Sports-related Concussion: Current Concepts in Diagnosis and Management

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Epidemiology and Pathophysiology of Concussion

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Visual Sequelae of Concussion

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Current Concepts: Concussion Diagnosis and Management

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Assistant Professor of Clinical Pediatrics, University of Pennsylvania Perelman School of Medicine
Pediatric and Adolescent Sports Medicine, Children's Hospital of Philadelphia

Vision Rehabilitation for Concussion Related Oculomotor Problems

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Professor of Optometry and Dean of Research, Pennsylvania College of Optometry
AAO Diplomat in Binocular Vision
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Epidemiology & Pathophysiology

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Overview

- Epidemiology of traumatic brain injury and sports-related concussion
- Definition of concussion
- Pathophysiology of concussion

Disclosures

- No financial disclosures
- Will not discuss off-label use of products
- I have sustained 3 sports-related concussions

Traumatic Brain Injury

More accurate approximation: 1.6 to 3.8 million sports-related TBIs occur each year

High School Concussion Incidence

- 2,651 concussions were observed in 10,926,892 athlete-exposures over 11 year period
  - Incidence rate of 0.24 per 1000
- Boys’ sports accounted for 53% of athlete-exposure and 75% of all concussions
- Concussion rate increased 4.2-fold over the 11 years (15.5% annual increase)

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Concussion Risk Factors

- Insufficient evidence to determine whether concussion risk is affected by age or level of competition
- Greater concussion risk American football and Australian rugby
  - Lowest risk: baseball, softball, volleyball, and gymnastics
  - Women – greatest risk is soccer
- BMI >27 and training time <3 hrs/wk likely increase the risk of concussion

Concussion Incidence: Gender

<table>
<thead>
<tr>
<th>Sport</th>
<th>Rate/1,000 Games</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS Football</td>
<td>1.55</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>College Football</td>
<td>3.02</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>College Ice Hockey</td>
<td>1.96</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>HS Soccer</td>
<td>0.59</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>College Soccer</td>
<td>1.38</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>HS Basketball</td>
<td>0.11</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>College Basketball</td>
<td>0.45</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>HS Baseball/softball</td>
<td>0.08</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>College Baseball/softball</td>
<td>0.23</td>
<td>0.37</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Grz et al Neurology 2013

What is a Concussion?

A complex pathophysiological process affecting the brain induced by traumatic biomechanical forces

- Functional disturbance rather than structural injury
- Onset of short-lived impairment of neurologic function that resolves spontaneously
  - Resolution of the clinical and cognitive symptoms typically follows a sequential course
  - Post-concussive symptoms may be prolonged
- May or may not involve loss of consciousness
- No abnormality on structural neuroimaging or identifiable biomarker

Consensus statement on concussion in sport, Zurich 2008

Neurometabolic Cascade

Adapted from Grz and Honda, JAT 2001
Concussion Symptoms

- **PHYSICAL**
  - Headache
  - Vision and swimming
  - Balance problems
  - Nausea
  - Nausea
  - Sensitivity to light
  - Sensitivity to sound
  - Nausea of brain origin

- **MOOD DISRUPTION**
  - More emotional
  - Irritated
  - Nervous
  - Depressed

- **SLEEP**
  - Sleeping more or less than usual
  - Trouble falling asleep
  - Feeling tired or drowsy

- **THINKING AND REMEMBERING**
  - Difficulty thinking
  - Difficulty remembering
  - Concentration
  - Feeling “mentally foggy”
  - Feeling slowed down

Clinical Concussion Course

- Neuronal Injury Threshold
- Symptom Threshold

Complete “Brain” Recovery

Subsequent brain injury prior to complete concussion recovery may cause further brain dysfunction and result in prolonged neurocognitive and neurobehavioral impairments and even death.

- Second Impact Syndrome
  - Brain swells rapidly and catastrophically after an athlete suffers a second concussion before symptoms from an earlier one have subsided

Metabolic Brain Injury

Delayed metabolic recovery after second concussion
**Functional Brain Injury**

- No differences were observed in terms of the accuracy of task performance as well as the time to complete the spatial memory navigation task between groups.

