

Mobile FEV₁: Evaluation of iPhone Spirometer

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Introduction

Lung function is measured for the both the diagnosis and management of pulmonary disorders. Spirometry is the most commonly used pulmonary function test; it is currently used as the gold standard for the measurement of many lung function parameters.^[1] Spirometry is a physiologic test that measures the volume and flow rate of air during a series of inhalations and exhalations. One such pulmonary function that is assessed with spirometry is the Forced Expiratory Volume in one second (FEV₁).^[1,2,3] Measurement of FEV₁ allows for the diagnosis and management of both restrictive and obstructive lung diseases.^[2,7,3,8] Longitudinal measurement of FEV₁ has been useful for the management of COPD and Cystic Fibrosis patients.^[5,6,7, 8,14]

Spirometry is traditionally measured in a physician's office and is underutilization making it difficult for the frequent monitoring of lung function values.^[7] Such serial monitoring of physiologic values for longitudinal management has been shown efficacious for several chronic conditions, both of the pulmonary system and otherwise.^[10] Importantly, serial monitoring of FEV₁ may improve patient compliance as well as afford the opportunity for health care providers to enhance patient education.

There is evidence that cellular phones have a place in healthcare to improve the quality of life of patients.^[TD4] Asthmatics communicating with healthcare providers via Short Message Service (SMS) have demonstrated better management of their asthma.^[11] Use of telemedicine methods in the management of COPD has demonstrated a reduction in hospital admissions and an improvement in patient's quality of life.^[21, 22, 23]

The focus of this present study was to develop a novel application on a mobile device such as the iPhone (Apple, Cupertino CA) to emulate spirometry and measure FEV₁. Utilizing the iPhone's capacity to record sound through it's microphone system, the application would translate vibratory sound waves into a near volumetric measurement of an exhaled breath. The ubiquitous nature this mobile platform creates a unique foundation for a proof of concept: a low cost and efficacious spirometer analogue could be implemented for patient use outside of a healthcare setting or alternatively as a low cost spirometry for physicians in developing countries.

