The State and Trends of Barcode, RFID, Biometric and Pharmacy Automation Technologies in US Hospitals

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Abstract

The standard of safe medication practice requires strict observance of the five rights of medication administration: the right patient, drug, time, dose, and route. Despite adherence to these guidelines, medication errors remain a public health concern that has generated health policies and hospital processes that leverage automation and computerization to reduce these errors. Bar code, RFID, biometrics and pharmacy automation technologies have been demonstrated in literature to decrease the incidence of medication errors by minimizing human factors involved in the process. Despite evidence suggesting the effectivity of these technologies, adoption rates and trends vary across hospital systems. The objective of study is to examine the state and adoption trends of automatic identification and data capture (AIDC) methods and pharmacy automation technologies in U.S. hospitals. A retrospective descriptive analysis of survey data from the HIMSS Analytics® Database was done, demonstrating an optimistic growth in the adoption of these patient safety solutions.

Introduction

In 1999, the Institute of Medicine estimated that the hospital mortality rate due to medication errors is as much as 98,000 patients per year, thereby making these errors a major public health concern. In their report, the committee recognized that addressing patient safety is the key component for the delivery of quality healthcare. It recommended improvements that have to be made in hospital systems and processes to reduce injuries. Different safety systems support the five rights of medication administration (right patient, right drug, right time, right dose, and right route) at various steps of the medication administration process. While electronic health record systems and computerized physician order entry are primarily focused on preventing order errors in the prescribing, transcribing and documentation steps, additional errors can transpire in the dispensing, and administering phases. It is estimated that the majority of medication errors occur at the prescribing (49%) and administration (26%) steps.

The years following the IOM report exhibited some small but insufficient progress in addressing medication errors through changes in health systems and policies. In 2004, the U.S. Food and Drug Administration (FDA) initiated a ruling to require all human medications and biological product labels to contain barcodes to help prevent medication errors and avert costs related to these adverse events. In 2012, as additional support to the FDA ruling, the Centers for Medicare & Medicaid Services (CMS) required hospitals to begin tracking medications starting from when a medication order is initiated, until its administration to the patient. The CMS measures suggest the implementation of assistive technologies such as automatic identification and data capture (AIDC) methods like barcoding, radio frequency identification (RFID) and biometrics in conjunction with pharmacy automation technologies like automated dispensing machines, carousels, and robotics, as part of Stage 2 Meaningful Use Core Measures.

Various AIDC methods have been demonstrated in literature to be effective in the reduction of medication errors and other adverse events. Barcode technology is used in various departments and processes in the hospital such as the laboratory, pharmacy, radiology, and medication administration. The technology typically uses a handheld barcode reader that registers and documents events of contact between medication, equipment, and healthcare personnel. Bar code medication administration (BCMA) is an integral part of preventing medication errors by making sure that the right patient is receiving the right medication at the point of administration. It is reported that BCMA systems have reduced the incidence of medication errors by more than 50%, and the risk of adverse drug events by 11% or approximately 20 events per day. The use of BCMA is also required in a closed-loop medication administration environment, which is the primary criteria for Stage 5 of the Healthcare Information and Management Systems Society (HIMSS) EMR Adoption Model (EMRAM), in addition to various levels of EMR system capabilities. It requires an electronic medication administration record (eMAR) that uses an AIDC method, which is integrated with the
computerized provider order entry (CPOE) and pharmacy information systems. A closed-loop environment significantly reduces medication errors, and increases patient identity confirmation before medication administration\textsuperscript{17}.

Bar code systems have also been applied to hospital laboratory processes. In neonatal intensive care units (NICU), barcoding in breast milk administration has been used to ensure that fragile, hospitalized infants who are separated from their mothers receive the right expressed milk at the right time from the right parent, eliminating the risk of transmitting infectious diseases caused by human immunodeficiency virus, cytomegalovirus, and hepatitis B virus\textsuperscript{16-21}. Barcoding has also been used to reduce adverse events and errors from the transfusion of blood products, which is estimated to occur once every 12,000 units transfused in the United States. Over 50\% of the mortality from transfusion-related injuries is attributed to errors in patient verification\textsuperscript{22-24}. Implementation of barcoding for transfusion verification has been demonstrated to be effective in preventing mismatched transfusions that may lead to the transmission of HIV, hepatitis B/C, and severe reactions such as acute hemolysis from ABO incompatibility\textsuperscript{24-26}.

