and sensorimotor changes in a patient who sustained a traumatic brain injury. We use sequences sensitive for hemosiderin deposits in the post- traumatic brain, to measure cortical thickness generally decreased in dorsal and ventral aspects of the brain, to evaluate main fiber tracts, magnetic resonance spectroscopy to highlight metabolic changes and functional magnetic resonance to detect failure in main brain networks.

Materials and Methods

From 830 cases evaluated with advanced MR we recovered 131 TBIs. 62 women and 69 men. Average age was 41.16yo for women with a standard deviation of 16. Average age for men was 45.4 yo, wiith a standard deviation of 16. For detection of hemosiderin we used susceptibility weighet sequence. Cortical thickness was obtained using Brain Suite. BrainSuite is produced and distributed as a collaborative project between Dr. David W. Shattuck's research group at the Ahmanson-Lovelace Brain Mapping Center at the University of California, Los Angeles and Dr. Richard M. Leahy's Biomedical Imaging Group at the University of Southern California. This software provides with brain segmentation, cortical thickness and volumes of cortex and central nuclei. Thickness decrease appearing in blue in the 3D maps, is abnormal and corresponds to a 35% below the maximum thickness. Diffusion tensor imaging was used to measure fractional anisotropy and parallel and perpendicular diffusivity in genu and splenium of the corpus callosum, cingulum, inferior longitudinal fasciculus, uncinate fasciculus and superior longitudinal fasciculus. Normal values were obtained from 40 normal patients with a mean age of 29yo , youngest 20yo and oldest 79yo. 21 female and 19 male. The values match normal values published elsewhere. Fractional anisotropy measures the water protons following the fiber tracts in one direction (anisotropy) and decreases when those tracts are damaged. Parallel diffusivity is related to axonal integrity and perpendicular diffusivity is related to myelin integrity. Magnetic resonance spectroscopy with low TE is set in frontal and posterior cingulate cortex, sensitive landmarks of brain metabolism. Creatine, a quite stable metabolite is used as standard. Metabolites measured are N-acetyl-aspartate (NAA/Cr= 1.7), creatine, choline (Cho/Cr= 0.7) and myoinositol mI/Cr= 0.5).We use resting state functional magnetic resonance with seed method to explore executive network, default mode network, salience network and the important hub located in BA9. We used 30 normal controls with intact networks. The connectivity analysis is based on linear correlation.

The patients were examined for changes after trauma in sleep, mood, behavior and anger, memory, depression, headache, coordination and motor skills and planning skills.

Results

Susceptibility sequence detected old hemosiderin deposits in 8% of the patients.

The most affected cortex in cortical thickness analysis was the central cortex in 88% of the patients, dorsolateral prefrontal cortex in 84%, lingual gyrus in 86% and right orbitofrontal cortex in 79% of the patients.

Regarding diffusion tensor imaging, the fractional anisotropy was abnormally decreased in right cingulum in 61% of patients, genu of the corpus callosum in 41% and splenium of the corpus callosum in 35% of patients. Parallel diffusivity was abnormally increased in genu of the corpus callosum in 37% of patients and splenium of the corpus callosum in 27%. Perpendicular diffusivity was abnormally increased in genu of the corpus callosum in 44% of patients and right cingulum in 44%.

The networks more affected in resting state fMRI are the hippocampal network in 83% of patients and posterior cingulum in 78% of patients.

In the areas clinically explored were sleep and memory changes in 78%, mood in 75%, headache in 69%, anger and depression in 64%, planning 52%, coordination and motor skills in 48% of patients.