*Slobounov, et al, 2010*

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**Functional Brain Injury**

- Working memory
  - n-back task (n = 1, 2, 3)
- Task performance revealed no difference between concussed vs. controls at any time points.

*Dettwiler et al, 2014*

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**Diffusion Tensor Imaging**

**Subclinical Concussions**

<table>
<thead>
<tr>
<th>NO Clinical Concussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO Cognitive Impairment</td>
</tr>
<tr>
<td>Pre-Season</td>
</tr>
<tr>
<td>Not Observed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YES Clinical Concussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES Cognitive Impairment</td>
</tr>
<tr>
<td>Pre-Season and In-Season (MRI) studies show no change</td>
</tr>
</tbody>
</table>

*Subclinical Concussion*  
- No clinically-observed symptoms, but measurable neurocognitive and neurophysiologic impairments  
- Might be cumulative over time

*Talenage, et al, 2011*
Long-term Neurological Impact

- Deficits from multiple concussions and repetitive sub-concussive impacts
  - Symptom-free high school athletes with a history of ≥2 concussions performed similar on cognitive testing to athletes with a recent concussion
  - More head impacts correlate with slower reaction times
  - 24% of collegiate athletes had impaired learning after a single football season
- Chronic Traumatic Encephalopathy

Summary

- Concussion is a clinical syndrome of biomechanically induced alteration of brain function, typically affecting memory and orientation, which may involve LOC
- Concussions are common and under-diagnosed
- Thresholds for clinical symptoms and neuronal injury vary between individuals and over time
- Metabolic and functional brain injury may persist beyond clinical symptom resolution
- Multiple concussions and repetitive sub-concussive impacts may contribute to long-term neurological impairments
Diagnosis and Management of Pediatric and Adolescent Concussion

Matthew Grady MD
Pediatric and Adolescent Sports Medicine
Sports Medicine and Performance Center
at The Children’s Hospital of Philadelphia

Why is Concussion a Pediatric/Adolescent problem

• The “job” of this age group is school work, not sports- so how does concussion affect reading, learning, socialization?
• 40,000,000 pediatric athletes vs 3,000 professional athletes- Who does concussion affect?

Objectives

At the conclusion of this activity, participants should be able to:

• 1. Be able to diagnose a concussion based on history and physical exam
• 2. Describe and demonstrate concussion specific physical exam techniques
• 3. Review rehab principles with goal of developing comprehensive ocular and vestibular rehab

Concussion: Medical Definition

• Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. (Zurich Concussion Guidelines 2012)

Disclosures

• No disclosures

Medical Definition

- No abnormality on standard imaging
  • Imaging is recommended only to evaluate possibility of other injuries as clinically indicated
- May or may not involve LOC (only about 10% with LOC)
- Most recover spontaneous
- Small percentage may have prolonged sx
So Do I have a Concussion?

- History (Story)
- Physical Exam
- Cognitive Testing

Concussion is a Clinical Diagnosis
Ask about History and Symptoms

**History:**
- Mechanism of injury
- Temporal association of symptom onset

**Symptoms:**
- Ask about all symptoms
- Patients may not report subjective symptoms on their own
- Patients may intentionally hide symptoms to prevent removal from play

Physical Examination

- PE has to focus on Function
  - Eye tracking, saccades, gaze stabilization, convergence, accommodation, King-Devick testing
  - Balance testing- heel to toe backwards eyes close, Bess Testing
  - Cognitive Function- computerized neuropsych test/SCAT 2/formal neuropsych

Eye Movements

- Eye Movements
  - saccades,
  - gaze stabilization
  - Tracking fast moving object
  - Convergence/accommodation

Signs and Symptoms

<table>
<thead>
<tr>
<th><strong>Physical</strong></th>
<th><strong>Cognitive</strong></th>
<th><strong>Emotional</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache/pressure in head</td>
<td>Difficulty concentrating</td>
<td>Irritability or mood changes</td>
</tr>
<tr>
<td>Nausea/vomiting</td>
<td>Difficulty remembering</td>
<td>Traumatic stress symptoms</td>
</tr>
<tr>
<td>Balance Problems</td>
<td>Feeling foggy</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vision problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue/Drowsiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity to light/sound</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Vertical tracking Problems

Computerized Neuropsychological testing: Strength

- Easy to administer
- Tests Brain function
- Individualized Baseline
- Can be repeated
- Can detect big vs small deficits

Tracking problem: chief complaint is headaches at school. Previous 3 exams were reported normal

Neuropsychological testing: Weakness

- Testing time and environment can affect scores
- Motivation affects scores
- Learned effect from taking test multiple times
- Is the baseline valid?

