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Concussion and long-term neurological health: *What does the science tell us?*

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BACKGROUND

Concussion, also known as mild traumatic brain injury (mTBI), continues to be a public health concern across all ages and sports. Historically, the injury was thought to result in rapidly resolved impairments, with only a small number of people reporting persistent symptoms. Research and clinical care have therefore centered their efforts on developing injury identification, management, and return-to-play strategies.

Over the past 15 years, there has been growing interest and scientific findings suggesting an association between concussion and/or head impact exposures to long-term decrements in neurological health. Neurodegenerative diseases, such as dementia, Alzheimer's disease (AD), chronic traumatic encephalopathy (CTE), and Parkinson's Disease (PD), have all been identified among the former athlete and general older adult populations with an injury history. A key question was, "Could this phenomenon be a part of the natural aging process, or do head impacts and/or concussions accelerate and increase the risk of neurological disease?"

In October 2021, the University of Michigan Concussion Center invited a panel of three nationally recognized concussion researchers for a roundtable discussion about **Concussion and Long-Term Neurological Health**. Through our conversation, we asked panelists to discuss: 1) current understanding of concussion and/or head impact exposure and long-term neurological impairment risk, 2) the effects of

concussion across the lifespan, and 3) ways to communicate these topics with to key stakeholders.

The panel included Dr. Raquel Gardner, a dementia neurologist and researcher from the University of California at San Francisco who focuses on understanding the epidemiology and mechanisms of long-term sequelae of traumatic brain injury in older adults and is a key investigator on the **Transforming Research and Clinical Knowledge in Traumatic Brain Injury (TRACK-TBI)** study aiming to improve outcomes in this vulnerable population; Dr. Thomas McAllister, a psychiatrist from Indiana University School of Medicine and co-lead investigator of the **Concussion Assessment, Research and Education-Service Academy Longitudinal mTBI Outcomes (CARE-SALTOS Integrated [CSI])** study; and Dr. William Meehan, a sports medicine and pediatric emergency medicine physician from Harvard University who also is a lead investigator of the **Neurologic Function across the Lifespan: a LONGitudinal, Translational Study for Former National Football League Players (NFL-LONG)** study.

KEY TAKEAWAYS

1. Risk for Neurological Impairment after Head Impact Exposure or Concussion

Numerous studies have attempted to identify an exact impact value (i.e., "concussion threshold") that results in a concussion. However, the roundtable researchers concluded concussions occur at varying magnitudes both within and between people. In addition to single impacts that result in a concussion, it is not uncommon for athletes to sustain multiple head impacts during games/practices, which may not rise to the level of concussive signs and symptoms. Throughout the literature, these impacts have been termed as "sub-concussive." Dr. McAllister disagrees with this terminology and shared that data from the CARE Consotium suggests concussions are occurring across a wide range of impact intensities, suggesting there is no universal threshold for injury, but rather individualized tolerance levels. And those levels may shift based on the number and magnitude of impacts someone sustains in a given day, week, or season.

While the short-term declines in neurological function due to concussion have been well described, the long-term consequences remain undefined. Dr. Gardner emphasized that those with a traumatic brain injury have an increased risk of dementia and Parkinson's disease. She added, however, that several thousand participants from TRACK-TBI and other studies will be needed to fully understand the relationship between cumulative head impacts and neurological impairment risk.

> "The way I think about traumatic brain injury and neurodegenerative diseases, it's one of many risk factors that if you're destined to get a neurodegenerative disease, having that traumatic brain injury might make you [develop dementia] sooner. It might [also] make you manifest symptoms of a neurodegenerative disease, whereas maybe someone else would have died in their late 80s and never manifested those symptoms."
>
> -**Dr. Raquel Gardner**

Understanding the connection between neurodegenerative disease and prior head trauma continues to be a targeted area of research. During the roundtable discussion, Dr. Gardner stated, "...single head injuries have been broadly associated with increased risk for a variety of neurodegenerative diseases. There are a lot of studies looking at increased risk of Parkinson's, all-cause dementia, some subtypes of dementia. And for Alzheimer's disease, I'd say there's the least amount of evidence for a direct, causal link between a single TBI and Alzheimer's neuropathology." Moreover, Dr. Gardner stresses that this relationship may be increased by genetic and social risk factors.

