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Pediatric skull fractures and intracranial injuries (Review)

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Abstract. The determination of plausibility of an injury arising from a fall leading to head trauma is a great challenge especially in young children. The present review is aimed to discuss important developments in the filed of head trauma cases especially in children. We explored various studies pertaining to head trauma injuries in children by exploring mainly PubMed, Google scholar and some library periodicals available in our library. Studies in the recent past explored the head injuries as a result of a low height fall. However, there are great amount of difficulties in assessment of height with certainty that caused head injuries like skull fracture or intracranial injury. Biomechanical thresholds have been estimated for young children for injuries such as skull fracture, but they have not been assessed against the injuries observed in a clinical setting. So, this review discusses current aspects of pediatric head injuries ranging from a minor head injury to a skull fracture. The present review concludes that recording full details of cause of head trauma such as fall height is essential for proper treatment planning and efficient management.

Contents

1. Introduction

Head injuries in pediatric patients as the result of a low height fall represent a challenging issue for clinicians, biomechanical engineers and medico-legal experts (1). The developmental nature of infants and young children, increasing mobility combined with under-developed muscles and reflexes, means that head injuries as the result of a fall are a common occurrence in most households (2). However, the majority of such incidents are thought to be benign, with only 4.8% leading to hospital attendance and <1% of falls resulting in either a concussion or skull fracture in infants. Despite this, Parslow *et al* (3) concluded that the most common cause of traumatic brain injury (TBI) in the 0-4 age group was a fall (38%). However, investigating only infants (age <1 years old), falls only accounted for 19% of the TBI cases with the most common cause of TBI being suspected assault (52%) (3). The percentage of children hospitalised with abusive head trauma varies with age, however studies have estimated the frequency as being between 25-30% (4). Due to this, clinicians are faced with the dilemma of trying to differentiate head injuries that have resulted from abuse and those that have not, particularly for this age group, when the child is unable to give a history. A fall is an incident that further confounds the problem, as whilst it is a common cause of head injuries presenting to hospital, it is also a common false account given by parents-carers later suspected of abuse (5,6). As a result researchers from differing professional backgrounds, clinical, legal and engineering, have attempted to establish what injuries could result from a low height fall.

There is no strict definition of a low height fall. Original research conducted by Helfer *et al* (7) investigated children <5 years old who had fallen from a bed or sofa and used a cut-off of <0.91 m. Since then it has variably been defined, with authors using cut-off heights from 0.91 to 1.52 m (8). Previously, authors have also documented mean heights for moderate/serious head injury when comparing head injury severity groupings (9,10). Mean heights have been reported between 0.91 and 1.32 m (11). A low height fall is an incident that is further confounded by there being no clear classification criteria. Due to all these factors it is difficult to establish a clear cut-off for a low height fall and thereby making it problematic to define head injuries that can result from such incidents. The controversy mainly endorsed a common false history provided by parents of affected child abuse (12). Chadwick *et al* (5) documented 7 fatal head injury cases with an initial history of a low height fall that the authors later attributed to abuse. Of which, 2 were the result of standing fall, 2 were a fall from a bed or table and 2 were the result of fall from an adults arms. Tarantino *et al* (13) documented 2 cases of children admitted

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after rolling off a couch, however both cases were later deemed as abuse. Duhaime *et al* (6) investigated the mechanisms of head injury in children and there were 24 cases classed as an inflicted injury. Of these cases, 8 had history of fall <1.22 m, which the authors defined as fall from a standing height, or fall from a bed, sofa or table. Feldman *et al* (12) investigated the mechanisms of a subdural haemorrhage (SDH) and in the abuse group, 41% (n=16/39) presented with a history of a fall <1.22 m. This therefore illustrates a low height fall is a common false history given by parents suspected of abuse and in particular a fall from household furniture or a standing height. A history low height fall is further confounded by previous biomechanical studies using an anthropomorphic testing device (ATD) reporting similar or greater accelerations as the result of fall to that seen in shaking, a common mechanism with or without impact associated with abuse (14,15). However, the biofidelity of the ATDs and the head injury thresholds used have been question by other authors (16,17).

2. Epidemiology of head injuries in children

TBI is significant problem worldwide; the World Health Organisation estimates incidence rates of mild TBI between 100-300 per 100,000 (18). In the USA, the 0-4 year age group has the highest emergency department (ED) incident rate of TBI, estimated at 1,256.2 per 100,000 (19). Hawley *et al* (20) concluded that 280 per 100,000 children (<16 years old) were admitted with TBI each year. Previous authors have documented a rate of 5.1 per 100,00 of children (0-4 years) admitted to an intensive care unit with TBI (3). The severity of the head injury also varies depending on the mechanism of the injury. Among minor head injuries, a fall is the most commonly recorded mechanism in those aged <1 year (69.4%) and those aged 2-4 years (62.7%) (20). Investigating children admitted to a pediatric intensive care unit, a fall was the commonest cause of TBI in the 0-4 age group (38%) (3).

