

The PartoPen in Practice: Evaluating the Impact of Digital Pen Technology on Maternal Health in Kenya

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ABSTRACT

This paper critically examines the use of digital pen technology at two key points in the healthcare system in Kenya: nursing student training and patient care in public labor wards. The PartoPen system – a digital pen software designed to enhance the paper labor monitoring tool known as the partograph – was evaluated with 95 nursing students at the University of Nairobi (UoN), and with 50 nurses in the labor ward at Kenyatta National Hospital (KNH). Students using the PartoPen had significantly higher scores on partograph worksheets than students using a silent PartoPen, especially on challenging and high-risk labor cases and on difficult sections of the partograph. In the maternity ward study, nurses unanimously reported positive improvements in the number of partographs they were able to complete, but these qualitative responses were not supported by the quantitative data. We discuss the results of both studies, and what these results suggest about the potential value of the PartoPen at different levels of the healthcare delivery and training hierarchy.

Categories and Subject Descriptors

D.2.0 [Software Engineering]: General

General Terms

Measurement, Design, Experimentation, Human Factors

Keywords

Digital pen technology, partograph, maternal health, ICTD, Kenya

1. INTRODUCTION

The WHO estimates that 300,000 maternal deaths, 814,000 neonatal deaths, and 1.02 million stillbirths result each year from childbirth complications [1]. Almost all of these deaths occur in developing countries, where many could be prevented by the presence of a skilled birth attendant carefully monitoring the progress of labor. The partograph is designed to assist in the labor monitoring process, and is defined by the WHO as: “A record of all of the clinical observations made on a woman in labor, the central feature of which is the graphic recording of the dilatation

of the cervix, as assessed by vaginal examination, and descent of the head. It includes an Alert and Action line which, if crossed when recording cervical dilatation, indicates that labor is progressing more slowly than normal and intervention is required” [2].

Despite the documented benefits of correct partograph use [3,4,5], several recent studies in Africa have reported a significant gap between knowledge and practice [6,7,8,9]. The primary barriers to partograph use described in these studies include lack of training and continuing education and limited human and organizational resources.

The goal of the PartoPen project is to mitigate some of the barriers preventing correct and widespread partograph use with an interactive digital pen software and partograph forms printed with a background dot pattern that is recognized by the pen. Using only the digital pen and the existing paper form, the PartoPen addresses training and resource barriers by providing audio-based decision support, patient-specific reminders, and partograph use instructions. Prior PartoPen work at KNH [10, 11, 12] suggested that the PartoPen could be useful in multiple healthcare settings from initial training, to training reinforcement, to use with actual patients. These results motivated the design and implementation of the two studies described in this paper, which focus on populations at two ends of the healthcare spectrum: nursing students with little training or clinical experience using the partograph, and nurses at KNH, who are extremely well trained and have had many years experience using the partograph and working in the labor ward.

2. RELATED WORK

In addition to the PartoPen, several other solutions have been proposed to increase partograph use and help remove adoption barriers. The WHO has created the Partograph e-Learning tool [13], which focuses on improving and reinforcing the training nurses receive on correct partograph completion. Partograph e-Learning CD-ROMs are distributed to facilities like UoN, but are not given to every student or directly incorporated into the nursing curriculum. Single copies of the e-Learning tool are often passed from student to student throughout the academic year, placing the primary responsibility for learning the material upon the students themselves. Less than half of the students who participated in the PartoPen study had used the e-Learning tool. In a 2010 study conducted at UoN, researchers from UoN and the University of Manchester evaluated the educational impacts of the WHO e-Learning tool on partograph knowledge among third and fourth year nursing students [14]. Using a before-and-after study design, researchers found that overall scores among students improved, but remained disappointingly low even after using the e-learning

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tool. Some of the possible explanations that were given for these results were unequal access to computers, varying levels of basic computer skills among students, and the inability to transfer the training program from one computer to another. This study also underscored the apparent ineffectiveness of the current lecture-based partograph training that is provided by UoN, which was also a key finding of the nursing student PartoPen study. The Manchester study concluded that further evaluation and modification is needed on the e-Learning tool before widespread implementation is warranted, and that educating midwives and obstetricians to be positive partograph-completing role models is a potential solution to operationalize the education nursing students' receive in the classroom.

Jhpiego, a non-profit based in Maryland, is developing a digital ePartogram [15] device to replace the paper partograph system in hospitals like KNH. Jhpiego is currently testing a revised ePartogram implementation, which uses an Android tablet, but at this time, no data has been reported.

To the best of our knowledge, the PartoPen system is the only standalone digital partograph solution that can be used interchangeably as a training tool *and* in active labor theaters without altering the currently paper-based system or requiring significant additional training on the technology itself.

3. PARTOPEN SYSTEM DESIGN

The current implementation of the PartoPen system uses Livescribe (LS) 2GB Echo digital pens, which can capture and synchronize audio and handwritten text, and digitize handwritten notes into searchable and printable PDF documents. The digital pens include a speaker, a microphone, a 3.5mm audio headphone jack, up to 8GB of memory capable of storing approximately 800 hours of audio recording, an OLED display, a rechargeable lithium-ion battery, and a micro-USB connector for charging and data transfer. The LS digital pens [16] capture handwritten input and digitize paper content by using a unique location tracking and page identification technique patented by the Anoto AB group [17]. The Anoto “dot pattern” used by LS pens employs an invisible grid system on each sheet of paper where each gridline is spaced 0.3mm apart (see Figure 1). At each grid intersection, a microdot is printed on the page slightly offset in one of four directions – up, down, left, or right of the intersection itself. Each dot encodes two bits of location information based on its location relative to the grid and relative to the dots around it. The digital pen tip contains an infrared camera that captures 72 snapshots per second of these 6x6 grids of dots (i.e., each photograph contains 36 dots). The X and Y coordinates represented by the dots in the snapshot are translated and interpreted by the digital pen, and are mapped onto a specific page address in the Anoto pattern space. The entire pattern space covers an approximate area of 4.6 million km², which represents roughly 73 trillion unique sheets of letter-sized paper [17].

