RESPIRATORY CARE Paper in Press. Published on July 02, 2013 as DOI: 10.4187/respcare.02545

Radio-frequency Tracking of Respiratory Equipment: Rationale and Early Experience at the Cleveland Clinic

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Key words: Radio-frequency identification (RFID), real-time locating systems, indoor tracking, equipment tracking

Word count (Abstract): 246

Word Count (body of text): 3184

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Abstract

Background: When respiratory therapists (RTs) seek respiratory care equipment, finding it quickly is desirable, both to expedite patient care and to avert respiratory therapists' wasting time. To optimize RTs' ability to quickly locate mechanical ventilators, we developed and implemented a radio-frequency identification (RFID) tagging system at Cleveland Clinic called eTrak. **Methods:** The Clinical Engineering and Information Technology groups at Cleveland Clinic collaboratively developed a WiFi-based RFID program that used active RFID tags (AeroScout Inc., Redwood City, California). Altogether, 218 ventilators and 82 non-invasive ventilator devices as well as a variety of non-respiratory equipment were tagged beginning in March 2010. The difference in time to locate equipment (pre-and post implementation) was assessed with a Mann Whitney Rank Sum test; $p<0.05$ indicated significance. **Results:** eTrak was adopted with a mean of 145 log-ons weekly over the first year of use. Use of eTrak was associated with a decreased time required for RTs to locate mechanical ventilators (from a median of 18 minutes [range 1 – 45 minutes] pre-eTrak to 3 (range 1 – 6) minutes post-eTrak (p <0.001). Surveys of RTs regarding whether equipment was hard to find before vs. after implementing eTrak showed a non-significant trend toward improvement. **Conclusions:** Implementation of an RFID tracking system with active tags placed on respiratory equipment was associated with shortened time for RTs to locate mechanical ventilators and trends towards enhanced satisfaction with finding equipment. These results extend the sparse experience with RFID tagging in healthcare and suggest benefits that warrant further investigation.

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Introduction

Radio-frequency identification (RFID) is the use of a wireless non-contact system that uses radio-frequency electromagnetic fields to transfer data from a tag attached to an object for the purposes of automatic identification and tracking. Some tags (i.e., passive) require no battery and are powered and read at short ranges via magnetic fields (electromagnetic induction). In contrast, active tags use a local power source to emit radio waves (at radio-frequencies). The tag contains electronically stored information which can be read from up to several yards away (1).

Radio-frequency identification tracking of equipment and/or inventory has been widely used in various business sectors and in the military to ensure product/equipment availability and delivery, minimize loss, and to facilitate business processes (e.g., supply chain management) (1-4). For example, based on the military origins of RFID for distinguishing friendly from hostile aircraft, more recent uses have involved active tracking of radioactive materials during transport (2). Similarly, large companies such as Walmart use RFID devices widely for inventory control.

Like all large hospital systems, Cleveland Clinic faces the challenge of locating respiratory care equipment (especially ventilators) and other commonly used devices (e.g., intravenous pumps) over a large main hospital and a larger multi-hospital care system. To address this challenge, we recently designed and implemented a system (called eTrak) that tracks respiratory equipment (e.g., mechanical ventilators and non-invasive ventilator equipment) through applied RFID tags. Specific issues that prompted us to develop an RFID tracking system for mechanical ventilators and non-invasive ventilator devices throughout the Cleveland Clinic Health System included:

1. The fact that difficulty locating hospital equipment causes undesirable delays in administering care to patients.

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2. The perception that when RTs spend undue time seeking the equipment they need to care for patients, time is wasted, leading to a decline in morale and engagement.
3. The erroneous assumption that misplaced equipment is permanently lost, potentially causing unnecessary expenditures for replacement.
4. The desire to locate large numbers of ventilators easily and quickly, which is critically important, especially in mass disaster scenarios and also aligns with cost-attentive imperatives for greater operational efficiency in all healthcare institutions.
5. The desire to facilitate preventive maintenance for equipment based on RFID tagging.

In the context of these needs, the current report describes the basic features of the eTrak system, early metrics of its use and impact, and some lessons based on early use.

