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A SYSTEMATIC REVIEW OF PATIENT TRACKING SYSTEMS FOR USE IN THE PEDIATRIC EMERGENCY DEPARTMENT

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□ **Abstract—Background: Patient safety is of great importance in the pediatric emergency department (PED). The combination of acutely and critically ill patients and high patient volumes creates a need for systems to support physicians in making accurate and timely diagnoses. Electronic patient tracking systems can potentially improve PED safety by reducing overcrowding and enhancing security. Objectives: To enhance our understanding of current electronic tracking technologies, how they are implemented in a clinical setting, and resulting effect on patient care outcomes including patient safety. Methods: Nine databases were searched. Two independent reviewers identified articles that contained reference to patient tracking technologies in pediatrics or emergency medicine. Quantitative studies were assessed independently for methodological strength by two reviewers using an external assessment tool. Results: Of 2292 initial articles, 22 were deemed relevant. Seventeen were qualitative, and the remaining five quantitative articles were assessed as being methodologically weak. Existing patient tracking systems in the ED included: infant monitoring/abduction prevention; barcode identification; radiofrequency identification (RFID)- or infrared (IR)-based patient tracking. Twenty articles supported the use of tracking technology to enhance patient safety or improve efficiency. One article failed to support the use of IR patient sensors due to study design flaws. Conclusions: Support exists for the use of barcode-, IR-, and RFID-based patient tracking systems to improve ED patient safety and efficiency. A lack of methodologically strong studies indicates a need for further evidence-based support for the implementation of patient tracking technology in a clinical or research setting.** © 2013 Elsevier Inc.

□ **Keywords—electronic patient tracking; barcode; RFID; IR; pediatrics; emergency medicine**

INTRODUCTION

Patient safety is of great importance in the pediatric emergency department (PED). The combination of acutely and critically ill patients and high patient volumes creates a need for systems to support physicians in making accurate and timely diagnoses. Emergency department (ED) overcrowding has been described as a key factor that adversely affects patient safety. Richardson reports a trend of increasing 10-day mortality among patients who present during times of hospital overcrowding (1). A review by Trzeciak and Rivers has found numerous sources which claim that overcrowding negatively affects markers of patient outcomes (2). Another concerning area where patient safety has been scrutinized is the PEDs and pediatric inpatient settings, where even the potential for lapses in facility security have lead to the implementation of preventative measures to protect patients (3–5). Combining a vulnerable population with

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a vulnerable location, busy pediatric health care settings have the potential for lapses in patient safety that negatively impact outcomes.

By addressing patient safety through the assessment of ED overcrowding, the Institute of Medicine (IOM) has identified the need for the implementation of innovative technologies to improve ED efficiency. In this regard, the IOM has suggested the adoption of robust information and communication systems to improve emergency care, including patient tracking technology—a system that may enhance throughput and improve accurate documentation and recording of workflow inefficiencies (6). Electronic patient tracking systems consist of electronic devices, sensors, and data collection systems to record the interactions of devices with strategically placed sensors in critical locations in patient care areas. Such a system would provide information regarding patient location, duration of stay, and contact with other health care personnel. This information could then be used by health care personnel in real time to provide remote patient monitoring in critical care areas. For example, patient-provider interaction information can give an alert when a patient needs to be reassessed; patient location information can be used to detect a security breach in a newborn nursery. Thus, a patient tracking system can provide valuable information that may lead to novel enhancements of ED safety. This same technology has already been used to enhance safety in many pediatric inpatient settings.

Tracking systems have been successfully applied in commercial and industrial processes. In health care, a slowly expanding body of literature exists on the various applications of tracking system technologies to potentially improve patient safety. This systematic review aims to enhance our understanding of current electronic tracking technologies, how they are implemented in a clinical setting, and the resulting effect on patient care outcomes and patient safety.

METHODS

Search Strategy

We searched the following databases to identify articles related to the applications of patient tracking technologies in the pediatric, PED, or ED setting: Ovid MEDLINE® (1950 to August 20, 2009 with Daily Update, In-Process, and Other Non-Indexed Citations), EMBASE (1980 to 2009 week 33), EBM Reviews (3rd quarter 2009), BIOSIS Previews (1969 to August 20, 2009), Database of Abstracts of Reviews of Effects (3rd quarter 2009), Cochrane Database of Systematic Reviews (3rd quarter 2009), PsycINFO (1806 to August week 3, 2009), ProQuest Dissertations and Theses (1861 to August 24, 2009), and Web of Science (searched August 20, 2009). We translated the original search strategy for Ovid MEDLINE with Daily Update to the other electronic databases. We tracked all selected articles backward using the Cited Reference Search feature in Web of Science for additional relevant articles. We also searched all works cited by our selection.