RFID technology has also been used in hospitals for the same purposes as barcodes. The technology uses radio waves for collecting and transferring patient data\textsuperscript{27}. Some of its advantages over barcode technology include the elimination of the “line-of-sight” requirements of barcode scanners, and the capability to program RFID devices. RFID has been demonstrated to be effective in supporting patient safety, eliminating medication errors, and other adverse events related to patient misidentification\textsuperscript{28-30}.

Other newer technologies enhance patient safety by providing patient security through identity verification systems that use biometrics. Biometrics are measurable characteristics of human beings that are unique to each individual. Biometric devices and their accompanying software in healthcare institutions permit the automatic authentication of patient and provider identity for different purposes such as secure EHR system access, and patient verification\textsuperscript{31}. The most common hospital implementation of biometrics are the use of fingerprint and iris scanning\textsuperscript{32, 33}. The unique authentication methods of biometrics make it difficult to mismatch and forge identities since no two irises or fingerprints are the same.

In the pharmacy, different hardware systems that work in conjunction with hospital information systems play a major role in assuring that the right drug, the right dosage and instructions are prepared for the right patient. Automated dispensing machines (ADM), or automated dispensing cabinets are the most commonly used devices for decentralized medication dispensing\textsuperscript{34}. These machines are storage devices that automate and track medication distribution at the point-of-care. ADMs have been shown in the literature to have a moderate effect in reducing medication errors by automating the dispensing process\textsuperscript{34, 35}. Carousels on the other hand are centralized medication storage and retrieval systems designed as a series of revolving shelves set on rails has been seen to reduce filling or dispensing errors by automating medication dispensing in the pharmacy\textsuperscript{36}. Lastly, stationary robotic compounding and dispensing systems that work in conjunction with ADMs and carousels to further increase the accuracy of dispensing the correct drugs, dosage and quantities to the right patients, have demonstrated clear benefits in patient medication safety\textsuperscript{37}. These pharmacy automation technologies all use a form of AIDC method to verify that medication orders are correctly linked to patient records, and monitor inventory supplies.

Motivated by the important role and potential that AIDC methods and pharmacy automation implementations possess in reducing medication errors, we aimed to determine the state and trends of adoption of these technologies in U.S. hospitals using a retrospective descriptive analysis of survey data from the HIMSS Analytics® Database.
Methods

Data Source

Data from the Healthcare Information and Management Systems Society (HIMSS) Analytics® Database was used in this study. The HIMSS Analytics® Database contains survey data on the use, implementation and planning status of health IT hardware, software and infrastructure of more than 5,400 non-federal U.S. hospitals, which is included in its catalogue of nearly 40,000 U.S. healthcare facilities\(^38\). The database is noted to be the “most comprehensive database” for hospital IT adoption, representing nearly all non-federal hospitals with greater than 100 beds, and more than 90% of all U.S. hospitals\(^39\). The annually updated database originally started as the Dorenfest 3000+ Database in 1986, and was integrated in 1998 with data from U.S. Integrated Health Delivery Systems, to form the Dorenfest IHDS+ Database. It was then acquired by HIMSS Analytics, a non-profit subsidiary of HIMSS, in 2004 to become the HIMSS Analytics® Database. The latest version of the database used in this study contains data for 2012, which was made available at no charge to academic researchers in July, 2014.

Measurement of Technology Adoption

The HIMSS Analytics® Database was used to explore specific data elements pertaining to AIDC and pharmacy automation technology users. In each data element, survey respondents indicated whether the technology is currently being used, with some elements containing information on plans for future adoption. The following hierarchy tree loosely represents the availability and organization of the database relating to the topic of interest. The HIMSS survey definition of each data element can be found in Appendix A.

