Improving Maternal Labor Monitoring in Kenya Using Digital Pen Technology: A User Evaluation

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Abstract— **Paper-based systems for monitoring maternal labor have been shown to reduce life-threatening complications in low-resource environments; however, significant barriers exist to the use of these tools in developing countries. This paper presents the PartoPen – a digital pen system that enhances a common labor-monitoring form known as the partograph. The PartoPen system provides real-time data feedback and reinforces birth attendant training, while retaining the paper-and-pen interface currently used by most healthcare workers. In this paper, the results from a preliminary user evaluation of the system in a Kenyan hospital are described. The qualitative results collected in this study indicate that the PartoPen system is easy to use, and addresses many of the current barriers facing effective partograph use in developing countries.**

Keywords-maternal health; ICTD; digital pen; partograph

I. INTRODUCTION

Maternal deaths are estimated to be between 350,000 and 500,000 worldwide, with approximately 99% of these deaths occurring in the developing world [1]. In addition, maternal morbidities, which include fistula, uterine rupture and prolapse, and mental health concerns, are estimated to be between 15 and 20 million cases per year. Treatment, if available, for these complications is estimated to cost $6.8 billion per year [2].

The World Health Organization (WHO) advocates the paper partograph as the single most effective tool for monitoring labor and reducing labor complications in developing countries. The partograph facilitates the tracking of maternal condition, fetal condition, and cervical dilation versus time during labor [3]. Used correctly, the partograph can serve as a tool for early detection of serious maternal and fetal complications during labor. Especially in rural clinics, early detection allows transport decisions to be made in time for a woman to reach a regional facility capable of performing emergency obstetric procedures. However, in order to be effective, the partograph must be used correctly. A recent study in Kenya reported that while 88.2% of the 1057 evaluated patient records contained a partograph, only 23.8% of the forms had been used correctly [4]. This is not unusual for developing countries where lack of training and continuing education, exacerbated by limited resources, represent serious barriers to effective partograph use [5, 6, 7].

The goal of the PartoPen project is to increase the effectiveness of the partograph using an interactive digital pen [8]. When used to record the progress of labor on the partograph, the PartoPen both validates entered data in real time and alerts attending health care providers to conditions that require additional observation or intervention. Local data processing on the digital pen interprets the measurements made on the partograph form, which ameliorates the form complexity and data interpretation challenges often cited as significant barriers to partograph use. The PartoPen thus provides a low-cost, and intuitive solution that directly addresses identified barriers to successful partograph use.

II. RELATED WORK

There is a large body of research that examines the potential relationships between paper-based systems and digital tools, particularly mobile phones. Mobile phone tools have been designed to simplify data collection [9, 10], improve community health worker performance and effectiveness [11, 12, 13, 14, 15], and digitize data from paper forms [16, 17].

Digital pens offer the unique affordances of retaining the physical motion of natural writing, and simultaneous creation of a paper and digital record. Digital pens have been customized for context-specific research tools [18, 19, 20, 21] due to their programmability, portability, audio and note synchronization, and their ability to digitize sketches as well as handwritten notes for easy transmission via email. Digital pens have also been explored in the context of health and disability research to support haptic audio feedback for those with visual impairments. The TraumaPen [22] integrates paper emergency patient intake forms with a digital display component to reduce redundancy of verbal data transmission between health care practitioners

Prior research related to improving the partograph includes the ePartogram device developed by Jhpiego [23], and the partograph e-Learning tool created by the WHO [24]. Three ePartogram implementations are currently being developed, including an Android tablet application, a digital clipboard

system, and a custom hardware solution. Testing and evaluation of these implementations has not yet been conducted. The e-Learning tool is administered to facilities like KNH via CD-ROM, and it used in classrooms or seminars for nursing and medical students. The e-Learning tool is designed solely for educational purposes, and does not contribute directly to improved labor monitoring at the point of care.

To the best of our knowledge, the PartoPen system [8] is the only standalone digital partograph solution that can be used interchangeably as a training tool *and* in active labor theaters.