Using this technology, the LS digital pens are able to interpret where on a page the pen-tip is at all times, and recognize ink strokes from the stored coordinate data. The pens can provide meaningful audio and text output in response to interactions on the specific form regions by interpreting the location information encoded in the microdots.

The PartoPen is appropriate for use in resource-challenged environments as it does not require network connectivity to operate (although it can utilize available connectivity to transfer patient data between clinics), and uses a rechargeable lithium ion battery that can be charged using a standard cell phone charger.

The dot pattern can be printed on standard printer paper using a standard 600dpi laser printer, thus form creation incurs minimal additional cost. The digital pens themselves are affordable, durable, consume very little power, require minimal training, and enhance – rather than replace – the common paper-and-pen system in near-ubiquitous use in the developing world.

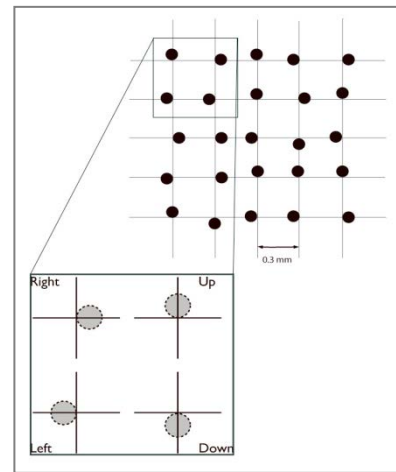


Figure1. The Anoto Dot Positioning System (DPS)

3.1 PartoPen Functionality/Features

Using the digital pen and paper technology described in the previous section, the PartoPen software provides three key pieces of functionality intended to facilitate partograph use and completion.

3.1.1 Use Instructions

One of the goals of the PartoPen system is to reinforce birth attendant training on correct use of the partograph, as lack of adequate training has been cited as a significant barrier to consistent use of the form. The WHO partograph user manual and a local partograph manual issued to clinics by the Kenyan Ministry of Health are the primary resources for partograph instruction in Kenya. These manuals are not generally portable, and are not easily located or utilized in busy labor wards. The PartoPen system makes the instructions found in these manuals accessible directly from the partograph itself. The PartoPen uses fixed print “button” regions around the partograph text to provide verbatim audio recordings of the instructions found in the partograph use manuals. Thus, by tapping on these “buttons,” nurses and nursing students receive short informational prompts on how to use each section of the form correctly.

The audio for each partograph section (e.g., fetal heart rate, contractions, etc.) is divided into short prompts less than 20 seconds long. By tapping the button a second time, users will hear the second prompt, and so on until all of the instructions have been played and the first prompt in the series repeats. The audio prompts are organized such that well-trained nurses can quickly access the high-level “refresher” prompts with only one or two taps, while students or new nurses can explore additional details of correct partograph use by tapping repeatedly on the same button.

3.1.2 Decision Support

One of the most commonly cited barriers to partograph use is the inability to interpret the data plotted on the partograph and to take appropriate action. Nursing students and less-experienced nurses often plot the data correctly on the partograph, but fail to derive

the meaning of the plotted data, or do not remember what actions to take based on the data that they have plotted. The decision support functionality of the PartoPen addresses this issue by interpreting plotted data based upon page location, and providing real-time feedback on the appropriate actions to take. Currently, the PartoPen provides decision support in three of the partograph sections: cervical dilation, liquor/amniotic fluid, and fetal heart rate.

The cervical dilation versus time graph has two decision support lines: the “Alert” line and the “Action” line (Figure 2).

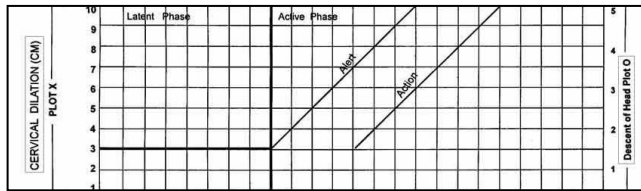


Figure 2. The cervicograph (where cervical dilation and descent of the fetal head are plotted) on the partograph. Shown are the “Alert” and “Action” lines, which are graphical indicators for birth attendants to recognize potentially high-risk labors when

Normal labor measurements are expected to stay on or to the left of the “Alert” line. If a measurement is plotted between the Alert and Action lines, the WHO protocol for the management of labor suggests several actions that should be taken for this patient. The “Alert” line was originally added to the partograph to provide an indicator of when to transport a woman to a facility that could provide emergency cesarean sections. Thus, in the event that the next measurement reaches the “Action” line, the patient can receive necessary care at an appropriate facility. Timely decision-making based on the cervical dilation measurements can be life-critical. The PartoPen system attempts to improve the responsiveness of this decision-making process by immediately calling attention to a concerning measurement and suggesting appropriate actions. On the PartoPen partograph form (see Appendix) four regions are defined: above the latent phase line, normal labor, between alert and action lines, and across the action line. Any measurement plotted above the latent phase line should be transferred onto the Alert line and the current clock time should be written below the measurement on the Alert line. If a nurse plots a measurement in this area, he or she will hear the decision support tone from the pen and the following text will scroll across the pen display: “Transfer measurement to the Alert line. Patient is now in active labor.” The second region – the triangle to the left of the Alert line indicating normal labor – does not trigger any response from the pen when a measurement is plotted there. Measurements plotted in the region between the Alert and Action lines will again trigger the decision support tone and suggested actions will scroll across the display. The region to the right of the Action line also responds to pen events by playing the tone and scrolling the suggested set of actions for that measurement.

3.1.3 Reminders

The labor ward at KNH delivers approximately 1000 babies per month during the “busy” months from October to March, or roughly 34 babies every day. On average there are 4-6 nurses working at a time. Based on survey data collected at the end of the PartoPen study, nurses on average are responsible for 5-7 patients during a day shift, and 7-10 patients during a night shift. The WHO recommends a maximum ratio of 1 nurse to 3 patients to ensure compliance with partograph completion protocols. In the

survey, nurses almost unanimously reported that staff shortage is the most common reason for low partograph completion rates. While the PartoPen does not replace nurses or supplement the shortage of nurses in the labor ward, it provides a reminder system intended to help busy and tired nurses keep track of when patients need measurements taken.

