Re-examining the requirements for verification of patient identifiers during medication administration: No wonder it is error-prone

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Patient identification errors are one of the major causes of medication errors. Most medication error studies to date have focused on reporting patient misidentification statistics from case studies, on classifying types of patient identification errors, or on evaluating the impact of technology on the patient identification process, but few have proposed specific strategies or guidelines to decrease patient identification errors. Our study makes three key contributions to the patient identification literature. To better understand the verification of patient identifiers (VPI) process, we first formalize the requirements for this process based on the Joint Commission's national patient safety guidelines. Second, we show the implications of these requirements by applying them to artifacts typically used in medication administration (e.g., patient's statements about their identity, patient's identification band, medication label, and medication order). Third, we evaluate whether nurses comply with these requirements when administering medications using data from clinical simulations. We found that nurses must choose from a considerable number of alternatives to fulfill the Joint Commission guidelines. Despite the number of available alternatives, a small percentage of nurses complied with the requirements for VPI, whether doing so manually or using barcode verification technology. Our findings suggest further study is needed to determine what strategies might improve compliance.

Keywords: Patient identification, medication administration, medication error

1. Introduction

Patient identification errors are a major source of medication errors (Lisby *et al.*, 2005; Mannos, 2003; Spruill *et al.*, 2009). During medication administration, failure to identify patients correctly can lead to patients receiving incorrect medications, perhaps resulting in adverse drug events and even death (Schulmeister, 2008). Moreover, patient misidentification may also harm the patients who fail to receive their intended medications because their medications were erroneously given to other patients (Hakimzada *et al.*, 2008; Ranger and Bothwell, 2004). Most medication error studies to date have focused on reporting patient misidentification statistics from case studies (Henneman *et al.*, 2010; Henneman *et al.*, 2012; Leape *et al.*, 1995), on classifying types of patient identification errors (Mannos, 2003; National Patient Safety Agency, 2004; Schulmeister,

2008), or on evaluating the impact of technology on the patient identification process (Henneman *et al.*, 2012; Patterson *et al.*, 2002; Snyder *et al.*, 2010).

According to estimates by the Institute of Medicine, hospitalized patients experience approximately one medication error per day of their stay (Institute of Medicine, 2006). Further studies have shown that approximately 26%–38% of medication errors occur during medication administration (Andersson and Townsend, 2010; Leape *et al.*, 1995) and that up to 80% of these medication administration errors may be due to patient misidentification (Lisby *et al.*, 2005). Although patient identification may appear straightforward, studies have shown it to be complex and error-prone (Henneman *et al.*, 2010; Mannos, 2003; National Patient Safety Agency, 2004; Sevdalis *et al.*, 2009; Spruill *et al.*, 2009).

Several organizations have suggested guidelines to increase the accuracy of patient identification, including the National Patient Safety Agency, the Joint Commission on Accreditation of Healthcare, and the World Health

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Organization. In 2003 the Joint Commission introduced "*Improve the accuracy of patient identification*" as the first of its National Patient Safety Goals and has since then updated it annually. The Joint Commission guidelines for fulfilling this goal are:

> Use at least two patient identifiers when providing care, treatment, and services … acceptable identifiers may be the individual's name, an assigned identification number, telephone number, or other person-specific identifier … the patient's room number or physical location is not used as an identifier … (Joint Commission, 2013)

Healthcare facilities may train their workers by using policies and/or procedures based on their interpretation of these guidelines. For example, Baystate Medical Center's (Springfield, MA) facility-specific guidelines are:

> … the two patient specific identifiers are: 1) the patient's stated full name (first and last) and 2) The medical record number on his/her ID band … match two patient specific identifiers directly associated with the individual and the same two identifiers associated with the medication, blood product, specimen ….

Although several research studies have discussed patient identification errors in healthcare processes, few have proposed specific strategies or guidelines to decrease these errors. Lane *et al.* (2006) propose a hierarchical protocol for the ideal medication administration process. Their research suggests comparing the patient's identification (ID) band to the patient's chart during medication administration, but does not specify how to deal with other artifacts. To decrease incidents of patient misidentification before chemotherapy administration, Spruill *et al.* (2009) suggest matching two patient identifiers, the patient's name and medical record number (MRN), between two specific artifacts, namely the patient's ID band and the chemotherapy product label. With respect to the medication administration process, Paparella (2012) recommends matching any two patient identifiers suggested by the Joint Commission across three specific artifacts: the patient's statements about their identity, the patient's ID band, and the medication order. These studies, however, appear to focus on specific processes (e.g., medication administration, chemotherapy),

specific artifacts (e.g., patient's ID band, patient's chart, chemotherapy product label, medication order), or specific identifiers (e.g., patient's name, MRN). Henneman *et al.* (2010) suggest a strategy that is applicable to any number of artifacts for a set of selected processes. First, their strategy proposes using any two patient identifiers suggested by the Joint Commission and matching those identifiers between two specific artifacts: the patient's ID band and the patient's statements about their identity. Second, their strategy proposes matching identifiers on other artifacts to either the patient's statements or the patient's ID band. They do not generalize their two-step strategy, however, to healthcare processes such as laboratory testing, which may not involve a patient wearing an ID band. Thus, it may be important to establish general guidelines that can be universally applied to a wider range of healthcare processes.

For verification of patient identifiers (VPI), it is crucial for healthcare workers to carefully select *pairs of artifacts* to match patient identifiers. The Joint Commission guidelines, however, focus on how to select identifiers but not on how to select the pairs of artifacts. Here we use the term *artifact* to mean an entity containing at least two patient identifiers and thus an entity that could be used in the VPI process. In our study, we consider patients to be artifacts and their statements about their identities to be patient identifiers.

