Canadian Sports Concussion Project

Summaries of Presentations

1. **Dr. David Mikulis , Senior Scientist, Toronto Western Research Institute-** ***The Challenges of Imaging a Concussion***

- Concussion results in insufficient disruption of tissue to be seen using clinical MRI scans. Therefore, no brain abnormalities are detected in concussed individuals using clinical MRI.
- Current research using advanced imaging methods has been successful in detecting brain abnormalities caused by concussion. These imaging methods include:
  - MRI diffusion imaging

    This method assesses the way tissue structure influences water movement. It can be used to assess white matter integrity by examining disruption of normally constrained water movement in axons.
  - Functional MRI

    This method measures differences in MRI signal intensity caused by blood flow changes that are coupled to neuronal activity. It is used to assess gray matter and can determine how well connected cortical regions are to each other.
  - Positron emission tomography (PET)

    This method uses radioactive tracers that seek specific targets in the brain such as tau or amyloid protein to detect evidence of neurodegeneration.
  - Magnetoencephalography (MEG)

    This method detects magnetic fields generated by active cortical neurons. Alterations in the location and frequency of these waves caused by concussion can be mapped.

- Advanced MRI has been successful in detecting the effects of concussion with the caveat that injury is only seen when data from many subjects (on the order of 10-12 individuals) is merged into a single group. This means that even with advanced MRI techniques, the diagnosis of concussion in a single subject cannot be made with confidence.
- PET tracers are under active investigation but current sensitivity and specificity are insufficient to establish the diagnosis of concussion in a single subject.

- The study of concussion using MEG is relatively new and shows promise but once again the diagnosis of concussion in a single subject cannot be made with certainty.
- Summary: No imaging modality is capable of establishing the presence of concussion in a single subject. Advances are being made in all imaging technologies including primary data acquisition (ultra-high field MRI) as well as novel data analysis methods (machine learning - a branch of artificial intelligence). The future is promising*!*

2. **Dr. Erin D. Bigler, Professor of Psychology and Neuroscience at Brigham Young University-** ***Understanding the latest developments in neuroimaging of sports concussion***

Given 21st century neuroimaging technology, understanding sports concussion begins with understanding how the brain injury affects various neural networks and the particular vulnerability of certain brain regions to head impact injuries. First the heterogeneity of injury was emphasized, showing supporting research that no two concussive brain injuries could ever be the same due to the unique circumstances of the individual, their genetic and developmental heritage, biomechanics of the injury and how both resiliency and vulnerability factors play out once the brain is injured. Based on neuropathological, neuroimaging and biomechanical research studies on concussion a "window of vulnerability" where injury to the brain is most likely to occur was presented, to include from the upper brainstem, through the thalamus and hypothalamus (in some including the pituitary) into the corpus callosum, cingulum bundle and deep white matter of the centrum semi ovale. Surface deformation and contusions are most likely to occur in the inferior frontotemporal regions and the polar areas of both frontal and temporal lobes. From this, concussive injury may be viewed as having the potential to injure both white as well as gray matter. Brief discussion was provided showing how evolutionary influences may have also contributed to the likelihood of which brain regions are damaged and how they may or may not recover. The increased likelihood of damage in the above mentioned regions permits the use of various neuroimaging techniques to undertake region of interest analyses relating structure-to-function comparisons of these areas to outcome. Various neuroimaging methods of analysis were presented including structural imaging, diffusion tensor imaging (DTI) where DTI tractography provides a method to extract major pathways in the brain along with resting state (rs) functional connectivity (fc) magnetic resonance imaging (MRI) mapping. Combining structural neuroimaging with tractography combined with rs-fcMRI permit the development of elegant network analyses, where concussion has been shown to disrupt these networks, especially in the short-term. How neuroimaging methods like these can be applied to monitoring outcome were presented with an emphasis on developing normative methods so that these advanced analysis techniques may be done on the individual concussed athlete and be used clinically to assess and treat the athlete. Hopefully, neuroimaging methods will provide greater objectivity in making some return-to-play decisions and clinical management of athletes.

