Early Childhood Concussion

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The unconsolidated motor and cognitive skills that are typical of the early childhood period place infants, toddlers, and preschoolers at risk for a variety of traumatic injuries. Such injuries may include mild traumatic brain injury or concussion. Knowledge regarding the risk, diagnosis, outcomes, and management of early childhood concussion is limited, especially compared with what is known about concussion in school-age children, adolescents, and adults. This state-of-the-art review aims to provide current knowledge on the epidemiology, physical signs, behavior, and clinical outcomes associated with early childhood concussion. Research on this condition has been challenged by the need to adapt methods to the unique physical, behavioral, and developmental characteristics of young children. We provide information on observable symptoms associated with concussion, recommended approaches to care, and suggestions for overcoming barriers to research in this area. Developmentally appropriate efforts are needed to improve our ability to identify, evaluate, and treat early childhood concussion.

Traumatic brain injury (TBI) results from a transfer of mechanical energy to the brain from external forces.[1] In its mildest forms, concussion and mild TBI (mTBI) lead to a range of transient physical–somatic, cognitive, and socioaffective symptoms and sequelae that vary according to multiple individual, environmental, and clinical factors. Concussion is a significant public health concern worldwide, with ≈2.7 million children affected annually.[2,3] Recent acceleration in concussion research can be attributed to large-scale, multicenter, international initiatives, resulting in shared data sets and consensus guidelines developed by multidisciplinary experts.[4,5] Knowledge gaps exist regarding the specific impacts of concussion sustained in early childhood. This narrative review will summarize the current state of knowledge on early childhood concussion, identify unique features of early concussion, highlight misconceptions and obstacles that hinder knowledge advancement, provide empirical evidence to support the need to study and treat early concussion, and suggest research and practice pathways. In this review, we primarily use the term concussion, but also reference studies of mTBI because there is a lack of consensus on this entity within the early childhood head injury literature. Most work in the field includes infants, toddlers, and preschoolers up to 6 years, but we consider studies covering the period of birth to 8 years to align with the World Health Organization definition of early childhood. Where studies included participants that overlapped the upper age limit, results were only considered if they could be applied to this defined early childhood range.

PREVALENCE AND CAUSES OF EARLY CHILDHOOD CONCUSSION

Establishing concussion rates in early childhood is complicated by diagnostic uncertainty at young ages.[4] Young children have the highest incidence of head injury visits

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to the emergency department in the United States.[5,6] This finding is confounded by the fact that young children are more likely than older children to be seen in the emergency department rather than other locations such as primary care practice.[7] Birth cohort and pediatric emergency department registry data from New Zealand and Australia suggest that children between 0 and 5 years constitute a high-risk group, with a yearly TBI rate of 1.85 per 100 children (compared with <1.17 in older children).[8,9] In a Canadian population-based study of physician diagnosed concussion, the highest incidence was observed among children aged 0 to 4 years and adults 18 to 30 years.[10] Nearly 350 000 children aged 0 to 6 years present with head injuries to US emergency departments each year,[4] whereas an additional 400 000 present to urgent care or family physicians.[11]

Falls are the main cause of injury in both preschool children (2–5 years, $N = 7080$) and school-aged children (6–12 years, $N = 5251$); however, the former are less likely to fall from a height.[12] For infants <1 year of age, the mechanism of falls is often attributed to actions of others (eg, being dropped or falling from a surface).[13–16] Over 1 year, falls are often attributed to increased mobility, exploration, and independence, and associated with climbing, walking, running, and jumping.[14] Although most injuries are accidental (98% in infants <1 year of age[17]), abusive head trauma may be present, especially in children aged <2 years.[18] However, because of uncertainties in injury history, nonaccidental concussions are infrequently identified.[19,20]

