A Vaporized Corticosteroid Delivery System for Long-Term Treatment of Pediatric Asthma

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Need: Asthma is a chronic respiratory disease with an estimated 300 million individuals affected worldwide[1]. Inhaled corticosteroids (ICS) are an essential part of asthma treatment, but they can be challenging for pediatric patients to use effectively, resulting in frequent exacerbations and decreased quality of life. Current methods for delivering corticosteroids include metered dose inhalers, dry powder inhalers, and soft mist inhalers; however, these devices are often expensive, challenging to administer, and have a low percentage of successful drug delivery, thereby highlighting the need for a more user-friendly and efficient system.

Design Inputs: Through literature review and one-on-one interviews, we learned that patients experiencing asthma exacerbations struggle to comply with treatment regimens because forceful inhalation can be challenging, and treatment compliance is difficult when medication does not provide immediate relief. To combat this, we sought to develop a system that circumvents the button-to-breath coordination required by conventional inhalers, reduces oropharyngeal deposition by reaching a lung delivery rate of greater than 9% (current metered dose inhalers), and costs less than or equal to $300 (current inhaler average[1]). Our design must also meet certain testable requirements to ensure its effectiveness. Specifically, the device must work for individuals of peak inspiratory flow (PIF) rate below 30 L/min, must generate droplets of mean particle diameter between 1-5 µm, the circuitry and replaceable medication cartridge must yield a final product no larger than current devices (approx. 6.0cm x 2.5cm x 2.5cm), and the dose administration protocol should have a maximum of three steps in order to facilitate ease of use.

Solution: Our proposed device incorporates a heated coil-based mechanism that vaporizes a suspension of corticosteroids. E-cigarettes have been shown to possess a pulmonary drug delivery rate of 24%, so we sought to model our design from this existing mechanism[3]. Our device is activated by inhalation using a micro pressure sensor, which sends a signal to a digital gated voltage regulator. This gives us a desired constant voltage that we will experimentally determine even as the lithium ion battery depletes. Recent studies suggest that smartphone applications increase medication administration adherence[2], so the device connects to a mobile device app that will remind patients to take their medication, track their symptoms, and allow them to communicate with their physicians.

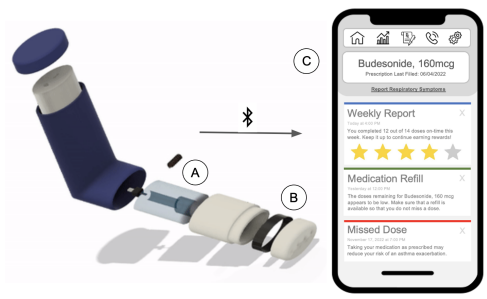

Figure 1. Proposed device schematic highlighting the coil-based vaporization technology (A), simplified breath-actuated delivery (B), and convenient tracking/monitoring software integration (C).

Verification/Results: To validate our device's design, we employed a JUUL e-cigarette device as a model vaporizer to simulate breath-actuated medication delivery. First, we filled the device with 0.1% weight/volume corticosteroid suspended in a 1:1 mixture of propylene glycol and vegetable glycerin. To mimic the conditions of drug administration, we collected the vapor in a vacuum sealed Schlenk flask, condensed the liquid in a dry ice acetone bath, and then determined the presence and integrity of the corticosteroid via liquid chromatography tandem mass spectroscopy (LC/MS) (Fig. 2). With this method, we can accurately assess the effectiveness of our novel inhaler design in delivering the medication to the lungs. Our preliminary results suggest that intact corticosterone is present in our vaporized condensate, as there are both identifier (346.5 g/mol) and quantifier ion peaks that are of comparable size and fragmentation pattern to a standardized solution analyzed without vaporization. However further studies are needed with more clinically prescribed medications such as budesonide (Pulmicort™).

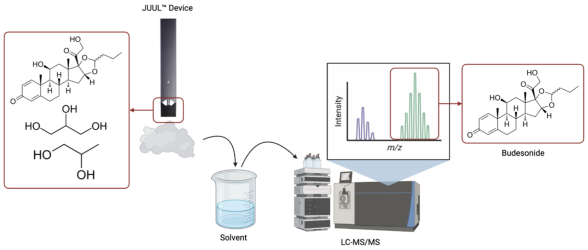

Figure 2. Proposed validation for quantitative/qualitative analysis of vaporized corticosteroids using a JUUL device model.

Conclusion: Future work will focus on optimizing the circuitry's footprint to make the device portable while delivering the desired voltage and constant power. Additional testing is necessary to ensure the stability and efficient operation of the device, which is critical to achieve optimal drug delivery to the lungs. Once validated, our novel corticosteroid delivery system will provide a new and improved method for pulmonary drug delivery, making medication adherence more accessible for patients and improving overall health outcomes.

References:

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3. Demoly, P., et al. (2014). DOI: 10.1016/j.rmed.2014.05.009.