Breaking the Barcode and RFID myth: Adoption paths for improving the medication process

Alejandro Romero, Élisabeth Lefebvre, Louis-A. Lefebvre

***Abstract*—** *The use of barcode has become a key primary technological strategy for improving healthcare service quality in general and point-of-care patient safety in particular. But will RFID eventually replace the widely adopted barcode technology for decreasing adverse medication events? This paper explores four different adoption paths for improving the medication process of an emergency department, namely full barcode implementation, full RFID implementation, migration and hybridization. Since medication errors are considered the most frequent type of adverse events occurring in hospitals, it appears rather crucial to gain a better understanding of the relative advantages and drawbacks related to each of these four adoption paths.*

***Keywords*—** Adverse medication events, RFID, barcode, technology adoption and medication process.

I. INTRODUCTION

REDUCING adverse medication events and improving patient safety are recognized as a high priority for the management of health care systems [1]. In fact, the Institute of Medicine (IOM) has reported that between 80,000 and 116,000 hospitalized patients die in the U.S. because of an adverse event [2]. The problem of medication errors is worrisome since one to two million of patients in U.S. are affected every year by medication-related problems [3]. Indeed, medication errors are considered as the most frequent type of adverse events noted in the IOM report [4] and, on average, a North-American patient experiences at least one medication error per day [5]. Beside their negative impact on human health, medication errors entail rather significant costs. Indeed, adverse drug events in hospitalized patients are responsible for more expensive and longer hospitalizations [6]. According to Bates [7], medication errors increase the length of stay by as much as 4.6 days and a longer stay costs $4,685 per event. In United States, the annual cost of medication errors is estimated to range between $1.56 and $5.6 billion [8]. Fortunately, research shows that about 50% of adverse medication events are preventable [7].

The introduction of information technology, such as Computerized Physician Order Entry (CPOE), e-prescribing, clinical decision support or smart pumps, can promote safe medication practice. Barcode and RFID technologies are the two main technological advances that hospitals are relying on to decrease the occurrence of adverse medication events. These technologies can enhance patient safety at any activity of the medication process. The use of barcode for the administration process tends to increase exponentially in healthcare organizations in the United States and Europe. According to a current review of relevant literature, adoption of barcode is mandatory to ensure the five rights of the medication administration process: right drug, right route, right patient, right dose, and right time [9]. In contrast, RFID, considered as a potential successor to barcode, offers more advantages [10] but its adoption rate remains much lower than the one experienced by barcodes. The extent to which the adoption of RFID is significantly affected by the omnipresence of the "old" barcode technology remains unknown.

This paper explores the potential adoption paths for barcode and RFID technologies in the medication process, namely ***full barcode implementation, hybridization, migration*** and ***full RFID implementation.*** More specifically, we will attempt to assess if each of these adoption paths is better suited to support the activities related to the stages of the medication process. This paper is structured as follows. The next section presents the different stages of medication process, provides a brief overview of the barcode and RFID technologies and examines the different adoption paths. The third section presents the methodology while some preliminary results are discussed in the fourth section. The fifth and last section offers some concluding remarks.

II. BACKGROUND

A. The medication process

Health governmental institutions, healthcare facilities and, researchers are actively involved in the improvement of patient safety [11]. Because patient safety in hospitals cannot be taken for granted, adverse medication events have become an important, frequently studied and discussed phenomenon [11]. Several studies have showed that errors are not produced by the negligence or incompetence of healthcare

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practitioners, but are rather the result of the organization of medication process, the way the medication service is delivered and the availability of resources [12]. The medication process is complex and error prone mainly due to the large number of processes and the wide array of healthcare facilities, professionals and personnel involved. Any process within medication system, combined with the context of limited resources, may represent a potential source of adverse medication events that can damage patients' health.

The process for ensuring the medication service in a hospital facility is lengthy and contains numerous steps [13]. The medication process covers five main stages: ordering, transcribing, dispensing, administering and monitoring (see Figure 3). Although many factors can contribute to medication errors, starting from the initial step of writing a prescription to the last step when monitoring the patient [14], previous research on medication errors tends to focus on two main stages, namely ordering and administration that are considered by Trossman [15] as less secure. In fact, adverse medication errors occur most frequently in ordering (34.7%) and administration (36.9%) stages [15] and 90% of these errors could be prevented [7]. Some researchers [13, 16] reported that inappropriate identification of the patient and incorrect doses are the two main causes of errors during these two stages.