3. **Dr. Paul Dufort, Computational Imaging Scientist, Toronto Western Research Institute -** ***Concussion and White Matter Damage: Insights from Machine Learning and Other Advanced Analyses***

   The field of machine learning (aka data mining, big data, or data analytics) is currently undergoing a period of explosive growth, transforming diverse domains from medicine, to commerce, to professional sports. Already prevalent in a range of other neuroimaging applications, it is now also beginning to appear in applications to concussion. Researchers with the Canadian Sports Concussion Project have recently applied it to the discrimination of retired professional football players from healthy age-matched controls, in work to be discussed in another session at this symposium. Machine learning differs from traditional statistical analyses in the questions it asks of the data. Where statistics is focused on assessing the likelihood that an observed difference between groups could have occurred purely by chance, represented by the p-value, the goal of machine learning is to produce a classifier capable of classifying individuals into their originating group, with success measured via the classification accuracy. Unlike traditional statistical regression-based techniques, machine learning algorithms excel in situations where the number of measured variables for each subject is much greater than the number the subjects, and can identify and exploit patterns among multiple variables to improve their discriminative accuracy. Accuracy is typically assessed under a cross-validation paradigm, and is compared against a null distribution of accuracies computed under repeated random label permutations. A highly accurate and statistically significant classifier is a strong indicator of consistent differences in the measured variables across two or more groups. However, dissection of accurate classifiers to make inferences about the functioning of the underlying system must be performed with caution. The linear classifiers most frequently used in neuroimaging produce a coefficient for each voxel in the analysis, and these coefficients are often used to create maps that are claimed to represent the physiological process under study. But recent work has demonstrated that large coefficients are as likely to subserve a noise cancelling function as to represent neural circuitry relevant to the studied phenomenon. Greater insight may accrue from training multiple classifiers at different brain locations and interpreting the spatial distribution of their accuracies, rather than by producing a single accurate classifier and attempting to dissect its internal functioning.

4. **Dr. Karen Davis , Senior Scientist, Toronto Western Research Institute , and Dr. Paul Dufort, Computational Imaging Scientist, Toronto Western Research Institute-** ***Applying Machine Learning Classifiers to Discriminate Concussed Athletes From Non-Concussed Subjects Based on Diffusion Tensor Imaging***

   Concussions can result in a range of cognitive and physical symptoms and associated brain pathologies. We recently reported that impulsivity correlated with white matter metrics of the uncinate fasciculus (UF) based on diffusion tensor imaging (DTI) in retired professional athletes (Goswami R et al. (2014) Brain Injury 28: 592-3). However, it is not known whether DTI of the UF can be predictive of concussion history in single subjects. Here we determined if a machine learning classifier could be trained to discriminate concussed retired athletes from healthy controls on the basis of DTI of the UF. DTI scans of 19 retired

CFL players (age 50 ±12yo) with a history of concussions and 17 age-matched controls (46 ±10yo) were obtained using 3T MRI. Data were pre-processed using the standard FSL DTI pipeline and TBSS was used to generate spatial maps of the fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (RD), and radial diffusivity (AD) projected onto a common white matter skeleton. Whole-brain skeletons were restricted to the left and right UF by transforming probabilistic tractography-based segmentations of each subject's UF into standard space, averaging, thresholding and taking their intersection with the TBSS skeletons. Eight support vector machine (SVM) classifiers (4 DTI metrics x 2 hemispheres) were trained to discriminate athletes from controls based on voxels from each hemisphere's uncinate tract. Performance was optimized over algorithm meta-parameters by grid search. Leave-one-out cross-validation computed accuracy and random label permutation tests assessed statistical significance. Classifiers based on MD and RD measured at voxels of the right UF achieved statistical significance ($p=0.018$ and $p=0.04$, respectively) with an optimal operating point sensitivity/specificity of 84/82% for the former and 79/82% for the latter. The areas under the ROC curves were 0.81 and 0.80, respectively. The spatial pattern of classifier weights revealed mean and radial diffusivities that were higher in concussed athletes than in controls at the orbitofrontal end of the uncinate tract, but lower in athletes versus controls at the temporal end. These data provide evidence for the use of machine learning with DTI to assess spatial locations of white matter abnormalities in concussed subjects that may not be identifiable with standard DTI approaches.

