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The Use of Technology for Urgent Clinician to Clinician Communications: A systematic review of the literature

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Abstract

Objective—Urgent clinician-clinician communications require routes of contact that are fast and dependable, and allow for the exchange of complex information. Despite the increasing focus on improving healthcare delivery systems over the past decade, few studies have examined the role of technology in clinician-clinician communication. The aim of this study was to review the literature examining the role of devices and technology in facilitating urgent clinician-clinician communication to identify critical areas for future research.

Materials and Methods—A search of Pub Med was performed using the terms (((“Critical Care”[Mesh] OR “urgent”))) AND (((hospital communication systems[MeSH Terms]) OR health communication[MeSH Terms]) OR interdisciplinary communication[MeSH Terms]). Commentaries and editorials were excluded.

Results—The initial search returned 272 articles, which were reviewed to identify articles describing: (1) the role of technological support or devices in clinician-clinician communication, (2) technology-based interventions that improved clinician-to-clinician communication in hospitals or acute care facilities related to critically ill patients, or (3) critical information exchange. A total of 16 articles were included in the final review. These were grouped into three categories: alphanumeric pagers; cellular and smart telephones; and novel uses of technology.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose

AUTHORS' CONTRIBUTIONS

All authors contributed to the conception and design of the study, analysis and interpretation of data, and drafting and revising the article. Each author gave final approval of the version to be submitted.

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Discussion—Breakdowns in clinician-clinician communication are complex and cannot be solved through the implementation of devices or technologically advanced systems alone. It is essential to understand the correlation between emerging technologies, a demanding workload, and clinician-clinician interaction. Enhanced communication of clinical ideas, opportunities for team discussion, and a sense of partnership and support require not just increased information, but enhanced delivery.

Keywords

Communication; Information Technology; Patient Safety

INTRODUCTION

Technology is evolving rapidly and plays a prominent role in the healthcare system. Over the past 20 years, clinicians have faced an increasing communication burden, due in part to the proliferation of devices such as pagers, smart phones, and tablets.^{1–3} Until the last several years, one-way numeric paging has been the main route of communication among clinicians and other multidisciplinary teams. The introduction of alphanumeric paging has allowed one-way communication to take place without the recipient having to respond via telephone call to each numeric page. Clinicians can now triage pages according to their content and urgency, reducing the wait time for pages to be returned and increasing satisfaction among healthcare teams.^{4–6} More recently, clinicians often turn to smartphones to accommodate their communication needs. With the growing adoption of mobile communications by hospitals, clinicians are more likely to consolidate communications to a single device. However, barriers, such as the reliability of signal strength inside hospital walls, remain an issue. Although the use of smartphones creates efficiencies in the delivery of patient care, potential unintended consequences such as inefficient communications, breach of confidentiality, compromised patient safety, and suboptimal patient care, have yet to be fully explored.

Effective and efficient communication between clinicians is essential to provide optimal care to patients.^{4–7} Miscommunication between clinicians and healthcare teams is known to be a major source of errors within the healthcare system, and has been identified as the most common cause of preventable death or disability during hospital admissions.⁸ Miscommunication due to unclear texts or failure of direct person-to-person communication has resulted in errors in patient management. For instance, smartphone usage impacts attentiveness in such a way that users become so engrossed in the messages that they ignore outside stimuli and are, therefore, distracted from other primary tasks.⁹

Urgent clinician-clinician communications that occur when patients are critically ill (e.g., intensive care) or experience a rapid change in their health status (e.g., respiratory arrest) require routes of contact that are fast and dependable, and allow for the exchange of complex information. Despite the increasing focus on improving healthcare delivery systems over the past decade, few studies have examined the role of technology in clinician-clinician communication. The aim of this study was to review the literature examining the role of

technology in facilitating urgent clinician-clinician communication to identify critical areas for future research.

METHODS

A search of Pub Med was performed using the terms (((("Critical Care" [Mesh] OR "urgent")))) AND (((hospital communication systems[MeSH Terms]) OR health communication[MeSH Terms]) OR interdisciplinary communication[MeSH Terms]). The initial search returned 272 articles. When the search results were restricted to a ten-year span from October 1, 2003 to October 1, 2013, English language, and human-based studies, a total of 146 articles remained. Titles and abstracts were reviewed for relevance and articles were advanced to full text review if they described: (1) the role of technological support or devices in clinician-clinician communication, (2) technology-based interventions that improved clinician-to-clinician communication in hospitals or acute care facilities related to critically ill patients, or (3) critical information exchange. Commentaries, editorials and studies not reporting empiric data were excluded (N=82). A total of 78 articles remained for full text review. Bibliographies of relevant publications were reviewed for additional sources (N=14). After further exclusion of 62 articles, 16 articles remained and are included in this review. These were grouped into three categories: alphanumeric pagers; cellular and smart telephones; and novel uses of technology. The search strategy and results are shown in Figure 1.