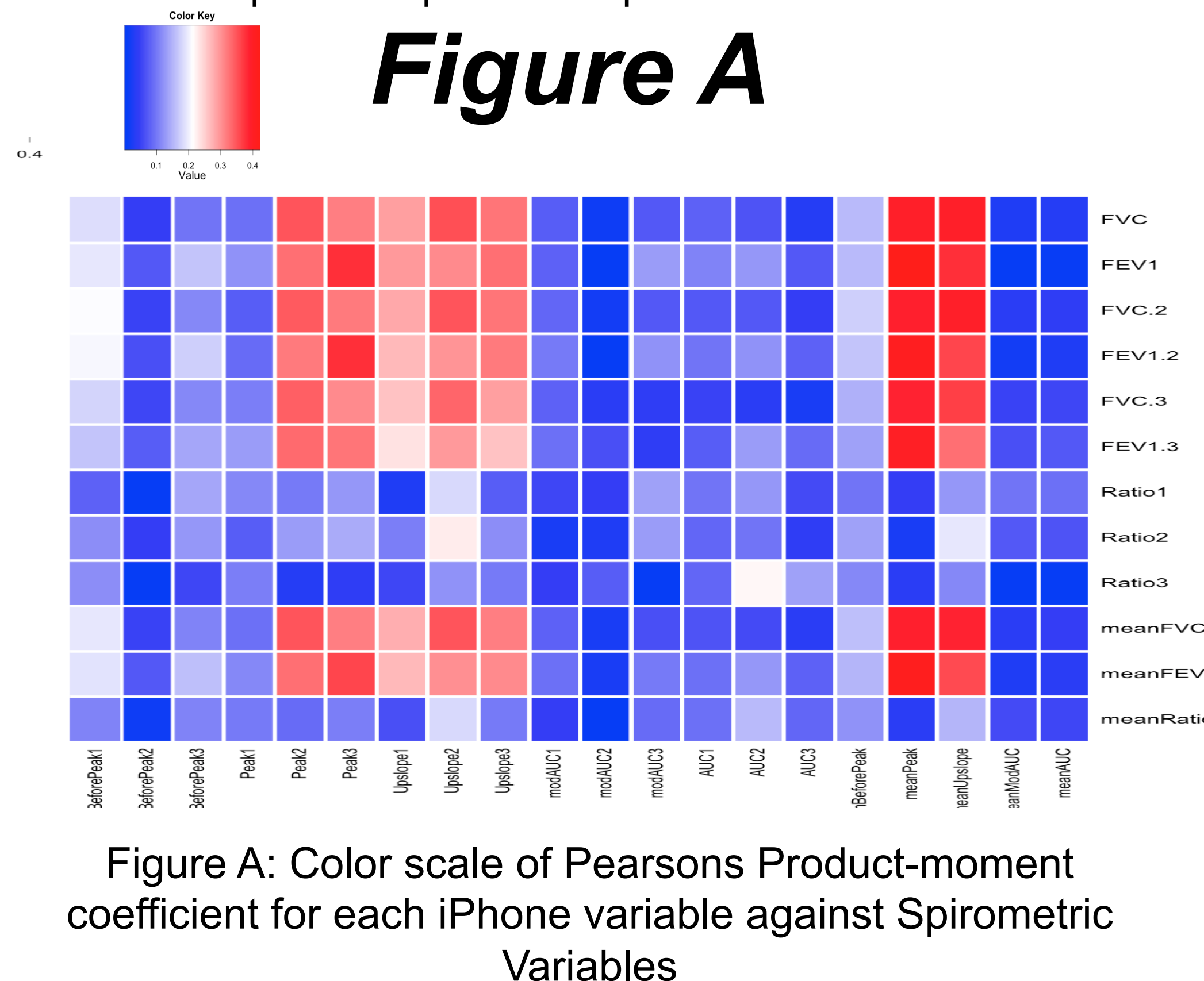


Methods

Study Population. Healthy student and administrative volunteers from the Hofstra North Shore – LIJ School of Medicine were recruited by verbal request for inclusion in the study population. The volunteers ranged from 18-58 years of age with a relatively even distribution of gender, BMI and smoking status (Table A).

Study Protocol. Volunteers were given a unique and anonymous identification number and, using a paper survey, self reported pertinent demographic values. A standard pulmonary diagnostic spirometer was calibrated before use and all tests were evaluated for quality by the KoKo PFT software. Three successive spirometric tests were then performed according to American Thoracic Society standards.^[2] Technique for use of the iPhone-based spirometer were kept similar to standard spirometry. However rather than exhaling into the mouthpiece of a spirometer, subjects exhaled into the speaker on the base of an iPhone held approximately one foot from the subject's mouth. Each subject performed three consecutive measurements with the iPhone.

Statistical Analysis. Our goal was to examine the correlation between different aspects of the flow-volume loop from the spirometer and the changes in amplitude measured by the iPhone across the length of an exhalation. R: A language and environment for statistical computing was used to perform all statistical analyses. Parameters extracted from spirometric testing were FEV₁ and FVC. The parameters extracted from the iPhone defined different aspect of the length and change in amplitude during exhalation. Both Pearson's product-moment correlation coefficient, single and multi variable linear models, and a post hoc power analysis was calculated between each spirometer parameter with each iPhone parameter. Analysis of the predictive value of the iPhone spirometer based on demographic information was performed. A final model incorporating iPhone parameters that best explained spirometric parameters was defined.



Results

Between July and August 2012, 53 volunteers provided demographic information (Table 1) and conducted both spirometer and iPhone measurements. Measurements were used and deemed acceptable if the Koko spirometer recorded the results without error. Descriptive statistics of the spirometer and iPhone results were calculated .

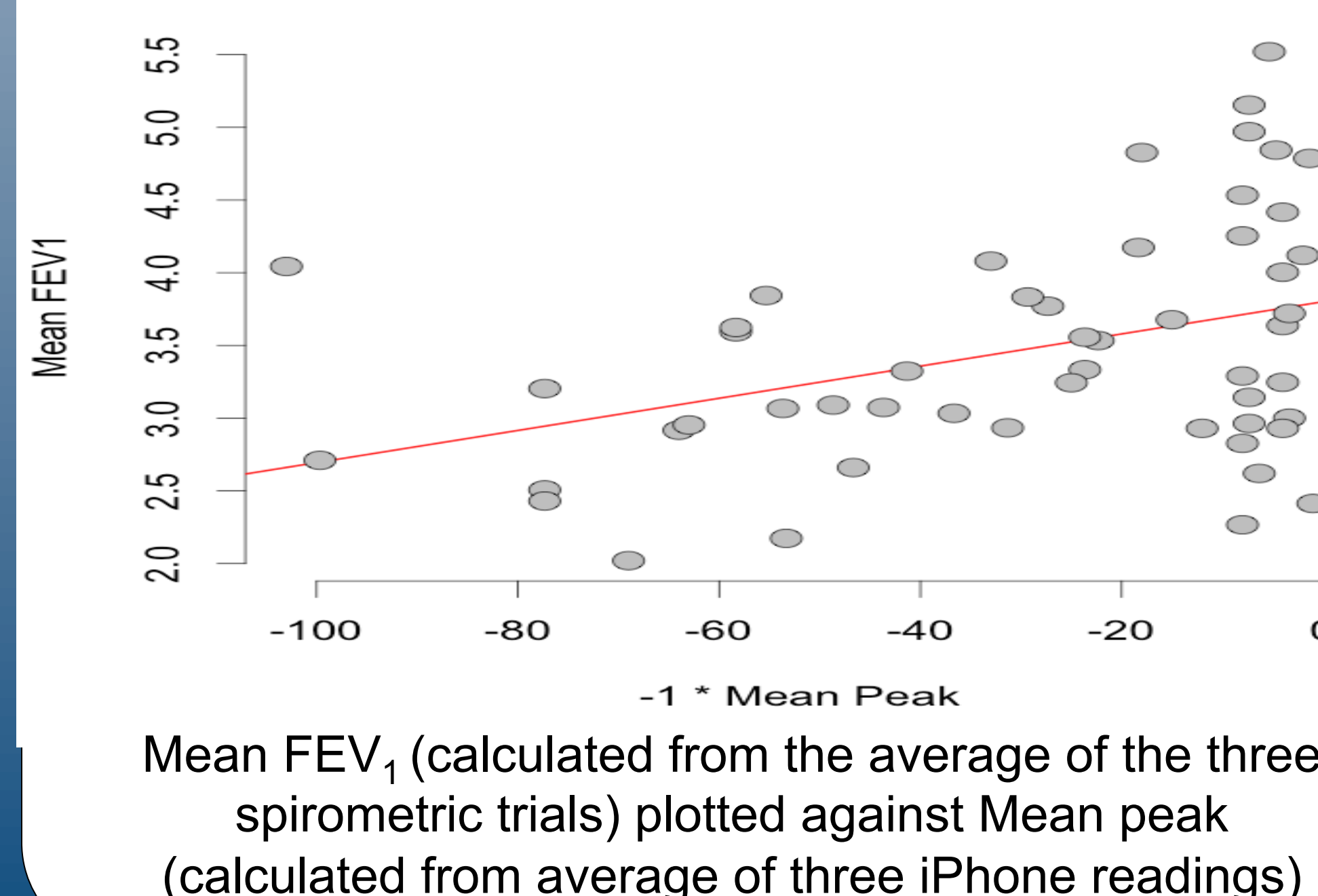
Pearson's product-moment correlation coefficient (PCC) was calculated between each parameter measured by spirometry and those measured by the iPhone (Figure A – heatmap). This analysis revealed the strongest correlations existed between FEV₁ and FVC (spirometer) and the Peak and Upslope parameters from the iPhone. As illustrated (Figure A), these iPhone parameters correspond to the beginning of an exhalation. This period is roughly analogous to the points from which FEV₁ is calculated, which lends credence to the potential of these measurements. Either Peak or Upslope could alone predict FEV₁ and FVC; however, to identify the best predictor of FEV₁ and FVC, we employed multivariate models that incorporated both Peak and Upslope. These models were even more highly significant than single variable models.