5. **Dr. Ahmed Ebraheem ,Concussion Fellow, Toronto Western Research Institute , -UHN co-Authors: Brenda Colella, Dr. Robin Green, Dr. Ruma Goswami, Dr. Charles Tator, and Dr. Carmela Tartaglia,: *Investigating the Role of Vascular Disease and White Matter Hyperintensities on MRI in Former Canadian Football Players***

Concussion is recognized as a clinical syndrome of biomechanically induced alteration of brain function which may or may not involve loss of consciousness (LOC) Although the majority of concussions are fully resolved, there is growing clinical and societal concerns about the long-term sequelae of multiple concussions. These effects have been linked to white matter integrity abnormality. White matter hyperintensities (WMH) are areas of increased signal on T2 and fluid attenuated inversion recovery (FLAIR) MRI. WMH volume can be a surrogate for loss of white matter integrity. WMH volume has been also correlated with decreased performance on neuropsychological speed of processing (SOP) and executive functioning tests.

We studied 26 former players and 13 controls to determine the relationship between white matter hyperinsity volume and concussions, vascular risk factors and neuropsychological performance. WMH volume was measured using OsiriX software. The total WMH volume was calculated for each participant. Cognitive function of all participants was assessed using a full battery of neuropsychological tests. Using SPSS, the relationship between WMH volume and the following was investigated: age, history of concussion, number of concussions, vascular risk factors: HTN, DM, cholesterol, alcohol and smoking; and speed of processing (SOP) and executive functioning tasks.

The following results were obtained: WMH correlates with number of vascular risk factors and age; WMH correlations with the SOP and executive tasks; WMH volume did not correlate with the following: history of concussion (player's vs controls), number of concussions among the athletes. Thus, there was a relationship between WMH volume and number of vascular risk factors as well as with age. There was a relationship between WMH volume and executive functioning tests. There was no relationship between WMH and history or number of concussions

The CSCP is recruiting more participants for these studies and we hope to investigate this in a larger sample size of athletes as well as non-athletes who have suffered multiple concussions. The possible implications include the following : control of vascular risk factors may prevent some of the cognitive deficits observed in those who have suffered multiple concussions. Prospective studies will be add additional information.

6. **Carmen Hiploylee: Research Assistant, Toronto Western Research Institute -** ***Financial Implications of Career-Ending Concussions and Postconcussion Syndrome in the Professional Hockey Player***

Career-ending concussions in the NHL have been reported to cause a loss of self-identity, difficulty in transitioning to retirement life, postconcussive symptoms, emotional distress, and a decline in quality of life. In addition to this, there are financial implications of career-ending concussions that have not yet been explored. The purpose of our study was to calculate the total salary cost due to missed games from career-ending concussions in the NHL. Through publicly available and online resources, we identified 37 NHL players from 1995-2014 who retired from a concussion in the NHL. Former NHL players who suffered a career-ending concussion in another professional hockey league or players whose retirement could not be definitively linked to their concussion were excluded from our financial analysis. The salaries for 2 of the 27 players could not be determined and so, the total salary cost calculated due to career-ending concussion was $117,191,045. This figure is severely underestimated as it does not include courtroom settlements, treatment of injuries, insurance costs etc. Interestingly, no career-ending concussions were found after 2011. This may be due to fewer enforcers employed in the game and thus, less fighting. Also, Chris Pronger's and Marc Savard's concussions in 2011 contributed to 42% of the final cost. These players were signed to long-term and high-paying contracts at the time and were deemed to be star players. Whoever suffered the financial impact of $117,191,045 is unknown and more transparency is required to further elucidate the full financial implications of career-ending

7. **Alex Terpstra, Graduate Student, Toronto Rehabilitation Institute, and Dr. Robin Green, Senior Scientist, Toronto Rehabilitation Institute -** ***Cognitive and Neuropsychiatric Characterization of Retired Professional Football Players with a History of Multiple Concussions***