Selecting pairs of artifacts for patient identification is not straightforward when several artifacts are involved in the process. As shown in Fig. 1, (a), (b), and (c) seem to meet the Joint Commission guidelines, but (c) may not prevent the patient from receiving the wrong medication if the top two artifacts pertain to one patient and the bottom two artifacts pertain to another.

The work reported here approaches VPI as a complex process that is currently poorly defined and error-prone. Our research makes the following key contributions to the patient identification literature:

1. To better understand the VPI process, we specify the requirements for this process so that they include directions on the selection of pairs of artifacts and are generalizable across processes and artifacts. By *requirements*, we mean those activities necessary to accomplish a task. Requirements often do not prescribe how the activities
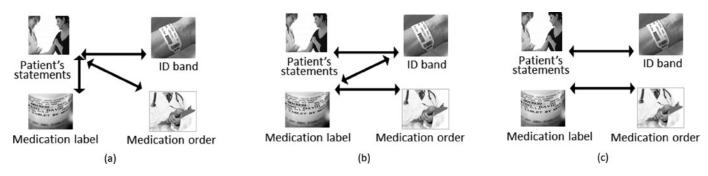

Fig. 1. Selection of pairs of artifacts.

are to be done, but instead specify the constraints that must be met for the activity to be considered successfully completed.

2. We show what these requirements mean for those artifacts typically used in medication administration. In this paper, the artifacts we consider include the patient's ID band, the medication order, and the medication label, as well as the patient's statements about their identity.

3. We evaluate whether nurses comply with these requirements when administering medications by analyzing data from clinical simulations (Henneman *et al*., 2010; Henneman *et al*., 2012). For those nurses who do not comply with these requirements, we analyze what they did incorrectly. We expect that understanding how the patient identification process is typically performed will lead to a better understanding of why the process is error-prone and subsequently lead to an improved process with better patient safety outcomes.

We focus on nurses, as they play a vital role in identifying patient identification errors; one study of medication errors collected from voluntary reports and patients' records found nurses were responsible for 86% of all intercepted medication errors (Leape *et al*., 1995). The insights from our study should be applicable to other types of healthcare workers performing VPI. As we show in this paper, there are a considerable number of acceptable alternatives for performing the VPI process. Nonetheless, evaluation of the data from the Henneman studies shows that nurses often do not select an alternative that complies with the requirements.

The remainder of the article is organized as follows. Section 2 presents our formalized requirements for VPI based on the Joint Commission guidelines. Section 3 shows how these requirements are applied to typical artifacts used in the medication administration process. Section 4 describes how we analyzed data collected from the Henneman studies to gain insight into how well nurses actually complied with the requirements for VPI, and Section 5 reports the results from this analysis. Section 6 discusses implications from these results and limitations associated with our work. Section 7 summarizes our findings and provides directions for future work.

2. Requirements for VPI

To make the Joint Commission guidelines for VPI more precise, we propose they be extended, as follows, to include guidance on selecting artifacts:

> Before an artifact is used, assure that at least two patient identifiers on that artifact have been matched with the corresponding identifiers from another artifact that is considered to be trusted.

An artifact is considered to be *trusted* if it is either known to have been previously verified (e.g., ID band on patient's wrist) or assumed to be correct based upon direct evidence. We define a *verified artifact* to be an artifact with at least two patient identifiers that have been matched with the corresponding identifiers from another artifact that is considered to be trusted. For example, if the ID band is considered to be trusted and the medication label has not yet been evaluated (i.e., it is an unverified artifact), matching the patient's name and date of birth (DOB) on the medication label with the name and DOB on the ID band allows the healthcare worker to now consider the medication label to be a verified, and thus trusted, artifact. Based upon direct evidence, some artifacts can be immediately considered to be trusted. For example, a patient's statements about their identity (e.g., name and DOB) are generally assumed to be correct and do not require further verification. Prior to the start of the VPI process, there must be at least one trusted artifact whose patient identifiers can be matched to those identifiers from unverified artifacts.

Most healthcare processes tend to involve several unverified artifacts. To perform the VPI process when two or more unverified artifacts are involved, a set of artifact pairs is identified. We introduce the term *artifact pair* to indicate that at least two identifiers on one artifact of the artifact pair are to be matched to the same identifiers on the other artifact of the artifact pair. In subsequent figures, we represent an artifact pair using a bidirectional edge between the two artifacts. A subset of the edges representing the artifact pairs should form a path from each unverified artifact that will be used in the healthcare process to a trusted artifact. The selection of the artifact pairs and the matching of the identifiers for those pairs do not have to occur in any prescribed order. After these matches have been successfully conducted, the initially unverified artifacts that occur on this path are considered verified. We therefore introduce the term *identifying set of artifact pairs* to indicate a set of artifact pairs that meet the extended Joint Commission guidelines for VPI when at least two common identifiers are matched between each artifact for each pair in the set.

- **Definition**: An **I**dentifying **S**et of **A**rtifact **P**airs (**ISAP**) is a set of artifact pairs adhering to the following conditions:

  ○ **Condition 1**: A trusted artifact is included in at least one artifact pair in the set;
  ○ **Condition 2**: For each unverified artifact that will be used, there is a subset of artifact pairs that form a path to a trusted artifact.