Methods of the Review

Two independent reviewers identified articles that contain, in part or whole, reference to patient tracking technologies (e.g., infrared [IR], radiofrequency identification [RFID]) as applied to pediatrics (e.g., neonatal intensive care units, newborn nursery care units, general pediatric inpatient environments, operating room environments, critical care environments, PEDs) or emergency medicine. Articles reporting clinically relevant applications of tracking devices (e.g., patient identification, parent-infant matching, medication identification) were included in the review. We excluded articles where the described primary application of the patient tracking technology was asset tracking, cost recovery, or in which the outcome was directly attributable to other types of financial transactions (e.g., patient billing).

We resolved conflicting opinions either by consensus, or in the event of continued disagreement, a third reviewer. We assessed level of agreement using kappa statistics. Two reviewers independently assessed quantitative studies for methodological strength using the "Quality Assessment Tool for Quantitative Studies Method" developed by Thomas, a tool deemed suitable for use in a systematic review of non-randomized studies (7,8). We extracted quantitative data using a standardized form.

RESULTS

Our search yielded 1930 unique articles. After the review, we selected 22 articles based on inclusion criteria. A thorough search of all works cited by our selection, and all external works, did not produce any additional articles. The level of agreement of article selection between the two reviewers was substantial, with a kappa score of 0.74.

We classified the 22 selected articles into five general categories: infant monitoring/abduction prevention, barcode-based patient tracking in the ED, RFID-based patient tracking in the ED, IR-based patient tracking in the ED, and combination IR/RFID-based patient tracking in the ED. Only five were quantitative in nature and thus could be scored based on their methodology (Table 1). We found all to be methodologically weak due to uncontrolled design and scarcity of methodological details provided.

Infant Monitoring/Abduction Prevention

We identified 10 articles; nine were descriptive in nature and characterized technologies or facilities that

Table 1. Methodological Analysis and Results of Quantitative Articles

Study	Category	Methodology Score	Analysis	Study Results
Ou Yang et al. (9)	Infant monitoring/abduction prevention	Weak	Minimal documentation of study design	15-min reduction in administrative time per newborn; projected 3744 work hours per year saved; perception of improved infant security
Bouman et al. (16)	Barcode-based patient tracking in the ED	Weak	No direct comparison of patient outcomes between intervention group and control	Improved coordination of care and highly accurate patient registration in the ED during mass casualty incidents
Chen et al. (20)	RFID-based patient tracking in the ED	Weak	Minimal documentation of study design	Reduced wait times from 303.6 min to 77.2 min (acute bed) and from 236.7 min to 73.1 min (ICU bed)
Macy and Johnston (21)	RFID-based patient tracking in the ED	Weak	Minimal documentation of study design	$30,000 USD saving over 4 months, more satisfied nurses and patients, and improved overall patient safety
Gordon et al. (25)	IR-based patient tracking in the ED	Weak	Protocol implementation errors, inability to control for dropouts due to device/user malfunction	User-dependent tracking systems tended to prematurely record events. Protocol implementation errors produced inadequate results.

ED = emergency department; RFID = radiofrequency identification; ICU = intensive care unit; IR = infrared.

implemented infant security systems and detailed how to implement such systems.

In the only quantitative study identified, Ou Yang et al. described the implementation of RFID-based infant security bracelets and an RFID telemonitoring system resulting in increased efficiency (9). This study reported a 15-min reduction in administrative time per newborn, totaling a projected 3744 work hours per year saved, as well as a perception of improved infant security. Unfortunately, as there was minimal documentation of study design, it is not possible to comment on strengths and shortcomings of this study and, as such, it was scored as methodologically weak (9).

The remaining nine articles describe various facilities and how they use tracking systems to promote infant security. Two of them describe an approach to selecting an infant security system (10,11). Most of these articles describe systems that are similar to currently used asset tracking systems (e.g., tracking of PED equipment such as beds and pumps) in which the infant is considered the asset. In such an application, infants are fitted with electronic devices that trigger locks or alarms if removed from a given area (3–5,12,13). Scanned electronic tags or barcodes can also ensure correct reunification after any mother-infant separation (for example, to prevent abductors from posing as family members). Other applications include infant-breast milk matching during times of mother-infant separation, which ensures the consumption of a mother's expressed breast milk to her own infant, and prevents possible exposure to viral infection or other contamination (14,15).

Barcode-based Patient Tracking in the ED

We reviewed four articles, one of which is quantitative.