The purpose of this presentation was to summarize our research characterizing preliminarily the neuropsychiatric and cognitive functioning of former professional football players with high concussion exposure. Twenty-two independently-living, employed or

recently-retired former professional football players were compared to case-matched controls (with no history of concussion) on neuropsychiatric and cognitive measures in a between-groups cohort design. The same comparisons between former professional football players and controls were made again after dividing former players into memory impaired vs. memory unimpaired sub-groups. Retired players were significantly higher on the Mania and Aggression (as well as Somatic Complaints) scales of our neuropsychiatric measure, and significantly worse on a stop-signal Go/No-Go task sensitive to response inhibition. As well, consistent with predictions, the memory-impaired sub-group differed significantly from their respective controls on the same measures as above, while the memory-unimpaired sub-group showed no differences on Mania and response inhibition and only modest impairments on Aggression. These findings raise the hypothesis of a core deficit to inhibitory control in former professional football players. Furthermore, the subgroup findings suggest that impairments were not exclusively explained by a pre-morbid cohort effect of professional football playing, though pre-morbid characteristics likely contribute outcome variance. Replication is needed in a larger cross-section of retired players. However, the results offer preliminary evidence that impaired inhibitory control could be an important early target for treatment and research.
Behavioural interventions for the Consequences of Multiple Concussions in Retired Professional Athletes

8. **Dr. Robin Green , Senior Scientist, Toronto Rehabilitation Institute , Co-authors: Brenda Colella, Lesley Ruttan, Sabrina Lombardi, Liesel Meusel, Lily Miguel-Jaimes, Charles Tator, and the Canadian Sports Concussion Project team members_** ***Treating the consequences of Multiple Concussions in Retired Professional Athletes.***

The purpose of this presentation was to discuss why and how to treat former professional athletes with a history of multiple concussions and subconcussions, and the progress of our treatment research to date. In the previous presentation, we presented our findings of reduced executive functioning (diminished response inhibition) and elevated emotional disturbances; we also discussed elevated risk of progressive, neurodegenerative disorders. Thus, the primary goals of our intervention research are to evaluate the feasibility and efficacy of treatments that (1) reduce current emotional and cognitive symptoms and (2) avert future degeneration. For current symptoms, our combination therapy approach, which has been shown to confer synergistic benefits of therapies, includes cognitive behaviour therapy (CBT; with demonstrated benefits for depression and anxiety and coping) and Goal Management Training (GMT; with known benefits for executive dysfunction). For offsetting future decline, we are providing environmental enrichment (EE), based on evidence from our lab in a related population (moderate-severe traumatic brain injury) that EE is associated with less neurodegeneration.
To date we have examined feasibility and preliminary efficacy in one face-to-face group. Retention was 5/6 patients; GMT attendance was 100% and 87% for those who completed. There was a significant drop in anxiety and depression from pre- to post-treatment. The satisfaction survey revealed a very favourable response to treatment, with participants

describing the interventions as very relevant and useful in everyday life. Compliance with EE was low, possibly attributable to the heavy demands of this self-administered, daily treatment, on top of the other two therapies. The next four groups, to be administered via the internet, are commencing within the next 1-3 months.

9. **Dr. Eric J. Huang, professor of pathology and neuropathology in the Department of Pathology at the University of California, San Francisco (UCSF)-** ***Neuroinflammation in Traumatic Brain Injury (TBI) and Neurodegeneration***

In the past decade, few issues at the intersection of medicine and sports have had as high a profile or have generated as much public interest as sports-related concussions. In recent years there has been a growing awareness and understanding that all concussions involve some level of injury to the brain and that athletes suspected of having a concussion should be removed from play for further evaluation. Despite the increased attention, however, confusion and controversy persist in many areas, from how to define a concussion and how multiple concussions affect the vulnerability of athletes to future injury, to when it is safe for a player to return to sports and the effectiveness of protective devices and other interventions in reducing the incidence and severity of concussive injuries. Parents worry about choosing sports that are safe for their children to play, about finding the equipment that can best protect their children, and about when, if a child does receive a concussion, it will be safe for him or her to return to play or if it might be time to quit a much-loved sport entirely. In addition, there are growing concerns that repetitive concussions (or traumatic brain injury) may lead to long-term consequence, leading to neurodegeneration in the aging process.

In my presentation, I will review the report of "Sports-Related Concussions in Youths", issued by the Institute of Medicine (IOM) in 2013. My discussion will focus on concussions within the context of developmental neurobiology and their long-term consequences in the aging process. Specific topics include (1) risk factors for sports concussions, post-concussion syndrome, and chronic traumatic encephalopathy (CTE); (2) the spectrum of cognitive, affective, and behavioral alterations that can occur during the chronic posttraumatic phases; (3) the relationship between CTE and other neurodegenerative diseases, such as Alzheimer's disease and frontotemporal dementia (FTD); and (4) chronic how persistent neuroinflammation caused by FTD gene progranulin mutation may contribute to circuit-specific neurodegeneration in animal models and in human disease. My presentation will also discuss future directions for the diagnoses and treatment of chronic consequences of concussions.

