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TILT TRACKER: TECHNICAL NOTE ON AN MHEALTH SYSTEM TO MONITOR AND PREVENT ULCER DEVELOPMENT AMONG POWER WHEELCHAIR USERS

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Approximately 85% of individuals with spinal cord injuries will develop a pressure ulcer, making these wounds one of the most common and preventable comorbidities associated with this condition. Pressure ulcers can be life threatening due to increased risk of infection, and hospitalization is often required for complex cases. Accordingly, there is a call in the spinal cord injury literature to develop innovative technology for the prevention of pressure ulcers. In response, an interdisciplinary team developed the Tilt Tracker, a dynamic mobile health system that objectively measures pressure redistribution practices in real time and is synchronized to a digital communication platform. This technical note will describe the concept and design of this innovative technology.

Key words: Spinal cord injury; Pressure ulcer; mHealth; Mobile technology

INTRODUCTION

One of the most common secondary health conditions associated with spinal cord injuries are pressure ulcers (1-4). The chance of developing pressure ulcers increases each year post injury, and approximately 85% of individuals with spinal cord injuries will develop an ulcer over the course of their lifetimes (5-7). Pressure ulcers are associated with increased mortality and limited independence, and complex cases often necessitate hospitalization (8,9). Mean costs of hospitalization can range between $75,000 and $150,000 per patient, and total national costs are estimated at $11 billion annually (10-12). In addition to notably high prevalence rates, increased risk of mortality, and financial costs, ulcer development is strongly associated with poorer life adjustment as well as reductions in physical and mental health-related quality of life (13-15).

Ulcer development is linked to an interconnected system of biopsychosocial factors, many of which are strongly influenced by health behaviors (16-19). Protective behaviors include, but are not limited to,

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medically directed pressure redistribution (PR) practices, proper nutrition, physical activity, and engaging in recreation (20,21). Further, prevention of ulcer reoccurrence is associated with similar behavioral and lifestyle factors (22).

Regardless of the degree of spinal cord injury, prevention of ulcer development is enhanced by PR practices (23). Also referred to as pressure relief or repositioning, PR most commonly includes forward and crosswise leans, vertical push-ups, or changing tilt and angles with the assistance of a power wheelchair (24). Although nutrition, skin moisturizing, and use of support surfaces are valuable care practices, PR is considered one of the primary preventative behaviors for reducing risk of ulcer development (12,23,25).

Considering the behavioral aspects critical to ulcer prevention, there is a call in the spinal cord injury literature to develop innovative technology to enhance preventative behaviors (26). In response, an interdisciplinary team developed the Tilt Tracker, a dynamic mobile health (mHealth) system that objectively measures PR and is synchronized to a digital communication platform. This system offers valuable health behavior surveillance and provides a range of intervention options. The purpose of this technical note is to describe the concept and design of the Tilt Tracker system.

CONCEPT

Utilizing mHealth technology is a valuable approach for health promotion and disease prevention (27-30). mHealth technology affords an intervention embedded within a person's daily context with unique opportunities to continuously monitor and provide health behavior feedback in real time (27). This approach benefits from valuable aspects of the Stepped Care Model (31). Specifically, this technology allows for flexible patient care, low-cost translation, and stepwise levels of care based on patient response to treatment.

The concept of the Tilt Tracker was based on meeting two overarching needs: 1) to develop an objective and ecologically-valid measurement system of PR behaviors and 2) to provide a dynamic, mobile platform that offers a range of interventions to enhance PR behaviors. First, objective PR measurement advances the current standard of care, which relies on retrospective patient report — data that are often inaccurate due to social desirability and recall error (32-35). The measurement system allows for ecological momentary assessment of actual PR behaviors in a discrete manner. Second, the concept for the Tilt Tracker technology was developed to offer a range of patient-provider communication modalities and personalized, in-the-moment interventions that adapt to the patient's behavior. In sum, this technology is expected to enhance critical health behaviors that prevent the risk of ulcer development among users of power wheelchairs.

DESIGN

The Tilt Tracker is an unobtrusive mHealth technology that synchronizes objective PR measurements to a digital communication system in real time. See Figure 1 for the structural flow of this technology.