Using barcoding to expedite patient registration in the ED during mass casualty incidents, Bouman et al. reported that the linkage of barcoded patient IDs to a computerized system (containing information such as urgency class and primary diagnosis) resulted in improved coordination of care and highly accurate patient registration. The methodology of this study was found to be weak, as there is no direct comparison of patient outcomes between the intervention group and a control (16).

A 2004 interview reported that by providing patients with barcoded wristbands that link up to their electronic medical record, average length of stay was reduced by 50 min, wait times were reduced from 45 to under 15 min, and the percentage of patients who left before treatment was cut by 5% (17). The methodology used in this study was not reported and thus, the reliability of this study cannot be determined. The implementation of an inexpensive barcode-based patient-triaging system that retrieves patient medical records instantaneously

and records patient location, physician encounters, ancillary services encounters, and discharges was reported to be well received by both staff and management, although time savings were not calculated (18).

Parker reviewed barcoding technology in the ED and described improved accuracy of both patient and specimen identification, increased ease of patient tracking, and the possibility of event recording, which can lead to improved quality assurance (19). Disadvantages included start-up costs, software incompatibility, and physical degradation of the patient barcodes during hospital stay.

RFID-based Patient Tracking in the ED

We identified five articles pertaining to RFID-based tracking, two of which were quantitative studies.

The first, a pre- and post-implementation study to determine effects of RFID technology on time taken to streamline patients through the ED observation unit, found that after implementing the tracking system, waiting time was reduced from 303.6 min to 77.2 min for an acute bed and from 236.7 min to 73.1 min for an intensive care unit bed (20). Other RFID applications in this system, such as high-risk reminder of critical laboratory values and reports, were simultaneously implemented and may have contributed to this outcome. As this study fails to sufficiently document methods used, it is difficult to interpret the study strength and the validity of the results. It was therefore scored as methodologically weak.

The latter study, a cost comparison between using RFID tags to monitor moderate-risk mentally ill patients rather than assigning them a one-to-one security guard, estimated a $30,000 USD saving over 4 months. This intervention also resulted in more satisfied nurses and patients, and improved overall patient safety. This study also used a pre- and post-implementation analysis and was ultimately found to have weak methodology, as it did not provide sufficient documentation of study technique (21).

We reviewed two descriptive articles describing the use of "smart chip" technology to transmit patient information. One study described the applications for RFID devices that are subcutaneously implanted to facilitate providing medical care to patients with an altered level of consciousness. In the event that a patient is unable to communicate with an emergency physician, patient identification and medical records may be easily accessed by scanning the chip and connecting to an external database (22). The second study describes a potential future application called "dynamic information/static clinician," where smart tags attached to patients would transmit information regarding patient location and information to a central electronic information board. This is contrasted with the current method of static information/dynamic clinician, whereby clinicians must travel to seek patient information/location, which is much more inefficient and cumbersome (23).

A survey of health care workers concluded that performance expectancy (i.e., a lack of confidence that this type of system will improve performance) and social influences (e.g., whether others expect ED staff to use RFID systems) were the most predictive factors in determining the success of RFID adoption (24).

IR-based Patient Tracking in the ED

One quantitative study compared the accuracy of various forms of patient event documentation, which included direct observation (a third-party observer records actual encounter), a user-dependent patient tracking system (a staff member manually documents encounter in computer database with keyboard and mouse) and a user-independent tracking system (IR sensor badge automatically records encounter). Data acquired by either the user-dependent or user-independent tracking system was compared to the control (direct observation) for accuracy and precision. The results demonstrated that in using the user-dependent tracking system, care providers tended to prematurely record events (i.e., would enter time stamps before the recorded event actually took place). When analyzing the user-independent tracking system, only 6.7% of total events were recorded. The study authors concluded that protocol implementation failures, such as failure to wear badges and failing batteries, produced inadequate results. This study was found to be methodologically weak due to the study design and the inability to control for patient dropouts due to equipment malfunctioning and user error (25).

Combination IR/RFID-based Patient Tracking in the ED

No quantitative studies were identified using combined technologies. Taylor described applications of tracking technologies as a component of patient-centered automation (26). For example, the process of automatically logging patients into the closest computer terminal (via IR or RFID technology, but not necessarily combined) can reduce documentation time and avoid misidentification. A similar strategy can be used to document physical movement of physicians in the clinical care area (26).

Gorsha and Stogoski described the implementation of the VERSUS tracking system, which uses both IR and RFID technology (27). The system primarily uses IR tracking technology; however, in the event of system deficiencies, an RFID backup is utilized to locate patient and staff sensors if the IR system is unable to detect it. Although several challenges were described, this facility qualitatively reports success as determined by patient and staff support (27).