Methods

Design of the eTrak System

The eTrak radio-frequency tracking system was developed collaboratively by the Clinical Engineering and Information Technology groups at Cleveland Clinic. Guiding principles that drove the design and that led to an in-house design were maintaining flexibility in developing the feature set and controlling costs.

The initiative began by evaluating various RFID platform technologies: Infrared, Ultrasound, Zigbee, and wireless technologies based on the 802.11 standard (WiFi). Based on an evaluation of the costs, capabilities, accuracy, and long-term supportability of the platform, it was decided to use the existing wireless network infrastructure and to base future real-time location efforts on the WiFi platform. Our approach was to utilize the existing network infrastructure as our backbone, supplement it as needed with compatible technologies to deliver

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room-level location, and build and extend the user interface based on ongoing feedback from our clinical users.

. Our approach was to utilize the existing network infrastructure as our backbone, supplement it as needed with compatible technologies to deliver room-level location, and build and extend the user interface based on ongoing feedback from our clinical users. This approach allowed us to get a workable location services system to learn from with a minimal investment up front. Because other institutional strategies (mobile workstations, VOIP telephony) paved the way for a location-ready wireless network, our infrastructure costs were limited to the application server and database. To provide the resiliency and performance needed for what would become a critical clinical application, we extended our existing hosting environment. Our investment in this regard was just over $100,000 as we were able to take advantage of enterprise licensing and a virtual server infrastructure. Internal resources were redeployed to focus on the initial build out of the eTrak application; it took a cross-functional team of web developers, business analysts, network engineers, and project managers 9 months to iterate through what was desirable and match that with what was possible. Through negotiation, an inventory of RFID tags with various capabilities was acquired for an average cost of $60 per tag. Given the experimental nature of our program, these costs were not charged back to departments that used the tags.

The eTrak system allows all RTs to log onto a web site to produce a map of the location of all ventilators in real time (Figure 1). Because equipment is characterized in eTrak by its type, model, and special features, the system allows users to locate specific types of equipment, e.g., a specific model of a ventilator with specific features, like a Drager Evita XL with SmartCare, etc.

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Core functional components of the eTrak system include:

- User log-on and user management.
- Location services
    - Device administration
    - Floor view of facilities
    - Ability to query for particular types of devices
- Reporting
- Online Help system and documentation.

Noteworthy features of eTrak include:

- The ability to "remember" the device and location that a last user profile accessed. For clinical units that routinely only access items on their floor or a particular type of equipment, this greatly simplifies the interface. They simply log on and see the floor they routinely access. Alternately, the system permits a search of the entire campus through a "Search All" feature.

- The ability to control who can see a particular category of assets. For instance, all healthcare providers who are designated as "Respiratory Therapists" can access all equipment in the ventilator - BiPAP /CPAP category of equipment. There are currently 300 pieces of RT equipment distributed among 43 equipment categories.

- Real-time calculation of the RFID position on the map scaled and plotted to the display screen. The screen can be panned and zoomed without flicker or other graphical detractors.

- The ability to "find more" of a particular asset. For instance, if a patient requires the particular capabilities of a particular ventilator type, the RT can locate other similar ventilators in the hospital by clicking a button.

RFID tags were strategically placed on each piece of equipment to prevent loss or damage to the tags. The preferred method of securing the tags was using a heavy-duty zip tie in a discrete but easily accessible location (Figure 2A). If no such location existed (i.e., small CPAP units), a heavy-duty Velcro-like product ("Dual-Lock," 3M, Minneapolis, MN) was used (Figure 2B). This has proved to be the strongest method for attaching the tag if a zip tie could not be used. Both methods allowed for easy tag removal and battery replacement. Care was taken to affix the tag to the machine itself and not to a stand or cart. This prevents a piece of equipment from being placed on a cart with the incorrect RFID tag.

Results

Early Experience Using the eTrak System

The impetus for implementing an RFID system was widespread dissatisfaction by respiratory therapists (RTs) with the time spent in searching for equipment, as demonstrated by low employee engagement scores (using the Gallup Corporation instrument; Gallup, Inc., Washington, D.C., U.S.A.) regarding the specific question: "I have the materials and equipment I need to do my work." Fifty percent of respondents to this question responded "no." Further inquiry by a focused survey within RT Departments indicated that inability to locate mechanical

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ventilators and bi-level noninvasive ventilators was responsible for most of this expressed dissatisfaction, with up to 20% of respondents indicating that equipment was too hard to find.