2. Concussion Incidence and Recovery Across the Lifespan

Concussion incidence varies across sports and ages. Across biological sexes, the highest rates of injury are observed in boys' football and girls' soccer. While much of the public focus has been on men's sports such as football and ice hockey, female athletes participating in ice hockey and soccer have nearly comparable concussion rates (Chandran et al., 2021). Furthermore, concussions in high school athletes are associated with the highest number of symptoms and the longest recovery time when compared to youth and collegiate athletes. The reasons why are not fully understood.

At the opposite end of the age spectrum, Dr. Gardner addressed concerns regarding the effects of concussion across the lifespan by highlighting work conducted by TRACK-TBI, a study that enrolls patients of all ages with concussion at level-one trauma centers. She noted that the study included patients who have chronic impairment based on normative scores against the population, and also those who have some amount of clinically significant cognitive decline. Overall, less than 10% of concussion patients enrolled in the study showed cognitive impairment, suggesting a majority of individuals who suffer concussion do not experience long-term cognitive deficits.

Dr. Meehan noted additional research may be necessary to understand how concussion and/or head impact exposure influences middle-aged to older adults. He highlighted the limitations in self-reporting symptoms, indicating those who report more prior concussions are also reporting higher levels of depression or anxiety or cognitive difficulties. He cautioned that recall bias may play a role, with those now having symptoms recalling more concussions. Ideally, he believes longitudinal studies, such as NFL-LONG, CARE-SALTOS, and TRACK-TBI, may assist researchers with answering these questions. Rather than relying on self-reported measures, studies should capture details on how the injury occurred, cumulative number of concussions and/or head impact exposures during a participant's athletic career, and objective measures of cognitive and neurological changes over several years.

3. Long-Term Effects from Participating in Youth Contact Sports
Current literature regarding the long-term effects of early-age participation in contact sports is inconsistent. Dr. Meehan discussed media claims that participation in youth contact sports may not be appropriate for athletes under the ages of 12-14. However, he indicated there is limited evidence to support age-restricted participation in contact sports. Rather than reviewing studies individually, the entire body of research should be reviewed to understand trends. Dr. Meehan noted, "In medicine, we gather a lot of studies and ideally they try to address the [research] question from a bunch of different angles. And then when you put them all together, if the majority point to one outcome, that's probably where the truth is."

Similarly, Dr. McAllister discussed the importance of longitudinal studies to investigate the long-term effects of head impacts and understand trends in individuals who may be at future risk for neurological declines. At present, clinical instruments may not be sensitive enough to detect neurological and/or cognitive changes due to head impact exposure occurring at the youth level and its effect through late adolescence. Through the work conducted by the CARE Consortium, he and his colleagues concluded, "Freshmen in college, or first-year cadets at the military service academies, across all sport cohorts had no group differences in any measures, whether it was balance, symptom reporting, cognition, etc." Although these findings do not address how these individuals will present in middle to late adulthood, some may find it reassuring that there is no association with cognitive and/or neurological changes in young adults from head impact exposure in youth sports.

IMPLICATIONS FOR STAKEHOLDERS & FUTURE POLICY

Discussions regarding the long-term effects of head injury from youth contact sports participation has been a pressing topic in the media and for schools, parents, students, coaches, and policymakers. In order to address some of these concerns, and focus on the evidence to date, the expert panelists described the conversations they have with athletes who are interested in participating in collision-type sports and how they address their concerns regarding future risk of developing neurological disorders as an adult.

Dr. Meehan typically counsels his patients by using current research, which indicates it is very unlikely that somebody will get one mild, sport-related concussion and go on to get dementia as a result. He said, "Dementia is unfortunately common, and everyone is at risk. [However], there is no convincing evidence that sustaining a few

sport-related concussions is going to increase [dementia] risk in any substantial way. There is evidence that concussions can have a cumulative effect…[but] for one or two sport-related concussions, the [cumulative] effect is so small and may be immeasurable in the clinic."