RESULTS

Alphanumeric pagers

Alphanumeric pagers have been used in healthcare since the late 1950's. At that time, the majority of devices were one-way numeric pagers able to receive numerical messages, but the users could not receive word-based messages or send any outgoing information. Pages were sent using a telephone key pad, and the message recipient replied by calling the number listed in the message. More recently pagers have evolved to incorporate text-based messages, and some systems are supported by web-based interfaces that allow for messages to be sent and received via the internet. Two-way pagers are also increasing in popularity, where the user can type a response using a small alpha-numeric keyboard embedded in the pager.

Six studies examined the use of alphanumeric pagers to relay critical information between clinicians.¹⁵⁶¹⁰⁻¹² Patel et al. studied pager messages sent to surgical interns at the University of Michigan Health System.¹ Paging data was reported over 18 months and were coded by two investigators who individually assigned sender type, message type, message modifier, and page quality. A total of 9,843 messages were received by the six interns. Of the total, 1,022 messages (10.4%) contained only numbers while the rest contained text or text and numbers. 75% of all pages contained patient information and 21% did not clearly reference individual patients. Results showed an inverse relationship – as the number of patients increased, the number of pages per patient decreased. Also, as the amount of the interns' workload increased, pager communications with messages requiring urgent care increased. Overall, the authors did not find a clear workload threshold where communication

breaks down, but the increasing intern workload had deleterious effects for quality of care. Similarly, Nguyen et al. compared distractions resulting from alphanumeric versus numeric paging at Stanford University Hospital's surgical intensive care unit (SICU).⁵ The web-based alphanumeric system allowed clinicians and nursing staff to online text-page from any internet-enabled computer in the hospital. Senders could select recipients' names from a dropdown menu and send alphanumeric messages up to 230 characters. Pager interruptions were tracked using paging logs and clinicians were surveyed about their perception of workflow disruption before and after implementation. The study found that the alphanumeric text-paging system was less disruptive to resident learning when compared with the numeric system (84.2% vs 97.5%, $P < .05$) and less disruptive to patient care (46.9% vs. 28.2%, $P < .05$).

Reddy et al. introduced a wireless alerts pager in the SICU that supported real-time notification of events including critical lab results, acute changes in patient status, and potential medication and allergy problems.⁶ Semi-structured interviews and clinical observations were performed to determine the impact of the system on workflow. The study found that event notification was faster and provided more accurate information regarding critical events, and clinicians reported improved collaboration. However, alerts disrupted information flow and existing work practices. The authors identified four challenges to the implementation: first, the simultaneous notification across the medical hierarchy prevented the residents and fellows from addressing a notification before the attending was alerted; second, the unidirectional nature of the alerts pager prevented any clinician from using the pager to respond to the problem; third, significant information overload in the absence of context; and fourth, disruption in the nursing workflow by providing physicians with alerts at the same time the nurses have access to the information.

In a second study, Reddy et al. examined the challenges to physicians' use of wireless alert pagers in the SICU at Cedars-Sinai Medical.¹² The alphanumeric pagers automatically notified the physicians of critical events such as critical trend alerts, dynamically adjusted alerts, exception condition alerts, and medication alerts. Most physicians reported the wireless technology promoted better collaboration, quicker event notification, and delivery of more accurate information regarding the critical events. However, the authors identified three challenges to the use of wireless pagers: first, a loss of control provided by moving issues up the hierarchy from residents to fellows and finally to attending physicians for adverse events due to the simultaneous information delivery to all hierarchical levels; second, the number of notifications and lack of prioritization for alerts created information overload and missing context; third, a lack of feedback mechanisms due to the unidirectional nature of the alert pagers.