3. Head injury severity

There is no international classification of head injury severity, therefore it varies between countries, clinicians and journal article authors, which makes it difficult when comparing studies. Severity can be measured according to the presenting neurological status, neurological outcome, mechanism or the extent of primary structural damage as evidenced on neuroimaging. Different authors utilized a different category when evaluating head injury severity. A classification system for neurological status is based on the Glasgow Coma Score (GCS) (21). The GCS was devised by Teasdale and Jennett (22) and modified in 1976 to assess the extent of coma after trauma. It identifies the level of neurological dysfunction in three separate components; motor, verbal and eye opening responses. Scores from each component are considered separately and combined to form an overall GCS score ranging from a total score of 3-15. However despite this, authors have used different methods when evaluating head injury severity particularly from a low height fall, with some documenting specific structural damage as identified on neuroimaging such as skull fracture (12) or a SDH13 and others using a defined scale such as minor versus serious (9).

4. Biomechanics of head injury

The application of engineering methods to the understanding of injuries in the human body was first pioneered in the automotive industry. The study by John Stapp in the 1950s progressed the understanding of tolerance levels of the human body and thus furthered the knowledge of crash protection (23). Since this original study, the field of biomechanics has focused on understanding the mechanical response of the body when exposed to an applied load to appreciate the factors that causes head injury and to improve safety.

5. Mechanisms of injury

The biomechanics of head injury has historically been split into two main areas, translation accelerations as the result of direct impact and rotational accelerations as a consequence of an indirect load such as an impact to the thorax producing whiplash on the head. Yet as it has been described by others, rarely would translation and rotational accelerations be seen in isolation, from either a direct or indirect impact to the head (24). Upon impact with an object, the head would deform and decelerate, thereby resulting in translational acceleration. Severe translation accelerations have been found to correlate with focal injuries including skull fracture and local brain contusion 20, although they have also been linked with contracoup injuries (25).

On impact with a flat surface, the skull deforms, bending inwards and produces a wave-like pattern. This results in tension on the inner surface and also on the outer surface of skull (Fig. 1). The fracture can initiate at the inner surface that is under tension and thus propagates towards the outer surface (Fig. 1). Fracture can also initiate on the outer surface in areas of tension (26).

Intracranial damage was generally thought to occur as a consequence of skull deformation from a translational impact, which can lead to brain motion and thus potentially causing a focal haematoma (27). Other authors have proposed that such injury may also be caused as a consequence of a pressure gradient established during translational impact (28). At the site of impact, the focal intracranial tissues would be exposed to a positive pressure and, due to motion of brain, locations distal to the impact site would be exposed to negative pressure (29) (Fig. 2). It has been suggested that this pressure gradient subjects the brain to shear stresses and thus causes cavitation whilst the positive pressure has been linked with the focal injuries (30).

Holburn (31) was the first author to state that is was rotation, as opposed to translation, accelerations that causes brain injury, producing injurious shear stress and strains. Longer impact durations with reduced magnitudes of acceleration were associated with diffuse axonal injury, yet shorter durations with increased acceleration were related to SDH (32). Rotational accelerations have also been attributed to bridging vein rupture in human cadavers (33), whilst mechanisms of injury have generally been split between translational and rotational accelerations, authors have stated that injury to head and, more specifically the brain, is likely through a combination of both.

6. Clinical assessment overview

Biomechanical thresholds for head injury in young children exist for skull fractures and adult thresholds exist for

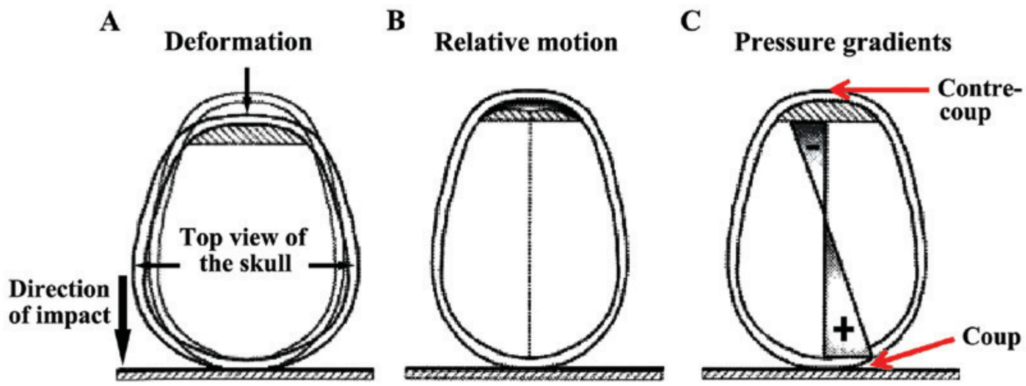

Figure 1. Skull deformation on impact with a surface.