In general, measurements on the partograph are either taken every half hour, or every four hours. For example, fetal heart rate is recorded every half hour and cervical dilation is recorded every four hours. In theory, all of the half-hourly measurements should be taken during the same half-hourly exam; the same is true for all of the measurements taken every four hours. Using this information, fetal heart rate and cervical dilation measurements drive the half-hourly and four hour reminders, respectively, for all measurements in these time brackets. For example, if a nurse only plots pulse (a half-hourly measurement) on the partograph without plotting fetal heart rate during the same exam, he or she will not receive a reminder in half an hour. The decision to implement the reminders in this way was designed to reduce the number of reminders a nurse would receive for a single patient, as nurses are already caring for more patients than is recommended during any given shift. A prior PartoPen study [11] also showed that nurses quickly become desensitized to pen output if audio is frequently emitted from the pen. Using fetal heart rate and cervical dilation as the reminder drivers was based on data from a 2011 study that identified these partograph sections as the most commonly filled out, with fetal heart being filled out 90% of the time and cervical dilation being plotted 97% of the time at KNH [18].

Reminders are implemented using separate timer threads that get created every time a nurse plots a fetal heart measurement or a cervical dilation measurement on the partograph. The timer is passed a patient identifier parameter that corresponds to the unique page ID encoded in the dots on the form. When the timer thread runs, the reminder tone (distinct from the decision support tone) is played, and the patient ID (captured during patient intake) scrolls across the OLED display along with a summary of the measurements that need to be taken at that time. If the nurse has not entered a patient ID, or the pen has failed to capture an entered patient ID, a general reminder message scrolls across the screen indicating the measurements that “a patient” needs attention at that time.

4. NURSING STUDENT STUDY

Training and continuing education have been cited as serious barriers to nurses’ willingness and ability to use a partograph form to monitor labor. The nursing student PartoPen study examined the potential benefits of using digital pen technology with nursing students at UoN. The goal of this study was to evaluate the impact of the PartoPen system on students’ abilities to correctly complete a partograph using case study patient data. The results indicate that the PartoPen system significantly improves student scores on partograph worksheets, especially for high-risk or complicated patient cases, which corresponds to increased audio output from the PartoPen.

4.1 Methodology

In June 2012, the PartoPen was evaluated with 95 nursing students at the University of Nairobi (UoN). Students were asked to use a PartoPen in one of three modes to complete a partograph worksheet. In addition, students were asked to participate in a focus group discussion following the worksheet task. Local research assistants recruited participants from the population of 148 third and fourth year nursing students at the UoN. All

students had previously been taught how to use the partograph to monitor labor during a 10-15 minute in-class discussion as part of the nursing curriculum, and during their clinical rotations in the maternity wards. The 95 student participants were separated into three groups. Group 1 was the control group; Groups 2 and 3 were the intervention groups, which focused on the discoverability of the functionality, and the affect on partograph performance, respectively. Each student in all three groups was given a partograph worksheet with two of three possible case studies, which represent two of three possible labor outcomes. Mrs. A's labor represents an uncomplicated timely labor that progresses without medical intervention. Mrs. B's data illustrate a case of prolonged or obstructed labor, which is addressed by the administration of oxytocin, a labor-inducing drug, and results in a spontaneous vaginal delivery (SVD). Finally, Mrs. C's labor progression illustrates an increasing number of complications, including fetal distress, and ultimately results in a cesarean section (CS).

Group 1 students completed a partograph worksheet task with a PartoPen in "silent logging mode," and received no instructions on how to use the technology. In the "silent logging mode" the digital pen recorded student answers, and logged when and where on the form student answers would have triggered feedback from a fully enabled PartoPen. This control group provided a baseline for students' performance on the partograph worksheet task.

Group 2 completed the same worksheet task, but used a fully functional PartoPen in "use" mode. The PartoPen software used for the student pilot had two key pieces of functionality: use instructions and decision support. For the nursing student study, the reminders (enabled only for the maternity ward study) were disabled. In addition, playing pre-recorded spoken audio provided the decision support, in contrast to the maternity ward decision support, which was provided by scrolling text across the OLED display. Group 2 received no training on how to use the PartoPen. In "use" mode, the digital pen logged when errors were made on the form, which were compared to the baseline results recorded from the first class of students. Students in this group received audio feedback from the pen when data was entered incorrectly on the form, and thus, corrected errors were also recorded in this mode. The data collected from this group tested the discoverability and intuitiveness of the PartoPen functionality.

Group 3 received a fully functional PartoPen and a 15-minute introduction and demonstration of the PartoPen system before completing the partograph worksheet task. The digital pen recorded errors, corrections, and all marks made on the partograph form. Thirty-four relevant instructional audio prompts were available for all students in Groups 2 and 3, but only the Group 3 students were informed how to access the instruction prompts by tapping the pen on the text to the left of the graphs on the form.

By comparing the results of Group 3 with the results of Group 2, we were able to determine the effect of providing a PartoPen tutorial on partograph performance. Group 2 attempted to simulate PartoPen deployments in which students/nurses do not receive training prior to using the device. Given that most of the PartoPen functionality is "pushed" to users during normal form completion, we hypothesized that training on the PartoPen system would not significantly alter the results of participants with the same level of prior partograph knowledge – Groups 2 and 3, respectively.

The Ethics Review Committee (ERC) at UoN and the Institutional Review Board (IRB) at University of Colorado Boulder approved the PartoPen research and study design, and all relevant issues of informed consent were addressed prior to participation.

