Head in the Game: Pediatric Concussion from Sidelines to Recovery

Nicholas Sader MD MSc FRCSC FAANS
Assistant Professor
Pediatric Neurosurgeon
Oklahoma Children's Hospital

Learning Objectives

1. Define concussion and understand its neurometabolic mechanisms
2. Be informed on the tools to assess concussion on the sideline and in the clinical setting
3. Understand pediatric concussion outcomes and persistent symptoms
4. Understand second impact syndrome and that laws the exist to help prevent it from occurring
5. Be informed on the CDC HEADS UP concussion campaign and the return to play/school guidelines
6. Understand how to treat recurrent concussions and clearance for patients with a history of a structural TBI
7. Current resources available for healthcare providers for pediatric concussion management

Disclosures

- No relevant disclosures

"But we don't operate on it?"

Introduction

- We see TONS of it and talk to families about it
- We help guide and counsel families of children who have it and provide referral to the appropriate resources and assist with return to activities
- Understanding concussion is essential as a pediatric neurosurgeon

History

- The recognition of concussion as a clinical syndrome separate from structural TBI is not new:
  - The Arabic physician Rhazes (10th Century) described the entity of concussion, and first used the term

  - The Italian physician Lanfrancus (1306 AD) discussed "commotion cerebri" as a separate entity from structural brain injury

McCrory Neurology 2001

Impact

- Traumatic brain injury (TBI) is a serious public health concern
  - 1-2 million sport-related concussions each year in children

Bryan, Pediatrics 2016

Pediatric Concussion

- Most TBI (70-90%) are mild in severity (i.e. concussion)
- Estimated cost to society in the United States from concussion (medical and loss of work): $17 billion

Cassidy, J Rehabil Med 2004

National Center for Injury Prevention and Control. Report to Congress on mild traumatic brain injury in the United States: steps to prevent a serious public health problem. Centers for Disease Control and Prevention. Atlanta, GA2003

What is a concussion?

Concussion in Sport Group (CISG) had its 6th meeting in Amsterdam in 2022:

- A traumatic brain injury caused by a direct blow to the head, neck, or body
- Results in an impulsive force being transmitted to the brain
- This initiates a neurotransmitter and metabolic cascade, with possible axonal injury, blood flow change and inflammation affecting the brain
- Symptoms/signs may be immediate or evolve over minutes or hours, and commonly resolve within days or may be prolonged

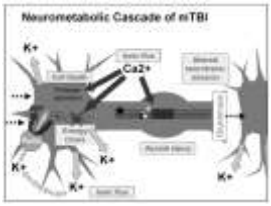
Patricios, British Journal of Sports Medicine 2023

What is a concussion?

- No abnormalities seen on structural neuroimaging (CT/MRI)
  - But may been seen in the research setting on advanced neuroimaging
- May or may not involve the loss of consciousness
- The symptoms or signs not explained solely by drug, alcohol, medication use, other injuries (cervical injuries, peripheral vestibular dysfunction) or other comorbidities (psychological factors or coexisting medical conditions)
- Concussion does not have severity levels

Patricios, British Journal of Sports Medicine 2023

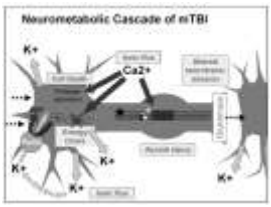
Neurometabolic Cascade



- Force to brain induces mechanoporation of lipid membranes

Giza, Neurosurgery 2014

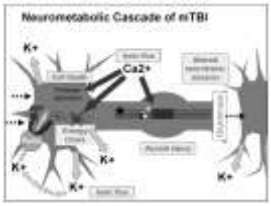
Neurometabolic Cascade



- Ion flux that trigger gated channels

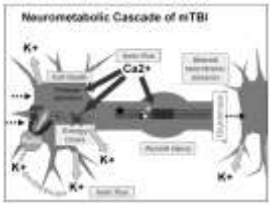
Giza, Neurosurgery 2014

Neurometabolic Cascade



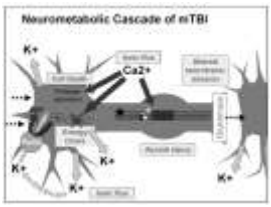
- Glutamate release leading to cortical-spreading depression

