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Device-related pressure ulcers from a biomechanical perspective

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Abstract Pressure ulcers (PUs) in the pediatric population are inherently different from those in adults, in their risk factors and etiology, with more than 50% of the cases related to contact with medical equipment at the care setting. The aims of this study were to: (i) Determine the mechanical loads in the scalp of a newborn lying supine, near a wedged encephalogram electrode or wire, which is deforming the scalp at the occiput. (ii) Evaluate the effect of a doughnut-shaped headrest on the mechanical state of tissues at the same site. We used finite element computational modeling to simulate a realistic three-dimensional head of a newborn interacting with the above devices. We examined effective (von Mises) stresses, shear stresses and strain energy density (SED) in the fat and skin tissues at the occipital region. The interfering wire resulted in the worse mechanical conditions in the soft tissues, compared to the lodged electrode and use of a doughnut-shaped headrest, with 345% and 50% increase in effective stresses in skin and fat tissues, respectively. Considering that elevated and localized tissue deformations, stresses and SED indicate a risk for PUs, our simulations suggest that misplaced medical devices, and using a doughnut-shaped headrest, impose an actual risk for developing device-related PUs. We conclude that guidelines for pediatric clinical care should recommend routine inspection of the medical device placement to prevent harmful contact conditions with the patient. Furthermore, improved design of medical equipment for pediatric settings is needed in order to protect these fragile young patients from PUs.

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1. Introduction

A pressure ulcer (PU) is a localized injury of weight-bearing soft tissues, typically (but not always) over a bony prominence, which develops primarily due to pressure, or pressure in combination with shear [1,2]. The elderly, frail, and individuals with impaired mobility and sensation are well known to be prone to PUs. However, there is a growing understanding that acutely-ill or immobilized infants and children can also be at a high risk for PUs and deep tissue injuries (DTIs) in particular [2,3]. PUs and DTIs in children, and especially in neonates, are inherently different from those in adults, in their risks and causative factors, etiology and characteristics of the affected tissues and wounds [4,5]. For example, in terms of epidemiology and biomechanics, PUs in adult patients develop mostly at the sacrum, ischial tuberosities and the calcanei, and are associated with prolonged sitting or supine lying which loads these bony prominences and highly deforms the overlying soft tissues. In the neonates however, the occiput is the largest bony prominence and hence, the head is the most common site for PU development [4,6–8]. Furthermore, typical adult chronic risk factors such as obesity and diabetes are nearly non-existent in infants, but unfortunately, in these young patients, the prevalence of congenital central nervous system dysfunctions such as cerebral palsy is greater. Hence, in the pediatric patient population there are unique mobility and spasticity issues which introduce inherently different risk factors compared to adults [3,4,6]. In addition, pre-term neonates in particular have not developed the fully-structured functional dermal tissues to protect them from mechanical loading [5]. Furthermore, the relative subcutaneous adipose volumes are greater in newborns and infants, and adipose tissues of newborns contain greater water/lipid ratio compared to adults, making fat tissue of newborns and infants inherently softer, more deformable, and more prone to deformation-inflicted DTI [5].

Importantly, and distinguishably from adults, more than 50% of the PUs in children and neonates are related to use or contact with medical equipment and devices at the care setting [6,9]. While recent advances in acute care (e.g. in heart-lung support and neurosurgery) significantly increase the survival rates of preterm neonates, infants and children, they also expose them to the high-risk care environment, particularly that of the neonatal and pediatric intensive care units (NICUs and PICUs, respectively) [10]. Saturated with equipment, wires and tubing such as continuous positive airway pressure (CPAP) masks, oxygen saturation probes, ECG/EEG electrodes and their wiring etc., the unique medical environment of NICUs and PICUs is in fact an extrinsic risk factor for device-related PUs [5,10]. When a stiff, curved object, such as an electrode, tube, catheter or wire, is wedged between the skin of an infant or child and the support surface (and especially if that happens near a weight-bearing bony prominence), elevated localized deformations occur in the skin and underlying soft tissues. The sustained exposure to such deformations may jeopardize the integrity and viability of these highly distorted tissues and cells, and so, initiate a deformation-induced injury through direct mechanical damage to cells, which is later exacerbated by localized ischemia and blockage of the lymphatics [5]. Furthermore, many medical devices that are designed to, or could be in contact with the body, are made from crude polymer materials that do not match the stiffness properties of the more fragile pediatric and particularly neonate tissues. The design principles and shapes of these pediatric devices are also typically scaled-down versions of adult devices, which do not necessarily fit the vulnerable pediatric population [5]. Indeed, the prevalence of PUs in NICUs is high, up to 23%, with more than 50% of the cases involving interaction with a medical device such as a mask or a tube [6,9]. The traditional guidelines and standard risk assessment tools do not normally account for interactions of the body with medical devices (which sometimes occur at unintended anatomical sites). However, progress is now being made in this regard, specifically targeting pediatric care, and new risk assessment tools are being developed [11–13]. In the hectic NICU and PICU environments, nurse inspections can easily overlook hazardous misplaced devices, particularly since the nurse is extremely busy with monitoring so many vital signs of these young and critically-ill patients [5]. Furthermore, if an inadequate mattress is used, i.e., one which is not soft enough to conform around an accidently interfering device or component, or which does not allow proper immersion and envelopment of the body of the patient, then greater deformations and stresses will occur in the soft tissues near the device. An appropriate mattress will yield to the interference, averting the loads and stresses away from the soft tissues [5].

In addition to catheters, tubes, sensors, probes, and wiring, doughnut-shaped and horseshoe-shaped headrests are used in many NICUs and operating rooms for positioning of the head of the