Epstein et al. studied the reliability of internet networks in transmitting time-critical alphanumeric messages both in and out of the hospital setting.¹¹ The delay between message initiation and delivery to three separate alphanumeric paging devices were measured. One device used the internal hospital network and the other two devices used internet pathways outside the hospital's local network. The two devices using internet pathways outside the hospital's network showed 1.3% and 33% of delays exceeding 100 seconds. On the other hand, the device that used the internal hospital network had an average delay of 8 seconds,

with 100% of 40,200 pages having delays <100 seconds. These results showed that the biggest influence on transmission reliability was the network used, and delivery systems involving processes outside the local hospital network are subject to periods of long delay.

Locke et al developed a web-based interdisciplinary paging system (WIPS) that allowed for non-urgent messages to be sent to a web-based task list and urgent messages to an alphanumeric team pager.¹⁰ Following implementation, the new system was evaluated using surveys and focus groups. Nearly 80% of nurses affirmed that the WIPS allowed for ease in sending urgent messages, and over 70% of trainees reported a manageable number of urgent messages. Both nurses and trainees reported improved response to urgent messages, and requested similar separation of urgent and non-urgent messages from other team members such as pharmacists and social workers.

These studies demonstrate that although the use of alphanumeric pagers has increased information transmission and provided new information routes to staff members, clinicians generally regard them as disruptive. Furthermore, in the context of urgent situations, delays in transmission are a threat to efficiency. Web-based alphanumeric-paging may reduce interruptions in patient care and improve physician work efficiency within a hospital setting, and the use of automated alerts allows multiple team members to receive information simultaneously.

Cellular and Smart Telephones

Seven studies evaluated the use of mobile devices and smartphones for urgent communication within hospitals.^{413–19} Soto et al. surveyed members of American Society of Anesthesiologists about modes of communication used in the operating room and intensive care unit and experiences with medical errors related to communication delays and device usage.¹⁴ Of 7,878 respondents, 65% reported using pagers as their primary mode of communications while 17% used cellular phones; 45% of pager users reported delays in communications compared to 31% of cellular phone users. The results showed that cellular telephone use was associated with a reduction in the risk of medical error or injury resulting from communication delay in comparison to anesthesiologists who used pagers (relative risk = 0.78; 95% confidence interval, 0.6234–0.9649). Overall, less time was required to relay important information by cellular telephone due to the bidirectional functionality, compared with those who relied solely on pagers who had to wait for a response.

Etchells et al. developed a real-time alert system for critical laboratory abnormalities that linked automated alerts with resources for decision support in the SICU.⁴ On-call physicians received alerts through text messages to both smartphones and alphanumeric pagers. The study examined the impact of the alert system on the frequency and severity of adverse events occurring due to the clinicians' lack of access to timely information. The system also provided a link to decision support related to the finding, which supplied treatment recommendations previously developed by a cohort of physicians. After implementation of the alerts, the rate of clinical actions completed in response to serious laboratory abnormalities remained at 50%, leading the authors to conclude that the implementation of real-time alerts and decision support did not improve clinical management or decrease frequency of adverse events. In 2010, Wu et al. replaced alphanumeric pagers with

smartphones for a general internal medicine team at an academic teaching hospital. Although residents perceived improvements in efficiency and communication with smartphones over conventional paging, nurses' overall satisfaction with physician's response time for urgent issues did not improve significantly despite a perceived reduction in the time required to contact a physician (27.6 vs. 11 minutes $P < 0.001$).¹⁸

Lo et al. conducted a similar study of General Internal Medicine staff at two teaching hospitals in 2012.¹⁵ The group conducted 31 in-depth interviews and compared clinicians' experiences with smartphones via a web-based alphanumeric paging system (i.e. an online webpage site). Overall, clinicians valued text messaging and email functions provided by smartphones during non-urgent situations, but favored the phone function during urgent situations. Nurses reported that smartphones resulted in a reduction of face-to-face interactions with the physicians and limited their chance for more meaningful interactions. On the other hand, residents enjoyed ability to obtain information passively via web-based pages. Both nurses and residents commented on the time-consuming nature of both devices, including having to answer direct calls which disrupted workflow, sending web-based pages repeatedly, or logging onto a computer to check for emails regularly. The study suggested that smartphone usage can reduce wasted time and allow increased accessibility of information; however, whether smartphones were perceived as helpful depended on the situational contexts such as urgency and time of day.