4.2 Results

Scores were calculated as a percentage of total points correct out of the total possible points. An unpaired t-test was performed to identify differences between groups, particularly if Groups 2 and 3 showed any improvement in performance over Group 1 – the control group. There was not a significant difference in the scores for Group 1 (M=.582, SD=.183) and Group 2 (M=.632, SD=.101); $t(25)=0.880$, $p=0.388$. There was also not a significant difference between Group 1 and Group 3 (M=.655, SD=.142); $t(23)=0.472$, $p=0.641$. These data are recorded in Table 1.

Table 1. Average scores on worksheet completion task divided by PartoPen functionality group number. This table illustrates an increase in student performance with increasing PartoPen functionality and training.

Group # and PartoPen Mode	Avg. Score
Group 1 – silent logging mode	58%
Group 2 – use mode, no training	63%
Group 3 – use mode, training	66%

The average scores for each group based on patient case study data are shown in Table 2. Using an unpaired t-test, the difference between Group 1 (M=.520, SD=.141) and Group 3 (M=.722, SD=.089) for the patient case study Mrs. C, a prolonged labor resulting in a CS, was found to be significant; $t(8)=2.709$, $p=0.0267$. These data suggest that for more challenging or complex labor cases, the availability and utilization of the PartoPen instruction prompts promotes more accurate form completion.

Table 2. Average scores on worksheet completion task divided by patient case study and group number. This table illustrates a significant difference (unpaired t-test with $p < .05$) between Groups 1 and 3 for a prolonged CS labor.

	Normal Labor	Prolonged SVD	Prolonged CS
Group 1	61.3%	58.6%	52.0%
Group 2	63.5%	62.9%	62.9%
Group 3	65.2%	62.7%	72.2%

After each group completed the worksheet task, students were asked to participate in a short focus group session. The focus group discussion centered on how the partograph is currently taught, how it is used in the classroom, and the students' experiences using the PartoPen to complete the partograph. Currently, the partograph is covered only briefly in the nursing curriculum; practice and actual use occur during students' clinical rotations in the labor ward. The students were asked if there were particular parts of the partograph that were difficult to complete, or which were not adequately covered in class or during clinical rotations. Students unanimously reported that plotting contractions was one of the most difficult sections of the partograph, because both duration and frequency are plotted together using a combination of bar charts and coloring patterns. Students also reported unanimously that plotting descent of the fetal head was challenging. Difficulties plotting descent of the fetal head can also be attributed to having to plot on the same graph as another measurement (cervical dilation), but may also be due in part to the

nursing school transitioning to a different partograph version that requires users to plot the descent in increments of one instead of two, and on the left side of the graph instead of the right.

In Chart 1, the completion scores for plotting contractions for each group are shown. These data illustrate that improvements were made in all three case studies (Mrs. A, B, and C) between groups that did and did not use the PartoPen when plotting contractions. There was a statistically significant improvement in contraction plotting on the Mrs. C case study between Group 1 (M=.513, SD=.232) and Group 3 (M=.803, SD=.139); $t(8)=2.399$, $p=0.0433$. In Chart 2, the student data for completing descent of the fetal head measurement is shown. For the descent measurements, there was significant improvement on the Mrs. C case study between Group 1 (M=.337, SD=.152) and Group 2 (M=.585, SD=.162); $t(10)=2.699$, $p=0.0223$. There was also a very significant improvement on descent plotting on the Mrs. C case study between Group 1 and Group 3 (M=.705, SD=.137); $t(8)=4.028$, $p=0.0038$. These results are consistent with the PartoPen functionality as audio from the pen is only triggered in cases where prolonged or obstructed labor occurs.

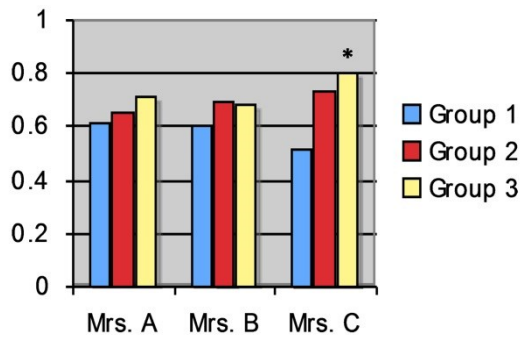


Chart 1. Partograph worksheet completion results for contractions organized by student group; * = $p < .05$

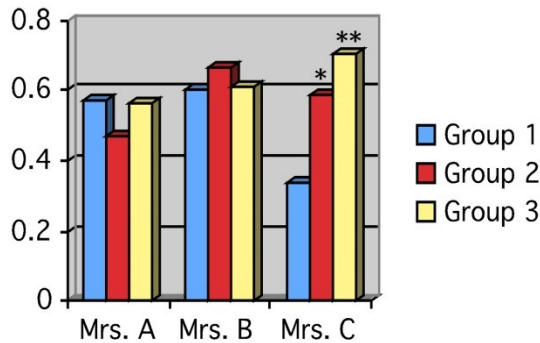


Chart 2. Partograph worksheet completion results for descent of the fetal head organized by student group and by case study; * = $p < .05$; ** = $p < .01$

Overall, the PartoPen study at UoN suggests that using the PartoPen in classrooms can improve students' ability to correctly complete a partograph form, particularly for complex cases, and for the most challenging sections of the form. The study results also suggest that training on the PartoPen device does not significantly affect student performance on partograph completion tasks. These results support the hypothesis that a significant increase in partograph completion and accuracy can be achieved with little or no training on the device itself due to the intuitive

design, push-based functionality, and enhancement – rather than replacement – of the current paper-based system.

5. MATERNITY WARD STUDY

The second PartoPen study took place at Kenyatta National Hospital (KNH). The primary goals of this study were to (1) evaluate the PartoPen for usability in labor wards; (2) determine if PartoPen use impacts partograph completion, and (3) investigate the broader impacts of the PartoPen on patient care and maternal health outcomes. The primary focus of the maternity ward study was the evaluation of the PartoPen as a clinical decision support system (CDSS), and the testing of its more advanced features, – reminders and reminder IDs – which were not active or necessary during the nursing student study.