Despite all the efforts made to improve medication safety, such as education, errors reporting, performance improvement initiatives and process redesign, adverse medication events continue to occur in all stages of the medication process. The reliance of various technologies like barcodes and smart pumps is considered as a new option to reduce medication errors [8], [13].

B. New technologies adoption for the medication process

Technology can lower the frequency of adverse medication events by improving quality and communication, by tracking patients and medication doses, by preventing errors, by facilitating a more rapid response after the incidence of an error, and by documenting and analyzing adverse events [8, 17]. In the last years, several healthcare institutions, including IOM and WHO, have started to focus on technological solutions for safe medication strategies [18]. According to the literature, the most common type of technology implemented in several healthcare facilities in the North America, Europe and Asia are Electronic Medical Record (EMR), Computerized Physician Order Entry (CPOE), Pharmacy Information System (PIS), smart infusion pumps and barcode technology. Besides their capacity to allow safe zero-error medication process and improve effectiveness, these technologies can decrease the costs of healthcare services since repetitive routine human activities could be automated [8]. Many of those technologies are being developed and directly integrated into the medication process while others are waiting for full implementation.

Among the most prevalent adopted technologies, barcode is used to verify patient identification, and to prepare, distribute and administer medication doses [19]. Since the Food and Drugs Administration (FDA) had suggested the use of barcode for tracking medicines in 2003, the healthcare facilities turned increasingly to barcode for ensuring the five's rights of medication [20]. The success of the barcode technology has been highly documented. For instance, the Veterans Affairs Medical Centre stated that the application of barcodes on patient beds and medication doses could reduce 86% of adverse events [20], allowing 5.7 millions of savings [21]. More recently, FDA reports that barcode adoption for the medication process can prevent 50% of adverse events [22]. In recent years, barcode adoption has become mandatory to ensure the quality of healthcare services. For instance, the American Recovery and Reinvestment Act of 2009 provides financial incentives to hospitals for the use of barcodes for the medication process [23].

RFID technology is "considered as the potential successor of barcode technology" [25, p.1]. RFID and barcode are conceptually similar and belong both to the same technology family, namely Auto-Identification and Data Capture (AIDC). The AIDC solutions share the same capacity to track objects, humans and animals. In the medication process, both the barcode technology and the RFID technology accomplish the same requirement, namely the identification of medicines and patients and they can both prevent adverse medication events. However, these two technologies are different because of two main reasons: i) barcode is read-only whereas RFID is read and write, and ii) barcode requires a line of sight for lecture whereas RFID is contactless, data being transmitted by radio frequency [21, 26]. Because RFID allows automatic lectures, manual labor can be replaced by semi or totally automated processes [27, 28, 29] and as a consequence, potential human errors could be prevented. Several technological organizations were quite optimistic about RFID potential and have envisioned that RFID would rapidly be implemented in healthcare applications [30]. For instance, ID TechEx estimated that the market of RFID solutions for healthcare in North America would grow from 90 million in 2006 to 2.1 billion in 2016 [31].

Even if RFID is often considered as more promising than barcode, RFID is not widely adopted in the healthcare and cannot totally replace the "old technology" barcode. It seems that "the prevalence of barcode, are likely to affect the adoption and diffusion of RFID technology" [25, p.1]. Nevertheless, some scholars predict that RFID, once more mature and less costly, could gradually replace the current barcode systems in healthcare [21] and healthcare facilities are currently facing several adoption paths as it will be discussed in the next section.

C. Adoption paths for barcode and RFID

In order to improve the safety of the medication process, the following adoption paths may be considered: ***full implementation of barcode technology, full implementation of RFID technology, integration or hybridization of both technologies, and migration from barcode to RFID***. Between the full barcode implementation aimed at the identification of assets, medicines and medical staff and the full RFID implementation meant to improve safety, stock control and real-time traceability, co-existence between barcode and RFID is increasingly being accepted by industry and academic: [21], [25], [32]. When an old and a new technology can fulfill similar tasks, the transition from the

older one to the new one can be reflected by the co-existence of both technologies. The older technology can be a prerequisite for full implementation of a new technology and even accelerate its adoption [25]. The old technology can be used for critical processes and as a backup solution while new technology performance is assessed. Nevertheless, "the longer the transition phase continues, the more it will become ingrained into application as a de-facto standard" [32, p.3]. Co-existence means that healthcare facilities can either migrate from barcode to RFID or chose a hybrid solution that capitalizes on both barcode and RFID (see Figure 1). The main focus of this paper is to analyse the different adoption paths and their potential for each stage of the medication process.