CLINICAL SIGNS AND SEQUELAE OF EARLY CHILDHOOD CONCUSSION

Although fewer studies address concussion in early childhood compared with adolescence, existing evidence suggests that early childhood concussion is not benign. Postconcussive signs and symptoms are reported in young children, but their clinical presentation and manifestations differ from those observed among older children and require a developmental approach for detection.[12,21–23] One study found that preschool children are less likely to have loss of consciousness, vomiting, headache, and drowsiness, but more likely to be irritable and agitated.[12] Using scales derived for older children, several studies report fewer or comparable number of concussion sequelae, or faster resolution of signs and symptoms in preschoolers compared with school-age children; however, symptom profiles differ according to age.[24–26] Although it may be that younger children have less symptom burden, poor developmental sensitivity of current measures could also underlie the findings. Accordingly, parents of younger children often report symptoms that are not typically associated with concussion such as "changes in feeding" and "being fussy" or "excessively irritable."[25,27] Using retrospective chart review, Suskauer et al[28] documented common postconcussive symptoms in children aged 3 to 6 years, such as headache and fatigue, but also signs not otherwise captured by standard checklists, such as stomachaches, regression in toilet training, and increased dependence (eg, clinginess). Similarly, in a review of clinical records, more than two-thirds of caregivers of children aged 0 to 4 years reported somatic symptoms (eg, vomiting, headache) and nearly half reported sleep issues.[29] Many also experienced atypical symptoms such as personality and appetite changes. Using a developmentally-appropriate approach by providing parents with examples of observable postconcussive symptom manifestations (REACTIONS: Report of Early Childhood Traumatic Injury Observations and Symptoms), Dupont et al[22] found that 0 to 2-year-olds displayed more sleep and comfort-seeking manifestations than 3 to 8-year-olds. Using the REACTIONS measure, evidence from a cohort of children who sustained concussion between 6 months and 6 years indicated significantly elevated physical, cognitive, and behavioral postconcussive symptoms compared with both orthopedic and noninjury comparison groups acutely, 10 days, and 1 month postinjury.[23]

A systematic review[30] concluded that, although subtle difficulties may be present in isolated areas (eg, theory of mind,[31] inhibition[32]), most aspects of cognition studied to date are largely preserved after early concussion. However, several studies underscore increased behavior and social problems.[28,33–37] Long-term academic outcomes are not well known because of lack of longitudinal data. One study compared cognitive test performance between children with TBI (63% categorized as mTBI) and children who sustained orthopedic injuries before age 6 years. Although children in both groups performed within normal limits on most cognitive measures, differences were identified in complex language testing and in reading comprehension with poorer performance among those with TBI.[38] Taken together, these findings underscore the potential impact of concussion in young children on complex cognition, socioaffective functioning, and behavior acutely and in the longer-term.

CHARACTERISTICS OF EARLY CHILDHOOD AND VULNERABILITY TO CONCUSSION

Several factors and characteristics distinguish the early childhood period from later stages of development. These are summarized in Fig 1.

Vulnerability

Historically, it has been argued that brain injuries sustained early in life are largely benign and not worthy of concern or follow-up. These statements may be based on incorrect interpretations of plasticity research[39] and with little regard to differentiating sensitive developmental periods within the early childhood span (eg, perinatal versus preschool) or discerning between focal and diffuse