PR measurement begins with sensor input integrated with mobile technology to push the data to

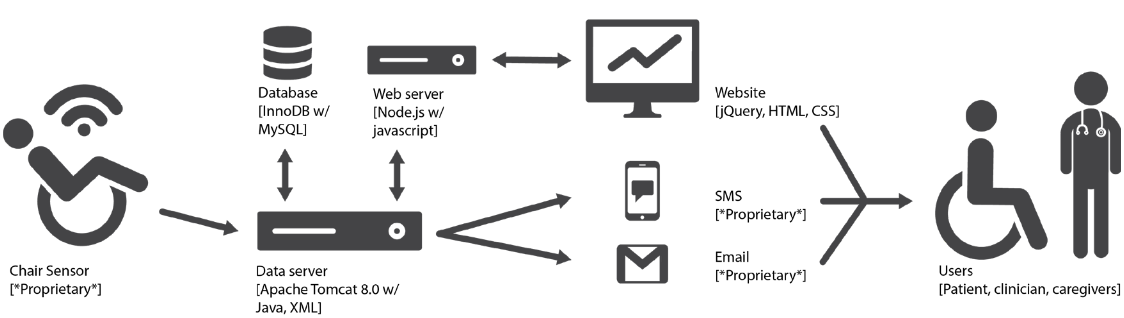

Figure 1. The mHealth system flow of the Tilt Tracker.

a secure server. This data is then securely stored, rendered, and distributed to a number of communication platforms for clinician and patient use.

Technology

The Tilt Tracker is installed under the seat base of a power wheelchair and does not physically make contact with the user. Placement under the hard seat pan eliminates the potential for ulceration or shearing. This device requires no interaction with the user, and mobile technology allows for remote controlling of the device. Remote control over the software eliminates user error and allows for discrete conflict resolution and iterative redevelopment of the software. The data can also be transmitted directly to the patients' and/or providers' communication platforms of choice (e.g., SMS text message, email, website), which eliminates the need for secondary app involvement.

The Tilt Tracker design includes a gyroscope, broadband connector, 4G/Wi-Fi adapter, pressure sensors, and a microcontroller. Custom software written in C# with Unity polls the sensors to collect PR data. Objective measurements of PR include angle, occupancy, and time. An algorithm then interprets the measurements to indicate a PR.

PR Measurement

Differences for angle were expected to vary based on their orientation in space utilizing gyroscope technology. Preliminary evidence for instrument accuracy and reliability regarding angle measurement has been demonstrated using a verification protocol that was developed for Food and Drug Administration product engineering. The gyroscope technology was originally tested at a range of angles a patient in a wheelchair is expected to recline (range of 0 to 70 degrees). The Tilt Tracker device rested at these standardized inclines, and the angle calculation was recorded 20 times per incline. The measurement was considered to pass if the angle recorded was within two degrees of the standard angle. The technology deviated on average by 0.6 degrees from the standard. Return values maintained a low standard deviation of 0.14 degrees. The testing demonstrated a passing value for every angle and every measurement, yielding a result of 100% accuracy under the pass criteria.

Per guidance from zero-defect sampling methods, tests with random variables that follow a binomial distribution require a full pass rate within at least 58 trials to infer 95% confidence in the consistency of the readings. Accordingly, an additional 60 trials were conducted at 0, 10, 20, 30, and 40 degrees. The Tilt Tracker device rested at these standardized inclines, and the angle calculation was recorded 60 times per incline, with 300 total trials. The same pass criteria used for the first round of testing was set for this series of trials. Again, the testing demonstrated a passing value for every angle and every measurement, yielding a result of 100% accuracy under the pass criteria.

Differences in human occupancy are measured by force sensitive resistors placed below the wheelchair pillow. These sensors are 0.5 mm thick and include two conductor planes that, when touching, complete a circuit indicating occupancy. Different weights applied to different surface areas identify positive readings. A variety of common seating materials (e.g., standard foam, gel, and air) were used in the testing to account for variability from seating products. Standardized weighted objects (8" × 8", 10" × 10", 12" × 12", 14" × 14") were systematically placed in specified locations similar to where an individual's weight would be distributed on a wheelchair seat. These weights were then applied until a pressure threshold was achieved. The sensitivity was iteratively set to increase maximal sensitivity. This process was repeated 60 times for every position, generating a total of 1,620 tests, which yielded 100% accuracy under our pass criteria. This preliminary evidence demonstrates viability of occupancy detection. Tests are being conducted to refine the current sensor technology, and exploratory studies are planned to examine infrared thermal measurement to detect human occupancy.

PR Detection

Once measurements have occurred, the software sends the data immediately to a secure web server. The dedicated web server receives angle and occupancy data from the chair sensors, interprets the data for PR detection, stores this in an encrypted database, and can distribute the data accordingly. See Figure 2 for the initial PR detection algorithm.