Balance: Make it difficult!

Neuropsych Testing

- Testing is a snap shot in time (which is not what it was developed for)
- Test scores = performance
- When the performance is not good what does that mean
  - Tired, hungry, emotionally upset, not motivated, performance anxiety
- Still just a PIECE of the PUZZLE
Acute treatment for concussion

- Based on this energy deficit model:
  1. Increase fuel delivery: Fuel that crosses blood brain barrier- lactate, Amino Acids ?
  2. Decrease fuel demands- physical exertion, cognitive exertion

Evidence for this is ?

Physical Exercise and Concussion: Animal Models

Cognitive activity definitions

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Complete cognitive rest</td>
</tr>
<tr>
<td>1</td>
<td>Minimal cognitive activity</td>
</tr>
<tr>
<td>2</td>
<td>Moderate cognitive activity</td>
</tr>
<tr>
<td>3</td>
<td>Significant cognitive activity</td>
</tr>
<tr>
<td>4</td>
<td>Full cognitive activity</td>
</tr>
</tbody>
</table>
Kaplan-Meier Curve of Symptom Duration after Concussion

### Cox Proportional Hazard Ratio

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>Hazard ratio</th>
<th>P</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>1.1759</td>
<td>0.249</td>
<td>0.8930 – 1.5484</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>1.0503</td>
<td>0.086</td>
<td>0.9930 – 1.1109</td>
<td></td>
</tr>
<tr>
<td>LOC</td>
<td>1.1504</td>
<td>0.392</td>
<td>0.8347 – 1.5854</td>
<td></td>
</tr>
<tr>
<td>Number prior concussions</td>
<td>0.9799</td>
<td>0.722</td>
<td>0.8763 – 1.0958</td>
<td></td>
</tr>
<tr>
<td>Total Initial PCSS</td>
<td>0.9015</td>
<td>0.003</td>
<td>0.9781 – 0.4696</td>
<td></td>
</tr>
<tr>
<td>Amnesia</td>
<td>1.297</td>
<td>0.067</td>
<td>0.9820 – 1.714</td>
<td></td>
</tr>
<tr>
<td>Cognitive activity days</td>
<td>0.9953</td>
<td>0.001</td>
<td>0.9936 – 0.9976</td>
<td></td>
</tr>
</tbody>
</table>

### Management beyond the Acute Phase:

- Long term cognitive function not injured by additional brain stimulation
- Work to the threshold of provoking symptoms- then REST, RECOVER, RETURN to activity
  - My personal rule- headache on 10 point scale can get 2 points worse before decreasing activity (physical or mental)

### Treatment

- In adolescent population, about 80-90% spontaneously recover in 4 weeks
  - Treatment is scale back school and ramp up slowly
  - Academic accommodations based on deficits- especially eye tracking ones
  - When in full school with no symptoms start Return to Play
- In those who do not recover in 4 weeks- active rehabilitation is needed.

### Long Term Treatment

- Cognitive Rehab- school work for most
- Aerobic Therapy – treats dysautonomia
- Vestibulo- Occular Therapy- Balance, saccades, gaze stabilization, convergence retraining- vestibular therapy/vision therapy (not both at same time)
- Mood- counseling/meds
Cognitive Therapy/Rehab
- School work in small increments - with breaks as needed
- Work until symptoms, rest, recover and restart work
- Persistent issues with cognitive deficits:
  - Speech-Language therapy
  - Neuropsychology evaluation

Eye tracking s/p rehab

Aerobic Rehab
- Daily Aerobic Exercise helps recovery
  - Exercise to threshold of symptoms
  - Goal 30 minutes/day every day
- Powerful benefits of:
  - Improved mood
  - Better sleep
  - Increased energy

Consequences of Prolonged Recovery
- Alterations in mood
  - Counseling
  - Support Groups
  - Psychiatry for mood stabilizers
- Amplified Pain Syndrome
  - CHOP Rheumatology Program
- Postural Orthostatic Tachycardia Syndrome: Dysautonomia
  - Cardiology

Vestibular/Oculomotor Therapy
- Weekly formal therapy with specialist
- Daily home exercise program essential!