10. **Carol DeMatteo, Investigator, CanChild Centre for Childhood Disability Research, McMaster University -*Measuring Compliance with Return to Activity Guidelines in Children, Postconcussion***

In a CIHR funded, 3 year prospective study of 360 children/youth 5-18 years with concussive injury, we will endeavor to answer the question: does adherence to the "Return to Activity" (RTA) and "Return to School" (RTS) guidelines, improve outcomes as measured by the duration of symptoms and prevention of repeated injuries? Four main factors are

being examined to measure 'compliance' or adherence to guidelines. These are: i) Symptoms – every 48 hours, ii) Actigraph accelerometers and log, iii) Cognitive activity scale, iv) Stage of guidelines. Actigraph cut points are well validated based on 3 sec epochs for 4 activity categories that correspond well to steps of guidelines: i) sedentary < 6, example-sitting in a chair awake, ii) light physical activity 7- 115, example – slow walk, iii) Moderate physical activity 116 – 201, example- brisk walk and iv) vigourous physical activity >201, example – jumping jacks. Data collection has only just begun but on preliminary analyses, youth are being 100% compliant with actigraph wear and symptom monitoring every 48 hrs. by text or email. The actigraph readings so far are showing a trend to coincide with the self-reported level of the guidelines. For example activity readings < 6 epochs when at step one and progressing to vigorous activity at step 5-6. When symptom scores increase the activity level readings decrease suggesting the youth are decreasing their activity when symptoms exacerbate. The return to school data is not so compliant. Using a proportional formula we will determine if the symptom measures align with actigraph readings and stage of guidelines. This measure of compliance will be the primary predictor variable. Early trends seem to suggest we are capturing what we hope to and should be able to analyze it and come to some conclusions about adherence to guidelines and relationship to outcomes.

11. **Dr. Nick Reed**, **Clinician Scientist and Occupational Therapist, Holland Bloorview Kids Rehabilitation Hospital d, & Michelle Keightley, Senior Clinician Scientist and Holland Family Chair in Acquired Brain Injury,Bloorview Research Institute-** ***Advances in Pediatric Concussion Research: Innovation in Research and Education Design***

    Provided symposium attendees with an overview of the research and educational programming taking place within the Concussion Research Centre at Holland Bloorview Kids Rehabilitation Hospital. The presentation aimed to present a series of problems currently facing the field of pediatric concussion, and provided some solutions in the form of research study designs and educational materials. The research study designs highlighted included the use of a multimodal approach to baseline and follow-up testing of youth athletes to inform how the pediatric brain and body respond to concussion. Further, Dr. Reed highlighted the need to provide youth and their families with concussion education and information at the right time and in the right way and presented several options to do so including the use of infographics, social media and regular educational events with messaging geared towards youth. Dr. Reed closed his presentation with a call to the broader research and health care community to consider the unique needs of children and youth with concussion and to work towards forming collaborations to best meet the needs of this vulnerable population.

12. **Dr. Charles Tator, Professor of Neurosurgery, Toronto Western Hospital Institute, and Hannah Davis*, Research assistant ,Toronto Western Hospital Institute - Clinical Features of Postconcussion Syndrome***