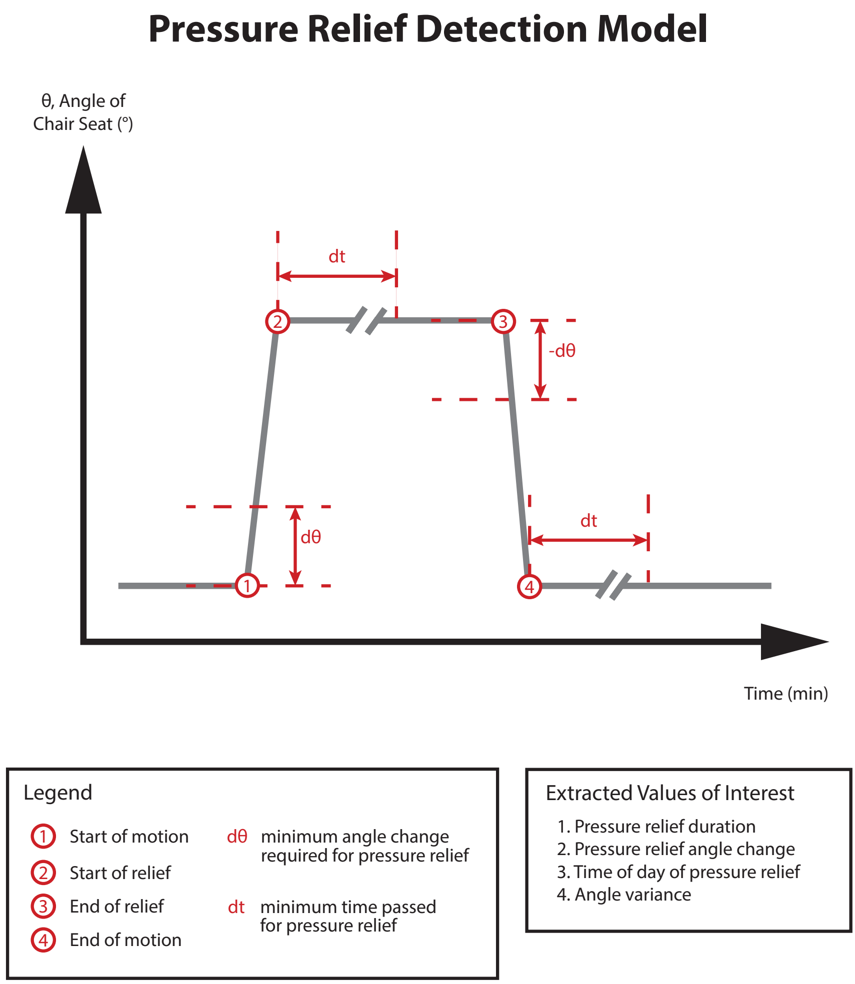

Figure 2. The model for detecting a pressure relief.

Presently, the algorithm has demonstrated preliminary accuracy in lab scenarios that include controlled trials and those that contain noise in the testing. Recordings of PR consist of continuous angles backward and forward from a starting point, complete angle back of approximately 45 degrees, and at least 30 seconds of delay at the tilted angle. The algorithm has properly and consistently identified each of the four points for classification in 15 controlled trials, with the goal of 60 trials to meet zero-defect sampling methods recommendations. Simulated PRs have also been recorded that include noise in the angle readings at various stages of the PR. Six noise scenarios have been constructed that include interruptions and contextual factors that could disrupt an accurate reading, such as conducting a reading when the wheelchair is positioned on a non-flat surface. Currently, 15 tests per noise scenario have been conducted, with the goal being 60 tests at each scenario. The current results have demonstrated preliminary evidence that the algorithm will properly and consistently identify each of the four points during controlled and noise scenarios. Ongoing scenario testing is being conducted, and future directions will include analyses of pressure changes by the force sensitive resistors as a PR is occurring.

PR Data Rendering and Communication

Once the measurement data has been received by the secure web server, the data is interpreted for an adequate PR and stored on an encrypted database. This server allows for the creation, reading, updating, and deletion of all data in the Tilt Tracker. The server can also send SMS messages and emails to wheelchair users to reinforce PR behaviors or to clinicians to alert for poor PR adherence. The current web server design uses an Apache Tomcat 8.0 server and runs Java script code.

To display the data, the Tilt Tracker web portal requests data from the web server and renders it in a web browser accordingly for the patients' and providers' use. The portal is password protected and allows the user to visualize PR adherence in a number of graphical interfaces. To contextualize PR adherence, patients and providers can review the PR data and set goals on the website (Figure 3).

