Design of a Digital, Interactive, Incentive Spirometer for Enhanced Respiratory Care

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SUMMARY

Pacific Science & Engineering Group (PSE) designed a new bedside incentive spirometer to minimize respiratory complications among postoperative patients. Current bedside incentive spirometers in widespread hospital use have several severe shortcomings, including inadequate patient feedback, no reminder mechanism to prompt patients to use them, and no means for physicians, nurses, or respiratory therapists to assess patient breathing performance and compliance. The PSE digital, interactive, bedside, incentive spirometer was based on physician, nurse, and patient input; it incorporated an enhanced feature set and user-friendly design. It will be useful in both hospital and home settings, and it will enable physicians and nurses to directly assess patients’ breathing performance progress. The prototype featured a user interface design based on human factors engineering principles and physician, nurse, and patient input. This new user interface is expected to significantly improve patient breathing performance and treatment adherence relative to incentive spirometers in current use. Given the widespread use of incentive spirometry among postoperative patients, this new user interface design offers significant commercial potential.

SPIROMETER DESIGN ELEMENTS

In the first Phase of this project, PSE systematically addressed all aspects of spirometer use necessary for designing a new digital incentive spirometer, including design of a software user interface, and a basic specification of its major engineering elements and aspects (i.e., air flow sensor, visual display, power requirements, speaker, physical controls, case size and shape, overall weight). We also prepared an engineering plan that defined the process needed to build a fully functional prototype digital incentive spirometer. Usability testing with representative patient and health care providers established that the design concepts for its software user interface enable a highly effective and satisfying user experience with a device that effectively performs its essential functions while also being easy to use and understand.

Figures 1 and 2 show examples of the user interface design concepts for the patient home screen that were developed and tested during Phase I. Both visual and auditory elements will be used to instruct, guide, and encourage patients in the proper use of the spirometer. Graphical and numerical information will be used to tell patients how their breathing performance has changed over time. Visual and auditory alerts will be provided to remind patients when it is time to perform another set of breathing tests.
Initial Prototype

Figure 3 shows three photorealistic drawings that convey several essential design elements and device features of our prototype device. The spirometer will be compact, lightweight, easy to hold, and easy to understand and use. As panel (a) shows, it will have a color display that conveys the visual interface elements for both the patient and clinician interfaces. Two large, easy-to-grasp handles allow patients to comfortably hold the device in either hand while performing breathing tests. The breathing tube connector is positioned to facilitate straight-on viewing of the display during a breathing trial. A clip for securing the breathing tube between device uses is located at the top right side of the device case.

Figure 1. Representative design concept for the patient user interface. Change in inhaled volume is continuously displayed as the patient inhales, relative to the target volume, shown as a horizontal line. Visual and auditory feedback is used to instruct and motivate patients.

Figure 2. The health care provider user interface can display individual patient performance data and trends in both graphical and tabular formats, with user-selectable time intervals (single trials, hours, days, weeks). A Patient Setup screen is used to input treatment parameters for each individual patient at the outset of a course of spirometry treatment.
The only control the patient needs to operate the spirometer, the green button, is prominently displayed on the front of the device next to the breathing tube. The buttons used by health care providers to input patient treatment parameters and review patient breathing data are on top of the device to avoid distracting the patient. The visual interface elements of the display will be supplemented by auditory and verbal cues that prompt and guide patients while performing breathing tests. Panel (b) shows the back of the device, with an attached air flow component. This disposable component (panel (c)) has been designed to completely entrain the interaction air volume and is the only part of the spirometer that will come into direct contact with a patient’s breath and respiratory secretions. This cost-effective and user-friendly design of the air flow component minimizes the need to sterilize the base unit while facilitating the easy replacement of the air flow component when preparing the device for a new patient.

We identified several additional features and capabilities that will be incorporated into future designs that would further enhance the value of the digital interactive incentive spirometer, versatility, and benefits for both patients and nurses.

Disposable Air Flow Sensor

The air flow sensor will be a disposable component intended for use by a single patient. The disposability of the air flow sensor will avoid the cost and logistical issues that arise if the air flow sensor was non-disposable and required sterilization between patients. Sterilization of medical devices can be costly and time consuming. For these reasons, the prototype was designed so that only its disposable air flow sensor component will come into direct contact with patients’ breath and secretions. Based on current market availability and pricing, the cost of the air flow sensor is expected to be approximately $10.00. This amount is less than half the cost of the current plastic analog disposable incentive spirometers in current widespread use, based on a price survey.

Link the Air Flow Sensor to Mobile Devices

We designed our incentive spirometer to be a highly versatile and cost-effective device. A key to this versatility was designing the air flow sensor to be a separate component of our incentive spirometer. This feature will allow the air flow sensor to be utilized as an attachment to mobile devices, such as smart phones and tablets. This innovation capitalizes on the rapidly emerging trend of applying sensor technologies to mobile devices, which promises to bring powerful new innovations to home health care. In addition to developing a dedicated incentive spirometer during Phase II, we will also investigate the possibility of developing a software application (“app”) that will enable mobile devices, such as smart phones and tablet computers, to function as an incentive spirometer when the air flow sensor are attached to them. When a patient is ready to return home from the
hospital, the air flow sensor can be detached from the incentive spirometer unit and taken home for use in conjunction with the patient’s mobile device.

**Capitalize on Advances in Telemedicine**

Given the increasing prevalence of telemedicine technologies in hospitals and clinics, we have investigated the feasibility of incorporating a wireless data transmission capability into the prototype spirometer. This capability would enable spirometry data to be wirelessly and automatically transmitted from the device to patients’ electronic medical records. Although providing this capability will entail added expense, the enhanced ability of health care professionals to monitor patient breathing performance and treatment compliance and to make timely interventions when indicated makes this a desirable feature.

**Facilitate Home Health Care of Respiratory Illness**

Our device is also well suited for longer-term use by patients with chronic respiratory illnesses in the home as well as clinical settings. Given the aging of the U.S. population, the practice of home incentive spirometry will likely become more widespread. An incentive spirometer that can be used safely, reliably, and effectively in patients’ homes without close supervision by health care providers is therefore highly desirable.

**FOLLOW-ON**

The goal of the next phase is to design, build, test, and refine the digital spirometer by incorporating the user interface and modular design that was developed in Phase I. The spirometer to be developed during follow-on would be a versatile, cost-effective medical device that would have a positive impact on patients’ well-being by reducing the incidence and severity of respiratory complications, increasing patient compliance through feedback and ease of use, while providing records of use and trend information to health care workers. Given the widespread practice of incentive spirometry throughout the world, the patient health benefits and commercial potential of this proposed device would be significant.