Discussion

When comparing the main clinical changes and the abnormalities found we can associate sleep, mood, depression and headache to the cingulum and corpus callosum. As cingulum is the fiber tract related to the limbic system, any structural abnormality is associated clinically with depression, memory loss, lack of social restraint, aggressiveness. Cingulum is a central structure in learning to correct mistakes, indicates that the cingulum is involved in appraisal of pain and reinforcement of behavior that reduces it. There are two primary parts of the cingulate cortex: the posterior cingulate cortex and the anterior cingulate cortex. The anterior is linked to emotion, especially apathy and depression. Here function and structure changes are related meaning any change within this structure would lead to a function change, particularly behavioral because of its function involving emotions. Damage to this area can have various effects on mental disorders and mental health. The posterior section is more related to cognitive functions. This can include attention, visual and spatial skills, working memory and general memory. Because of its location, the cingulum is very important to brain structure connectivity and the integration of information that it receives Damage to the cingulum also simultaneously damages the hippocampus. This is vital because the hippocampus is pivotal in memory storage and its damage is associated mild cognitive impairment. The posterior cingulum forms a central node in the default mode network of the brain. It has been shown to communicate with various brain networks simultaneously. The posterior cingulum has been implicated as a neural substrate for human awareness in numerous studies of both the anesthesized and vegetative (coma) state. Imaging studies indicate a prominent role for the posterior cingulate cortex in pain and episodic memory retrieval. The failure to control the posterior cingulum/ default mode network (DMN) activity can lead to attentional lapses in TBI patients. The corpus callosum (CC) is a thick band of nerve fibers that divides the cerebrum into left and right hemispheres. It connects the left and right sides of the brain allowing for communication between the hemispheres. The CC transfers motor, sensory, and cognitive information between the brain hemispheres. The most common clinical symptoms in the lesions of the splenium of the corpus callosum (SCC) are confusion and irritability (50%). Other frequent clinical manifestations are dysarthria, disconnection syndrome, ataxia, and headache. Mutism, hallucinations, psychosis, and hemispheric disconnection are more specific findings of SCC lesions. The splenium regulates mutism or hallucinations because the right and left hemispheres generate independent nonsense, the censure of which is necessary and normal, and requires an intact splenium. Dorsolateral prefrontal cortex has been implicated in planning complex cognitive behavior, personality expression, decision making, and moderating social behavior. The basic activity of this brain region is considered to be orchestration of thoughts and actions in accordance with internal goals. The most typical psychological term for functions carried out by the prefrontal cortex area is executive function. Frontal orbital cortex (Brodmann area 11) is interconnected with the hypothalamus, requesting the basic needs of an individual (for preservation of individual and species) and on the other hand with the filter of neocortex. The lesions in this area produce avoidance of social interaction and aggressive behavior. It plays an important role in sensory integration, modulation of autonomic reactions, learning, decision making for emotional and reward-related behavior, and pleasantness of foods. The lingual gyrus is a brain structure that is linked to processing vision, especially related to letters. It plays an important role in vision and dreaming.

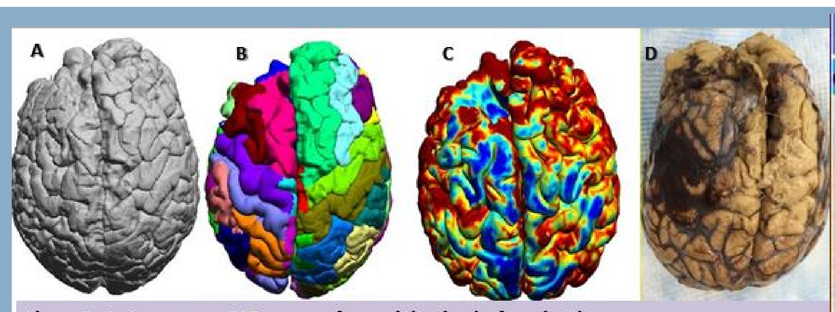

Figure 1. Autopsy case. MR was performed the day before death
A. 3D reconstruction B. Segmentation C. Cortical thickness D. Autopsy specimen

Anatomical structure	FA	Normal	SD
Genu corpus callosum	0.528348	0.74	0.04

Anatomical structure	FA	Normal	SD
Splenium corpus callosum	0.793856	0.78	0.03

Figure 2. Same patient as in figure 1. Abnormal fractional anisotropy in the genu of the corpus callosum, This is due to the genu hitting the falx.

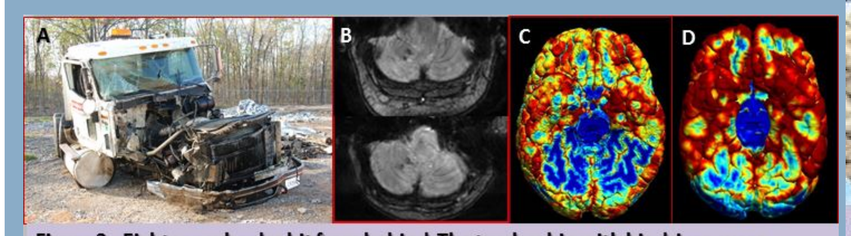

Figure 3. Eighteen wheeler hit from behind. The truck cabin with his driver were ejected. A. Truck cabin B. Susceptibility images in 2011 (above) and 2013 (below). Hemosiderin deposits in the cerebellum entrapped in the microglia C. Cortical thickness (blue is decreased cortical thickness, red normal) in 2011 and D. in 2013