III. THE PARTOPEN SYSTEM

The PartoPen provides data validation, task-oriented reminders, and context-specific audio feedback in real time. Tapping the pen in different areas on the WHO partograph form provides additional audio instructions taken directly from the WHO partograph manual, which reinforces birth attendant training. The pen detects abnormal labor progression by analyzing data entered on the partograph form, and provides context-specific audio feedback to encourage birth-attendants to take appropriate action.

The PartoPen is able to operate in resource-challenged environments. It requires no network connectivity to operate, although when available, it can take advantage of network resources. The dot pattern, printed on the partograph forms using a standard laser printer on standard white printer paper, allows the pen to synchronize written text with recorded audio. Most importantly, the PartoPen is low cost, durable, consumes very little power, requires minimal training, and enhances rather than replaces the simple paper tool in ubiquitous use in the developing world.

The PartoPen system uses off-the-shelf digital pen technology. The digital pens used in the PartoPen system interact with printed microdots on paper forms, and do not require any external location-detection device to detect pen placement or gestures. The digital pen used to implement the PartoPen system includes a speaker, a microphone, 3.5mm audio headphone jack, up to 8GB of memory storage (or 800 hours of audio recording storage), an OLED display, a rechargeable lithium-ion battery, and a micro-USB connector for charging and data transfer (Figure 1). The ink cartridges come in a variety of colors, can be ordered through the pen manufacturer, and are easily replaced without needing to replace the entire pen.

The digital pens interact with the paper partograph form using a Dot Positioning System (DPS), as illustrated in Figure 2. The infrared camera in the tip of the pen detects microdots printed on the paper. The microdots can be printed using any standard laser printer (with a resolution of at least 600 dots per inch), thus making the partograph form production cost very low. The microdots encode X and Y coordinates, which the pen uses to detect its location on the page. The PartoPen leverages the DPS

Figure 1. The digital pen used in the PartoPen system is depicted. The speaker, microphone, OLED display, USB connector, audio jack, memory storage, and replaceable ink tip are identified.

system to trigger certain actions, such as audio prompts when health workers tap or write in specific areas of the form. For example, if a nurse taps one of the "instructional text" areas on the form, it will trigger an instructive audio prompt from the digital pen's speaker. The audio prompts can be recorded in multiple languages, and can be updated if protocols or use instructions change over time.

IV. USER EVALUATION

In addition, an initial feasibility assessment of the PartoPen was conducted in August 2011 at seven urban and rural health clinics in Kenya. We found that the paper partograph is required in all labor theaters, but form accuracy and completion were as previously reported by others [25]. In March 2012, the first iteration of the complete PartoPen system was evaluated at KNH with nurses in the labor ward.

A. Study Site

The maternity wing at KNH contains 22 beds, but often holds upwards of 40 patients. Patients are separated into "normal" and "acute" rooms, based on whether pregnancy complications have occurred. The number of nurse-midwives per shift varies between five and ten. There is one OB/GYN medical professional who is on call throughout the day, as well as medical students who are completing their clinical requirements. The nurse-midwife community at KNH is close-knit, and the researchers observed that many arrive earlier and leave later than their shifts require in order to enjoy the evident camaraderie. These social times gave the researchers additional opportunities to inquire about PartoPen use, while allowing the nurse-midwives to ask questions about the system and build rapport with the researchers.

B. Methodology

During this one-week evaluation, six of the KNH labor ward nurse-midwives were interviewed and asked to complete a practice partograph worksheet with the digital pen. The

interviews and worksheet tasks were conducted with individual nurses because nurses were too busy with patients to participate as a group. Semi-structured interviews took place before and after the nurses completed the partograph worksheet. The pre-worksheet questions focused on current perceptions of partograph use in the labor ward, and the current issues nurses experience when charting the partograph. The nurse-midwives then received a 10-minute demonstration of the PartoPen functionality, which highlighted key elements of the system's functionality, including audio decision support and time-based reminders. Participants were then asked to complete a worksheet by plotting sample patient data on the partograph form using the digital pen. Each nurse completed the same "practice patient" worksheet, which illustrated a case of prolonged labor and subsequent labor augmentation or induction. This task took, on average, 15 to 20 minutes. After completing the worksheet, individuals were asked about the usability and practicality of the system. The entire process took 30-40 minutes.