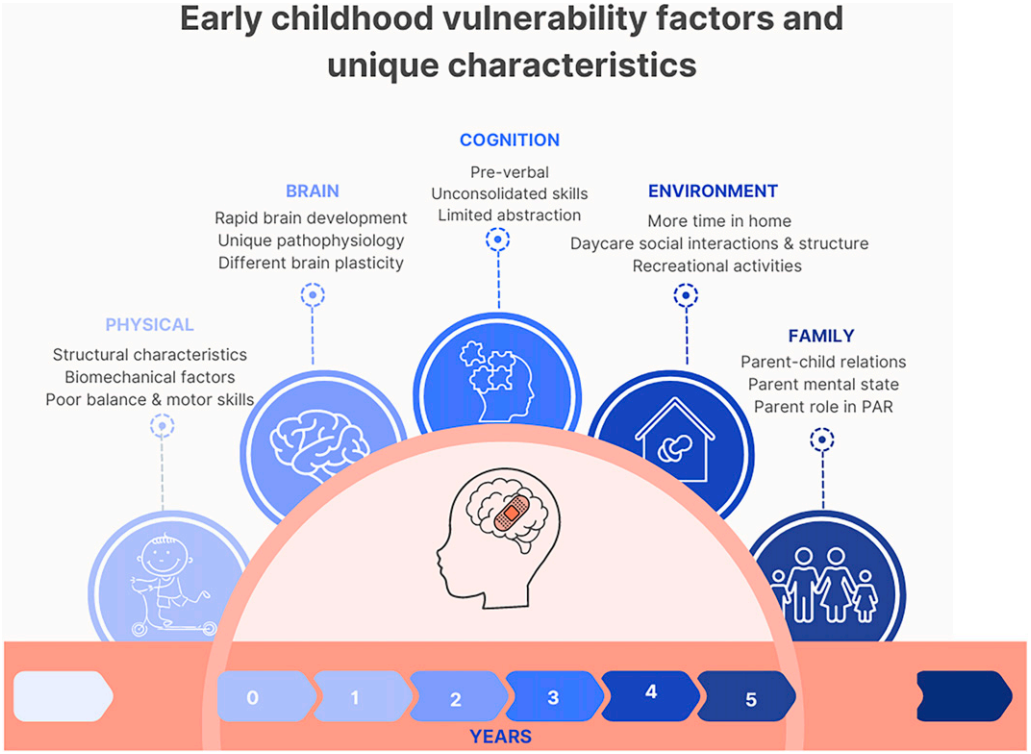

FIGURE 1

Early childhood vulnerability factors and unique characteristics: This figure represents aspects of early childhood that should be considered in understanding the risk for, occurrence, and consequences of concussion at this age. Although some elements are also relevant to later childhood, adolescence, or adulthood, they present in a unique manner, leading to distinct early concussion profiles. Physical characteristics and motor abilities differ considerably from those of older children. The brain undergoes an intense period of development and maturation. Cognitive skills are emerging, but still limited. There are greater environmental variations such as whether the child is at home or in daycare, and recreational and sports opportunities are also dissimilar. Family factors, while also important in older children, are much more salient and parental influence is stronger. PAR: Perception, Attribution, and Response to TBI (as per the Perception, Attribution, and Response after Early Noninflicted TBI model by Beauchamp et al[52]).

insult or other markers of injury severity.[40,41] There is evidence that, at least for cognitive and behavioral outcomes, earlier injury can disrupt ongoing brain development leading to significant ongoing impairment; however, this is more clearly shown for severe injuries.[40,42,43] In a mixed TBI severity sample, infants had less favorable developmental outcomes than toddlers after controlling for a range of covariates including severity, mechanism of injury, and socioeconomic status.[44] A study specific to concussion sustained between 1.5 and 5 years found that younger age at injury was predictive of poorer outcome.[45] Additional studies focusing on early childhood concussion are necessary to establish whether an age vulnerability effect exists specifically for this group.

Physical and Cerebral Factors

Physical and neurodevelopmental factors characteristic of the young child increase the risk of concussion. Young children have a larger head to body ratio than older children and adults: at birth, the head is one-fourth the total body length, whereas in adults, it is one-seventh. Facial profile, head shape, circumference, and strength are all biomechanical factors that increase vulnerability to traumatic injury.[46] Given the same mechanical force, very young brains are more likely to suffer more severe injury because of relatively large and heavy heads and weak cervical ligaments and muscles, as well as the fragility of their thin, pliable skulls and unfused cerebral sutures.[47] The first years after birth are characterized by rapid and dynamic brain development, which sets the tone for cognitive and behavioral skills.[48] Disruption during this period may place the child at risk for adverse consequences.

Social Factors

Through early childhood, the quality of the child's environment, especially parent mental state and quality of home context, is critical for development.[49,50] We found that early

childhood concussion is associated with reduced quality of parent–child relationships, and that parenting stress contributes to outcome prediction.[37,51] We have reviewed the evidence supporting a critical role for parents in early childhood concussion recovery and developed a framework (the PARENT model) depicting how parent's ability to perceive, attribute, and respond to their child's postconcussive symptoms influences management and recovery.[52]

KNOWLEDGE GAPS AND BARRIERS

A number of factors contribute to challenges in the detection and description of concussion among young children, creating barriers to research within this area.

Diagnosis and Terminology

Recently updated diagnostic criteria and definitions for concussion and mTBI[1,53] aim to provide unified standards to improve the quality and generalizability of research and clinical care; however, none specifically apply to early childhood. Regardless of the age at which concussion occurs, there is currently no in vivo biomarker or measure with sufficient sensitivity and specificity to objectively diagnose concussion; consequently, diagnosis is based largely on a history of a blow or force to the head combined with symptom report. Reliance on self-report poses an additional hurdle in young children given their limited vocabulary and understanding of abstract concepts. Caregiver or other third-party reports are also challenged by difficulties differentiating the etiology of specific signs such as fatigue, sleep disturbances, affective lability, balance problems, and nausea, which are common at young ages even in the absence of any underlying medical cause. Measures to differentiate developmental norms from signs of concussion are only recently proposed.[22] Diagnostic challenges impact the quality of data collection to characterize young children with concussion.[30] The consequences of such limitations are highlighted in a study of 1 372 291 patient visits to US emergency departments for children aged 0 to 6 years, which found that >80% were diagnosed using the general label "unspecified injury to the head."[4] Use of this code decreased with patient age, in favor of more specific concussion diagnoses.