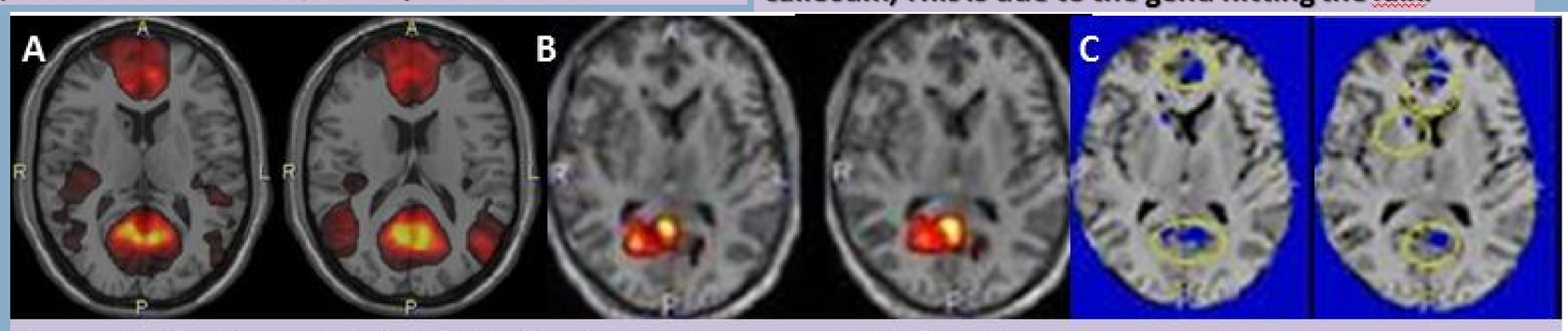

Figure 4. Resting state fMRI. Default mode network. A. Seed in posterior cingulum. Connected with anterior cingulum, angular gyrus B. Same patient as in figure 3. No connection with anterior cingulum nor angular gyrus C. z-score. Compared with a normal pool. Decreased connectivity in anterior cingulum (blue)

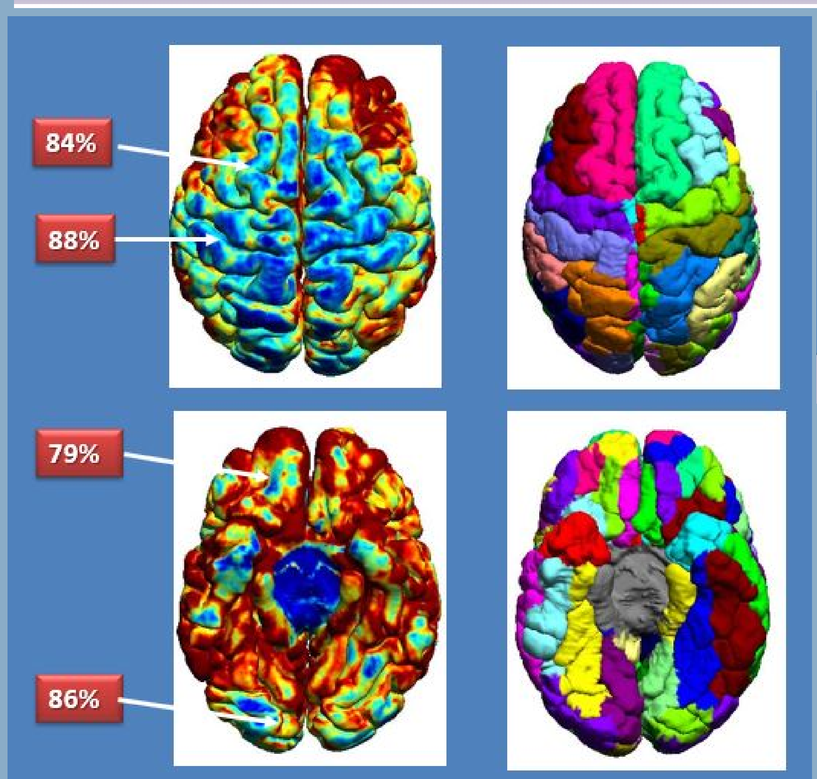

Figure 5. Locations more affected in cortical thickness

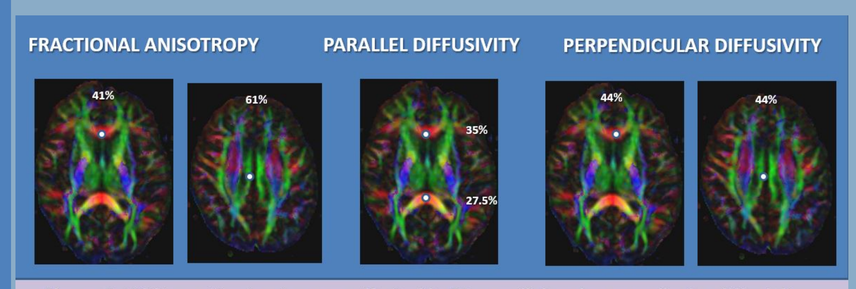

Figure 6. White matter tracts more affected in FA, parallel and perpendicular diffusivity

Conclusions

Addition of susceptibility sequence, tridimensional T1WI with reconstruction of cortical thickness, Diffusion Tensor imaging with measurement of fractional anisotropy, parallel diffusivity and perpendicular diffusivity and resting state fMRI contributed to explain the patients clinical and neuropsychological picture, not possible with computed tomography and standard magnetic resonance sequences..