Design and Roll-Out of the eTrak System

The Cleveland Clinic Health System (CCHS) consists of a main campus hospital and 8 regional hospitals within Northeast Ohio. In implementing eTrak at all CCHS hospitals, we undertook to tag 218 ventilators and 82 non-invasive ventilator devices (e.g., bi-level non-invasive ventilators) with active RFID devices.

Based on the institutional needs to implement a system, requirements for the eTrak system were refined over the course of 2010, and the first release went live in March 2010. RFID tags from AeroScout, Inc. (Redwood City, California [Figure 2]) were used. Tagging the target respiratory devices (i.e., mechanical ventilators, bilevel non-invasive ventilators, portable capnography units, bedside spirometers, chest vest units, epoprostenol administration setups) was undertaken by a team of RTs and was completed over 8 weeks. Non-respiratory devices (e.g., deaf talk machines, computers on wheels, intravenous pumps, wound vacuum units, rental beds and equipment, and various patient monitors) were also tagged. Altogether, more than 8,000 items were tagged for tracking a total of 135 different types of equipment.

Various strategies were undertaken to announce the availability of eTrak use. For example, a series of "in service" talks were delivered to potential users. One-page training aids, as well as short "how to" video features were also prepared.

Impact of the eTrak System

Over the period from June 2012 to February 2013, we recorded 145 ($\pm$ 29) log-ons (mean ± standard deviation) to the eTrak system weekly (Figure 3). The number peaked at 202 log-

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ons/week during the influenza season and was lowest (n= 64 users/week) in December 2012. Individual log-ons may have involved finding multiple devices and individuals may have made multiple log-ons.

Baseline (pre-implementation) measurement included the time required to find a mechanical ventilator (i.e., the time from the RT's being notified of the need for the equipment to care for a patient and actually physically procuring it), which was undertaken by a survey of 25 staff RTs (including supervisors) at the Cleveland Clinic main hospital (of 300 total main campus RTs, 8 %). These RTs agreed to prospectively log the aforementioned times, which were collected and analyzed, both before and after eTrak installation. Implementation of the eTrak system was associated with a significant shortening of the time needed to locate mechanical ventilators by RTs (Figure 4). Specifically, before implementation, the median time was 18 minutes (range 1 – 45 minutes) and decreased to 3 minutes post-eTrak (range 1- 6 minutes, $p < 0.001$, Mann Whitney Rank Sum test).

To assess the impact of eTrak on RTs' perceptions regarding equipment availability, two respiratory care departments at the Cleveland Clinic main campus (in the Anesthesia and Respiratory Institutes, respectively) were surveyed before and again after implementing the eTrak system. The "pre" survey was conducted during the first quarter of 2010 (n = 69 completed surveys) and the "post" survey was conducted during the second quarter of 2011 (n = 55 completed surveys). The results (Figure 5) indicate non-significant trends toward improved satisfaction in finding ICU ventilators, transport ventilators and non-invasive bilevel ventilators/CPAP devices, with the largest change in the latter category.

Several challenges were experienced in implementing the eTrak system. For example, the initial set of RFID tags had a short battery life, requiring replacement and ultimate selection of a

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different vendor which currently supplies the tags (AeroScout, Inc., Redwood City, California). This initial struggle with decreased battery life led to decreased enthusiasm from the staff in realizing the usefulness of the system. Some users reported problems with the software, citing difficulties with log-on procedures and occasional inaccuracy of the indicated device location. However, we cannot be sure to what extent this reflects user error versus software bugs.

As a qualifying point, data within the eTrak system (i.e., serial numbers and 12-digit tag MAC [media access control] address, a unique identifier assigned to network interfaces for communications on the Intranet), must be manually entered into the system. In a large facility such as ours, this means hundreds of lines of data entry. The reliability of the data relies on these data being entered mistake-free. As the tag was placed on a machine, the person placing the tag transcribed the machine and tag information and sent that via email to a designated person to be entered into eTrak. Although none was observed, the possibility for error is evident.