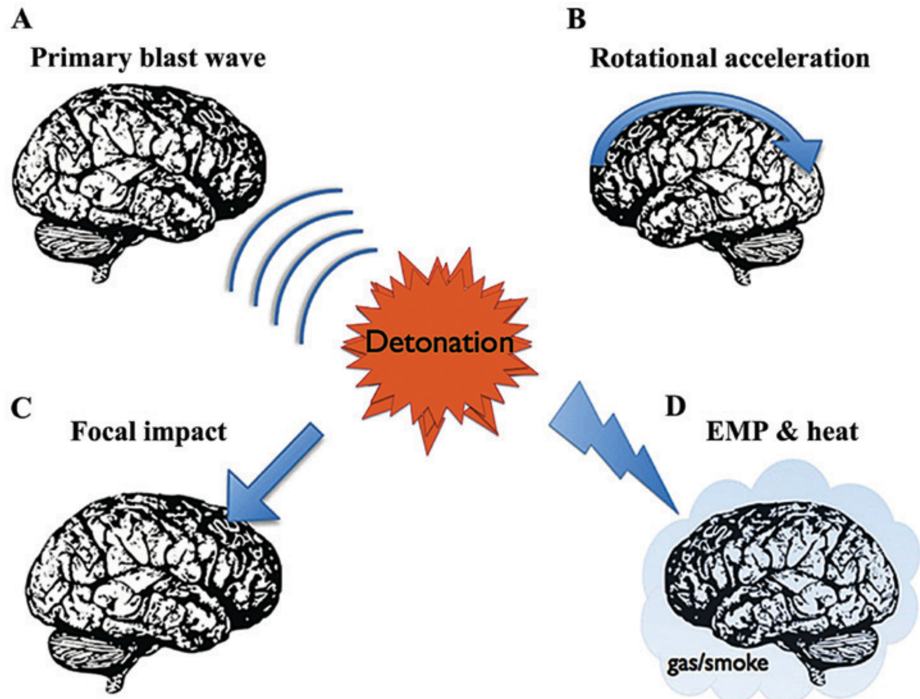

Figure 2. (A) Translation acceleration on impact with a surface. (B) Pressure gradient formation due rotational acceleration. (C) Focal impact induced on the head. (D) EMP and heat effect.

intracranial injuries (34). Skull fractures and intra cranial injuries, including SAH, SDH, and EDH6, are the result of trauma (27) that results in material failure, whether it be fracture of a cranial bone or rupture of a bridging vein between the brain and sagittal venous sinus within the subdura. However, the biomechanical thresholds for these injuries have not been assessed against the clinical features present in a young child who presents to a hospital having suffered from a head injury. Establishing markers that could inform the clinical and forensic assessment of head injury in young children when physical child abuse may be suspected, inform head injury prevention strategies and also inform biomechanical studies, both physical and computational.

7. Biomechanical variables

In the epidemiology research, fall height has often been the only biomechanical variable considered to have an effect on head injury severity. However, it has been clearly shown that other variables including surface impacted, body mass and point of impact have the potential to influence head injury severity (35). Lyons and Oates (36) investigated the momentum on impact and found no significant results. Although it was unclear if the authors considered the position of the child prior to falling, however they did take general measurements of the height fallen. Only Thompson *et al* (37), considered other biomechanical factors when conducting epidemiology research relating to injuries from low height falls. The variables included, potential energy, change in momentum, impacted surface, impact velocity, fall characteristics and patient characteristic body mass index (BMI) which were compared between minor and moderate/serious injuries. They observed that furniture height, fall height (vertical distance to the centre of mass of body), impact velocity and BMI were significantly different between the minor and moderate/serious injury groupings ($P<0.05$). Whilst the authors analysed considerable detail on the falls, they only investigated children who attended the ED, thus limiting the number of serious injuries captured and as a result the final sample size. A larger sample size may have resulted in further variables, e.g. potential energy and momentum, being significantly different between the minor and moderate/serious injuries.

8. Conclusions

This review highlights the need to record full details of falls when children present with a head injury, including the height-object from which they fell, their position prior to the fall and the surface and body part on which they impacted. These features have the potential to inform clinical decisions, when assessing young children with a head injury.

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