A previous systematic review identified five key features of CDSSs that strongly correlated with improved patient outcomes: (1) automatic delivery of decision support, (2) integrated rather than stand alone solutions, (3) computer generated decision support, (4) systems that prompt physicians to record a reason for choosing alternate care, and (5) systems that provide a recommendation in addition to an assessment [19]. The PartoPen was designed to provide four of the five CDSS features identified in the systematic review to assist nurses in providing quality, timely care to patients (1, 2, 3, and 5). The quantitative evaluation metric for the maternity ward study was partograph completion, as determined by an objective grading rubric. The system was also qualitatively evaluated using occupational observation and participant surveys.

5.1 Methodology

The maternity ward study was designed as a before-and-after study that compared partograph completion rates before and during the PartoPen intervention. "Completion" was measured using a partograph completion rubric previously developed by KNH staff for hospital administrative purposes. According to this rubric, a complete partograph has measurements for all of the partograph form sections, and a complete labor summary. A research assistant scanned the 369 partograph forms completed in the month prior to PartoPen introduction (June 2012). During the month of PartoPen use (August 2012), 457 partograph forms were initiated.

There were three phases in the introduction of the PartoPen system at KNH and PMH: (1) training nurses how to use the PartoPen system, (2) introducing the PartoPen system for use during 2-3 shifts per day, and (3) establishing sustainable infrastructure and gradually reducing researcher support in the labor wards.

During the first phase, small groups of nurses received a 10-20 minute introduction to the project and were trained on how to effectively use the system during their shift. Nurses were given a demonstration of the PartoPen functionality to introduce them to features of the system (reminders, audio decision-support, and additional instruction access), as well as a brief tutorial on exchanging pens during shift changes.

In phase two, researchers introduced the PartoPen system in both KNH and PMH labor wards during the day shifts – approximately 7:30AM until 6:00PM. During the introduction week, the PartoPen functionality and the study design were adjusted to fit various environmental factors that had previously been unknown, such as modifying reminder sounds and text wording to account for noisy and busy environments, and simplifying the patient reminder ID system to allow nurses to create short, personalized

identifiers for patients, rather than relying on the handwriting recognition in the pen to capture the patient's full name.

During the third phase, no changes were made to the code or the study design in order to keep study conditions consistent for data collection purposes. Quantitative data was collected using a back-end logging system implemented on the digital pens; these data were downloaded every day at the beginning of the morning shift. Data logged by the pens included the following time-stamped variables: when audio prompts were played, which audio prompts were played when measurements were made, how many times instruction buttons were tapped, when the partograph form was started and completed, and which pen completed the form. Qualitative observations were also recorded during the three weeks of PartoPen use. At the end of the three-week use period, nurses were asked to complete a survey on their experience before and during the PartoPen project.

Again, the ERC at KNH and the IRB at University of Colorado Boulder approved the maternity ward research study, and all relevant issues of informed consent were addressed prior to participation.

5.2 Results

Previous partograph studies [5-9,18] that look at completion rates, data quality, and outcomes, do not disclose how partographs are evaluated, or use varying degrees of subjective evaluation to determine partograph completeness. At KNH, partographs are evaluated using a rubric that has "complete" and "incomplete", "correct" and "incorrect" boxes for each partograph category – fetal heart rate, moulding, cervical dilation, etc. For each partograph category, the partograph being evaluated is marked as either complete or incomplete, and correct or incorrect. Due to the wide range of variation in how partographs are used and completed, this basic evaluation rubric does not capture *how* complete a partograph is, nor how useful the data recorded on the partograph is. After the initial data collection phase, we began developing an objective evaluation rubric for measuring partograph completeness.

This rubric is built upon the basic tenants of the evaluation tool used by KNH. The rubric has grading criteria for each partograph category, including a separate set of grading criteria for the labor summary printed at the bottom of each partograph. For each partograph category there are three grading criteria: measurements recorded, symbols correct, and spacing correct. The total possible number of points for each of these grading criteria is determined by the admission time and delivery time of the patient. For example, if a patient is admitted at 1:00 PM, and delivers at 4:00 PM, there would be seven possible points for each of the half-hour measurements (fetal heart rate, pulse, contractions, etc.), plus two possible points for each four-hour measurement (cervical dilation, descent of the fetal head, etc.) Fetal heart rate would then be evaluated on "measurements recorded" out of seven points, such that if the nurse plotted seven marks on the fetal heart rate portion of the partograph, 100% completion for measurements recorded would be achieved. For fetal heart rate, the partograph would also be evaluated for correct symbols (i.e., a solid dot with connecting lines between each dot/measurement) and correct spacing (i.e., one box between each measurement), which would be evaluated out of six points as there are only six spaces between seven possible measurements.

One of the potential drawbacks of the evaluation rubric used in this study is the equal weight that is given to each of the partograph categories. In reality, there are several partograph

measurements that should be weighted more heavily to reflect their level of importance in the labor monitoring process. A 2011 study by Qureshi et al. [18], highlights that contractions, cervical dilation, descent of the fetal head, and fetal heart rate are four of the most important measurements recorded on the partograph. In addition, that study observed that a lack of equipment and resources (such as urine analysis strips and blood pressure cuffs) is a common factor that leads to incomplete partograph records.

All of the partographs collected during the pilot study were first categorized by delivery mechanism – spontaneous vaginal delivery (SVD) and cesarean section (CS). The CS deliveries were further categorized into emergency CS (EmCS) and "other", which includes voluntary CS and CS due to previous CS scars. Deliveries of twins, triplets, or deliveries lasting less than one hour were noted among the SVD partographs, but not included in the initial data analysis because partographs a) are not designed to monitor multiple births, and b) do not provide beneficial monitoring for labors that are less than one hour.

Using this grading rubric, two pairs of graders evaluated partographs from both June (before the PartoPen intervention) and August (during the PartoPen intervention). A total of 397 patient files were collected and scanned for the month of August, and 352 patient files were collected and scanned for the month of June.