Patient with neuropsychological symptoms after a traumatic brain injury were interpreted as malingering or there was no method to visualize the damage produced in the brain.

We explore the cortex, the fiber connections and finally the functional activity in that same brain that is malfunctioning as a result of a damage to the morphological components

Figure 7. Networks more affected in TBI

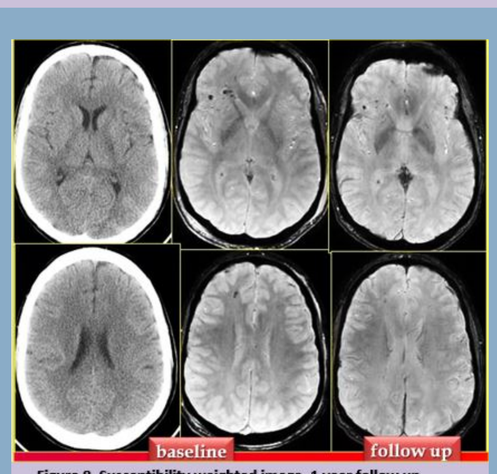

Figure 8. Susceptibility weighted image. 1 year follow up

References

Bonnelle V, Ham TE, Leecha R, Kinnunenc KM, Mehtad MA, Greenwoode RJ,and Sharpa DJ .Salience network integrity predicts default mode network function after traumatic brain injury PNAS March 20, 2012 4690–4695.

Bigler ED, Victoroff J. Neuroimaging biomarkers for the neuropsychiological investigation of concussive brain injury (CBI) outcome.2019. in Concussion and traumatic encephalopathy. Causes Diagnosis and Treatment.Cambridge Universioty Press.Ch6.

Fischl, B., and Dale, A.M. (2000). Measuring the thickness of the human cerebral cortex from magnetic resonance images. Proc.Natl. Acad. Sci. USA 97, 11050–11055

Gonzalez-Toledo E. LSU protocol for brain trauma (2013) and Forensic Neuroradiology. Cognitive changes in brain trauma and changes in criminal brains. Eduardo Gonzalez-Toledo, Neuroradiology.52Supp1.September 2014:156-157

Harlow (Harlow,JM. Letter to the editor. Boston.Med.Surg.J. 39:507,1849

Kumar R, Husain M, Gupta RK, Hasan KM, Haris M, Agarwal AK, et al.Serial changes in the white matter diffusion tensor imaging metrics inmoderate traumatic brain injury and correlation with neuro-cognitive function. J Neurotrauma 2009; 26: 481–95.

Kraus MF, Susmaras T, Caughlin BP, Walker CJ, Sweeney JA, Little DM.White matter integrity and cognition in chronic traumatic brain injury:a diffusion tensor imaging study. Brain 2007; 130: 2508–19

Mallera JJ,Thomson RHS, Lewis PM, Rose SE,Pannek K, Fitzgerald PB.Traumatic brain injury, ajor depression, and diffusion tensor imaging: Making connections. Brain Research Reviews. 2010:213-240

Mac Donald CL, Dikranian K,Bayly P,Holtzman D,Brody D. Diffusion Tensor Imaging Reliably Detects Experimental Traumatic Axonal Injury and Indicates Approximate Time of InjuryThe Journal of Neuroscience, October 31, 2007 • 27(44):11869 –11876

Palacios EM Sala-Llonch R Junque C, Fernandez-Espejo D, Roig T, Tormos JM, Bargallo N and Pere Vendrell P. Long-term declarative memory deficits in diffuse TBI:Correlations with cortical thickness, white matter integrity and hippocampal volumen. Cortex . 2013 : 646 -657

Proal E,Álvarez-Segura M, de la Iglesia-Vayá M, Martí-Bonmatí L, Castellanos FX, Spanish Resting State Network (SRSN) Actividad funcional cerebral en estado de reposo:redes en conexión.Rev Neurol 2011; 52 (Supl 1): S3-S10

Turken AU, HerronTJ, Kang X O'ConnorLE,SorensonDJ, Baldo JV and Woods DLMultimodal surface-based morphometry reveals diffuse cortical atrophy in traumatic brain injury. BMC Medical Imaging 2009, 9:20,