Neurometabolic Cascade



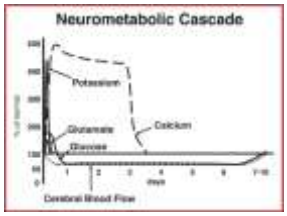
- Energy Crisis: The cells energy reserve are depleted attempting to restore homeostasis
  - ATP membrane ionic pumps shift into overdrive

Neurometabolic Cascade



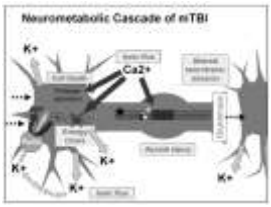
- Depletion of energy reserves with normal or reduced cerebral blood flow
  - Mismatch of supply and demand

Neurometabolic Cascade



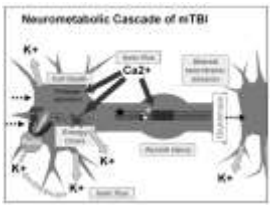
- Calcium influx into cell
- Sequestered by mitochondria
- Oxidative metabolism impaired and further worsens the energy crisis

Neurometabolic Cascade



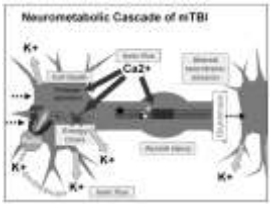
- After initial period of hyperglycolysis, glycolysis is impaired for 7-10 days
- Thought to correlate to greatest vulnerability to second impact

Neurometabolic Cascade



- Microtubules and cytoskeleton become injured

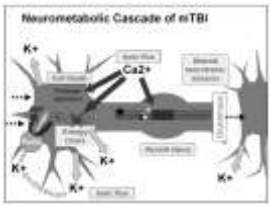
Neurometabolic Cascade



- Altered Neurotransmission
- GABAergic neurons become dysfunctional

Giza, Neurosurgery 2014

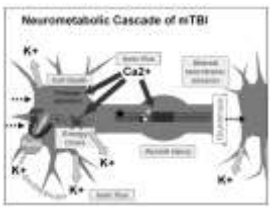
Neurometabolic Cascade



- NMDA receptors become dysfunctional

Giza, Neurosurgery 2014

Neurometabolic Cascade



- Inflammatory factors and abnormal protein aggregation within cells

Giza, Neurosurgery 2014

Connection with signs/symptoms?

Physiological perturbations after concussion and proposed clinical correlates.

Post-TBI pathophysiology	Acute symptom / clinical correlate
Ionic flux	Migraine headache, photophobia, phonophobia
Energy crisis	Vulnerability to second injury
Axonal injury	Impaired cognition, slowed processing, slowed reaction time
Impaired neurotransmission	Impaired cognition, slowed processing, slowed reaction time
Protease activation, altered cytoskeletal proteins, cell death	Chronic atrophy, development of persistent impairments

Giza, Neurosurgery 2014

Diagnosing a Concussion

- The diagnosis of a concussion is a clinical judgement (history and exam)
- A diagnosis can be made even if the screening tests are negative
- Some common symptoms include:
  - Confusion
  - Headache
  - Vision disturbances (double/blurry)
  - Photophobia
  - Dizziness or imbalance
  - Nausea or vomiting
  - Memory loss
  - Ringing ears
  - Difficulty concentrating
  - Sleep disturbances

Red Flags/Warning Signs

- Any period of loss of consciousness or Glasgow Coma Scale (GCS <15) require more careful evaluation
  - Neurologic deficits
  - Altered mental status
  - Seizures
  - Weakness or numbness
  - Worsening headache
  - Intractable vomiting
  - Deteriorating status
- The presence of any of these red flags necessitates removal from play, appropriate on-site treatment and immediate transport to a hospital for further evaluation

Diagnosis/Care

Child Sport Concussion Assessment Tool - 6 (SCAT6)