In the Canadian Sports Concussion Project, at the Toronto Western Hospital, one of the major projects is an analysis of the demography and predictors of the postconcussion syndrome (PCS). We performed a retrospective cohort study of 284 consecutive concussed patients seen in our clinic 221 of whom had PCS on the basis of at least three symptoms persisting at least 1 month. A uniform, internationally accepted definition of concussion was used. The 221 cases showed considerable heterogeneity in clinical features of PCS. They averaged 3.3 concussions with a range of 0 to 12+ concussions, and 62.4% occurred in sports and recreation. PCS was commonly associated with multiple concussions, but 23.0% in the present series had PCS after only one concussion. The median duration of PCS was 7 months at the time of examination, with 11.8% lasting more than 2 years. The average age was 27 years (range 10-74). The average number of persistent symptoms was 8.1. 26.2% had a previous psychiatric condition, ADD/ADHD, a learning disability, or previous migraine headaches. The prevalence of arachnoid cysts and Chiari malformation in PCS exceeded the general population. Females with PCS were older ($p=0.05$), had fewer total concussions ($p<0.0004$), had a higher prevalence of previous migraines ($p<10\text{-}8$) and had more persistent symptoms ($p<0.008$) than males. Patients concussed in sports and recreation were younger ($p<10\text{-}8$), had a shorter duration of PCS ($p=0.05$), and had fewer persistent symptoms ($p=0.04$) compared with concussions from other causes. In most of our cases of PCS, the condition was very disabling, and lasted for months or years, underlining the importance of finding prevention and treatment strategies.

13. **Carmen Hiploylee Research assistant ,Toronto Western Hospital Institute-** ***Follow-Up Study of Recovery from Postconcussion Syndrome***

Individuals who do not fully recover from a concussion within the normal time frame (~10 days) is said to have postconcussion syndrome (PCS). People with persisting symptoms still continue to recover after this time frame but there are some who do not. The purpose of our study was to seek differences between these two groups with persisting PCS (defined in this study as symptomatic ≥ 3 months). The patient population seen for a potential diagnosis of PCS by Dr. Charles Tator, a staff neurosurgeon at the Toronto Western Hospital, was considered for this study. A total of 257 patients seen by C.T. from Jan 1997-June 2013 were mailed questionnaires regarding their recovery from PCS. Data from the patients' medical charts were combined with data from their returned questionnaires for comprehensiveness. There was a total of 141respondents (54.9% response rate) and 31 exclusions due to positive CT/MRI scans, recovery ≤ 3 months, involvement in litigation, and malingering as determined by the TOMM. Recovered respondents reported recovering 11.7 ± 7.7 months (M ± SD) after injury and all recovered respondents recovered within 3 years. For the non-recovered group, the average duration of PCS was 4.5 ± 4 years. These two groups did not differ in age (22.9 ± 13.1 years vs. 27.7 ± 15.1; recovered vs. non-recovered), sex (50% male, 56.3%), total number of concussions (2.6 ± 2.6, 2.9 ± 3.3), whether they sustained a subsequent concussion (16.7%, 28.8%), and cause of concussion (56.7% sports-related, 62.5%; $p\geq 0.05$). However, 100% of the recovered group who received return-to-play guidelines by C.T. complied with these guidelines whereas only 78.4% of the non-recovered group complied ($p\leq 0.05$). Ongoing PCS sufferers reported 10.3

symptoms. The most frequent symptoms being headaches, difficulty concentrating, and fatigue. Four naturally occurring symptom time courses were identified using machine learning. Lastly, there was no difference in the subjective symptom relief from treatments tried between the two groups. Further research is required with a larger population and at longer time intervals to identify other factors that could predict recovery trajectories. Recovery from PCS can occur as long as 3 years.

14. **Dr. Douglas D. Fraser, Director, London Translational Research Centre, Western University- Concussion Research at Western University**

Western investigators are associated with 4 University Faculties, 3 Research Institutes, 2 Hospital systems and 1 Sports Medical Centre. Thus far, Western Concussion investigators are actively studying concussion biomarkers and outcomes in female varsity athletes, in adolescent male hockey players and in those individuals with multiple concussions suffering chronic symptoms. The investigations focus primarily on biomarkers and include combinations of clinical exams, balance testing, neuropsychological evaluations, brain injury protein measurements, immunological alterations and pathological changes observed on 7T MR imaging. Several laboratory investigators also study concussion using human cadaver cranium, human brain tissues maintained in vitro (cerebrovascular endothelial cells, pericytes and astrocytes) and rodent fluid percussion brain injury models. Concussion epidemiological and mapping studies using data from our South-Western referral region have been completed, and targeted concussion prevention programs have been developed. For example, we held in collaboration with the Sports Legacy Institute and the Hamilton Tiger Cats Football club, our first sport concussion education and awareness event. Our focus on concussion research and awareness at Western University recently culminated with the second annual "See the Line" event, chaired by retired professional hockey player Eric Lindros, and included a Concussion Symposium and Gala/Dinner (www.seetheline.ca).