I. Barcoding
   A. Laboratory Department
      • Breast Milk Administration
      • Transfusion Verification
   B. Pharmacy Department
   C. Radiology Department
   D. Medication Administration
      • Complete Closed-Loop Medication Administration

II. Radio-frequency Identification (RFID)
   A. Laboratory Department
   B. Pharmacy Department
   C. Radiology Department
   D. Medication Administration

III. Medication Administration Processes

IV. Biometrics
   A. Fingerprint Scanning
   B. Iris Scanning

V. Pharmacy Automation
   A. Automated Dispensing Machines (ADMs)
   B. Carousels
   C. Robotics

Data Analysis

The Microsoft Access files of the HIMSS Analytics® Database, from 2008 to 2012, were queried using SQL from inside an R script. The R script gathered the results of the SQL queries, assembled together the data from separate years, and exported Office Open XML spreadsheets (XLSX files). All source code used in this paper is available for free reuse, commentary and contribution at \(\text{http://github.com/fabkury/itsos}\). Exploratory analyses were done to inspect the technology adoption rates in U.S. hospitals. Hospitals with missing values were not considered in the analysis of each data element individually.
Results

Barcoding Use

Bar code medication administration (BCMA) had the highest growth in adoption, averaging an increase of about 7% per year from 2008 to 2012 compared to 6.4%, 2.2%, and 1.15% for Pharmacy, Laboratory, and Radiology departments respectively (Figure 1). Barcoding use in the Laboratory department had the highest hospital adoption at 84.2% in 2012, compared to 73.9%, 58.1%, and 50.8% for Pharmacy, medication administration, and Radiology respectively. Within hospitals that use barcoding in the Laboratory (n=4509), 7% (n=324) use the technology for transfusion verification, while only 2% (n=89) use it in breast milk administration in 2012. In the same year, within hospitals that use BCMA (n=3114), 67.8% (n=2110) attest to having a complete closed-loop medication administration system, while 12.3% (n=384) indicate that they do not, and 19.9% failed to provide the detail. Table 1 includes a summary of adoption rates for bar coding, and Figure 1 for annual trends.

RFID Use

RFID medication administration had the highest growth in adoption, averaging an increase of about 0.4% per year from 2008 to 2012 compared to 0.25%, 0.24%, and 0.14 for Laboratory, Pharmacy and Radiology departments respectively (Figure 2). Similarly, RFID medication administration had the highest adoption rate in 2012 at 1.87% compared to 1.57%, 1.55%, and 1.12% for Laboratory, Pharmacy and Radiology departments respectively. A summary of the adoption rates is shown in Table 1.

Table 1. Percent use (%) of Bar code and RFID technologies by Department

<table>
<thead>
<tr>
<th>Department</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008</td>
</tr>
<tr>
<td><strong>Barcode</strong></td>
<td></td>
</tr>
<tr>
<td>1. Laboratory</td>
<td>75.3</td>
</tr>
<tr>
<td>2. Pharmacy</td>
<td>48.3</td>
</tr>
<tr>
<td>3. Medication Administration</td>
<td>29.9</td>
</tr>
<tr>
<td>4. Radiology</td>
<td>46.2</td>
</tr>
<tr>
<td><strong>RFID</strong></td>
<td></td>
</tr>
<tr>
<td>1. Medication Administration</td>
<td>0.27</td>
</tr>
<tr>
<td>2. Laboratory</td>
<td>0.57</td>
</tr>
<tr>
<td>3. Pharmacy</td>
<td>0.49</td>
</tr>
<tr>
<td>4. Radiology</td>
<td>0.54</td>
</tr>
</tbody>
</table>
Medication Administration Process

For all hospitals in 2012 that either use bar code or RFID in their medication administration process (n=2901), 97.1% (n=2818) of the hospitals have tags on the medications, 89.4% (n=2594) have them on their patients, and 59.2% (n=1718) on nurses. Patient tagging had the highest growth in adoption per year at 3.4%, followed by nurse (3.38%) and medication (0.96%) tagging and from 2008 – 2012 (Figure 3).

Biometrics

The use of fingerprint scanning had an average annual adoption increase of 1.23% per year from 2008, leading to a total of 15.9% (n=871) adoption within all hospital respondents (n=5467) in 2012. Iris scanning technology has an average annual adoption rate of 0.02% from the same time frame, and is only currently being used in 13 hospitals (0.02%) in 2012. Only 2.49% (n=136) hospitals in 2012 plan to expand or adopt the fingerprint technology in the following years, in contrast to only 12 hospitals (0.22%) for iris scanning.