DISCUSSION

This systematic review synthesized the existing literature on various patient tracking technologies, applications in pediatric or emergency care settings, and the impact of these technologies on the delivery of patient care.

A large proportion of relevant identified literature discussed passive tracking technologies (where the device does not emit a signal without external electronic stimulation) as a means to prevent infant abduction. All reviewed articles were descriptive studies except one, which showed improved efficiency and cost reduction in a Taiwanese hospital. Although they collectively supported the use of a passive tracking safety system to provide infant security in their respective care facilities; none provided quantitative data that such a system provided substantial risk or harm reduction. As infant abduction is relatively uncommon and most centers instituted such systems as a proactive measure, it may be difficult for these facilities to measure statistically significant improvements in safety or risk reduction (3–5).

The remainder of the articles discussed the use of patient tracking technology in the ED and identified barcoding, IR, and RFID as potential technologies. Combinations of different modalities (IR and RFID) into the same system have been made to increase system reliability. Most of the reviewed articles were descriptive in nature and did not provide quantitative evidence to support the benefits of the implementation. Although one study reported that a patient tracking system reduced time to streamline patients through the ED, its weak methodology made it difficult to justify the conclusions. In the most objective study reviewed, from Gordon et al., the authors were unable to produce statistically significant results, mainly due to protocol implementation error (25).

There were no identified studies that commented on the use of passive tracking technologies in the pediatric ED. This seems to be an understudied area.

In the majority of the quantitative articles reviewed, poorly described methodology was the main reason for weak methodology scores. In terms of future research, it seems as though pre- and post-implementation studies are the most commonly used means of documenting an interventions effect of health care outcomes. An attempt by Gordon et al. to simultaneously document each encounter with manual as well as IR and RFID to determine which system is more accurate, resulted in system malfunction and user error (25). It was the only study to attempt to validate the accuracy of electronic timestamps over manual. We were therefore unable to identify any studies that could quantitatively determine which system was most effective in accurately tracking patients.

Most quantitative studies that supported the implementation of tracking technologies utilized a pre- and post-study design. The use of this study design often fails to take into account confounding factors that occur in addition to the implementation of a new technology, such as user familiarity and implementation support personnel that otherwise would not be involved in a typical clinical setting, and as such, reduces methodological strength. However, this study design is an efficient way of assessing the effect of the implementation of new technology in a real clinical setting. We propose that comparison of this technology in simulated clinical settings may be of more benefit in accurately determining its effects on patient outcomes.

This systematic review suggests that the use of patient tracking technology for a variety of clinical applications is on the rise as a means to improve patient care. Further studies are needed to examine the accuracy and precision of patient tracking technologies in real or simulated patient care environments to determine the kinds of applications that can be achieved with existing systems. By demonstrating the accuracy and precision of such systems, clinicians and administrators alike will be able to make sound decisions in selecting technologies for use in clinical care settings. The use of the best technologies for clinical applications of patient tracking systems will lead to advances in addressing ED overcrowding, patient access, and ultimately, patient safety.

Limitations

The databases chosen for the search and the search terms used were selected to provide the largest amount of relevant articles; however, it is still possible that some relevant articles were not included. Also, the review documented only published literature on this topic.

CONCLUSIONS

Twenty-two relevant articles were identified, with substantial agreement between the two reviewers. Barcode-, IR-, and RFID-based technologies have all been used as a means of electronically tracking patients in the pediatric department or ED, although this review was unable to identify a superior technology. Support exists for the use of electronic tracking to improve patient safety via increased security and improved ED efficiency. Overall, a lack of methodologically strong studies indicates a need for future research to provide solid evidence-based support for the implementation of patient tracking technology in a clinical or research setting. We propose that comparison of this technology in simulated clinical settings may be of more benefit in accurately determining its effects on patient outcomes.

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ARTICLE SUMMARY

1. Why is this topic important?

Electronic patient tracking has the potential to track and document ED inefficiencies, monitor and quantify effects of newly implemented strategies, and improve patient safety. A comprehensive understanding of the literature to date can assist administrators who seek to utilize such technology and can guide future research.

2. What does this study attempt to show?

This study shows the types of patient tracking technology that exist, various areas of application, and effects of this technology on patient safety.

3. What are the key findings?

We found that barcode technology, radiofrequency identification, and infrared technology can be used in the pediatric and emergency departments (EDs) to document patient flow, improve patient safety, and enhance ED throughput. We also found a lack of methodologically strong studies in this area, indicating a need for further research.

4. How is patient care impacted?

The use of electronic patient tracking systems shows promise as a means to improve patient safety via enhanced security and increased ED efficiency. Also, this technology may be used as a documentation tool to validate the positive effects of other technologies on health care delivery.