Of the patient files collected in June, 155 were duplicates, did not contain a partograph, had a blank partograph, the patient arrived in the second stage of labor, or the patient underwent a planned cesarean section. When a patient arrives in the second stage of labor, the woman usually gives birth shortly after arriving at the hospital, thus not warranting the use of an ongoing monitoring tool like the partograph. Similarly, women coming to the hospital to receive a scheduled cesarean section are not monitored using the partograph because they are often not yet in labor. Of the 397 patient files collected in August, 206 of them fell into one of the no-partograph categories listed above. The remaining patient files – 191 for August and 194 for June – were separated into spontaneous vaginal deliveries (SVD), cesarean sections (CS) that were not scheduled or voluntary, and intrauterine fetal deaths (IUFD). In August, there were 151 SVDs, 30 CSs, and 10 IUFDs. In June, there were 153 SVDs, 31 CSs, and 10 IUFDs.

The collected partographs were graded and checked by two pairs of research assistants according to the evaluation rubric previously described. Each partograph received two scores: a composite completion score and a summary score. The composite score was calculated by dividing the number of points received by the total number of points possible for all three grading criteria (mark existence, correct mark symbol, and correct mark spacing) for each partograph section (fetal heart rate, cervical dilation, etc.). The summary score reflects the completion percentage for the partograph summary section at the bottom of the form, which summarizes the labor and is usually completed after a patient delivers.

Chart 3 depicts the average summary scores for each birth outcome, illustrating a highly significant improvement for CS cases, and general improvements across the board. Chart 4 depicts the average composite scores for each birth outcome (SVD, CS, and IUFD). The averages for June and August are approximately the same for all three categories.

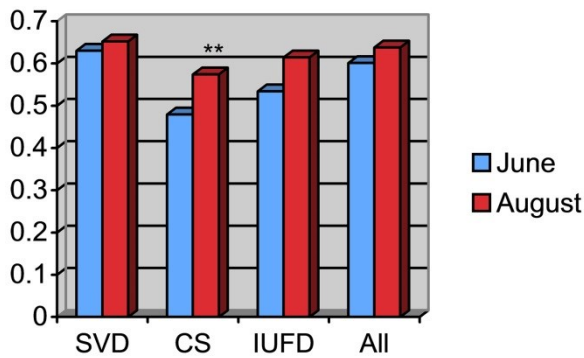


Chart 3. Average partograph completion scores for the summary section of the form by spontaneous vaginal delivery (SVD), cesarean section (CS), and intrauterine fetal death (IUFD). Improved completion rates for all birth method categories, with a significant difference occurring for CS cases.

The improvement in completion scores for the summary section of the partograph can be attributed to several possible factors. First, the partographs used in June were slanted and blurred due to frequent photocopying, whereas the partographs used in August were each printed individually (to assure the unique dot pattern on each form). This made the August partographs significantly easier to read and complete. Second, the improvement in summary scores is likely a result of the increased awareness and underscored importance of the partograph that occurred during the PartoPen study. The lack of improvement in completion rates for the composite partograph scores as a result of the increased focus on the partograph is likely due to the effects of understaffing. Understaffing thwarts completing the graphical portion of the partograph because the ratio of nurses to patients (often between 1:5 and 1:10) does not allow for regular half-hour measurements to be taken for each patient. The PartoPen system cannot replace trained staff members, and does not directly address the understaffing barrier facing partograph completion. The nurses' self-reported improvements in partograph completion rates may be explained by the higher completion percentages for the summary section of the partograph despite little or no improvement in the completion of the graphical portion of the partograph.

In order to approximate the difference in clinical decision support effectiveness between the “built-in” alert and action lines on the partograph and the added audio decision support for the PartoPen corresponding to these lines, the partographs were examined to see how many crossed the action line. Chart 5 depicts the percentages of partographs with a cervical dilation measurement plotted across the action line for SVDs and CSs for both June and August. The number of SVDs that crossed the action line went down from roughly 8% in June to 4.6% in August. These data suggest that more patients in June had partographs that indicated potential cases of obstructed or prolonged labor that may not have been acted upon. The decrease in SVD cases crossing the action line in August is a reasonable indicator that decision making improved in August, with more potential obstructed labor cases being addressed before the action line was crossed. Labors crossing the alert line in August may have been addressed with oxytocin augmentation and artificial rupture of the membranes – two recommendations emitted by the PartoPen when the alert line is crossed. These actions may have accelerated and strengthened the labors, which might have otherwise been prolonged if left unaddressed.

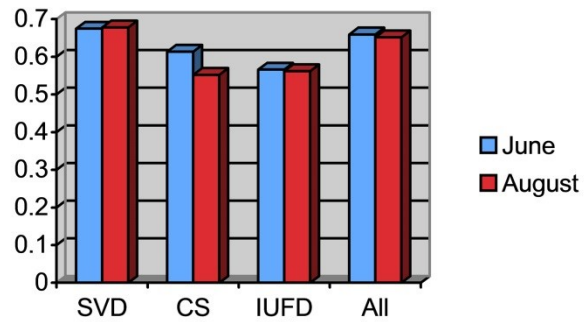


Chart 4. Average partograph completion scores for the graphical sections of the form by spontaneous vaginal delivery (SVD), cesarean section (CS), and intrauterine fetal death (IUFD). No significant differences were found for any birth method category.

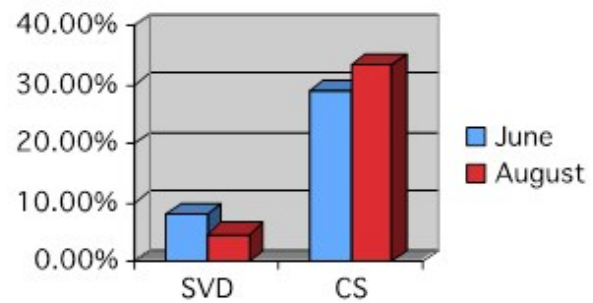


Chart 5. Percentage of partographs that had a cervical dilation measurement plotted across the action line by spontaneous vaginal delivery (SVD) and cesarean section (CS). There were fewer SVD cases with a measurement across the action line in August, and more CS cases with a measurement across the action line in August.