Together, between our statistical modeling and post hoc power analysis, our results show that a significant relationship exists between measurements from the iPhone and spirometer. Mean FEV = $\beta_1 + \beta_2(\text{Weight}) + \beta_3(\text{Weight}^2) + \beta_4(\text{Height}) + \beta_5(\text{Height}^2) + \beta_6 \ln(\text{Age}) + \beta_7(\text{Gender}) + \beta_8(\text{Smoking History}) + \beta_9(\text{Mean Upslope}) + \beta_{10} \ln(\text{Mean Peak}) + \beta_{11}(\text{Mean AUC}) + \epsilon$ And using the above, we get: Multiple R² = 0.712 Adjusted R² = 0.641 p-value = 2.734e-08

	Age (years)	Height (inches)	Weight (lbs)	BMI	Pack Years
Mean		27	66.33	151.56	24.04
Minimum	18	59	100	18.01	0
Maximum	58	74	290	39.33	6

Figure B

Mean FEV vs. Mean Peak



Conclusions

This current study is, to our knowledge, the first attempt to quantify pulmonary function via a mobile phone. Though caveats exist with the technique and technology, this novel usage of the iPhone represents a powerful method for reaching a broad patient population. Moreover, the ability of patients to frequently assess their pulmonary function outside of a clinical setting could allow for better monitoring of their chronic diseases. This approach also allows for both patient empowerment and education.

Recent studies have begun to define new methodologies for screening patient populations for chronic lung disease (Nelson, Chest 2012). An iPhone application, such as the one we have developed and verified, could be used at home provide a major boon to patients on the edge of progressing from one tier to the next (i.e.- questionnaire use to peak flow evaluation).

A recent Lancet Commission recommendation laid out a plan for more accessible and innovative uses of technology.^[25] The use of an iPhone application to accurately predict FEV₁ improves access both domestically and globally. In areas without adequate personnel to analyze spirometry results, the iPhone easily transfers data and facilitates communication between patient and healthcare provider. Whereas domestically, the application would most likely be used outside physicians' office as a way to longitudinally track the progression of pulmonary disease.

This study presents a viable method for the audio-based assessment of pulmonary function using an iPhone application. We show a strong correlation between results gathered via this device with those gathered from diagnostic spirometry. Predictive modeling identified several parameters of the iPhone results that would allow for the use of this device to predict FEV₁, an important marker of airway health. We foresee this device as the basis of a new method for physicians to reach a broad patient population and identify changes in pulmonary health.



Screen Shot of graphical representation of volunteers exhalation. The Sharp slope up (upslope) and the time at the flat top (time at peak) correlated with FEV₁ and FVC on standard spirometer.

Selected Bibliography

1. Sood A, Redlich CA. Clin Chest Med. 2001 Dec;22(4):783-93.
2. Miller MR, Hankinson J, et al; ATS/ERS Task Force. Standardisation of spirometry. Eur Respir J. 2005 Aug; 26(2):319-38.