8-page series of questions meant to be used by healthcare professionals

- Supports the clinical diagnosis of concussion
- Ideally within 72hrs (up to 7 days)
- Ages 8 to 12

Child SCAT6
British Journal of Sports Medicine 2023

Diagnosis/Care

Child Sport Concussion Office Assessment Tool - 6 (SCOAT6)

14-page series of questions

- healthcare professionals in office setting
- Supports the clinical diagnosis of concussion
- After 72 hrs
- Ages 8 to 12

Sport Concussion Office Assessment Tool 6 (SCOAT6)
British Journal of Sports Medicine 2023

Diagnosis/Care

Acute Concussion Evaluation (ACE)

- 1 page series of questions
- healthcare professionals in office setting
- Can be used for diagnosis but also tracking symptom domains
- Important for track and proper referral

Diagnosis/Care

Concussion Recognition Tool 6 (CRT6)

- 2-page screening tool
- Non medically trained to help identify concussion and aid in the immediate management

The Concussion Recognition Tool 6 (CRT6)
British Journal of Sports Medicine 2023

https://www.swaymedical.com

Outcomes

- 25-30% experience persistent symptoms
- Symptoms continuing beyond 28 days are termed:
  - Persistent postconcussion symptoms (PPCS)
- Children's learning, social development, and mental health
- Physician's poor at predicting

Barlow. J Child Neurol 2016
Yeates. Arch Pediatr Adolesc Med 2012
Zemek. JAMA 2016

Centers for Disease Control and Prevention. Report to Congress: The Management of Traumatic Brain Injury in Children; Division of Unintentional Injury Prevention. Atlanta, GA. 2018

Outcomes

Table 1:
5P Risk Criteria for Risk Assessment of PPCS

Risk Factor	Categories	Points
Age group	5 to 7	0
	8 to 12	1
	13 to 18	2
Sex	Male	0
	Female	1
Prior concussion and symptom duration	None / <1 week	0
	1 to <3 weeks	1
	≥3 weeks	2
Migraine history	No	0
	Yes	1
Answering questions slowly	No	0
	Yes	1
Tandem stance: number of errors	0-3	0
	≥4 or unable to do test	1
Headache	No	0
	Yes	1
Sensitivity to noise	No	0
	Yes	1
Fatigue	No	0
	Yes	1

PPCS = normal persistent postconcussion symptoms

Total 5P Clinical Risk Score = 0-12

Clinical Risk Score for Persistent Postconcussion Symptoms Among Children With Acute Concussion in the ED

Outcomes

Score Calculator

	0	1	2
Age of patient	5 to 7 years	8 to 12 years	13 to 18 years
Sex of patient	Male		Female
How long did the patient's previous concussion last?	Less than 1 week	1 to less than 3 weeks	3 weeks or longer
Does the patient have a history of migraines?	No	Yes	
Did the patient answer questions more slowly than normal on a cognitive evaluation?	No	Yes	
On the SEC Tandem stance walking test, how many errors did the patient make in 20 seconds?	0 to 3 errors		4 or more errors, or unable to do test
Does the patient have a headache?	No	Yes	
Does the patient have sensitivity to noise?	No	Yes	
Is the patient tired or fatigued?	No		Yes

Submit

https://www.5pconcussion.com/en/scorecalculator

Score Calculator

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Does the patient have a headache?	No	Yes	
Does the patient have sensitivity to noise?	No	Yes	
Is the patient tired or fatigued?	No		Yes

Submit

Score Calculator

0 — 12

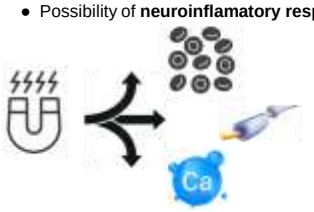
The patient is MEDIUM risk for having persistent symptoms lasting beyond one month.