Discussion

Early experience with an RFID program for healthcare equipment at the Cleveland Clinic shows that use of the internally developed, so-called eTrak system significantly shortened the time needed for RTs to find a mechanical ventilator. Given the mean observed time savings in locating a mechanical ventilator using eTrak (15 minutes/ventilator), RTs seeking 4 mechanical ventilators over the course of an 8-hour shift would have saved 1 hour (12.5% time savings). Also, though not achieving statistical significance, associated trends toward improved RT satisfaction regarding having the equipment needed to perform one's job were also observed.

While our observations are preliminary, they extend the relatively sparse available experience with RFID related to respiratory therapy. There are many reports of RFID use in healthcare in general (2-9) As a case in point, at Nemours Children's Hospital (Orlando, FL),

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RFID supports the concept of a single logistics center for the hospital from which to monitor and run operations. Interest in the technology seems high, as it has potential to be applied beyond asset location to temperature and humidity monitoring as well as to improving patient and clinician workflows. Scattered reports also describe using RFID technology to detect retained surgical sponges (6,9), to monitor endotracheal tube position (8), and for recording operating room timestamps (7). However, except for a laboratory-based study which reported the ability of RFID tags on ventilators to cause electromagnetic interference (4), we are unaware of any specific reports of using RFID technology to tag mechanical ventilators. Also, only a few reports describe hospital-wide application of RFID technology. For example, Britton (2) has summarized experience at 6 other institutions and a pilot experience at his own hospital, the Royal Alexandra Hospital in Renfrewshire, United Kingdom (2). At the Bon Secours Health System in Virginia, RFID labeling of 12,000 pieces of equipment was undertaken at 3 separate hospitals, with reported benefits of decreasing by 30 minutes per shift the time that nurses spent searching for equipment and decreasing equipment disappearance. At the Advocate Good Shepherd Hospital in Illinois and the Holy Name Society Hospital in New Jersey, RFID tracking programs were implemented (without statement of results) and at St. Vincent's Hospital in Alabama, an RFID program was undertaken to track and manage surgical instruments, e.g., for location, sterilization, and maintenance. Again, no specific data were cited regarding outcomes or the impact of this RFID program. In another example of RFID use in healthcare, Roberti (10) described use of 1900 active RFID tags in a 500-bed Georgia hospital to cover 75% of the million square feet of the facility. Whether ventilators were tagged was not stated. Taken together, the promise conferred by RFID tagging ventilators aligns with a larger trend to use

RFID tagging for inventory control and management in general, involving healthcare and other business sectors.

Several references provide comprehensive reviews of the literature on RFID in healthcare. Wamba (11) reviewed 22 articles in the Journal of Medical Systems from 1997 to 2011 and presented a list of future research directions. Mehrjerdi (12) reviewed active and passive tags in terms of cost and identified technical and managerial problems for RFID applications including reliability, identification range, and implementation costs. Yao et al. (13) reviewed RFID applications, perceived benefits, and barriers to adoption. They also described critical success factors and concluded that RFID technology in healthcare is still in the infancy stage, compared with that in other areas of application. Regarding implementation, Ting et al. (14) reported that most of the literature focuses on the benefits of RFID in healthcare with little attention to project management issues. Their paper provides a case study that illustrates the developmental framework and 23 critical issues that must be taken into consideration in the preparation, implementation, and maintenance stages of an RFID project. They concluded that the task is complex, with many challenges remaining unaddressed and they cited 5 areas for future research. Finally, Boulos and Berry (15) reported a state-of-the-art review of real-time locating systems using various technologies including light, camera, infrared, sound, ultrasound, Bluetooth, Wi-Fi and RFID. They listed 12 examples of mobile assets related to respiratory care that can be tracked.

Our data contribute to the available literature on RFID in healthcare in four ways. First, we report experience with a new, locally designed RFID system. Second, this RFID tracking program was implemented in a large academic medical center. Third, to our knowledge, ours is the first report of tagging mechanical ventilators and CPAP devices. Finally, we report quantitative data regarding the impact of the RFID program on the time needed to find the equipment as well as engagement scores before vs. after implementing the system.