The number of CSs that crossed the action line went up from 29% in June to 33% in August, which suggests that more of the CSs in August had a partograph that recommended a cesarean section as one possible course of action. These results may indicate that fewer unnecessary C-sections were performed in August, possibly as a result of more complete and accurate labor monitoring documentation.

5.3 KNH Post-Use Surveys and Interviews

After three weeks of using the PartoPen system consistently on every shift, nurses were asked to fill out a short survey that captured demographic information about the participant, and gathered before-and-after information about PartoPen use. The survey consisted of eight Likert scale questions, and six free-form response questions.

On average, nurses self-reported an improvement of +2, on a scale of 1 to 10, in partograph expertise during the PartoPen project, a 9 out of 10 for usability of the PartoPen, and a 9.2 out of 10 for usefulness. Nurses also reported that the number of partographs they completed during the PartoPen study was, on average, 25% more than they completed before the study. This increase in partograph completion rates is supported by initial data analysis on the partograph forms, and by an internal report by the hospital administration. In addition to the functionality provided by the

PartoPen, which encouraged higher rates of partograph completion, the general increase in conversation and interest in the partograph due to the PartoPen study was also a likely contributing factor to the improved partograph completion rates.

Overall, the quantitative data gathered from the surveys suggest an increase in partograph knowledge among nurses, an increase in the number of partographs completed, and strongly positive perceptions of the PartoPen's usability and usefulness.

5.3.1 Usability Issues

The nurses emphasized the necessity of a functional cap for the pens to keep ink from getting on their uniforms. One nurse, after getting ink on her uniform, remarked "Here, take it back, I won't use it unless there is a cap - or I'll bring you my laundry!" Caps for the pens were distributed to the nurses, although the currently available cap for the Livescribe Echo pen was considered difficult to use. A makeshift lanyard system was created to allow nurses to wear the pens around their necks, but a shirt clip or similar way to attach the pen to a pocket would be preferred. Other pen design improvement suggestions included having different colors of ink available, and making the pen thinner and lighter.

5.3.2 Observations and Nurse Perceptions

During the first week of the study (the implementation and training phase), researchers observed nurses getting reminders from the pen, shaking their heads, and dismissing the reminder. Upon further investigation, researchers realized that the reminders nurses were receiving were for patients who had already delivered or had received a cesarean section. New functionality was added to the PartoPen that enabled a reminder ID system and a reminder cancellation system. The reminder ID system (pictured in the Appendix under the "Summary of Labor" section) was implemented to give nurses a way to create custom identifiers for patients that would scroll across the display when a reminder for that patient was triggered. Nurses write the identifier in one of the reminder ID boxes at the bottom of the form when a patient is admitted. The handwriting recognition engine in the pen interprets and stores this identifier and displays it for all future reminders for this patient. The reminder cancellation system addresses the issue of outstanding reminders for a patient that has already delivered or has been prescribed a cesarean section. A blue box at the top of the form (pictured in the Appendix in the top right-hand corner of the form) was created for nurses to sign their initials in once a patient has delivered or has been transferred for a cesarean section. The act of initialing in the blue box cancels any existing reminders for that patient, and thus nurses will not receive unnecessary reminders.

The reminder and decision support functionality used in the maternity ward study relied on distinct pen tones and scrolling text on the pen. Nurses informed the researchers that while this implementation helped reduce the distractions associated with long audio prompts, they were unable to look at the OLED display to see which patient needed an exam if they were in the middle of another delivery. The text displayed for both reminders and decision support prompts is only scrolled five times before the display returns to showing the current clock time. Several modifications could be made to address this problem, including implementing a repeat button that would re-scroll the most recent text, continuing to scroll the text until the nurse uses the pen again, or implementing an audio based reminder system that uses an audio recording (made by the nurses themselves) of the patient's name, which is played back for that patient's reminders.

The last solution is currently being developed, and will be tested in the next phase of PartoPen studies.

Displaying the time on the OLED display on the pens proved to be an important feature of the PartoPen system. Because measurements and exams are time-based, and each observation is associated with the time it is taken, nurses often ask each other for the clock time. Nurses also used their mobile phones to get the time, but hospitals are increasingly restricting the use of personal phones during nurses' shifts to reduce distractions and increase nurses' involvement with the patients. Nurses began using the PartoPen to determine the exact time measurements were taken, increasing the accuracy of recorded data.

5.3.3 Patient Referral

The issue of patient referral from surrounding district hospitals and health centers was frequently mentioned among the nurses and doctors at KNH. Patients frequently arrive at KNH past the point of effective care due to the many delays in seeking, reaching, and receiving quality care. This issue, combined with often severe understaffing and resource shortages, is one of the key areas of future work for the PartoPen project.

Of the IUFD cases collected in August, 30% were referral patients. In June, 20% of the IUFD cases were referred from other hospitals. Of the CS cases collected August, 10% were referral patients. In June, 13% of the emergency CS cases were from referral patients. Only 3% of SVD cases in both June and August were from patients who had been referred from other hospitals.

These data illustrate that the majority of complicated and high-risk cases that occur at KNH are from patients who are referred from other hospitals. The low completion rates for both CS and IUFD partographs underscore the challenge of attending to high-risk patients that arrive without appropriate documentation or any record of labor history from the referring hospital. The time needed to perform a comprehensive intake exam on a referred patient could be reduced if the patient arrived with a completed partograph illustrating the progress (or lack of progress) of the labor, as well as the complications that led to the patient's referral. This time could potentially be reduced further if data was transferred to the receiving facility before the patient arrived. The PartoPen system, if implemented at district level hospitals and health centers – the primary referring facilities to hospitals like KNH – could transmit partograph data to the receiving facility before the patient arrives, giving nurses, doctors, and surgeons adequate time to review patient information and prepare.