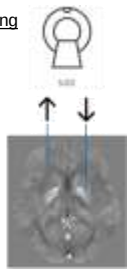
https://www.5pconcussion.com/en/scorecalculator

Biomarker

Sadler , J Neurol Neurosurg Psychiatry 2023

- Novel extension of susceptibility-weighted imaging
- Possibility of **neuroinflamatory response**





Specific Aims

1. Assess post-acute differences in QSM between children with concussion and a comparison group of children with mild orthopaedic injury (OI)

2. Determine whether post-acute QSM makes an incremental contribution to the prediction of PPCS at 4 weeks post-injury, over and above the acute 5P risk score

- Children (N=967) aged 8-17 years with concussion or OI were recruited from 5 Canadian pediatric emergency departments
  - Alberta Children's Hospital (Calgary)
  - Children's Hospital of Eastern Ontario (Ottawa)
  - Centre Hospitalier Universitaire Sainte-Justine (Montreal)
  - Stollery Children's Hospital (Edmonton)
  - British Columbia Children's Hospital (Vancouver)

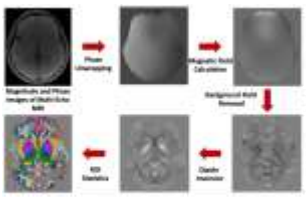
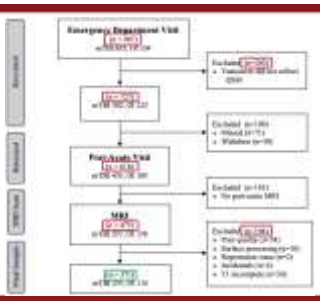


Table 3:

White Matter ROI	Grey Matter ROI
Frontal	Thalamus
Parietal	Basal Ganglia
Temporal	Hippocampus
Occipital	
Insula	
Corpus Callosum	

- Individualized z-scores were calculated for each ROI for each participant

$$ZScore_i' = \frac{(X_i' - \mu_i)}{\sigma_i}$$



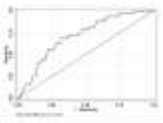
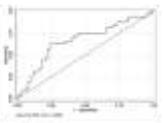
Aim 1

Multivariable Linear Regression Analyses
- Covariates: Age at injury, MRI Scanner, and Sex

- Did not reveal a statistically significant difference in any post-acute ROI QSM Z-score between concussion and OI children in any region

Aim 2

- Increased frontal white matter susceptibility was significantly associated with predicting parent-rated reliable change in cognitive symptoms (p=0.001)
- Model with frontal white matter and the 5P risk score performed better at predicting parent-rated reliable change in cognitive symptoms than the model with the 5P risk score alone (p=0.0021)
- No statistically significant association between QSM regions and other three PPCS outcomes (Parent Somatic, Child Cognitive + Somatic)

QSM region only model	SP risk score only model	Combined QSM region and SP risk score model
		
AUC = **0.71**(0.62-0.80)	AUC = **0.67**(0.56-0.78)	AUC = **0.73**(0.64-0.82)
Sensitivity = 65.6%	Sensitivity = 59.4%	Sensitivity = 84.4%
Specificity = 68.1%	Specificity = 75.9%	Specificity = 56.0%
PPV = 28.4%	PPV = 32.2%	PPV = 27.0%
NPV = 91.1%	NPV = 90.6%	NPV = 94.9%

- No significant group difference in post acute QSM ROI between concussion and OI children
- Susceptibility within the frontal white matter as a potential MRI biomarker that predicts persistent symptoms in children with concussion compared to the current clinical benchmark
  - Suggest a potential pathophysiological substrate associated with persistent symptoms
- Potential for using QSM to assist in the clinical management of concussion in children
- Currently looking at follow up 3- and 6-month MRI scans

Future: Test a-priori in different population + improvement in QSM reconstruction and analysis

Collaborating Authors

Dr. Jay Riva-Cambrin
MSc, MD, FRCSC

Dr. Keith Yeates
PhD, RPsych, ABPP, FCAHS

Dr. Brad Goodyear PhD

Dr. David Gobbi PhD

Dr. Richard Frayne PhD – University of Calgary
Dr. Ashley L Ware PhD – University of Calgary
Dr. Miriam Beauchamp PhD - Centre Hospitalier Universitaire Sainte Justine
Dr. William B Craig MD – University of Alberta
Dr. Qeyeh Dean MD PhD – University of British Columbia
Dr. Roger Zemek MD – University of Ottawa

