Conformal Wearable Electronics to Monitor Congestive Heart Failure

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Over 5.8 million people in the U.S. and 23 million people worldwide live with congestive heart failure (CHF) wherein the heart cannot adequately maintain blood circulation [1, 2]. More than half of those who develop CHF die within 5 years of diagnosis [3]. Complications of CHF is the leading cause of hospitalizations in the U.S. [4]. In 2015, CHF was responsible for $24 billion in healthcare costs and is projected to double in the next 15 years [3]. CHF is now the only cardiac disease increasing in prevalence in the U.S. [1].

The leading risk factors of CHF include hypertension, diabetes, and prior incidents of myocardial infarctions (MI) [5]. More than a quarter of MI survivors are diagnosed with CHF within 30 days after hospital discharge [6] and more than one-third will develop CHF within 7-8 years after an MI [2]. By monitoring MI patients for early symptoms of CHF, complications, hospitalizations, and deaths can be prevented [7]. CHF monitoring includes 1) tracking onset of symptoms for the purposes of early detection, and 2) monitoring symptoms to manage diagnosed CHF. Due to the progressive severity of CHF, it is advantageous to track the onset of the disease during its early stages.

Presentation of symptoms follows the order of physiological dysfunction, namely: cardiac, pulmonary, and renal conditions. Therefore early warning signs of CHF include: changes in hemodynamic parameters (e.g. stroke volume, cardiac output, heart rate, blood pressure) followed by shortness of breath/wheezing while later signs of CHF include fluid retention and weight gain [7]. More than 25% of infarcted patients wait ≥ 6 hours after noticing initial symptoms before seeking medical help [8]. Delayed medical attention increases hospitalization time, deaths, and total health care costs [1]. **CHF disease management is time-sensitive. Early detection and treatment is critical for improving mortality rates** [9]. While non-invasive technologies exist on the market for later stage CHF monitoring based on fluid retention, **there remains an unmet need to continuously yet non-invasively monitor patients with a history of MI for the earliest signs of CHF.**

Using our proprietary conformal, wearable sensors, we propose to continuously monitor hemodynamic parameters combined with respiratory parameters to detect and alert of early CHF signs. We have developed low-cost disposable Band-Aid© format ultra-sensitive sensors that simple adhere to the skin for continuous monitoring (Figure 1a). We have shown that we can monitor respiration parameters (rate and volume) [10] (Figure 1b) as well as high-resolution pulsatile blood flow (in which hemodynamic parameters can be derived) [11] (Figure 1c). The sensors easily attach to a bluetooth unit for real-time data transmission to a smartphone for alerts and the cloud for physician monitoring. Using machine-learning algorithms, variations from baseline can be detected and the patients and caregivers notified at the earliest onset of symptoms.

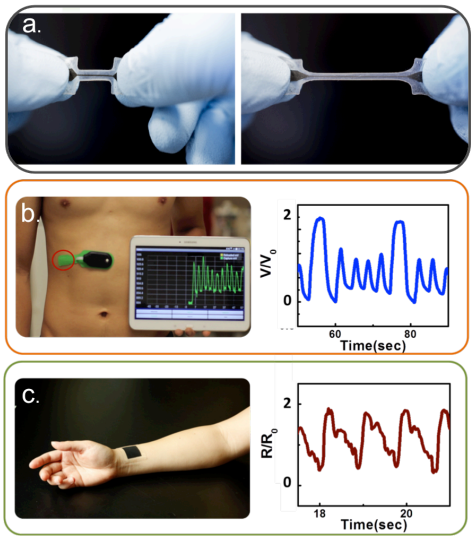

Figure 1: Physiological monitoring with conformal sensors. (a) Shows how soft and stretchy the piezoresistive sensors are. (b) Respiration monitoring (including tidal volume) and (c) radial artery pulse waveform.

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