Solvoll et al. aimed to understand how unnecessary interruptions from mobile devices can be reduced through the implementation of an Internet Protocol-based (IP-based) wireless phone system that converts voice signals from telephones into an internet-based digital signal that can be transmitted to a pager.¹³ Participant observations, non-structured interviews, and responses to open-ended questions were collected for 11 selected physicians for 135 work hours with the primary focus on mobile device interruptions. The data was analyzed separately for each clinic based on five factors: (1) frequency of interruptions, (2) clinical situation, (3) context, including location, (4) route of communication (pagers vs. wireless/mobile phones), and (5) importance of the call and whether it was answered or not. The preference to use a phone vs. pager varied by specialty and years in practice. Generally, the physicians indicated that a transition from pagers to wireless phones would lead to more interruptions initially, but decrease to baseline over time. Overall, the IP-based phone system was ineffective at reducing the number of mobile phone interruptions for the physicians observed.

In 2010, Quan et al. implemented a Web-based smart phone messaging system at the University Health Network to replace the numeric paging system and identified the consequences associated with implementation of this technology.¹⁹ With the implementation, residents were provided with smartphones that they used for communication. The study compared interruptions pre- and post-implementation to analyze the volume and time distribution of messages. During the pre-implementation phase, interruptions were all numeric pages to the residents. During the post-implementation phase, interruptions increased 233% (i.e., from 3 pages received per resident per day pre-implementation to 10 messages received per day resident per day post-implementation) from emails sent directly to the team smartphones from the Web-based messaging system.

Physicians reported increased interruptions, accountability, and tactics to improve personal productivity. Increased interruptions occurred due to the elimination of traditional barriers to paging (e.g., having to wait by a phone) and sending a message was easier, leading to frustration from physicians because they were constantly getting paged. In addition, nurses, pharmacists, and social workers felt it was their responsibility to notify the physicians about all issues of concern. Lastly, nurses, pharmacists, and social workers often exaggerated the urgency of the issue in their messages to elicit responses from the physicians and ensured physicians dealt with the issue promptly.

Smith et al. monitored the frequency, volume and response time of messages between doctors and nurses on the general internal medicine wards using a smartphone-based email system.¹⁷ The email content was analyzed based on urgency, language, emotion, subject content, and type of interaction. Of the 13,717 total emails from nurses, 39.1% requested a call back, 18.9% requested a response by email, and the remaining 42% indicated no response was necessary from physicians. Only 50% of those participants that requested a response by email received a response, with a median response time of 2.3 minutes. Content analysis determined messages with a requested response were primarily non-urgent. The two most frequent reasons for smartphone usage were to convey information (91%) and to request physician action (36%).

In addition to functionality, unintended consequences of cellular and smart telephone use for communication of protected health information have been investigated by several authors. Visvanathan et al. noted that mobile communication comes with risks such as loss of confidentiality and data security, noise, infection control, and cross-contamination, and Warwick concluded a one-size-fits-all approach is not effective when devising policies for secure smartphone use.^{20,21} Therefore, healthcare organizations should analyze their employees' data needs and phone usage in order to provide a secure and functional environment for clinicians and patients.

These studies demonstrate the potential of smartphones to decrease the time required to send urgent messages, but there are some pitfalls and downsides to this increased use of technology. Older physicians may be reluctant to abandon traditional pager devices, and the transition from paging to phone-based systems may temporarily increase the rate of non-urgent interruptions. Healthcare organizations could benefit from coherent and practical policies and procedures to regulate smartphone usage in the workplace in order to improve patient care, maximize work efficiency, and decrease adverse outcomes.

Novel uses of technology

Curry studied the effect of blogging as a means of clinician-clinician communication in the cardiac ICU. Blogger.com is a Google application that requires a Google account to be setup prior to joining the blog. An initial email was sent to nurses to invite them to the blog. Once the invitation was accepted, all communication occurred through the blog. The blog had 180 hits weekly on average and has had more than 24,000 hits since being implemented. Within the ICU setting, 62% of the blog readers are viewing from Windows and 37% are using iPhones[™]. Users indicated that blogging helped to promote two-way communication between the physicians and nursing staff, and blogging became a valuable method to relay

important updates and changes. Barriers included a lack of understanding of technological social media, outdated software systems, and limited hospital policies to incorporate a blog into the cardiac ICU setting. Blogging also increased compliance with quality measures, updated staff on need-to-know information such as changes in policies and procedures, and provided up-to-date educational resources.⁷