Future Directions: CHOP
Study Design
100 unique patients ages 11-17 years
Treated for concussion in children's hospital affiliated concussion program
7/1/2013—2/14/2014
Vision examination including assessment:
- Visual acuity
- Binocular vision (eye teaming)
- Accommodation (focusing)
- Eye movements (saccadic function)
- Convergence Insufficiency Symptom Scale with additional mTBI questions
Results

- **Vestibular and Vision Deficits**
  - Vision Problems 69%
  - Vestibular Problems 55%
  - Both Vision and Vestibular Deficits 49%
  - Only Vision Deficits 16%
  - Only Vestibular Deficits 20%

*Prevalence of Vision Problems After Concussion in Children 11-17 years old*

Christina L. Master, MD, CAQSM, Mitchell Scheiman, OD, Michael Gallaway, OD, Arlene Goodman, MD, CAQSM, Roni Robinson, RN, MSSN, CRNP, Stephen R. Master, MD, PhD, Matthew F. Grady, MD, CAQSM
Disclosures

• The speaker and authors of the work presented have no financial interest in the tests discussed

Concussion

• Complex process resulting from an impulsive blow - can be to body or head
• Any new neurological symptom like headache, dizziness, fogginess
• Loss of consciousness in less than 10%
• Nearly 4 million a year, women and kids appear more vulnerable


The Concussion Conundrum

• Value of sport vs. risk
• Learned an enormous amount over past decade
• Doubling of concussion rate may relate to increased recognition, speed and size of athletes
• Collision sports (football, soccer) associated with chronic traumatic encephalopathy (CTE)

Why Do We Need a Rapid Sideline Test for Concussion?

• Following a concussion, you are 3 times more likely to have another one, most risk is early
• Multiple concussions associated with prolonged recovery and multiple symptoms
• Multiple concussions linked to long term cognitive and behavioral disturbances
• 43% hid a concussion, 22% would do it again!

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Neuro/Clin Pract, 2013

Concussion = most common form of mild traumatic brain injury =
...“I got my bell rung!”

Evaluation of Diagnostic Marker Test

• Phase 1 - The test makes sense as a marker
• Phase 2 - Can distinguish obvious cases from controls (boxers)
• Phase 3 - can distinguish less typical instances (other athletes)
• Phase 4 - large scale studies
• Phase 5 - used in clinical trials, completed for low contrast acuity in MS

JAMA 259:1699:1988
New Acronym:  
For Testing Vision in Any Field, We Need to RAISE the Bar!  
- Reliable  
- Available  
- Inexpensive  
- Standardizable  
- Effective and Efficient

Standardized Assessment of Concussion (SAC) (30 points)  
- Orientation: date, year, time of day  
- Immediate memory: 5 words to remember, tested in 3 trials  
- Concentration: digit span backwards, months of the year backwards  
- Does not test brainstem or cerebellar dysfunction  

SCAT3 for Sideline Testing  
- Takes 20 minutes  
- Not all components validated, expert opinion  
- Glasgow coma scale- not useful to determine concussion  
- Requires experienced professionals  
- Abnormal score not established  

BESS Test  
(30 points of SCAT3)  
- 36% (poorer score) vs. 5% controls  
- Scoring reliability is questionable  
- Takes about 3 to 5 minutes  
- May be affected by fatigue and leg injury

Components of the SCAT 3:  
Symptom Checklist (22 points)  
- Includes many of the symptoms of concussion  
- Quick  
- Subjective and many athletes have been noted to under-report symptoms  
- 26% of “symptom free patients” still have cognitive changes  

Why Test Eye Movements?  
- Impaired eye movements are a established indicator of suboptimal brain function  
- May capture dysfunction not observed in cognitive testing

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*J Int Neuropsych Soc 2001;7:693*

*J Int Neuropsych Soc 11:58, 2005*
Neurology of Concussion

- Many symptoms not captured by cognitive testing
- Photophobia: widespread, over-stimulation
- Blurred vision: afferent or efferent dysfunction
- Diplopia and vertigo: brainstem, cerebellar paths

Is Vision Part of the Concussion Testing Puzzle?