The researchers used a standard grading rubric, which follows the WHO standards for correct partograph completion, to evaluate the worksheets. The primary goal of this evaluation process was to gain an initial impression of common partograph errors. In addition, researcher observations during the worksheet completion task were coded to determine the frequency of errors made by the PartoPen system. Rapid, iterative design changes were made to address observed PartoPen errors, and subsequent nurses used updated versions of the PartoPen software to complete the worksheet.

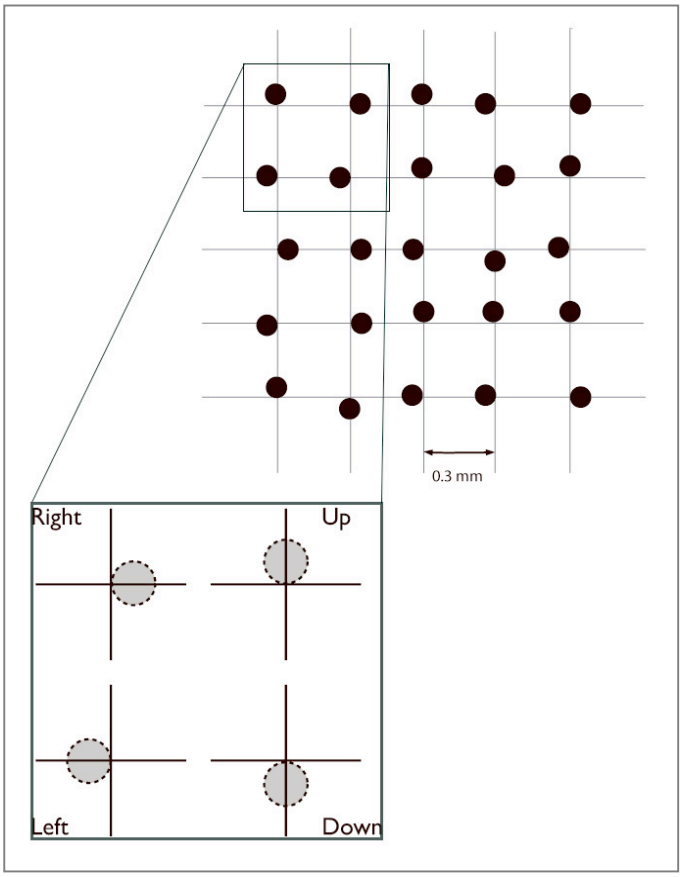

Figure 2. The Dot Positioning System (DPS) uses printed microdots, as seen above, arranged in specific patterns. The dot pattern allows the digital pen to determine where on the form it is placed, thus allowing the pen to interact in meaningful ways with specific form regions. The dot pattern is patented by Anoto AB Group.

V. OBSERVATIONS

A. *Perceptions of Current Partograph Use*

The KNH nurse-midwives who were interviewed indicated that the number of patients per nurse-midwife ranges from 5 to 15. In contrast, the WHO recommends a maximum of three patients per nurse-midwife, so that patient measurements can be taken half-hourly, which is the time interval required by partograph completion protocols. The high ratio of patients to nurse-midwives appears to be a primary reason for the low partograph completion rates observed at KNH. As two midwifes stated:

"When a midwife has more than three patients, she can not take half hourly measurements for each one."

"It depends on the ratio of the patients you have. If you have more than three people in labor, you can't fill it."

As the largest referral hospital in Nairobi, many patients are admitted to KNH after initial treatment at a district or regional level care facility. KNH nurses and doctors indicated that the difference in the level of care available at satellite healthcare facilities often led to unmanageable complications after transfer to KNH. In addition, the partographs used at district hospitals are rarely sent with the patient due to district record keeping protocols. This imperfect referral system contributes to low rates of partograph completion at KNH. The key suggestion by KNH doctors was for a referral system based on partograph data at the district hospitals, which would alert KNH to patients' conditions before arrival. The integration of the PartoPen into such a system is described in Section V.