Dr. Meehan also emphasized the importance of considering individual injury characteristics and recovery trends. Specifically, he said, "we look at increasing recovery time, we look at the worse symptoms with successive injuries, whether or not they seem to be occurring with less and less force, if they have deeper cognitive declines with successive injury." Depending on how the patient presents in the clinic, they may be advised to participate in non-contact sports.

The panelists recommended educating patients about other forms of physical activity that do not involve head impact exposure, with Dr. McAllister describing how he would approach this conversation if he was concerned about the long-term effects of head impacts with one of his children. "I think there is a phenotype of people, whether it is after one, after two, after ten [concussions], to show a decline in the rate of recovery after concussion… if it were my kid, and I saw that kind of pattern, I would be a lot more adamant about saying, 'Hey this really might not be the right activity for you,'" he said.

> "It is not the end of the world if you have a concussion, but I think it is a risk-benefit trade off. If they're getting more concussions with less force or apparent impact…They're taking longer to recover…The symptoms are worse, etc…those would be the warning signs."
> -**Dr. Thomas McAllister**

Dr. Gardner further commented that athletics are part of a healthy lifestyle, but clinicians need to be upfront about the research regarding neurodegenerative diseases even after one concussion. For patients participating in collision sports (e.g., football), "It is important that people understand that they are taking a risk, but everyone in their day-to-day lives decides what level of risk they're willing to take," he said.

Lastly, Dr. Gardner highlighted the importance for clinicians to take opportunities to educate patients on ways to promote brain-healthy lifestyles. "At the [high school] level, it is far more important to be developing brain-healthy lifestyle behaviors: participating in athletics, avoiding smoking, drugs, etc, she said." Dr. Gardner further described differences in brain genetics as potential contributing factors to neurological resiliency. Specifically, she said, "some brains are more vulnerable and some are more resilient. It may not be appropriate to compare [one patient] to another because they may not have the same brain [make-up]." Overall, it is important for clinicians to educate patients on aspects of their lives they can control that will have a positive influence on their health.

AREAS FOR EDUCATION, RESEARCH, & POLICY CONSIDERATION

- **Improved Educational Efforts**
  Concussions continue to be under-reported and therefore untreated, highlighting the need for continued education. Athletes, parents/guardians, coaches, and administrators should know the signs and symptoms of concussion and how to access healthcare. In parallel, improved education for care providers (e.g., primary care, nurse practitioners, etc.) who manage sport and recreation concussions on returning to the classroom and returning to activity is needed.

- **Continued Support of Large Scale Research**
  The impact of concussion and/or head impacts on long-term neurological health is not fully understood. Continued investment in large-scale research programs is needed to clarify the relationship and develop targeted mental and physical health interventions.

- **Policy Evaluation and Change**
  Sporting organizations and local regulatory bodies should continually evaluate and modify game and practice regulations in order to promote safe participation in sports. Reducing sport-related injuries increases athletes' careers and supports their long-term health.

WHAT'S NEXT FOR LONG-TERM STUDIES ON CONCUSSION?

Since 2014, the **U-M Concussion Center** has co-led the NCAA-U.S. Department of Defense CARE Consortium, the largest concussion and repetitive head impact study ever conducted. The CARE Consortium has become a national leader in studying the natural history of concussion among both military service academy cadets and NCAA student-athletes. The CARE Consortium was recently awarded $42.65 million to launch the CARE-SALTOS Integrated (CSI) Study (2021 through 2026) to examine the long-term effects of head impact exposure among military service members and NCAA student-athletes for 10+ years. Findings from the CSI Study, along with TRACK-TBI, NFL-LONG and others will help shape policy and medical care to the benefit of athletes, military service members, and the general population.

University of Michigan Concussion Center

The University of Michigan Concussion Center maximizes societal and individual health through the relentless pursuit of concussion knowledge. The Concussion Center amplifies its impact by facilitating the development and sharing of groundbreaking ideas that translate laboratory, clinic, and community observations into interventions that reduce concussion risk and improve outcomes in those affected by the injury. Learn more about the Concussion Center at: **concussion.umich.edu**.

REFERENCES

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