QUANTITATIVE ACOUSTIC ANALYSIS OF INHALER SOUNDS FOR
THE OBJECTIVE ASSESSMENT OF INHALER ADHERENCE IN
PATIENTS WITH CHRONIC RESPIRATORY DISEASES

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When: 8 February 2016 at 9.00am
Where: Trinity Biomedical Sciences Institute, Room B1.06

Asthma and chronic obstructive pulmonary disease (COPD) are two of the most prevalent chronic respiratory disorders. Over 800 million people suffer from these diseases and over four million people die annually. Although both asthma and COPD are incurable, symptoms can be effectively controlled through the delivery of medication to the lungs. Inhaler devices are employed to deliver medication to the airways in the treatment of asthma and COPD. An inhalation step is required to extract the medication from the inhaler and deliver it to the airways. However, despite the proven clinical efficacy of inhaler devices, they can be difficult to operate and adherence levels for inhaler medications are subsequently poor (averaging around 50%). Poor inhaler adherence results in reduced clinical outcomes for patients and large financial costs for healthcare providers. Adherence is a critical aspect of inhaler use that should be continually monitored, however, there is currently a lack of objective methods available for this purpose.

In this thesis, an acoustic based approach is taken to objectively monitor inhaler adherence and respiratory health. An acoustic recording device was recently developed for use with the commonly used Diskus inhaler. This electronic device objectively records the audio signal of inhaler use but the analysis and interpretation of the acquired data remains subjective. In the studies detailed in this thesis, acoustic signal processing methods that can objectively and automatically analyse the audio signals of inhaler use are reported. To detect and analyse the sounds generated during inhaler use, several temporal, Fast Fourier Transform (FFT) and Mel Frequency Cepstral Coefficient (MFCC) derived features are employed. The central aim of this thesis is to investigate if the features employed are both sensitive and specific in detecting and analysing the critical steps related to correct inhaler use, and if so, then can an objective and automatic system be developed to assess inhaler adherence.

The main findings of the studies detailed in this thesis were that temporal and spectral features of inhaler inhalation signals can be used to estimate the peak inspiratory flow rate (PIFR) and inspiratory capacity (IC) in the Diskus inhaler. It was also found that temporal and spectral acoustic features can be employed to estimate the quantity of drug extracted from an inhaler device.
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Furthermore, it was reported that the relationship between temporal and spectral features and PIFR also exists for the common Turbuhaler and Evohaler inhaler devices, once a critical level of turbulent airflow is reached. These findings imply that analysing inhaler adherence using acoustics may be more suited for inhaler devices with medium-to-high levels of airway resistance. It was also found that temporal/spectral features have a low variability within subjects and that the spectral envelope of inhaler inhalations is repeatable across a range of PIFRs. The effect of exhaling into a Diskus inhaler was quantified for the first time in a study detailed in this thesis. The exhalation factors that influence inhaler drug delivery were also investigated in detail within this thesis. In addition, temporal and spectral acoustic features were used to detect and analyse this critical error. A series of algorithms were developed to detect inhalation sounds, blister sounds and analyse overall inhaler user technique in a further study detailed in this thesis. It was found that the algorithms developed could perform with a high level of accuracy, in comparison with expert human raters. The system described in this thesis is now subsequently being employed in several multi-site clinical trials, encompassing approximately 600 people.

In conclusion, the original contribution to knowledge in this thesis lies in the translation of the signal processing methods to the field of inhaler acoustics. The systems developed can be employed to analyse patients’ adherence to their inhaler medication. The main findings of this thesis help establish the characteristics of sounds generated during inhaler use and demonstrate the potential of using objective signal processing methods in the analysis of inhaler acoustic recordings. Quantitative data on inhaler adherence and subsequent analysis of respiratory health may assist healthcare professionals in monitoring patients’ inhaler use and aid with the effective treatment of asthma and COPD. Improved inhaler adherence may lead to improved clinical outcomes for patients and financial savings for healthcare providers.