King-Devick Test

- Sideline test, takes less than a minute
- Trainer or qualified person administers
- Based on saccadic eye movements, requires attention, concentration, language
- May help coaches and trainers with game time decisions

King-Devick Test

- Rapid number naming, norms for ≥14 years
- Time to read all 3 cards = score
- Objective, takes <1 minute, anyone can do!

Eye Movements During K-D and Under Hypoxia

King-Devick Score (sec) Change in K-D score (sec)

K-D Scores Worse after Trauma in Boxers and MMA Fighters

King-Devick Test: Penn Collegiate Athlete Study

Pre-season testing (219 athletes) → Post-season

Testing on sidelines at time of concussion (n=10):
All except one had worse scores vs. baseline by an average of 5.9 seconds (range 0 to 28 seconds)

Group 1: Concussion during season (n=13)
Group 2: No concussion (n=206)

Baseline Data: Professional Team

<table>
<thead>
<tr>
<th>Group</th>
<th>Concussion during season (n=13)</th>
<th>No concussion (n=206)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>52.6</td>
<td>51.3 (6.6)</td>
</tr>
<tr>
<td>13</td>
<td>43.9 (5.7)</td>
<td>38.2 (3.5)</td>
</tr>
</tbody>
</table>

P<0.001, accounting for age and # concussions

University of Florida Data

- 28 athletes diagnosed with Concussion
- 14/28 had worsening by 2 points on SAC
- 22/28 had worsening on KD testing
- Worse baseline visual motor and visual memory scores on IMPACT correlate with worse KD scores

University of Florida (n=217)

KD in Amateur Rugby

- Premier Rugby Team followed for a season
- 22 concussions overall
- 5 were diagnosed at the time of the event
- Players were routinely tested postmatch - 17 unrecognized concussions were diagnosed this way
- Undetected concussion 3 to 4 times more than detected
Concussion Sideline Assessment: Composite Measure?

- Standardized Assessment of Concussion (SAC)
- Balance Error Scoring System (BESS)
- King-Devick Test

Pelham Youth Hockey League: Pre-Season Baseline (n=121)

NANOS Poster 2014

Eye as a Window: Potential Game-Changers

- Need testing in place once treatments emerge that protect and repair
- Structure-function correlations need to be done in head trauma-blast model
- Vision is a great model for sideline as well as testing over the longer term

Blast Injury Rodent Model

- Retinal nerve fiber and ganglion cell layer loss

Conclusions

- Assessment and management needs to be standardized for concussion
- Neuro-ophthalmology needs a coordinated clinical, educational and research effort to validate testing
- The King-Devick test is a new sideline screening tool for concussion
- A composite or sequential testing paradigm (App) is likely to be best
Concussion Anatomy

- Cerebral cortex, brainstem, cerebellum
- All pathways vulnerable in concussion

Concussion Tests: 2 Types

- Testing for diagnosis:
  King-Devick (K-D) test,
  Standardized Assessment of Concussion (SAC)
- Testing for management:
  ImPACT, other computerized testing, formal neuropsych


<table>
<thead>
<tr>
<th>Athletes with K-D and SCAT2 (n = 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline K-D time, seconds</td>
</tr>
<tr>
<td>Baseline immediate memory (SCAT2), total/15</td>
</tr>
<tr>
<td>Baseline SCAT2 SAC, total/30</td>
</tr>
</tbody>
</table>

Relation to K-D score baseline, accounting for age (linear regression models)

| SCAT2 immediate memory score | <0.001 |
| SCAT2 SAC subtotal (orientation, immediate memory, concentration, delayed recall) | 0.008 |