Funding and Support

UNIVERSITY OF CALGARY
CUMMING SCHOOL OF MEDICINE
Clinician Investigator Program

CIHR IRSC

CLINICAL NEURO SCIENCES

CAP

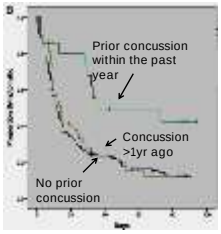
CSCI + SCRC

perc

Outcomes

- Prospective cohort study
- 280 Patients, 11-20yrs

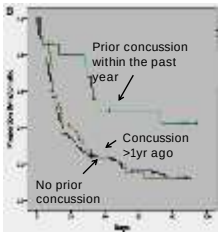
- Kids with a prior concussion are at risk for prolonged symptoms (median: 24 days vs. 12 days (p=0.02)



Eisenberg, Pediatrics 2013

Outcomes

- Median symptom duration was even longer for patients with multiple concussions (28 days, P=0.03) and for those who sustained a concussion within previous year (35 days, p=0.007)



Eisenberg, Pediatrics 2013

PEDIATRICS

Benefits of Strict Rest After Acute Concussion: A Randomized Controlled Trial

- RCT of strict rest after acute concussion; age 11-22 yrs; 99 kids enrolled:
  - Kids who followed typical recommendation ("take 1-2 days rest before stepwise return to school/activity") recovered faster and had better symptom resolution, compared to a group with 5 day of mandatory rest
  - No difference in neurocognitive or balance outcomes

Thomas, Pediatrics 2015

Second Impact Syndrome

- Diffuse cerebral edema thought to result from impaired autoregulation that occurs with subsequent concussive injury

Second Impact Syndrome

- Varying degrees of rest have been recommended in the past and when to return to activities

Zackery Lystedt Law (House Bill 1824)

- May 2009
  - Washington state was the first to pass actual law requiring removal of youth from play after concussion on the day of injury, with required clearance from a licensed health provider prior to RTP
  - Every state followed adopting similar law

https://www.cdc.gov/heads-up/media/pdfs/stories/031210-zack-story.pdf

Zackery Lystedt Law (House Bill 1824)

"There is no one tougher than my son. Sometimes players and parents wrongly believe that it shows strength and courage to play injured. Battling pain is glamorized. Zack couldn't swallow or hold his head up. Strength is seeing Zack stand up out of his wheelchair and learning to talk again."

- Victor Lystedt, Zack's Dad.

https://www.cdc.gov/heads-up/media/pdfs/stories/031210-zack-story.pdf

Rowan's Law

- June 2016
  - Ontario, Canada was the first province to pass a law similar to previous
  - All other provinces in Canada have adopted something similar
  - Rowans Law Day last Wednesday in September

https://www.ontario.ca/page/rowans-law-day

Recovery

- Current guidelines recommend rest for the first 24 to 48 hours
- Avoiding physical and cognitive activities that worsen symptoms
- Must be restricted from physical activity, sports, and playground activity until cleared by a healthcare professional

Recovery

- Allows symptom burden to decrease
- Followed by the gradual return to cognitive and physical activities as tolerated
- This approach minimizes both the risk of secondary injury and the potential social isolation and academic consequences of prolonged removal.

HEADS UP Concussion (CDC)

- It is a campaign initiative to help coaches, parents, patients, and medical professions with the diagnosis, prevention, treatment and return to play surrounding concussions

https://www.cdc.gov/heads-up/index.html

6 Step Return to Play

- Remove from sport if sustained concussion
- Take at least 24h off from sports; get medical clearance.
- After that, do these 6 steps, with a minimum of 1 day between
- If symptoms come back or new symptoms, contact medical professional

Return to School

- Most kids can return to school 1 to 2 days after concussion
- Can shorten their recovery and reduce likelihood of mental health symptoms
- Letter for schools to be filled out by medical professional
  - Help school provide strategies for support and recovery