Assessment

Most assessment tools and measures for concussion have not extended to infants, toddlers, or preschoolers. Potential barriers include rapid changes in function during early childhood requiring different measures across short age spans, as well as concerns regarding behavior and cooperation affecting testing validity. In consensus meetings that aimed to identify common data elements and outcome measures for pediatric TBI, experts noted that "childhood and adolescence represent a wide range of developmental levels and even most pediatric measures are inappropriate for infants and toddlers."[54] The workgroup identified relatively few assessment tools specific to young children. Assessment barriers affect accurate monitoring and understanding of recovery. A challenge in children is how to determine when children have recovered from clinical, functional, and neurophysiological perspectives,[55] and this challenge is likely to be amplified in the youngest ones. For example, young children might recover well in relation to the outward physical manifestations of the injury, but could have disrupted cerebral or cognitive functioning that affects their behavior but is not visible or readily assessable using direct measures. In a study of caregiver perspectives after early childhood concussion, parents reported feeling distressed over their inability to detect concussion-related sequelae in their young child and relief when obvious symptoms (eg, repeated vomiting) dissipated.[56] Although such physical symptom resolution may reflect recovery, it may be unclear if the child has completely returned to preinjury function, or if subtle changes (eg, behavior dysregulation) associated with the concussion persist.[52] As may be the case for older children, unidentified sequelae of early childhood concussion may lead to unmet care needs and misattribution of an individual's behavior.[57]

Exclusion From Large-Scale, Longitudinal Research Initiatives

As reflected in systematic reviews,[21,30] several single-site longitudinal studies address early childhood concussion and 1 multicenter study of early concussion is ongoing.[58]

TABLE 1 Behavioral and Nonverbal Manifestations of Early Childhood Concussion

	Associated Manifestations
Cognitive	Easily distracted
	Needs more repetition
	Clumsier than usual
	Changes in speech
Somatic or physical	Appetite changes
	Complains of stomachache
	Holds their head
	Looks pale
	Rubs eyes
	Reacts to loud noises
	Does not want to go outside
	Longer or more frequent naps and sleep
Mood and behavior	Fussiness
	Excessive irritability
	Cries more
	Throws tantrums
	Does not want to participate in activities
Comfort seeking and dependence	Clinginess
	Stays close to parent
	Wants to be held
	Regression in toilet training
	Does not want to be alone

This stands in contrast to the large-scale, multicenter cohorts established to study concussion in older pediatric groups and sports contexts.[59] It is possible that, similar to older children, early concussion resolves within a few weeks to months of injury, with minimal risk of consequences for global development, attention, and language.[42,60–62] However, findings indicating a more protracted pattern of symptom recovery,[23] and subtle, long-term cognitive and behavioral changes[28,31,35,63] suggest the need for further investigation. There is also little to no information available on the impact of early childhood concussion on cumulative effects across the lifespan, despite support for the idea that experiencing childhood concussion places individuals at increased risk for repeated injuries thereafter.[57,64,65] Significant attention has focused on the effects of repetitive concussion within a contact sport season, and there is concern that a history of multiple concussions is a risk factor for poor outcome.[2,66,67] It is possible that a toddler who sustains a concussion from a fall at age 2 years may then sustain 1 or more concussions at school-age or adolescence, especially if involved in contact sports. The development of ways to track the occurrence and document the effects of multiple concussions from birth could inform the consequences, if any, of cumulative concussions. There is a paucity of randomized clinical trials, intervention studies, and prevention initiatives, as highlighted by the Centers for Disease Control and Prevention[68] in a report recognizing that young children are essentially missing from all research types.

Limited Definitions and Guidelines

The concussion community meets in the context of international, multidisciplinary consensus meetings, and these typically lead to concerted definitions, reviews, and guidelines that have strong clinical uptake.[1,53] The recently updated American Congress of Rehabilitation Medicine criteria for mTBI,[1] although developed to be used across the lifespan and across settings, may be more difficult to apply to early childhood because of limited empirical evidence and the need for developmental adaptations of the criteria (eg, how to recognize acute signs in preverbal children). The Amsterdam Sports Concussion Consensus[53] underscores a lack of available evidence in 6- to 12-year-olds; children aged <8 years have been particularly disregarded.[69] The revised sports concussion