Our experience has also provided an opportunity to learn and share some recommendations about implementing an RFID system that may have value for others. These recommendations are: 1) when designing the system and its use characteristics, set the active tag signaling to maximize battery life. Short-lived batteries create a time-intensive burden for system maintenance, 2) plan for system maintenance and monitoring needs, 3) roll out implementation in a phased way, with small groups "going live" sequentially, and 4) plan for and design the metrics that will be used to assess system input so as to assure their availability before and after implementing the system.

Several limitations of this study warrant comment. First, though the eTrak system is adaptable to a variety of settings, our study does not address the generalizability of our findings to other settings, e.g., regarding the system's impact on locating equipment. Furthermore, our data regarding the time interval between the RT's being notified of the need for equipment and finding it was based on a small sample from the main Cleveland Clinic hospital but not from other hospitals in our system. Such a comparison with larger groups and between hospitals within our system will be the subject of further inquiry. Second, as a pilot experience, our study necessarily leaves unanswered several important questions, e.g., what is the rate of adoption in settings other than that in which the system was developed? What is the cost-effectiveness of RFID tracking? Though a robust analysis of cost-effectiveness is clearly not available from this study, the savings of 1 hour of RT time per shift permits a crude estimate of the breakeven for adopting the eTrak system. At an average staffing of 100 RTs daily earning an average salary of $59,416 per year (16), implementation of the eTrak system is associated with capturing

$2856.54 of productive work per day or $1,042,400 annually. Third, we present the number of total weekly log-ons to eTrak as on overall metric of utilization, recognizing that this number likely exceeds the number of unique individual users of eTrak, i.e., a single user logging on twice would be responsible for two log-ons.

Overall, our early experience suggests that RFID tracking of mechanical ventilators and other RT equipment confers a desired benefit of more efficient equipment location and may enhance RT satisfaction. Further investigation is needed to clarify remaining unanswered questions, including the generalizability of these findings to other healthcare settings and the cost-effectiveness of RFID tracking.

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Figure Legends

Figure 1. Screenshot of the eTrak system display as it would appear to an RT seeking a piece of equipment. Note that metadata text identified the type of equipment, identifying information (e.g., serial number), and information about the battery life of the RFID tag, allowing preventive maintenance to avoid battery failure that would cause the equipment to disappear from view.

Figure 2. Image of the RFID tag used. A. Attachment with Dual-Lock. B. Attachment with zip tie.

Figure 3. Number of weekly log-ons to eTrak June 30, 2012 to February 28, 2013. Numbers along the bars indicate the specific numbers of log-ons for each period specified.

Figure 4. Median time between when the RT began to look for a mechanical ventilator and finding it before vs. after implementing the eTrak system

Figure 5. Results of focused surveys of RTs in two departments regarding the ease of finding equipment. The two surveys were conducted before (pre) and after (post) implementing the eTrak system. The indicated percentages denote the percentage of respondents who believe that equipment was too hard to find.

References

1. Wikipedia - http://en.wikipedia.org/wiki/Radio-frequency_identification. Accessed February 4, 2013.

2. Britton J. An investigation into the feasibility of locating portable medical devices using radio frequency identification devices and technology. J Med Eng and Tech 2007; 31: 450 – 458.

3. Ashar BS, Ferriter A. Radiofrequency identification technology in health care: Benefits and potential risks. JAMA 2007; 298: 2305 – 2307.

4. Van der Togt R, van Lieshout EJ, Hensbroek R, Beinat E, et al. Electromagnetic interference from radio frequency identification inducing potentially hazardous incidents in critical care medical equipment. JAMA 2008; 299: 2884 – 2890.

5. Wicks AM, Visich JK, Li S. Radio frequency identification applications in hospital environments. Hosp Top 2006; 84: 3 – 8.

6. Macario A, Morris D, Morris S. Initial clinical evaluation of a handheld device for detecting retained surgical gauze sponges using radiofrequency identification technology. Arch Surg 2006; 141: 659 – 662.

