Traumatic Brain Injury in Surfing: A Meta-Analysis of Biomechanical Forces, Protective Measures, and Neurosurgical Implications in an Emerging Olympic Sport

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Objectives

- **Synthesize epidemiologic data** from published studies to define the prevalence, mechanisms, and severity of surfing-related traumatic brain injuries (TBI).
- **Evaluate protective measures,** with a focus on helmet usage, barriers to adoption, and current gaps in evidence regarding their efficacy.
- **Assess neurosurgical implications** by reviewing reported surgical interventions and neurological outcomes following surf-related TBI.
- **Identify critical knowledge gaps** in surveillance, prevention strategies, and return-to-play (RTP) guidelines, with the goal of informing evidence-based safety recommendations for recreational, competitive, and Olympic-level surfers.

Methods

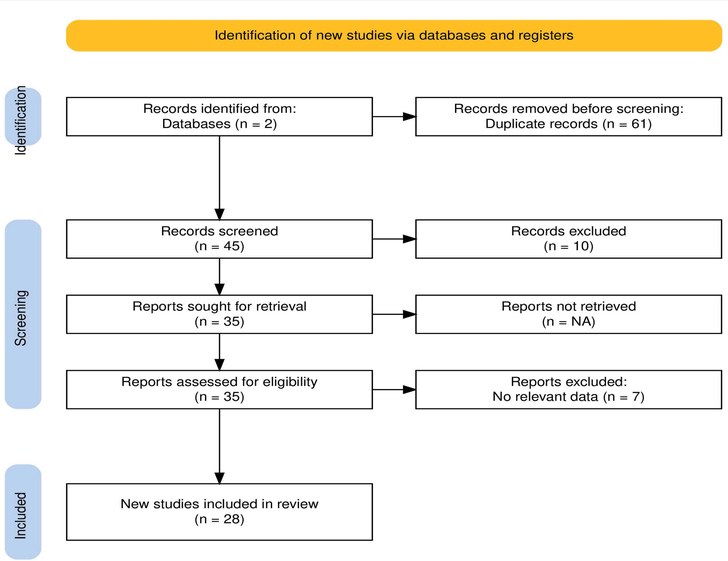

Figure 1. *Kai Lenny, a big-wave surfer, recovering in the emergency department following a major wipeout at Pipeline, HI, holding a fractured surf helmet. This image underscores the high-energy forces transmitted to the head during impact and the potential role of protective equipment in preventing catastrophic injury.*

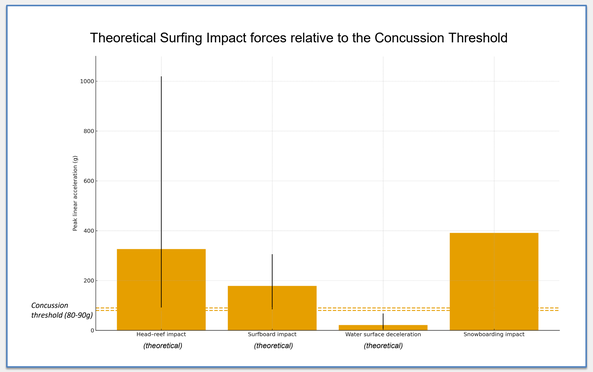

Figure 2. *Theoretical estimates of head impact forces in surfing compared to a measured snowboarding impact reference (Bailly et. al. 2017). Calculations were derived using fundamental kinematics to approximate peak linear acceleration (g). Head–reef and surfboard impacts may frequently exceed the accepted concussion threshold (≈80–90 g), while water-surface deceleration may approach this range in higher-energy wipeouts. These values suggest that common surfing mechanisms may generate forces capable of inducing traumatic brain injury.*

Take-Home Message

Surfing's expansion into an Olympic sport demands rigorous expansion in injury surveillance, protective equipment design, and neurosurgical preparedness.

Results/Discussion

Epidemiology and Mechanisms of Injury

A total of **28 studies (1965–2025)** met inclusion criteria, encompassing **>50,000 surfing-related injuries** from **eight countries**.

- **Demographics:** Male surfers comprised **80–99%** of all cases, with mean ages in the **third decade of life**.
- **Injury type:**
- **Lacerations** were the most common diagnosis (**≈40–45%** of craniofacial injuries).
- **Concussions/mild TBI** represented **5–20%** of cases but are likely **severely underreported**.
- **Severe injuries:** including **skull fractures, intracranial hemorrhage, and spinal trauma** were consistently noted across trauma cohorts.
- **Mechanism of Injury:**
- **Surfboard impact: ≈**55%
- **Seafloor impact:** 10–17%
- **Water surface deceleration:** ≈10%
- **Collisions with other surfers/fins:** 5–10%

Protective Measures

Helmet use was **inconsistently reported**, ranging from **8–18%** across studies.

- No study to our knowledge directly evaluated **helmet efficacy** for concussion prevention.

Barriers to adoption

- Cultural stigma, hydrodynamic drag, and impaired spatial awareness.
- Existing surf helmets primarily mitigate **linear impact and skull fracture**

Neurosurgical Outcomes

Across reviewed cohorts, **3–30% of hospitalized surfers required surgical intervention**, primarily for **cranial or cervical spine injuries**.

Critical Knowledge Gaps

- **No Return-to-Play guidelines** specific to surfing-related TBI were identified.
- **Long-term outcomes** (e.g., post-concussive syndrome, CTE) remain unstudied.
- Complete lack of **surf-specific biomechanical force quantification for helmets and wipeouts**
- Absence of **helmet efficacy trials** addressing both linear and rotational impact
- Need for **standardized injury surveillance** and **evidence-based concussion protocols**

Conclusion

Surfing's rise as an **Olympic and globally competitive sport** brings increasing exposure to **significant head trauma**. This meta-analysis reveals that **traumatic brain injury in surfing is frequent, likely underreported, and poorly managed**, with **surfboard impact** representing the dominant mechanism.

Despite clear risk, **helmet use remains low**, and **no evidence-based return-to-play or concussion management frameworks** exist for surfers. The **neurosurgical burden** including craniotomies, spine procedures, and rare fatalities highlights the need for improved clinical vigilance in coastal and competition settings.

To safeguard athlete health, the field must now prioritize:

- **Surf-specific biomechanical modeling** of impact forces and helmet efficacy
- **Design and validation of next-generation helmets** targeting rotational acceleration
- **Creation of standardized injury registries and RTP guidelines** informed by neurosurgical expertise

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