Fig. 2 provides two examples of an ISAP and one example of a non-ISAP. In this figure, the bidirectional edges between the artifacts represent the artifact pairs. Each edge is labeled with a letter, A-F, with each dark edge indicating that the artifact pair is in the ISAP and a light edge
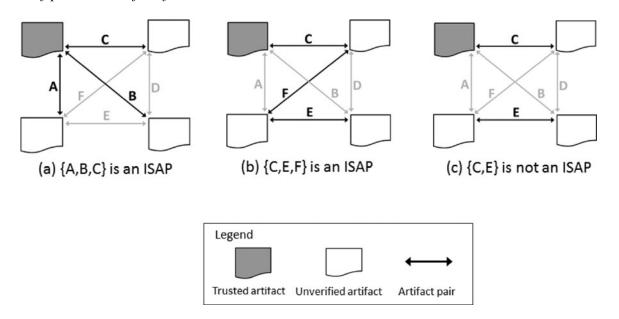
Fig. 2. ISAP and non-ISAP examples.

indicating that the artifact pair is not in the ISAP. In Figure 2(a), the set of artifact pairs, {A,B,C}, satisfies both conditions and is an ISAP: a trusted artifact is included in at least one artifact pair in the set (A, B, and C satisfy Condition 1); for each unverified artifact on the top-right, bottom-left, and bottom-right, there is a subset of artifact pairs that form a path to the trusted artifact: {C}, {A}, and {B} respectively (satisfies Condition 2). In the same way, in Figure 2(b), {C,E,F} is an ISAP because a trusted artifact is included in at least one artifact pair in the set (C satisfies Condition 1); for each unverified artifact on the top-right, bottom-left, and bottom-right, there is a subset of artifact pairs that form a path to the trusted artifact: {C}, {F,C}, and {E,F,C} respectively (satisfies Condition 2). In Figure 2(c), {C,E} is not an ISAP because for each unverified artifact on the bottom-left and bottom-right, there is no path to the trusted artifact (violates Condition 2).

Given this definition of an ISAP, we formalize the requirements for VPI so that the requirements include directions on the selection of artifact pairs and are generalizable across processes and artifacts.

- **Requirements for VPI**: For each artifact pair in a selected ISAP, at least two of the identifiers on one of the artifacts in that pair should be matched to the corresponding identifiers on the other artifact of that pair.

The requirements do not impose a specific ordering of the matching of identifiers among the artifact pairs. For example, in Fig. 2(a), given the ISAP {A,B,C}, the artifact pairs can be selected in any order (i.e., ABC, ACB, BAC, BCA, CAB, or CBA) for VPI.
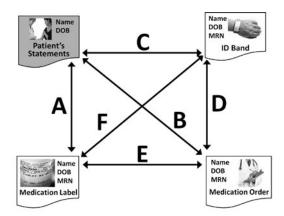
3. Implications of requirements for VPI for the medication administration process

To understand the implications of the requirements for VPI, we applied these requirements to a specific set of artifacts typically used in medication administration (i.e., patient's statements, medication label, medication order, and ID band) and associated patient identifiers (i.e., name, DOB, and MRN). The following assumptions underlie our study:

- A patient's collective statements about their identity are considered a trusted artifact.
- All other artifacts are initially considered unverified artifacts, unless explicitly stated otherwise.
- If at least two patient identifiers are determined to be correct for an artifact, all of its identifiers are assumed to be correct.
- The medication label contains patient identification information.

These assumptions may not always be correct, as addressed in the Discussion. In this paper, we evaluate the requirements for VPI during the medication administration process for a *patient-identified medication,* meaning that the medication contains patient identification information (e.g., medications for chemotherapy; Jacobson *et al.*, 2009; Spruill *et al.*, 2009). Labels for common medications (e.g., aspirin) often do not contain this information. While the label on a patient identified medication includes patient identification information in a human readable form, the barcode on the medication label does not necessarily include this information, since the FDA's Bar Code Label Requirements do not require patient identification information be included in medication barcodes (FDA, 2011).

Note:
- Trusted artifact: Patient's Statements
- Unverified artifacts: Medication Label, Medication Order, and ID Band

Fig. 3. Six artifact pairs with at least two of the same types of patient identifiers.
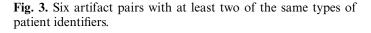
Fig. 3 shows the typical artifacts and associated patient identifiers used in the medication administration process. The four typical artifacts result in six artifact pairs (A-F) potentially available for VPI. To perform the VPI process, an ISAP must be selected using a subset of the six artifact pairs. In addition, for each artifact pair in the selected ISAP, at least two identifiers on one artifact in the pair should be matched to the same identifiers on the other artifact in the pair. The two identifiers are selected from a small set of alternatives: the alternatives are restricted either to two available identifiers (i.e., name and DOB) for each of the three artifact pairs A-C, or three available identifiers (i.e., name, DOB, and MRN) for each of the three artifact pairs D-F. Because the identifiers are selected from a such a small set of alternatives, we do not consider alternatives in selection of identifiers in this paper.

For the typical artifacts shown in Fig. 3, where there is one trusted artifact and three unverified artifacts, the total number of possible ISAPs[1] is 38. Among these 38, the total number of ISAPs composed of the minimum number of artifact pairs is 16, which we term a minimal ISAP. Identifying the minimal ISAPs is a similar problem to finding a spanning tree—a minimal set of edges that connect all vertices in a complete graph in which each pair of vertices is connected by an edge (Kosowski and Kuszner, 2005). For each minimal ISAP, additional matches for VPI could be performed by including one or more extra artifact pairs in the set. A minimal ISAP ensures that healthcare workers conduct at least a minimal number of matches to successfully perform the VPI process. Fig. 4 shows these 16 possible

minimal ISAPs[2] illustrating that VPI can be accomplished in multiple ways. Each minimal ISAP is composed of 3 artifact pairs that can be selected in any order. In our subsequent analysis, we determine whether the nurses in the study conducted at least this minimal matching.