7. Marjamaa RA, Torkki PM, Torkki MI, Kirvela OA. Time accuracy of a radio frequency identification system for recording operating room timestamps. Anesth Analg 2006; 102: 1183 – 1186.

8. Reicher J, Reicher D, Reicher M. Use of radio frequency (RFID) tags in bedside monitoring of endotracheal tube position. J Clin Monit Comput 2007; 21: 155 – 158.

9. Rogers A, Jones E, Oleynikov D. Radio frequency identification (RFID) applied to surgical sponges. Surg Endosc 2007; 21: 1235 – 1237.

10. Roberti M. Hospital saves by using RFID to bring asset management in-house. RFID Journal. www.rfidjournal.com/articles/view?7802, accessed March 20, 2013.

11. Wamba SF. RFID-enabled healthcare applications, issues and benefits: an archival analysis (1997-2011). J Med Syst 2012;36:3393-3398.

12. Mehrjerdi YZ. Radio frequency identification: the big role player in health care management. Journal of Health Organization and Management 2011;25(5):490-505.

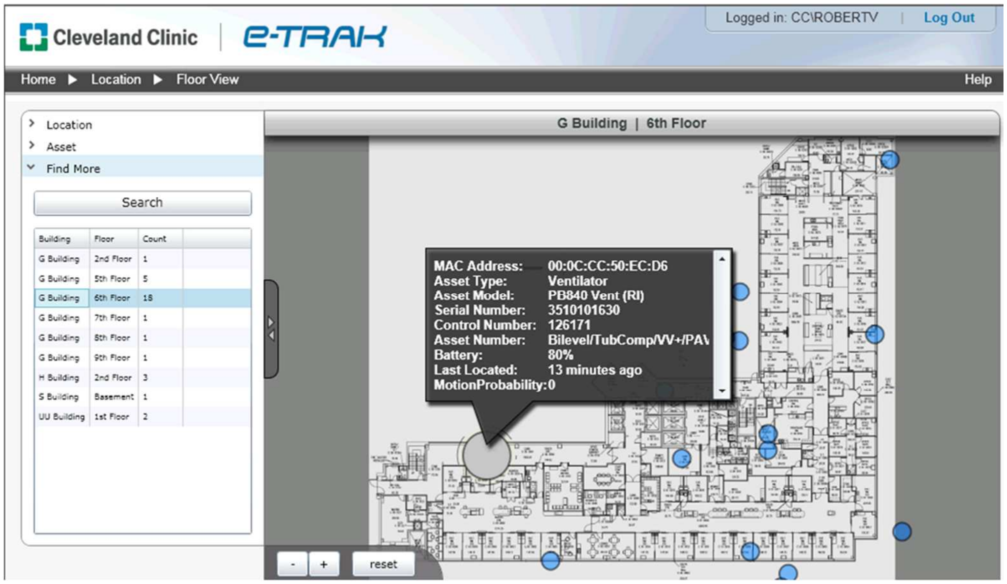
13. Yao W, Chu C, Li Z. The adoption and implementation of RFID technologies in healthcare: a literature review. J Med Syst 2012;36:3507-3525.

14. Ting SL, Kwok SK, Tsang AHC, Lee WB. Critical elements and lessons learnt from the implementation of an RFID-enabled healthcare management system in a medical organization. 2011;35:657-669.

15. Boulos MNK, Berry G. Real-time locating systems (RTLS) in healthcare: a condensed primer. International Journal of Health Geographics 2012;11:25.

16. Registered respiratory therapists' salaries. www.salary.com/registered-respiratory-therapist-salary.html, accessed March 23, 2013.