The KNH medical staff also reported issues with partograph use. Several interview participants reported that junior doctors, interns, and new nurses can make mistakes completing the partograph because they have been inadequately trained how to plot the data.

"Number one, you get new nurses coming to the labor ward who do not know how to use the partograph, so we have to educate them on how to use the partograph. Number two, you get students and they are using a partograph and they make mistakes. Even the doctors themselves, they do not know how to plot. They ask us."

The current system for correcting errors on the partograph forms is to replace the incorrect form with a new form, and re-plot the correct data, rather than correct the mistakes on the existing form. This practice can also contribute to low partograph completion rates and transcription errors. Despite

these problems, the nurse-midwives were vocal advocates of the partograph:

"It is very helpful. We cannot do without the partograph. It is an important tool for monitoring labor."

"If it is used appropriately it is very helpful, but if you don't use it appropriately, it will not help you. I think it is helpful because you can make an immediate intervention just by looking at it. You just look at it and evaluate, and you take quick action."

B. Pen Usability

Handwriting recognition, and interrupted and repetitive audio prompts, were the largest sources of PartoPen use issues during the worksheet completion task. Cervical dilation, plotted with an 'X' on the form, was incorrectly categorized by the digital pen 50% of the time, and repeated and interrupted audio had a desensitizing effect on participants, who started to ignore the audio prompts later in the task. To improve the handwriting recognition rates, a binomial classifier was implemented, which significantly reduced the number of incorrectly classified 'X's. Before the last two participants completed the worksheet, the code was modified to prohibit audio interruptions or repetitive audio within a certain time frame. The last two participants did not exhibit the desensitization observed with the first four nurse-midwives who completed the task.

A common practice during the worksheet completion task was for participants to think for several seconds before plotting data on the partograph. During the thinking interval, participants would rest the digital pen tip on the partograph form, which could trigger an unintended audio prompt. One participant was so distracted by the unintended audio while he was thinking that he put the digital pen down, took a ballpoint pen out of his pocket, and used this pen to rest on the form while he thought about the measurement. Once he had finished thinking, he put the ballpoint pen back in his pocket and made the measurement on the partograph with the digital pen

Pilot study participants made several common errors during the worksheet completion task, the most common of which was plotting the measurements on the incorrect vertical time line. Participants would trace the vertical time line up and down the form to plot the measurements in the different areas of the form, but would often get interrupted or distracted in the busy labor ward environment. The non-intuitive time scale on the partograph is a significant source of user error.

The second most common error was incorrectly plotting the descent of the fetal head. The partograph used in the worksheet completion task was slightly different from the partograph currently used in the KNH labor ward, which was the primary reason for the errors when plotting this measurement. Currently KNH is transitioning to the newer WHO partograph, the version currently employed by the PartoPen system. Thus, in future studies at KNH, the errors associated with form differences should be reduced.

After participants completed the worksheet using the PartoPen, they were asked several questions about the system. One important finding is that the knowledge of the nurse-midwives at KNH exceeds the current information available on the pen. Because of this, the PartoPen was seen primarily as an alert or reminder tool, rather than a source of useful medical knowledge.

"It alerted me that I had to take an action. The patient was going into distress. It is good for reminding even though I already know what to do."

Participants were divided about whether the PartoPen would be helpful in managing the high patient load at KNH. One participant saw the audio reminders as being helpful because she sometimes gets overwhelmed when working with many patients, and the pen would help her remember.

"When working with many patients, it is easy to overlook things when you're overwhelmed. This would help even when you are overwhelmed."

Figure 3. Two medical residents working together to complete the worksheet task.

Another participant, however, saw the audio reminders as unhelpful, because with so many patients, she would not be able to respond to the audio reminders anyway.