4. Experimental evaluation of nurse compliance

To gain insight into how well the requirements for VPI are performed during medication administration, we evaluated the data from Henneman *et al.*'s studies (2010, 2012) to determine whether emergency department nurses in a simulated clinical setting complied with the requirements for VPI. The study was carried out at a 600-bed, urban, level 1 trauma, pediatric and tertiary referral center with an annual ED census > 100,000. The study was approved by the hospital's institutional review board, and all nurse participants read and gave informed consent. The following subsections describe the procedure for collecting data and generating the sequences of nurses' activities, and our approach for analyzing how well nurses complied with the requirements for VPI.

4.1. *Study procedure*

Nurses administered medications in two different experiments. Twenty-eight nurses gave a medication to each of two patients (i.e., 56 trials) without the help of barcode verification technology (i.e., Manual Medication Administration (MMA)) and twenty-five nurses gave a medication to one patient (i.e., 25 trials) with the support of barcode verification technology (i.e., Barcode Medication Administration (BCMA)). The experiments used the same four artifacts and associated patient identifiers typically used during in medication administration, as described in the previous section. In both experiments, a researcher led each nurse to a series of numbered rooms where students acting as patients were waiting. Each patient had an ID band secured to their wrist. For each patient, the researcher gave the nurse a medication order and a medication, each labeled with the patient identification information. The nurse then performed a medication administration process on each patient. All nurses wore an eye-tracking device that included a camera for recording a video with crosshairs showing where each nurse was looking throughout the process. In both experiments, nurses were told that the purpose of the study was to evaluate how healthcare workers use visual cues to perform tasks (Henneman *et al.*, 2010); thus, they

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[1] $38 = (\sum_{i=3}^{6} C_i^6) - 4$, where 4 is the number of non-ISAPs composed of 3 artifact pairs that do not satisfy either Condition 1 or 2.

[2] When the order of examined artifact pairs is considered, the total number of possible minimal ISAPs is 96 ($= (C_3^6 \times 3!) - 24$), where 24 is the number of non-ISAPs composed of 3 artifact pairs that do not satisfy either Condition 1 or 2.
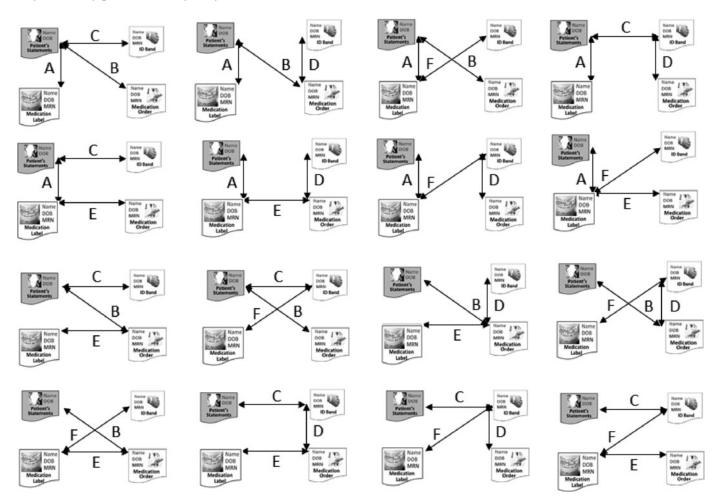
Fig. 4. Possible minimal ISAPs when there is one trusted artifact and three unverified artifacts.
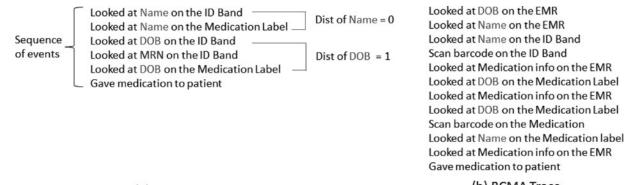
were not aware that the purpose of the study was to evaluate the VPI process.

After completing the simulations, we reviewed the eye tracking videos for quality. Of the 56 videos created during MMA, we discarded 12 (21%) videos because of insufficient video quality, leaving 44 (79%) videos for our analysis. We included all 25 (100%) of the videos created during BCMA in the analysis.

We carefully translated the videos into traces. By *trace*, we mean the complete sequence of VPI-related events performed by a nurse. We defined event names based on a set of predefined activities associated with VPI during medication administration. Given the standardized set of event names, two researchers independently reviewed the videos and created the event sequences. In the few cases when there was disagreement between these two researchers on an event assignment, a third researcher reviewed the video and made the final decision on the event assignment. Fig. 5 shows shortened sample traces using MMA and BCMA (where EMR is an abbreviation for Electronic Medical Record).

In analyzing the traces, we considered that an actual match between identifiers on two artifacts is unlikely to

occur if there are too many intermediate events between the first and second part of the match. To denote the distance between theses intermediate events, we define *Inter-Identifier Distance (Dist)* to be the shortest distance (i.e., the number of intermediate events) between the first and second part of a match between identifiers on an artifact pair within a trace. We assume a shorter *Dist* is more likely to lead to an actual match because working memory gradually decays, becoming progressively less precise as information is retained for longer periods of time (Cornelissen and Greenlee, 2000). In Fig. 5 (a), the *Dist* of the match for name is 0 because there are no intermediate events between the first and second part of the match. The *Dist* of the match for DOB is 1 because there is one intermediate event (i.e., Looked at MRN on the ID Band) between the first and second part of the match. In our analysis, when determining whether nurses actually performed the match or not, we considered three values of *Dist*: $Dist = 0$, $Dist \leq 1$, and *any Dist* (i.e., $Dist \leq$ infinity), to observe how compliance with the requirements varied depending on how relaxed we assumed the *Dist* value could be. In the Discussion, we address the limitations of these three choices of *Dist*.