RESPIRATORY CARE Paper in Press. Published on July 02, 2013 as DOI: 10.4187/respcare.02545



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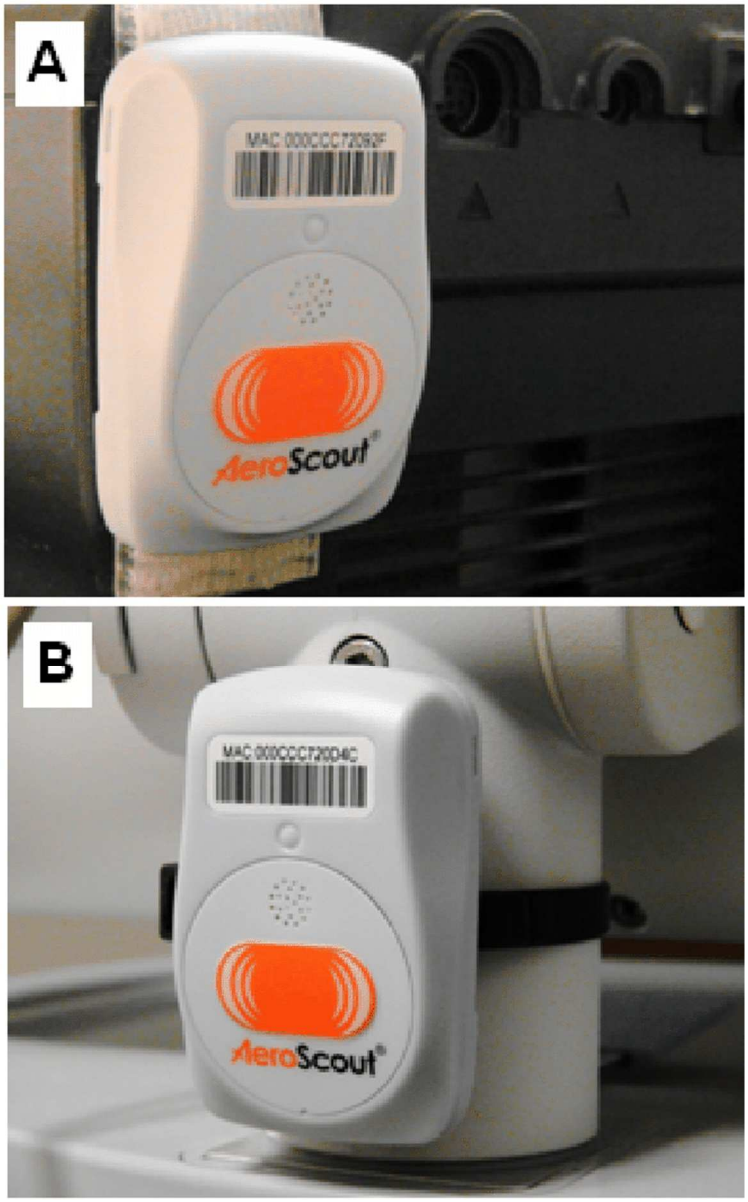

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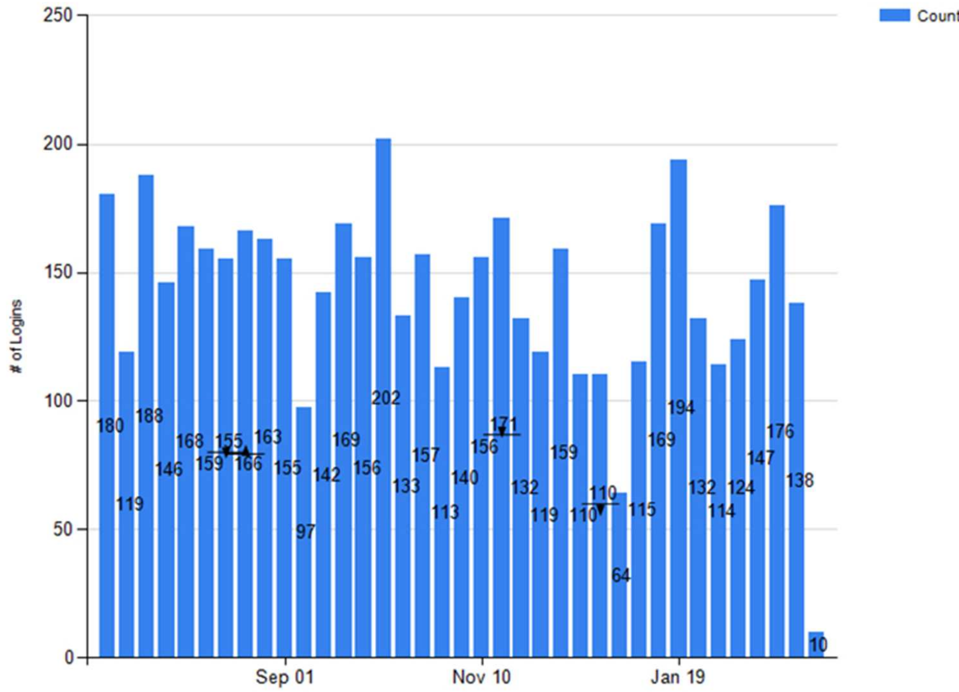