"This would help, but you have to have a smaller number of patients. The way it's alerting you, we're observing after 30 minutes. It we have more than five patients we can't do it accurately. So I think it's helping you, but with a good number of patients."

Other participant feedback focused on the physical characteristics of the digital pen. It was suggested several times that a lanyard was needed for the pen, and that a cap was necessary to keep ink from getting on their coats. One participant said the pen was a bit heavy, but she would still use it. Participants were also very interested in the durability, battery life, ink replacement aspects of the system, and the ability of the pen to correctly read a form that had been distressed (e.g., spilled on).

Overall, the perceived usability of the system was high. Participants were able to use the PartoPen without any training, and discovered the functionality of the system by using the partograph as they normally would. A ten second tutorial was enough to explain how to turn the volume up and down on the pen, and how to access instructions if needed.

"I would use it all the time. It is easy to carry, and helpful."

"This will go a long way in increasing our monitoring of patients with the partograph. It alerts you early, it alerts you on time, and it is just a normal pen."

VI. Future Work

Two further pilot studies will be conducted in June and July 2012. The first study will evaluate the PartoPen system in University of Nairobi classrooms with approximately 100 third and fourth year nursing students. The objectives of the in-class study are to determine the usefulness and appropriateness of the PartoPen system as a training tool, determine the necessary amount of training and instruction required to full-utilize the PartoPen functionality, and to encourage discussions about how the PartoPen system would ease the transition from in-class work to clinical settings. The second study will be conducted at KNH and Pumwani Maternity Hospital, both of which are located in Nairobi. The objective of the second study is to measure the impact of the PartoPen system on the partograph completion and error rates over a period of one month. Partographs completed with the PartoPen system during the month-long study will be compared to the partographs completed without the PartoPen one month prior to PartoPen use.

Future work will also focus on integrating the PartoPen into the current patient referral system. Using the PartoPen to fill out a partograph form simultaneously creates a paper record and a digital record, which is stored on the pen. This digital record can easily be transmitted from a PartoPen at the district level hospital to the referral hospital using a cellphone connection, a series of SMS messages, or an Internet connection. The paper partograph form can then be kept at the district level hospital for their record keeping purposes, while the digital record can be printed out at the referral hospital before the patient even arrives. Improving the referral system and improving partograph completion rates are essential for improving the overall level of patient care, and reducing the rates of maternal mortality caused by mismanagement and poor labor monitoring.

VII. Conclusions

The PartoPen provides a flexible and intuitive tool, that is novel with respect to other solutions that have been proposed to improve partograph adoption. The PartoPen supports existing WHO protocols, but can be easily adapted to local protocols and languages, making it adoptable by any clinic in any part of the world. Retaining the current paper-based system also reduces the training overhead that is often introduced by high-tech solutions, and provides the potential for interfacing with the large number of other commonly used paper forms in the healthcare sector. Retaining paper, however, does not create a digital disadvantage. The PartoPen system provides a seamless bridge between paper-based systems, which have yet to be supplanted, even in developed countries, and electronic medical record systems. Providing a link between digital and paper data is a key feature of the PartoPen system, which will make it useful for sustaining the delivery of quality healthcare and improving the maternal condition at the community level. Finally, the flexible PartoPen software allows the pen to be used at all levels of care, from undergraduate nursing students to experienced nurse midwives, from rural birth attendants to trained physicians. As one study participant said: "It's perfect for research, it's perfect for care."

The PartoPen facilitates monitoring and evaluation by capturing time stamped digital data. Implementing the PartoPen will not only improve partograph completion rates, and thus improve quality of care, but will improve accountability in the current system, which has the potential to inform and accelerate adoption of policy initiatives regarding maternal care. The PartoPen's use as a research tool will thus provide long-term health impacts at the highest level of care. In order to reach Millennium Development 5 – improving maternal health – large-scale impact must be made. The PartoPen system directly addresses some of the most significant barriers to delivering quality maternal care in developing countries using an innovative technology applicable at *all* levels of care.

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