The current web portal design allows goals for PR angle, duration, and time between subsequent PRs to be made. The current design also allows for an Excel download of angle data, a PDF download of PR data visualizations, input of patient medical history, documentation of events throughout patient treatment, patient control of viewing permissions, and enrollment for the communication services (e.g., SMS, email). This current design uses a Node.js web server, runs Java script code, renders pages with HTML5 and CSS, renders graphs with Google Charts, and generates PDFs with jsPDF.

Beta testing of the mHealth software system was conducted, and the system is considered ready for use in the pilot intervention study. Testing was an iterative process in which the engineering team trialed the functions of the communication platform while building its capabilities. Stakeholders from the spinal cord injury medical team (e.g., physicians, psychologist, physical therapists, occupational therapists) tested the functionality and made recommendations for changes. This process occurred over the course of two years during which software engineers and designers from the University of Utah's GApp Lab, a partner in this proposal, developed and refined the software.

CONCLUSION

The Tilt Tracker technology is poised to make a significant impact because it offers objective measurement in real time to enhance personalized care for individuals who use a power wheelchair. Objective measurement prevents data inaccuracies due to

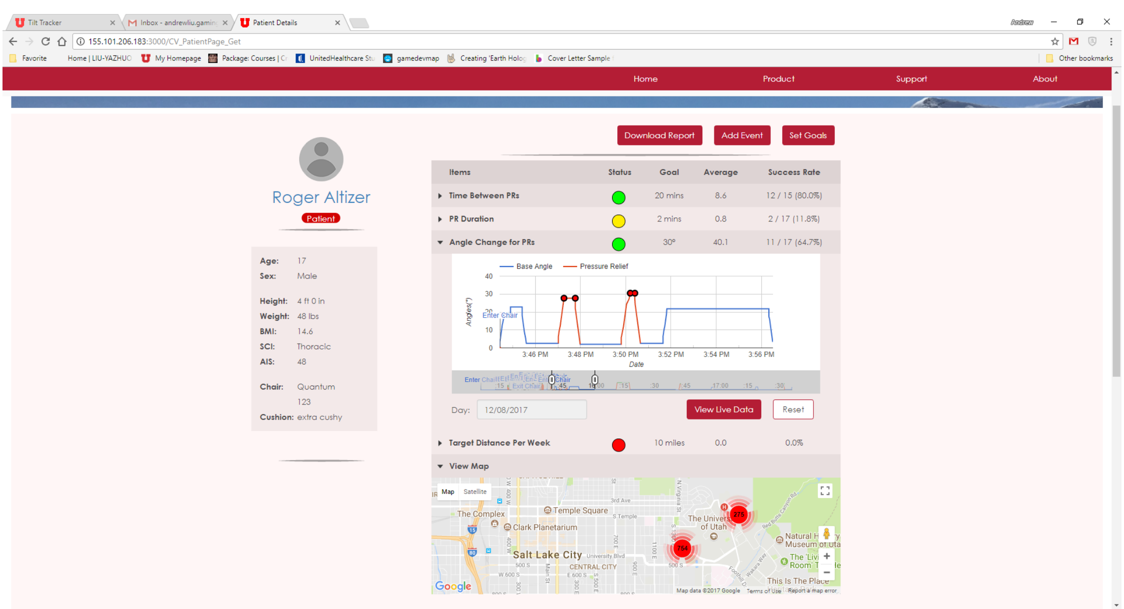

Figure 3. The website profile describing pressure relief behaviors.

self-reporting biases, such as social desirability and recall error (32-35). Further, this device monitors PR behaviors in real time. This monitoring not only allows for ecological momentary assessment of actual PR behaviors but provides a range of opportunities for in-the-moment interventions.

In order to enhance patient-provider communication and overall usability, the mHealth platform was designed to bypass middle processes so that it can transmit data directly to patients' and/or providers' communication platforms of choice (e.g., SMS text message, email, website). This eliminates the need for secondary apps to analyze, render, and disseminate the data or other second level technology that creates an unnecessary—and often preventative—barrier to accessing and using digital information.

Future goals of the research team are to develop more robust tests of the technology and to target this technology for the provision of stepwise levels of care based on patient behavior and response to treatment. Ongoing scenario testing of the PR algorithm is being conducted, and future directions will include analyses of pressure changes detected by force sensitive resistors. Specifically, the research team has begun a lab study characterizing actual pressure changes that occur while a PR happens. A primary goal is to develop predictive models for adequate PR behaviors based on this data. The research team is also developing intervention options with an emphasis on personalization, including behavior-pertinent alerts, individualized digital-based health education, and social media integration. Together, this assistive technology is expected to have significant value in improving ulcer prevention for individuals living with disabilities that require the use of a power wheelchair. Improved ulcer prevention will ultimately promote greater independence and fuller participation in community living.

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