Pharmacy Automation

The adoption of automated dispensing machines increased at an average annual adoption rate of 2.08% from 2008, leading up to an 81% hospital use in 2012. ADMs are predominantly used in the Medical or Surgical departments, followed by the Emergency department and the operating rooms (Figure 4). In contrast, robotic technology average annual adoption rate is around 0.04% within the same 4-year timeframe, leading to 7.88% hospital use in 2012. Carousel hospital use increased from 2.9% in 2010 to 5.67% in 2012. About 20.32% of hospitals that are already using carousels plan to expand and acquire more.

Table 2. Percent use (%) of Biometrics and Pharmacy Automation

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biometrics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Fingerprint Scanning</td>
<td>11</td>
<td>12.8</td>
<td>14.3</td>
<td>15.1</td>
<td>15.9</td>
</tr>
<tr>
<td>2. Iris Scanning</td>
<td>0.15</td>
<td>0.23</td>
<td>0.23</td>
<td>0.19</td>
<td>0.24</td>
</tr>
<tr>
<td><strong>Pharmacy Automation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Automated Dispensing Machines</td>
<td>72.7</td>
<td>75.9</td>
<td>78.9</td>
<td>80.4</td>
<td>81</td>
</tr>
<tr>
<td>2. Carousels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Robotics</td>
<td>7.72</td>
<td>7.98</td>
<td>8.2</td>
<td>8.09</td>
<td>7.88</td>
</tr>
</tbody>
</table>
Discussion

Overall, we found that from 2008 to 2012, medication administration had the highest annual growth rate for both bar code (7%) and RFID (0.4%) technologies. This may be due to healthcare legislation such as the HITECH Act in 2009, which stimulated investments in health IT, and set deadlines to meet specific meaningful use criteria\(^40\). The data also shows that about 67.8% of hospitals with BCMA have a closed-loop system. This raises the optimism for more hospitals to reach Stage 5 of the HIMSS EMRAM\(^16\).

Bar code adoption in laboratory (84.2%) and pharmacy (73.9%) departments in 2012 are high, which may be attributed to regulations by the FDA, and the amount of inventory tracking inherent in both departments. We also notice the low adoption rates for breast milk administration and transfusion verification, which may be attributed to the relatively low error rates compared to general medication administration\(^21\), and the lack of consensus and economic resource\(^18\), \(^41\). Adoption of RFID technology is also generally low, which is consistent with previous studies explaining costs and negative perceptions as major barriers of implementation\(^42\).

Details on the utilization of bar code and RFID tags on patients, medications, and nurses in 2012 show both high rates for medications (97.1%) and patient (89.4%) tags, but moderate use for nurses (59.22%). This may have implications on the requirements of closed-loop medication administration and information in the eMAR because a record containing the identity of the healthcare provider who dispenses and administers the medication is important in tracking and record transparency.

For biometrics use in hospitals, the data shows a slower annual adoption of both fingerprint and iris scanning technologies (1.23% and 0.02% respectively), with comparatively low overall adoption. Low adoption may be due to the costs in implementing biometrics within existing EHR systems and workflows. Pharmacy automation technologies such as ADMs seems to show a steady growth (2.8%), with high hospital adoption (81%) in 2012. In contrast, adoption is relatively low for carousels and robotics (5.67% and 7.88% respectively), which is most likely due to the hardware costs.

In summary, although the benefits of AIDC methods and pharmacy automation technologies in reducing medication errors seem to be increasing, current adoption trends, careful consideration of individual hospital systems, costs, and clinical workflow should guide administrative decisions leading to greater adoption. Organizational leadership and the cooperation of hospital staff will continue to be important in the ongoing adoption of these technologies\(^43\). Findings from this study may provide decision makers with a benchmark for strategic planning and deployment of these technologies for raising the quality of healthcare through the improvement of patient medication safety.
Limitations

The main limitations of the HIMSS Analytics® Database are similar to other studies based on data from surveys. The data relies on accurate self-reporting from hospital administrators via completion of a phone interview and an IT inventory survey. Survey respondents who represent their healthcare institution may not have the information to answer some specific parts of survey questions, or may decline to volunteer the information, leading to varying response rates for each data element. Some data elements lack more granularity and other specific process details that may open new opportunities for research and analyses. In common with many surveys, the time period during data collection may not accurately reflect the current state of affairs in these organizations.