Fig. 5. Sample shortened traces from nurses using MMA and BCMA .

We also accounted for the fact that it was sometimes unclear which identifier the nurse was fixating on during the BCMA trials, largely because of glare on the computer screen. To address this limitation, we considered two assumptions: (i) while looking at the artifact, the nurse did not fixate on any identifiers on the artifact (which indicates a lower bound for the true number of identifier that the nurse fixated on) and (ii) while looking at the artifact, the nurse fixated on every identifier on the artifact (which indicates an upper bound for the true number of identifier that the nurse fixated on). Under the former assumption, we found that almost no nurses complied with the requirements for VPI using BCMA. Hence, we considered only the results under the latter assumption in our analysis. While using this assumption yielded the best possible performance of nurses complying with the requirements for VPI, a still surprisingly small percentage of nurses complied with the requirements, as is addressed in the Results and Discussion.

4.2. *Analysis approach*

Although in Section 3, we described the 16 possible minimal ISAPs for the situation where there is one trusted artifact and three unverified artifacts used in the medication administration process, in this section, we examine several specific cases and identify the possible minimal ISAPs allowable for each. These include whether the ID band is to be trusted or not, if it is not trusted whether it is to be used or ignored, and whether the process uses barcode technology or not.

Ideally, the ID band should be verified and secured to the patient during registration prior to conducting the medication administration process, meaning that the ID band could be considered a trusted artifact. Studies have shown, however, that some patients' ID bands contain incorrect information (Dhatt *et al.*, 2011; Renner *et al.*, 1993; Sevdalis *et al.*, 2009; Snyder *et al.*, 2010). To show the impact of assuming a trusted ID band on the requirements for VPI, we take into account two cases in our analysis: the ID band is not initially considered a trusted artifact (i.e., it is an un-

verified artifact) and the ID band is initially considered a trusted artifact.

The leftmost column of Fig. 6 includes a description of these two cases regarding the ID band. Note that the first case is divided into two sub-cases depending on whether the nurse verifies and uses the ID band or ignores the ID band. We use the abbreviation *ID Band Used (BU)* and *ID Band Ignored (BI)* for the first case and *ID Band Trusted (BT)* for the second case. The third column indicates the number of trusted artifacts and unverified artifacts for each case. The fourth and fifth columns show the abbreviations for each of the five cases depending on MMA and BCMA, a figure depicting the case, and the list of possible minimal ISAPs associated with the case. Note that scanning the barcode on the patient's ID band is mandatory for conducting the process in BCMA, so *BCMA_BI* is not a possible case; in the other BCMA cases, scanning the barcode on the patient's ID band must be included in an artifact pair as represented by the dotted edge.

For each of the five cases, we identify all possible minimal ISAPs that satisfy the aforementioned conditions. For example, as shown in Fig. 6, the conditions for an ISAP in the case of *MMA_BU* are: a trusted artifact (i.e., patient's statements) is included in at least one artifact pair in the set (satisfies Condition 1); and for each unverified artifact (i.e., medication label, medication order, and ID band), there is a subset of artifact pairs that form a path to the trusted artifact (satisfies Condition 2). The total number of possible minimal ISAPs satisfying these conditions is 16, as shown in Fig. 4. The total number of possible minimal ISAPs in the cases of *MMA_BI* and *MMA_BT* are 3 and 8, respectively.

In BCMA, barcodes are placed both on the patient's ID band and the medication label. Before giving medications to a patient, the nurse scans the barcode on the patient's ID band to automatically match the patient identifiers on the ID band with those from the EMR, thereby opening the patient's medication order screen within the EMR. Scanning the barcode on the ID band thus replaces the task of manually performing VPI between the ID band and
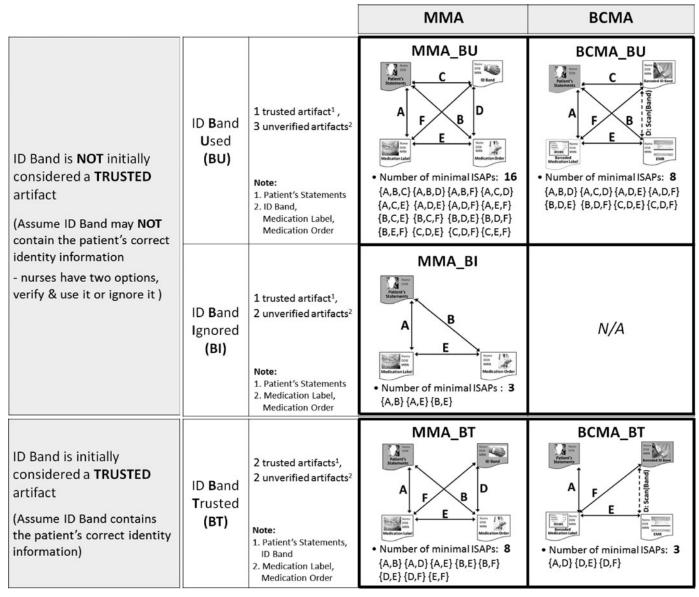
			MMA	BCMA
ID Band is NOT initially considered a TRUSTED artifact (Assume ID Band may **NOT** contain the patient's correct identity information - nurses have two options, verify & use it or ignore it)	ID Band Used (BU)	1 trusted artifact[1], 3 unverified artifacts[2] Note: 1. Patient's Statements 2. ID Band, Medication Label, Medication Order	**MMA_BU** (diagram: A, B, C, D, E, F) • Number of minimal ISAPs: **16** {A,B,C} {A,B,D} {A,B,F} {A,C,D} {A,C,E} {A,D,E} {A,D,F} {A,E,F} {B,C,E} {B,C,F} {B,D,E} {B,D,F} {B,E,F} {C,D,E} {C,D,F} {C,E,F}	**BCMA_BU** (diagram: A, B, C, D: Scan(Band), E, F) • Number of minimal ISAPs: **8** {A,B,D} {A,C,D} {A,D,E} {A,D,F} {B,D,E} {B,D,F} {C,D,E} {C,D,F}
	ID Band Ignored (BI)	1 trusted artifact[1], 2 unverified artifacts[2] Note: 1. Patient's Statements 2. Medication Label, Medication Order	**MMA_BI** (diagram: A, B, E) • Number of minimal ISAPs : **3** {A,B} {A,E} {B,E}	*N/A*
ID Band is initially considered a TRUSTED artifact (Assume ID Band contains the patient's correct identity information)	ID Band Trusted (BT)	2 trusted artifacts[1], 2 unverified artifacts[2] Note: 1. Patient's Statements, ID Band 2. Medication Label, Medication Order	**MMA_BT** (diagram: A, B, D, E, F) • Number of minimal ISAPs: **8** {A,B} {A,D} {A,E} {B,E} {B,F} {D,E} {D,F} {E,F}	**BCMA_BT** (diagram: A, D: Scan(Band), E, F) • Number of minimal ISAPs: **3** {A,D} {D,E} {D,F}