Richardson et al. completed a qualitative study to understand how the use of Hands Free Communication Device (HFCD) systems affected hospital communication.¹⁶ HFCD systems allow physicians to directly communicate with one another using voice-controlled badges that are Voice-over Internet Protocol (VoIP) based and are linked to one another over a wireless local area network. Twenty-six semi-structured interviews of clinicians at a community hospital and an academic hospital were conducted and recorded. Researchers asked subjects questions regarding their understanding of “why HFCD systems were installed, how these systems impacted communication, and if these systems resulted in surprises or unintended consequences.” Physicians and staff members reported that HFCDs allowed them to locate staff and obtain help in a more direct manner than when previously relying on communication technologies such as telephones or overhead pages alone. HFCDs improved communication access, but users felt a lack of control over the timing of the communication (e.g., when with patients) and the proper use of HFCDs.

O’Connor et al. implemented wireless email to facilitate communication among members of an interdisciplinary healthcare team in an intensive care unit (ICU) at a community hospital in Mississauga, ON.²² Prior to the implementation, ICU staff members used various communication methods, including numeric pagers or overhead paging. With the implementation of wireless email through Blackberry handheld devices, the number of email messages transmitted and received during a five month period was recorded by reviewing the email accounts associated with each specific device. 85% (106/125) of the ICU staff members who used the devices completed a survey assessing their perceptions on the impact of wireless email on communication, team relationships, staff satisfaction, and patient care. During five months of the six month study period, staff sent and received an average of 5.2 and 8.9 messages per day, respectively. In the following five-month period, “the volume of messages sent and received decreased by 35% ($p<0.001$) and 12% ($p=0.0018$), respectively.” Overall, the majority of staff members reported that “wireless email improved speed (92%) and reliability (92%) of communication, improved coordination of ICU team members (88%), reduced staff frustration (75%), and resulted in faster (90%) and safer (75%) patient care.” Staff members rarely (18%) reported negative effects on communication which primarily related to a decrease in face-to-face clinician communication and inappropriate personal usage of wireless email.

These studies demonstrate how novel technologies can be used to improve urgent clinician-clinician communications and ultimately with patient care. Novel technology not only enhanced access to real time fast-paced information, but also reduced potentially harmful breakdowns during patient care. However, barriers include clinicians losing autonomy and a lack of understanding of technological systems. In addition, the culture of an institution and cultural shifts required to adopt new methods of communication are major determinants of success.

DISCUSSION

Fundamental to effective multidisciplinary teams is effective communication. With such a high prevalence of adverse events occurring due to poor communication, it is imperative that we improve clinician-clinician communications.²³²⁴ While technology has rapidly advanced, the result thus far has been more-but not necessarily better-communication. Clinicians today use one and two-way alphanumeric pagers, mobile and smart-phones to transmit information, but remain over-burdened with non-urgent information, and no single device or system has resulted in optimal communications. While all clinician-clinician communications are important, rapid and accurate communication in urgent situations is critical. Delays in transmission and response time, disruption and distraction, and decreased face-to-face communication are all challenges that remain. Given the problems associated with alphanumeric paging and the rapid advancement of communication technologies, healthcare providers are looking at alternative strategies for improving communication during urgent situations. We reviewed the literature to identify studies examining assessments of and interventions aimed at improving technology for urgent clinician-clinician communications. Most studies were before-and-after studies that investigated enhancements to alphanumeric paging systems and/or the integration of smart phones as clinical communication tools. Quantitative metrics focused on clinician satisfaction, how often devices were used, and/or the impact on clinician-clinician communication. Qualitative findings documented the users' perceptions of improved access and decreased response time, but also described challenges related to loss of hierarchy with team-based messages and increased interruptions during the implementation process. In most studies, there was evidence for device-based communication interventions that indicated positive effects on the quality of care for patients.

Across the studies, there was a clear preference of clinicians towards the use of smart phones over alphanumeric pagers, both for the ability to directly relay information and the ability for two-way text messaging.¹⁵¹⁷¹⁸ However, those studies examining the feasibility of replacing pagers with mobile or smart-phones entirely reported an increase in interruptions related to the ease of contact.¹⁹ This resulted in increased satisfaction among those initiating contact, but increased frustration among physicians. In addition, delays in transmission remain a threat to efficiency and safety, leading to potential harmful breakdowns in patient care. More novel uses of technology such as blogging produced mixed results, with major barriers including institutional climate and infrastructure. Although the vast majority of studies reviewed reported quasi-experimental data, interventions that used technology to separate urgent from non-urgent communications using email or other queue-based methods showed promising results, including decreased response time for urgent communications, increased satisfaction on the part of nurses, and a perception of more manageable and easily prioritized workload on the part of trainees. Interestingly, no studies in our review compared the use of technology to in-person communication.