Return to School

- Ongoing multi-source assessment is crucial as students reintegrate into school environment
- Evaluations from teachers, caregivers, parents ect. must be combined to develop an overall impression of the child's recovery and integration into school

Oklahoma State Department of Health

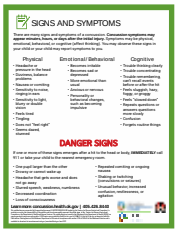
- Excellent resources on concussion for:

OKLAHOMA State Department of Health

https://oklahoma.gov/health/health-education/injury-prevention-service/concussions.html

Parents and Guardians

OKLAHOMA State Department of Health



https://oklahoma.gov/health/health-education/injury-prevention-service/concussions.html

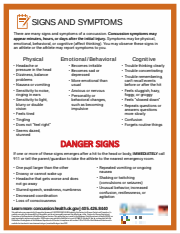
Youth Athletes

OKLAHOMA State Department of Health

https://oklahoma.gov/health/health-education/injury-prevention-service/concussions.html

Coaches

OKLAHOMA State Department of Health



https://oklahoma.gov/health/health-education/injury-prevention-service/concussions.html

Return to Learn


RETURN TO LEARN:
DAILY TO LEADS AFTER A CONCUSSION

WHAT IS A CONCUSSION AND HOW CAN IT IMPACT LEARNING?

CONCUSSION SIGNS TO WATCH FOR IN THE CLASSROOM

EXAMPLES OF SCHOOL SUPPORTS


RETURN TO LEARN PROTOCOL
OVERVIEW

PHASE 1

PHASE 2

PHASE 3

PHASE 4

PHASE 5

To learn more about supporting students returning to learn after a concussion, visit https://concussion.health.ok.gov

Contact us: concussion@health.ok.gov | 405.426.8400

https://oklahoma.gov/health/health-education/injury-prevention-service/concussions.html

Return to Play


RETURN TO PLAY:
BACK TO SPORTS AFTER A CONCUSSION

Before you begin:

WHEN IN DOUBT, SIT THEM OUT


RETURN TO PLAY PROTOCOL

STEP 1: BACK TO REGULAR ACTIVITIES

STEP 2: LIGHT AEROBIC ACTIVITY

STEP 3: MODERATE ACTIVITY

STEP 4: HEAVY NON-CONTACT ACTIVITY

STEP 5: PRACTICE AND CONTACT

STEP 6: RETURN TO PLAY

Learn more: concussion.health.ok.gov | 405.426.8400

https://oklahoma.gov/health/health-education/injury-prevention-service/concussions.html


PedsConcussion
LIVING GUIDELINE FOR PEDIATRIC CONCUSSION

Reed, N.*, Zemek, R.*, Dawson, J., Ledoux, AA., et al. (2023). Living Guideline for Pediatric Concussion Care. www.pedsconcussion.com. https://doi.org/10.17605/OSF.IO/3VWN9

Multiple Concussions

- Varies by institution/provider

- Persistent post-concussive symptoms:
  - consider taking season off
- Two concussions in one season:
  - consider taking season off
- Persistent cognitive deficits:
  - formal neuropsych testing, consider return to play when recovered

Ellis, Neurosurg Focus 2016

Multiple Concussions

- 3 lifetime concussions
  - consider taking season off or retirement

- 4 concussions
  - strongly consider retirement

Ellis, Neurosurg Focus 2016

Structural TBI (Skull Fracture/Blood in Head)

- Will be asked for clearance
- Controversial with no established guidelines:
  - Symptom free and negative follow up imaging (at 3-6 months)

  - No sports allowed for 1 year with follow up visit and scan at 1 year. Return to play pathway is considered.

Multidisciplinary Care is Essential

- Occupational Therapy
- Physical Therapy
- Neuropsychology
- Vestibular Therapy
- Neurology
- Sports Medicine
- Neurosurgery
- Psychiatry/psychology

QUESTIONS? Thank you!

Nicholas Sader. MD MSc FRCSC FAANS
Email: Nicholas.Sader@ouhealth.com
@NicholasSader