Fig. 6. Available artifact pairs and associated minimal ISAPs for the five cases.

the medication order. The nurse also scans the barcode on the medication to match the medication name and dose in the medication with those from the medication order in the EMR. As described in Section 3, the label on a patient identified medication includes patient identification information in a human readable form, but the barcode on the label does not necessarily include patient identification information; thus, a nurse still needs to manually perform VPI on the medication label using human-readable patient identifiers on the medication.

As shown in Fig. 6, the conditions for an ISAP in the case of *BCMA_BU* are: a trusted artifact (patient's statements) is included in at least one artifact pair in the set (satisfies Condition 1); and for each unverified artifact (i.e., barcoded medication label, EMR, and barcoded ID band), there is a subset of artifact pairs that form a path to the trusted artifact (satisfies Condition 2). The total number of possible minimal ISAPs satisfying those conditions is 8 ({A,B,D}, {A,C,D}, {A,D,E}, {A,D,F}, {B,D,E}, {B,D,F}, {C,D,E}, and {C,D,F}). Note that *D: Scan (Band)* is included in every ISAP. The conditions for an ISAP in the case of *BCMA_BT* are: a trusted artifact (patient's statements or barcoded ID band) is included in at least one artifact pair in the set (satisfies Condition 1); and for each unverified artifact (i.e., barcoded medication label and EMR), there is a subset of artifact pairs that form a path to the trusted artifact (satisfies Condition 2). The total number of possible minimal ISAPs satisfying those conditions is 3 ({A,D}, {D,E}, and {D,F}).

5. Results

The number of possible minimal ISAPs described in the previous section leads to several observations. First, the
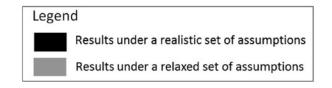
VPI process can be accomplished in multiple ways, which vary depending on the assumptions one makes about the context of the process, as described in Fig. 6. Second, BCMA reduces the number of alternatives for conducting the process by at least 50%, regardless of whether the ID band can be trusted or not: the number decreases from 16 to 8 when the ID band *is not* initially considered a trusted artifact, and from 8 to 3 when the ID band *is* initially considered a trusted artifact. Third, trusting the ID band reduces the number of alternatives for conducting the process by at least 50%, regardless of whether BCMA is used or not: the number decreases from 16 to 8 in MMA, and from 8 to 3 in BCMA.

Fig. 7 reproduces Fig. 6, but replaces the descriptions of available artifact pairs and associated minimal ISAPs with the numbers of traces complying with the VPI requirements (i.e., the nurse matched at least two identifiers for each artifact pair in a selected minimal ISAP) for each of the five cases. Since the success rate for matching at least two identifiers (upper numbers in non-italics) was often very low (e.g., 0%–5% for MMA_BU), we wondered whether nurses matched at least one identifier instead of the recommended two identifiers. We therefore also counted the number of traces matching at least one identifier for each artifact pair

in a selected minimal ISAP (lower numbers in italics), although we do not recommend this practice. The number of traces complying with the requirements for VPI was determined for each of the three values of *Dist* (*Dist = 0*, *Dist ≤ 1*, and *any Dist*), as described in Section 4.1. For example, in the case of *MMA_BU*, of the 44 traces, the number of traces complying with the requirements for VPI by matching at least two identifiers is: 0 (0%) for *Dist = 0*; 1 (2%) for *Dist ≤ 1*; and 2 (5%) for *any Dist*. The number of traces complying with the requirements for VPI by matching at least one identifier is: 9 (21%) for *Dist = 0*; 18 (41%) for *Dist ≤ 1*; and 25 (57%) for *any Dist*.