Despite the technological advancements in information and communication over the past twenty years, there is still limited evidence indicating improved ability of healthcare professionals to effectively communicate critical information or during critical events. While

there are high rates of satisfaction following the implementation of communication interventions, there is less compelling evidence toward improved patient care. Given the importance of effective communication in urgent clinical settings, further development and evaluation of technology to improve communication between clinicians is needed. Prospective studies assessing actual, rather than reported, communication between clinicians will help determine which devices improve physician work efficiency and reduce interruptions in patient care. Future research should aim to determine whether smart phones are reliable enough to fully replace alphanumeric pagers for urgent clinician-clinician communications, and how unintended consequences such as distractions, interruptions and information overload affect patient care. In addition, further examination of internet-based protocols for real time alerts and diverting non-urgent messages and the response time for emails or web-based queues is needed to create data-driven algorithms and determine the reliability of the technology. Simultaneous team-based communication should also be examined for its effect on individual clinician response and task management, particularly in the urgent clinical settings. Finally, the studies in our review focused primarily on communication between nurses and trainees, but more research is also needed as to the applicability of technology-based interventions to intra-team communications and multi-directional interaction within a range of medical specialties.

Breakdowns in clinician-clinician communication are complex and cannot be solved through the implementation of devices or technologically advanced systems alone. It is essential to understand the correlation between emerging technology, a demanding workload, and clinician-clinician interaction. Enhanced communication of clinical ideas, opportunities for team discussion, and a sense of partnership and support require not just increased information, but enhanced delivery.

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SUMMARY TABLE

What is already known on this topic

- A variety of electronic devices are currently used for clinician-clinician communication
- No guidelines currently exist for methods of urgent clinician-clinician communication
- Miscommunication between clinicians is known to be a major source of errors

What this study added to our knowledge

- Despite the ubiquity of alphanumeric pagers, they are associated with transmission delays and high levels of clinician disruption
- Smartphone usage is associated with decreased transmission time but higher rates of clinician interruption
- Novel uses of technology to overcome the challenges associated with pagers and smartphones include blogging and wireless email.
- Most studies examining the effectiveness of communication devices in urgent contexts are before-and-after studies that relied on quantitative metrics focused on user satisfaction, method of use, and/or the effect on clinical communication

HIGHLIGHTS

- Alphanumeric pagers are ubiquitous but unreliable.
- Smartphones reduce transmission time but increase rates of clinician interruption.
- Novel uses of technology for communication include blogging and wireless email.
- Research comparing communication effectiveness of different devices is needed.

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Figure 1. Search Stragery

Figure 1 shows the PRISMA diagram for the study search methods.

Table 1

Included Studies

Author, year	Study type	Device(s) studied	Clinicians studied	Findings
Alphanumeric pagers				
Epstein et al., 2013	Quasi-experimental	Alphanumeric pager wireless networks	Anesthesiology	<ul style="list-style-type: none"> The reliability of communication device was heavily influenced by the type of network used (internal or external). Long delays were observed when using delivery networks that involved internet pathways outside of the local hospital network.
Patel et al., 2010	Retrospective Mixed-methods	Alphanumeric pager	Surgical trainees at an academic hospital	<ul style="list-style-type: none"> There was an inverse relationship with the patient data – as the number of patients increased, the number of pages per patient decreased. There was not a clear workload threshold where communications break down, but quality of care was effected due to the increasing intern workload.
Locke et al., 2008	Quasi-experimental	Web-based paging system	Trainees and nurses	<ul style="list-style-type: none"> Nearly 80% of nurses affirmed that the system allowed for ease in sending urgent messages. Over 70% of trainees reported a manageable number of urgent messages. Nurses and trainees reported improved response to urgent messages.
Nguyen et al., 2006	Clinician survey	Alphanumeric pagers	Trainees, attending physicians and nurses on surgical floors and in outpatient clinics	<ul style="list-style-type: none"> The alphanumeric text-paging system was less disruptive to resident learning and patient care when compared with the numeric-only system. Participants rated the alphanumeric-paging system highly because it has the possibility to reduce interruptions in patient care, improve physician work efficiency, and overall satisfaction.
Reddy et al., 2005	Qualitative (clinician interview)	Wireless pager alert system with automated real-time notifications	Trainees, attending physicians, nurses and pharmacists in the SICU	<ul style="list-style-type: none"> Event notification was faster for the clinicians; however, the alerts disrupted information flow and existing work practices. Challenges included: 1) loss of hierarchal context, 2) unidirectional nature of information flow, 3) information overload and missing context, and 4) disruption of organizational roles.