6. DISCUSSION AND CONCLUSIONS

Continued use and self-reported perceptions of the PartoPen system suggest that nurses believe that the PartoPen system provides a noticeable benefit to them and their patients. However, after completing the data analysis, no statistically significant improvements to partograph completion were found at KNH. These results can be explained by a number of possible factors. First, the small improvements that were observed are most likely attributable to the increased focus and discussion about the partograph during the study. In addition, the printed forms were easier to read and complete than the blurry photocopied versions that had been in use, which was cited by several of the nurses as a positive outcome of the study. Second, the rubric used to evaluate "completion" went through several iterations, and continues to be improved and refined by project researchers and our medical partners. While all of the data was graded using the most recent version of the rubric, a comprehensive standard for evaluating partograph completeness is still being developed. Third, the

nurses at KNH are among the best-trained nurses in Kenya. The minimum-viable-product model of the PartoPen software that was deployed at KNH to test the concept did not provide the depth and breadth of functionality that would have been necessary to move the needle for these highly skilled nurses. However, it is encouraging that despite the introduction of a new technology, and the implementation of a month-long study, the partograph completion results according to the rubric remained relatively unchanged. The results obtained from the clinical study motivate the continued refinement of a standardized partograph evaluation metric, and a carefully designed study that directly evaluates the impacts of PartoPen use on partograph completion *and* patient outcomes. Strong medical partnerships were developed through collaborations with KNH and UoN during the studies. These partnerships will provide the foundation and necessary support to conduct medical outcome studies with partograph completion and PartoPen use as the independent variables. A comprehensive study that ties partograph use and maternal outcomes has not been conducted since 1994 when the World Health Organization evaluated partograph use in Southeast Asia, and several aspects of that study were considered controversial [20].

The data from the nursing study suggest that individuals with minimal training on the partograph and limited exposure to its use in clinical situations have significant potential to benefit from using the PartoPen system. Rural and traditional birth attendants are similar to nursing students in the amount of partograph training they have received, which motivates a continuation of the clinical study that attempts to identify where along the healthcare continuum the PartoPen system can provide the greatest benefit to healthcare providers and patients.

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APPENDIX



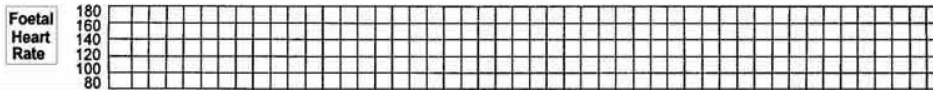
PARTOGRAPH

Partograph complete

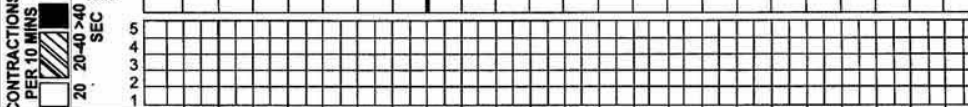
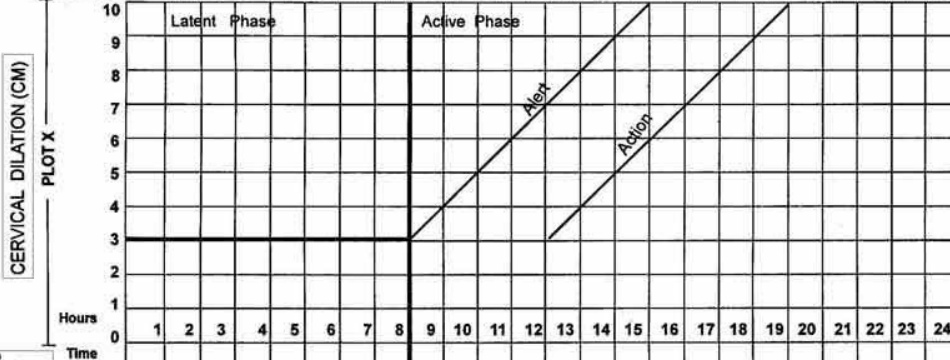
KNH329

Name..... Age..... Gravida..... Para..... IP No.....

Date of admission..... Time of admission Ruptured membranes Hours on admission

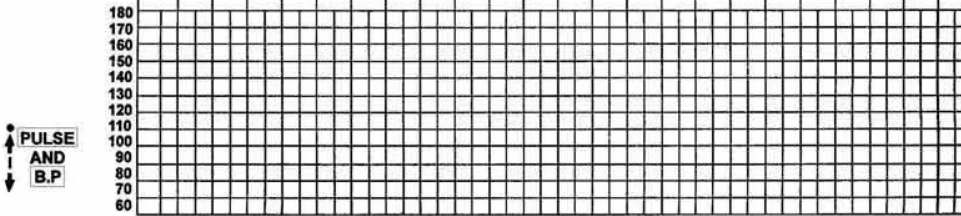


LIQUOR C/B/M/F MOULDING



Oxytocin UI drops Min

DRUGS GIVEN AND IV FLUIDS



TEMP RESP

URINE { PROT ACET VOL

Descent of Head Plot O

stop
repeat next
volume mute

SUMMARY OF LABOUR

1st Stage Induction labour: Yes/No Duration _____ Hrs No. of VE _____

2nd Stage Mode of delivery: _____ Duration _____ Mins: Oxytocin/Egometrine IV/M

3rd Stage Baby Alive/SB M/F Apgarscore 1 Min _____ 5Min _____ Resuscitation Yes/No Duration _____ Mins

Placenta complete/incomplete Membranes complete/Incomplete Cord normal/Abnormal Placenta Wt _____

Blood loss _____ M/s. Perineal tear/Episiotomy. Repair Yes/No Mother BP _____ Pulse _____ Temp _____ Resp _____

Baby Length _____ Weight _____ Gm. HC _____ Cm Drugs given _____

Delivered by: _____ Time and Date of Delivery _____

PartoPen Reminder IDs: _____