We compared results for what we consider a *realistic* set of assumptions (i.e., the ID band is not trusted, requiring its verification before being used and *Dist ≤ 1*) and a *relaxed* set of assumptions (i.e., the ID band is trusted and *any Dist*). In Fig. 7, the results under the realistic assumptions are shown with a black background. The results under the relaxed assumptions are shown with a gray background. Under the realistic assumptions, the number of traces complying with the VPI requirements by matching at least two identifiers is 1 out of 44 (2%) for MMA and 3 out of 25 (12%) for BCMA, and by matching at least one identifier is 18 out of 44 (41%) for MMA and 14 out of 25 (56%)

			MMA (n=44)			BCMA (n=25)		
ID Band is NOT initially considered a TRUSTED artifact (Assume ID Band may **NOT** contain the patient's correct identity information - nurses have two options, verify & use it or ignore it)	**ID Band Used (BU)**	1 trusted artifact, 3 unverified artifacts	**MMA_BU** (Number of minimal ISAPs: **16**)			**BCMA_BU** (Number of minimal ISAPs: **8**)		
			Dist = 0	Dist ≤ 1	Any Dist	Dist = 0	Dist ≤ 1	Any Dist
			0/44(0%) *9/44(21%)*	1/44(2%) *18/44(41%)*	2/44(5%) *25/44(57%)*	3/25(12%) *11/25(44%)*	3/25(12%) *14/25(56%)*	8/25(32%) *16/25(64%)*
	ID Band Ignored (BI)	1 trusted artifact, 2 unverified artifacts	**MMA_BI** (Number of minimal ISAPs: **3**)			*N/A*		
			Dist = 0	Dist ≤ 1	Any Dist			
			1/44(2%) *7/44(16%)*	2/44(5%) *15/44(34%)*	4/44(9%) *25/44(57%)*			
ID Band is initially considered a TRUSTED artifact (Assume ID Band contains the patient's correct identity information)	**ID Band Trusted (BT)**	2 trusted artifacts, 2 unverified artifacts	**MMA_BT** (Number of minimal ISAPs: **8**)			**BCMA_BT** (Number of minimal ISAPs: **3**)		
			Dist = 0	Dist ≤ 1	Any Dist	Dist = 0	Dist ≤ 1	Any Dist
			1/44(2%) *15/44(34%)*	2/44(5%) *21/44(48%)*	11/44(25%) *28/44(64%)*	6/25(24%) *13/25(52%)*	9/25(36%) *16/25(64%)*	16/25(64%) *18/25(72%)*

Legend
■ Results under a realistic set of assumptions
▨ Results under a relaxed set of assumptions

Fig. 7. Number and percentage (rounded to the nearest integer) of traces complying with the requirements for VPI by matching at least two identifiers (upper numbers in non-italics) and by matching at least one identifier (lower numbers in italics).
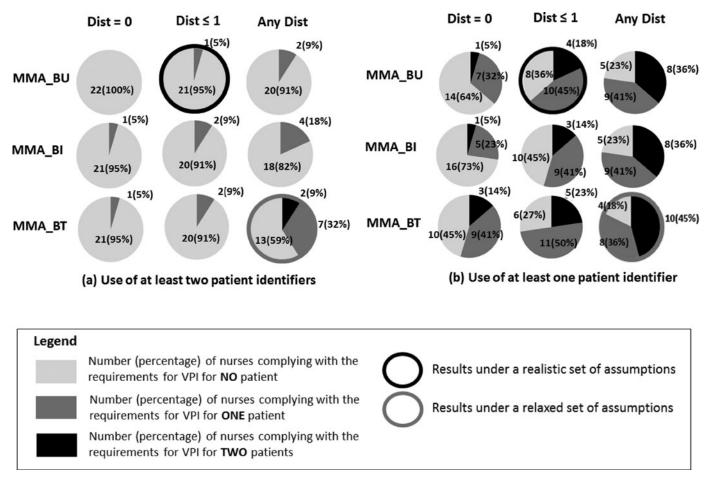
Fig. 8. Number and percentage (rounded to the nearest integer) of nurses complying with the requirements for VPI for no patient, one patient, and two patients.

for BCMA. Under the relaxed assumptions, the number of traces complying with the VPI requirements by matching at least two identifiers is 11 out of 44 (25%) for MMA and 16 out of 25 (64%) for BCMA, and by matching at least one identifier is 28 out of 44 (64%) for MMA and 18 out of 25 (72%) for BCMA.

We wondered whether nurses who complied with the requirements for VPI for one patient were more likely to do so for the other patient. We analyzed how many nurses consistently complied with the VPI requirements for both patients by analyzing the traces for MMA (traces for BCMA are not applicable for this analysis because nurses each interacted with only one patient). Fig. 8 shows the number of nurses complying with the requirements for VPI for no patients, one patient, and two patients, using either at least two identifiers shown in Fig. 8 (a) or at least one identifier shown in Fig. 8 (b). For example, in the case of *MMA_BU,* for each of 22 nurses interacting with two patients, the number of nurses complying with the requirements for two patients by matching at least two identifiers is: 0 (0%) for any three values of *Dist* (see pie charts in MMA_BU in Fig. 8 (a)). The number of nurses complying with the requirements for two patients by matching at least one identifier is: 1 (5%)

for *Dist = 0*, 4 (18%) for *Dist ≤ 1,* and 8 (36%) for *any Dist* (see pie charts in MMA_BU in Fig. 8 (b)).

In Fig. 8, the results under the realistic assumptions are shown in pie charts within a black border. The results under the relaxed assumptions are shown in pie charts within a gray border. Under the realistic assumptions, the number of nurses complying with the VPI requirements for two patients by matching at least two identifiers is 0 out of 22 (0%), and by matching at least one identifier is 4 out of 22 (18%). Under the relaxed assumptions, the number of nurses complying with the VPI requirements for two patients by matching at least two identifiers is 2 out of 22 (9%), and by matching at least one identifier is 10 out of 22 (45%).