Author, year	Study type	Device(s) studied	Clinicians studied	Findings
Reddy et al., 2003	Qualitative (clinician interview)	Wireless pager alert system with automated real-time notifications	Trainees and attending physicians in the SICU	<ul style="list-style-type: none"> Physicians reported improved collaboration, quicker event notification, and delivery of more accurate information regarding the critical events Challenges included: 1) loss of control, 2) the notifications created information overload, and 3) a lack of feedback mechanisms.
Cellular and Smart Telephones				
Quan et al., 2013	Mixed-methods	Web-based smartphone messaging system	Four general internal medicine teams at a single hospital	<ul style="list-style-type: none"> Clinicians reported increased interruptions due to the elimination of traditional barriers to paging. There was a 233% interruption increase from emails sent directly to the teams' smartphones.
Lo et al., 2012	Qualitative (clinician interview)	Smartphones	General internal medicine teams at an academic hospital	<ul style="list-style-type: none"> Clinicians valued the text messaging and email functions, especially during urgent situations. Nurses, social workers, pharmacists, and therapists appreciated the ability to directly relay urgent information to the physicians instead of having to wait for return calls.
Smith et al., 2012	Quasi-experimental	Smartphone-linked email system	Trainees in the general internal medicine wards at two hospitals	<ul style="list-style-type: none"> Content analysis determined messages with a response request (call or email) were primarily non-urgent; Only 50% of those participants that requested a response by email received a response Smartphone usage was mainly to convey information (91%) and to request clinician action (36%).
Solvoll et al., 2012	Qualitative (clinician interview)	Internet Protocol (IP)-based wireless phone to pager system	Attending physicians at two clinics	<ul style="list-style-type: none"> The IP-based phone system was ineffective at reducing the number of mobile phone interruptions. The preference to use a phone vs. pager varied by specialty and years in practice.
Eichells et al., 2011	Stepped-wedge clinical trial	Pager and smartphone clinical alerting system with embedded decision support	General internal medicine teams at an academic hospital	<ul style="list-style-type: none"> Implementation of the real-time alerts and decision support system did not improve clinical management or decrease the frequency of adverse events due to inaction.
Wu et al., 2010	Quasi-experimental	Smartphones	General internal medicine teams at an academic hospital	<ul style="list-style-type: none"> Replacing alphanumeric pagers with smartphones and email increased resident ability to prioritize tasks There was significant change in nursing perception of ease of contacting physicians urgently, despite a perceived reduction in the time required to contact a physician (27.6 vs. 11 minutes)

Author, year	Study type	Device(s) studied	Clinicians studied	Findings
Soto et al., 2006	Qualitative (clinician interview)	Intra-operative modes of communication	Members of the American Society of Anesthesiologists	<ul style="list-style-type: none"> 65% used pagers as their primary mode of communications, 17% used cellular phones. 45% of pager users reported delays in communications compared to 31% of cellular phone users Bidirectionality was the main reported advantage of cellular phone use
Novel Uses of Technology				
Curry, 2012	Mixed-methods	ICU blog	Cardiac ICU nurses	<ul style="list-style-type: none"> Blogging helped to promote two-way communication between physicians and the nursing staff. Blogging also increased compliance with quality measures and provided up-to-date educational resources.
Richardson et al., 2008	Qualitative study (clinician interview)	Hands-free communication device (HFCD)	Pediatric anesthesiologists and operating room nurses	<ul style="list-style-type: none"> Clinicians and staff members reported that HFCDs allowed them to locate staff and obtain help in a more direct manner. Users felt they needed more training on the proper use of HFCDs.
O'Connor et al., 2009	Mixed-methods	Wireless e-mail	Medical-surgical ICU teams at a single hospital	<ul style="list-style-type: none"> Participants reported that wireless email improved coordination of ICU team members, reduced staff frustration, and resulted in faster and safer patient care. 18% of staff members reported negative effects on communication related to a decrease in face-to-face clinician communication and inappropriate personal usage of wireless email.