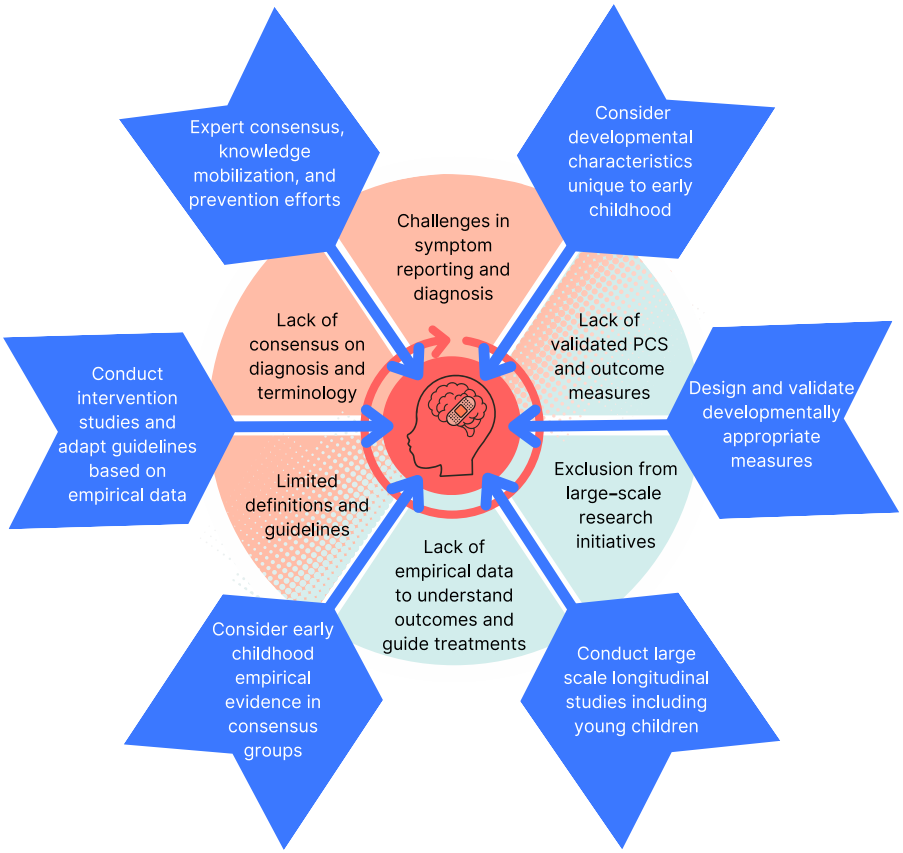

FIGURE 2

Targets for Assessment, Research, Guidelines, Empirical studies, Terminology/Diagnosis, and Symptoms (TARGETS) of early childhood concussion: This figure presents a visual summary of obstacles and challenges to research and clinical practice within the field of early childhood concussion, and suggested avenues and initiatives for overcoming these barriers. PCS: Post-concussive symptoms.

definition now includes sports and exercise-related activities.[53] This terminology is more applicable to younger children and, combined with recommendations for early life entry into organized sports because of inactivity concerns in older children,[70] suggests that work is needed to either adapt existing guidelines for use across the entire pediatric span or to begin a distinct process for generating guidelines for early childhood.

Conclusions and Future Directions

Infants, toddlers, and preschoolers present with unique individual and environmental characteristics that require a developmentally appropriate approach after concussion. The exclusion of young children from large-scale initiatives delays the development of evidence-based guidelines to inform concussion identification and management in this age group. Proactive monitoring, health care, and day care or school interventions may be important to promote long-term health and well-being in some children after early childhood concussion.[55]

A qualitative study involving pediatric emergency medicine physicians suggests that current ambiguity in diagnosis and lack of clear discharge and intervention guidelines is a barrier to initial concussion care among young children.[71] With the development of appropriate clinical education and guidelines, practitioners will be able to better identify and care for concussion among young children. Table 1 provides a list of possible behavioral manifestations of early childhood concussions based on previous studies. Figure 2 summarizes gaps and opportunities in early childhood concussion. We believe the most urgent actions are the need to improve identification of early childhood concussion, to educate families and health professionals about monitoring recovery in a similar framework to that used for older children and adults, and to develop age-appropriate return-to-activity guidelines. Once we can recognize, monitor, and treat early concussion, we will have a better understanding of its incidence and sequelae and can use this knowledge to reinform prevention and intervention efforts during early childhood.

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ABBREVIATIONS

mTBI: mild traumatic brain injury
TBI: traumatic brain injury

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