6. Discussion

Although we extended the Joint Commission guidelines for VPI to include guidance on how to select artifacts, we believe this extension is consistent with the intent of the guidelines and is needed in order to determine compliance. We then evaluated whether nurses complied with these requirements during clinical simulations of medication

Table 1. Summary of results under the realistic assumptions (i.e., the ID band is not trusted, requiring its verification before being used and Dist ≤ 1 is considered): percentage of traces complying with the requirements for VPI by matching at least two identifiers (first row) and by matching at least one identifier (second row)

	MMA	BCMA
At least 2 identifiers	2%	12%
At least 1 identifier	41%	56%

administration. Our study found that a small percentage of nurses complied with the VPI requirements regardless of whether they used MMA or BCMA. These results were achieved under the assumption that the nurse fixated on every identifier on the computer screen when screen glare obscured our ability to identify what the nurse was actually fixating on during the trials. Thus, the number of identifiers measured in this analysis is an upper bound of the true number of identifiers that the nurse actually matched; still, only twelve percent of nurses complied with the requirements for BCMA and only two percent complied for MMA. Nurses' failures to comply with the VPI requirements suggest the need for further studies to achieve improvements in nurses' compliance with these requirements.

Table 1 summarizes the results under the realistic assumptions. This table shows the percentages of traces complying with the VPI requirements by matching at least two identifiers and by matching at least one identifier for MMA and BCMA.

Reducing the requirement of using at least two identifiers to using at least one identifier considerably increased the percentage of nurses complying with the requirements (the percentages increased from 2% to 41% for MMA; from 12% to 56% for BCMA), but will presumably increase the likelihood of patient identification error. One study reported that approximately 11% of the time there are at least two patients in the emergency department with the same last name (Henneman *et al.*, 2010). Nurses complying with the requirements for VPI also did not consistently comply with the requirements for both patients under the realistic assumptions, either using at least two identifiers (0% of nurses complied with the VPI requirements for two patients; see Fig. 8 (a)), or at least one identifier (18% of nurses complied with the VPI requirements for two patients; see Fig. 8 (b)).

The use of barcodes in improving accurate patient identification has obtained considerable attention. Several studies suggest that the barcode verification technology that supports medication administration has the potential to improve patient safety by reducing medication errors (Paoletti *et al.*, 2007; Poon *et al.*, 2010; Rivish and Modeda, 2010). Despite this benefit, some studies have shown that barcode verification technology may create new kinds of errors and have unexpected impacts on patient safety (Akowski *et al.*, 2008; Patterson *et al.*, 2002; McDonald, 2006). Our results show that the use of barcode verification technology improved compliance with the VPI requirements (the per-

centages increased from 2% to 12%). The increase in the percentages, however, was not statistically significant ($p = 0.117$; Fisher exact test), probably due to our small sample size. One possible interpretation of this result is that the improvement in compliance, though not statistically significant, is due to a reduction in the cognitive burden associated with a lower number of possible ISAPs.

Our study has several limitations. First, the clinical simulations from the Henneman studies were conducted at a single hospital using emergency department nurses. We do not know whether the observed nurse behavior is comparable to that exhibited by other healthcare workers in other settings. Second, the simulated setting may not accurately reflect the actual clinical setting where there is more time pressure, noise, and interruptions. We would expect compliance to be even lower in a clinical setting where these pressures exist. Third, we had to discard 12 videos (21%) because of eye-tracking failures. Fourth, because of our small sample size, this study does not provide conclusive evidence about nurses' behaviors. Fifth, we assumed a patient's collective statements about their identity to be correct because at least one artifact must be trusted at the start of the process, but this may not always be true (e.g., altered level of consciousness, intellectual disability, language problem, patient deception). Sixth, we considered two situations in our analysis depending on whether the ID band was trusted or not. We do not know, however, whether or not nurses had been trained to trust the ID band. Seventh, we analyzed our results considering three values of intermediate events. If we knew more precisely the acceptable number of intermediate events between the first and the second part of a match, we could simplify the analysis of determining whether a nurse performed a match or not. Finally, our study made the assumption that if at least two patient identifiers were determined to be correct for an artifact, all of its identifiers were assumed to be correct; however, our study did not account for the case that two patients have two of the same identifiers (e.g., same name and DOB, but different MRNs).

7. Conclusion

We found that a small percentage of nurses in our study complied with the requirements for VPI, whether verifying patient identifiers manually or using barcode technology.

Our findings suggest several ways of improving nurse compliance with the VPI requirements that should be studied further. One possible reason for low nurse compliance with VPI requirements could be that nurses are not being trained adequately to fulfill these requirements. Nurse compliance might be improved by more carefully explaining the VPI requirements, especially with respect to the selection of artifacts. Another reason for low compliance might be that the large number of alternatives allowed by the requirements makes the requirements difficult to remember. Thus, it may be possible to improve compliance with the

VPI requirements by simplifying the process, perhaps by reducing the number of alternatives. For example, one way to reduce the number of alternatives for VPI, thereby reducing cognitive burden, would be to train healthcare workers to select one trusted artifact and use it to verify each of the other unverified artifacts that will be used. Compliance with the VPI requirements could also potentially benefit from better-designed barcode technology. For instance, if barcode labels on patient identified medications were required to include patient and medication information, verification of both patient and medication information could be performed automatically via barcode scanning. Selected strategies should also account for concerns that have been noted in other studies, such as time pressures, nurses' confidence in their existing practices, and the potential to irritate patients (Paparella, 2012; Phipps *et al.*, 2012). Finally, subsequent studies should determine if improving compliance with the VPI requirements reduces the number of errors that occur, especially those that reach the patient, since that is the ultimate goal of VPI.

Acknowledgments

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