15. **Dr. Richard Wennberg, Neurologist,** Toronto **Western Research Institute (TWRI), and Carmen Hiploylee, Dr. Charles Tator:** ***Concussions, convulsions, seizures and epilepsy: Are there any connections?***

It is commonly stated that concussion is a risk factor for the development of post-traumatic epilepsy. However, it is difficult to find data to support this statement. A source of confusion may be under recognition of the existence of concussive convulsions (tonic-clonic motor seizures with loss of consciousness occurring within seconds of head impact), which are benign, nonepileptic phenomena.

We analyzed the incidence and prevalence of seizures, convulsions and epilepsy in a consecutive series of 330 post-concussion patients followed by one concussion specialist (CT). The mean number of concussions per patient was 3.3 (sd 2.5), mean age at first clinic visit was 28 years (sd 14.7), and mean follow-up after the most recent concussion was 1.4 years (sd 3.0).

Eight patients were identified whose medical records made mention of the occurrence of seizures or convulsions or a possible diagnosis of epilepsy. Upon detailed review of these

patients' histories and investigations (MRI, EEG) by an epilepsy specialist (RW) none of the identified patients could be considered to have a definite diagnosis of epilepsy. Specifically, three patients had histories of transient symptoms incompatible with epileptic seizures (e.g., multifocal paraesthesiae, hours-long spells of multimodality hallucinations). One patient had a clear history of syncopal convulsion. Two patients had classical histories of concussive convulsions. One patient (with more than 10 previous sports-related concussions) had experienced for many months 30-60 second episodes of deja-vu followed by throbbing headaches, which eventually ceased spontaneously along with resolution of other post-concussion symptoms; multiple investigations (including consultations with different epileptologists, MRIs and routine and sleep deprived EEGs) were negative for epilepsy. Migraine, in retrospect, would seem to be the most likely diagnosis. One patient (with 5 sports-related concussions) was described to have had a single tonic-clonic convulsion in the months between the third and fourth concussion, with no investigations at the time, and then 4 years later had an episode of reflex syncope with syncopal convulsion. The latter event makes it highly probable that the first event was also nonepileptic, and the patient does not meet the diagnostic criteria for epilepsy.

In summation, no definite cases of epilepsy could be identified in this series of 330 post-concussion patients. The prevalence of epilepsy in the general population is estimated to be approximately 7/1,000 individuals, with an annual incidence of approximately 0.5/1,000. In this large series of post-concussion patients, the prevalence of epilepsy was lower than in the general population and we found no evidence of an increased incidence of epilepsy post-concussion. It would appear that concussion should not be considered as a risk factor for the development of post-traumatic epilepsy

16. **Namita Multani, Research Analyst ,Toronto Western Hospital Institute & Dr. Carmela Tartaglia, Clinical Researcher, Toronto Western Research Institute (TWRI):** ***White Matter Changes in Retired Football Players with Multiple Concussions***

Repetitive concussion is common in various contact sports, such as football. The effects of multiple concussions can proceed for several years post-injury. Information pertaining to chronic neuropsychological symptoms and white matter integrity in retired football players is scarce. Nineteen male ex-professional football players and 17 age and education-matched male healthy controls were recruited to examine neuropsychological symptoms and their relation to white matter changes. All participants underwent imaging (MRI) and neuropsychological assessment. Compared to healthy controls, former players reported significantly greater memory, executive, behavioral, language, sensory, headache and constitutional symptoms. In addition, whole brain analysis with tract-based spatial statistics showcased increased axial diffusivity (AxD) in the right superior longitudinal fasciculus (SLF) in former players. The right SLF is involved in visual spatial function and regulating behavior. In fact, the subjects' performance on the Rey Visual Design Learning Task (RVDLT) long-term delay total score negatively correlated with the right SLF AxD. The former players were further assessed to determine change in symptomology over time, particularly since their last concussion. There was a significant increase in the number of executive, language, motor and sensory complaints in retired players. Overall, our findings

demonstrate loss of integrity in part of the right SLF and a relationship with visuospatial memory in retired professional football players with multiple concussions. Additionally, there is an increase in self-reported symptoms over time in retired football players. These findings suggest chronic white matter deterioration in retired players with multiple concussions and its probable relation to visual memory.