Dual wireless epidermal electronic systems with in-sensor analytics for neonatal intensive care

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INTRODUCTION:

In neonatal intensive care units (NICUs), continuous monitoring of vital signs is essential for clinical care, particularly in case of sever prematurity. Existing medical platforms in the NICU require multiple hard-wired, rigid interfaces to a neonate's fragile, under-developed skin and, in certain cases, invasive lines inserted into their delicate arteries. These platforms and their wired interfaces pose risks for iatrogenic skin injury, create physical barriers for skin-to-skin parental/neonate bonding, and frustrate even basic clinical tasks. Alternative technologies that bypass these limitations and provide additional, advanced physiological monitoring capabilities would directly address an unmet clinical need for a highly vulnerable population.

RATIONALE:

It is now possible to fabricate wireless, battery-free vital signs monitoring systems based on ultrathin, 'skin-like' measurement modules. These can gently and non-invasively interface onto the skin of neonates with gestational ages down to the edge of viability. Four essential advances in engineering science are required for devices of this type: (1) schemes for wireless power transfer, low noise sensing and high speed data communications via a single radio frequency link with negligible absorption in biological tissues, (2) efficient algorithms for real-time data analytics, signal processing and dynamic baseline modulation implemented on the sensor platforms themselves, (3) strategies for time-synchronized streaming of wireless data from two separate devices and (4) skin-safe designs that enable visual inspection of the skin interface and magnetic resonance imaging (MRI) and X-ray imaging (XR) of the neonate. The resulting systems can be much smaller in size, lighter in weight and less traumatic to the skin than any existing alternative.

RESULTS:

We report the realization of this class of NICU monitoring technology, embodied as a pair of devices that, when used in a time-synchronized fashion, can reconstruct full vital signs information with clinical-grade precision. As shown in the figure, one device mounts on the chest to capture

electrocardiograms (ECGs); the other rests on the base of the foot to simultaneously record photoplethysmograms (PPGs). This bi-nodal system captures and continuously transmits ECG, PPG and skin temperature (from each device) data, to yield heart rate, heart rate variability, respiration rate, blood oxygenation and pulse arrival time, as a surrogate of systolic blood pressure. Successful tests on neonates with gestational ages ranging from 28 weeks to full term demonstrate the full range of functions in two Level III NICUs.

The absence of wires, together with the thin, lightweight, low modulus characteristics of these devices allow for interfaces to the skin mediated only by weak van der Waals forces, with magnitudes that are nearly ten times smaller than those associated with adhesives used for conventional hardware in the NICU. This reduction greatly lowers the potential for iatrogenic injuries.

CONCLUSION:

The collection of advances outlined here serves as the basis for a wireless, skin-like technology that not only reproduces capabilities currently provided by invasive, wired systems as the standard of care, but also offers multi-point sensing of temperature and continuous tracking of blood pressure, all with significantly safer device-skin interfaces and compatibility with medical imaging. By eliminating wired interfaces, these platforms also facilitate therapeutic skin-to-skin contact between neonates and parents, which is known to stabilize vital signs, reduce morbidity and promote parental bonding. Beyond use in advanced hospital settings, these systems also offer cost-effective capabilities with potential relevance to global health.

Wireless, skin-like systems for vital signs monitoring in neonatal intensive care. (**A**) Images and finite element modeling results for ECG and PPG devices bent around glass cylinders. (**B**) A neonate with an ECG device on the chest. (**C** and **D**) A mother holding her infant with a PPG device on the foot and an ECG device on the chest **(C)** and on the back **(D)**.

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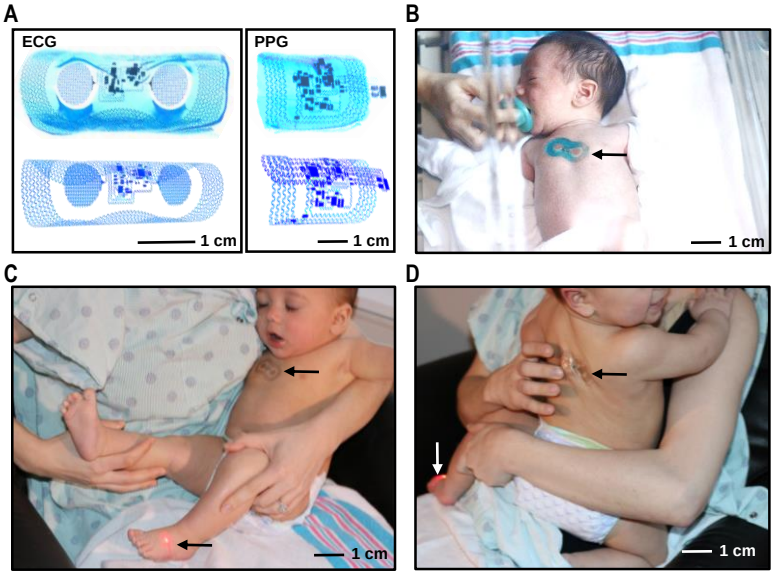
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