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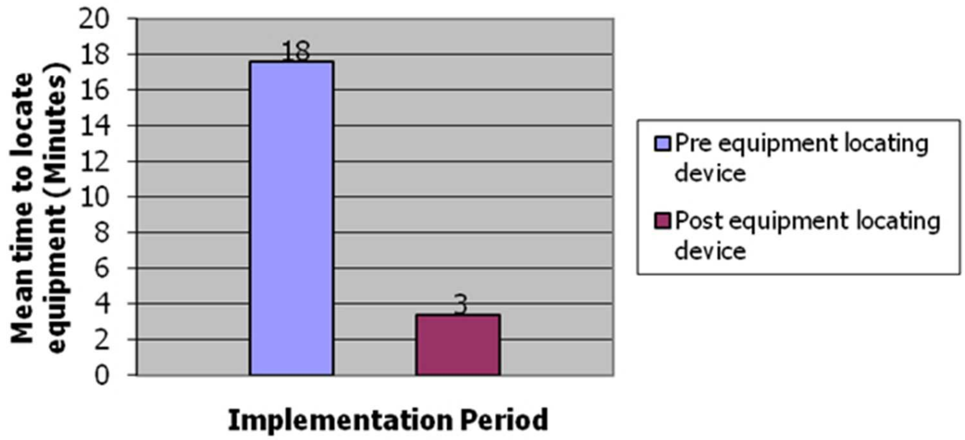

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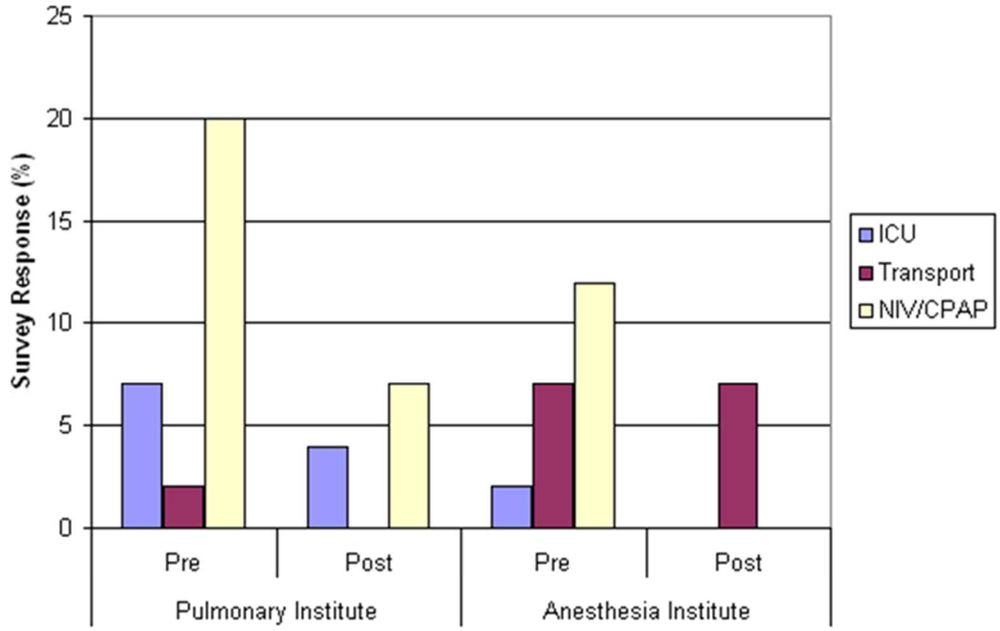

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