Regardless of its limitations, to our knowledge, the HIMSS Analytics® Database is currently the most complete survey of health IT adoption and implementation in nearly all non-federal U.S. hospitals. It is a valuable resource that continues to be refined and expanded every year, providing researchers with trends that contribute to more strategic hospital investments and planning.

Conclusion

The increasing adoption of AIDC methods and pharmacy automation technologies across all U.S. hospitals sizes demonstrates interest in ensuring patient medication safety towards the improvement of quality of care. A comprehensive knowledge of the adoption rates, trends and evidence demonstrating the effects of implementing these technologies may contribute to individual hospitals’ strategic decision-making. The database provided by HIMSS Analytics™ with the support of the Dorenfest Institute are capable of providing analytic data on these and other matters that may serve as indicators for healthcare access and delivery. The same knowledge may stimulate the development of future health policies supporting the five rights of medication administration.

Acknowledgement

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Disclaimer

The views and opinions of the authors expressed herein do not necessarily state or reflect those of the National Library of Medicine, National Institutes of Health or the US Department of Health and Human Services.

Competing Interests

The authors declare no competing interests.
References

# APPENDIX A. HIMSS Data Element Definitions

<table>
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<tr>
<th>Data Element</th>
<th>Definition</th>
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| **Barcoding**                | **Laboratory** Bar code technology used in the laboratory department to improve the efficiency of operations for functions such as specimen identification, specimen collection, and specimen processing.  
  **Pharmacy** Bar coding is used by the pharmacy department for inventory control of drugs.  
  **Radiology** Bar code technology used in the radiology/imaging department(s) to improve the efficiency of operations of functions such as patient tracking, film tracking, and the completion of imaging services.  
  **Medication Administration** Barcode technology used by nursing services to improve the efficiency of operations such as patient identification, nurse identification, medication identification, and closed loop medication administration processes that improve patient safety.  
  **Closed-Loop Medication Administration** An environment where the medication process is electronic from initial entry by physicians using CPOE, to pharmacies for order validation and bar coding the medications, to the automatic dispensing machines, to the actual administration of the medication at point of care by the nurse where the nurse scans patient bar code and the medication bar code which initiates clinical decision support for the five rights of medication administration. |
| **RFID**                     | **Laboratory** RFID technology used in the laboratory department to improve the efficiency of operations for functions such as specimen identification, specimen collection, and specimen processing.  
  **Pharmacy** RFID is used by the pharmacy department for inventory control of drugs.  
  **Radiology** RFID technology used in the radiology/imaging department(s) to improve the efficiency of operations of functions such as patient tracking, film tracking, and the completion of imaging services.  
  **Medication Administration** RFID technology used by nursing services to improve the efficiency of operations such as patient identification, nurse identification, medication identification, and closed loop medication administration processes that improve patient safety.  
  **Medication Administration Processes** Elements that are bar coded or have an RFID tag in the medication administration process |
| **Biometrics**               | **Fingerprint Scanning** Software that allows a user to scan a fingerprint image and compare the digitized image data with fingerprints image data in a database.  
  **Iris Scanning** Biometric identification by scanning the iris of the eye; Retinal recognition by means of scanning blood vessel patterns of the retina and the pattern of flecks on the iris. |
| **Pharmacy Automation**     | **Automated Dispensing Machines** A medication dispensing cabinet that automates the storing, dispensing and tracking of narcotics, floor stock and PRN medications in-patient care areas. Provides secure access to medications, while eliminating narcotic counts and keys. Interfaces with hospital ADT/billing systems to improve charge capture and materials management systems to track inventory  
  **Carousels** Physical devices that store day to day pharmaceutical supplies for manual or automatic picking of items for patient and nursing unit supply.  
  **Robotics** Robotic technology used by pharmacies to conduct dispensing and cart fill functions and to deliver medications to medication cabinets for restocking. |