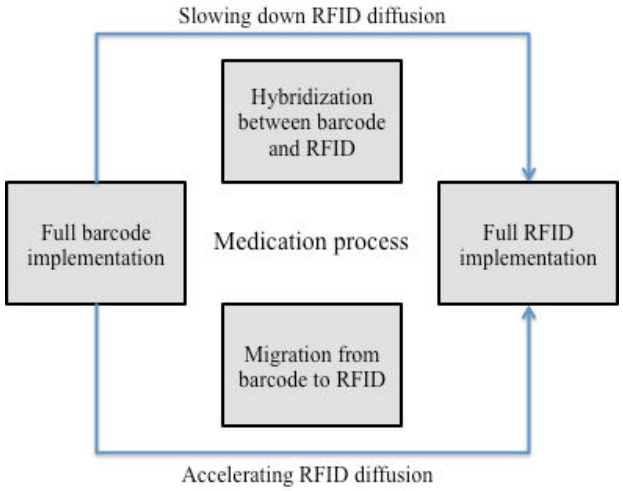

Fig 1. Adoption paths (adapted from [33])

III. Methodology

A. Participating organizations

Hospital A represents the primary research site but other healthcare entities, government institutions, associations and technology organizations also gave valuable inputs and insights (see Table I). In total, eight organizations and 27 healthcare professionals and key managers participated to the field research study.

While the medical clinic and three hospitals (hospital A, hospital B and hospital D) are implementing new pharmacy equipment for supporting the preparation and distribution of medication doses using the barcode technology, only one hospital (hospital C) went forward with a RFID pilot project for assessing the potential of this technology for medicine distribution. However, the hospitals A, B, C and D, and the medical clinic use neither barcode nor RFID for identifying medication doses and patient during the administration of medicines. The government institution is involved in different programs for decreasing medication errors by automating the medication process and is also involved in the technological projects undertaken in three hospitals (A, B, D) and in the medical clinic. The pharmacist association represents the perspective of pharmacists and pharmaceutical scientists. The technology provider works with different healthcare organizations in order to develop new equipment and software for the medication process and is involved in the projects undertaken in hospitals A, B and D.

B. Participants

The vast majority or 88% of individuals who participated to the focus groups and who were interviewed are well aware of the characteristics of barcode technologies and are involved in the development and implementation of barcode applications in their organizations. In contrast, fewer participants (44%) are knowledgeable about the RFID technology characteristics (Table 1). But, just 11% have been involved in a RFID pilot project.

C. Data collection strategies

We rely on multiple sources of empirical evidence in order to allow triangulation and strengthen the validity of results [34]. Data collection was based on:

(i) Multiple on-site observations allowed us to carry out the medication process mapping.

(iii) Focus groups were conducted in order to identify and analyze critical activities, sources of errors and technological solutions.

(ii) Semi-structured interviews were conducted for the validation of the medication process mapping and for the analysis of the different adoption paths.

(iii) We also examined internal and external documentation to evaluate the key drivers and the main factors influencing the selection of any adoption path.

Within the scope of this paper, we will focus mainly on the medication process in the emergency department of the hospital A, a 600-bed hospital.

D. The primary research site: the Emergency Department in hospital A

The Emergency Department has been selected as the primary research site because of the high frequency of adverse medication events. This 45-bed department is characterized by a high volume of patients with critical and sometimes life-threatening conditions: it attends to approximately 33,000 patients annually requiring a wide variety of immediate and unplanned healthcare services. For patients with less critical conditions, the hospital emergency room waiting time to physician varies widely and can be exceptionally long during certain periods. For each of the three different shifts, the average number of staff members is slightly less than 45 persons: this includes physicians, nurses, technical assistants, clerks, nurse assistants and orderlies. The work environment in the emergency department is dynamic, complex, fast-paced, extremely demanding and therefore prone to medication errors.

The emergency department is divided into three main services, namely, ambulatory, acute care and reanimation, and has its own pharmacy (secondary pharmacy) with the most frequently used medicines. The central hospital pharmacy is responsible to give medication services (on average, more than 300 doses per day) to the emergency department.

TABLE I
PROFILE OF PARTICIPANTS

Organizations	Participants	Number of participants	Knowledge of barcode technology	Knowledge of RFID technology
	Internal participants			
Hospital A (primary research site)	Chief pharmacist	2	2	-
	Pharmacist	4	4	-
	IT project manager	1	1	1
	Chief nurse	2	2	-
	Technical assistant	3	3	-
Hospital B	Chief pharmacist	1	1	1
	Pharmacy project manager	1	1	1
Hospital C	Chief pharmacist	1	1	1
	Pharmacist	2	2	2
Hospital D	Chief pharmacist	1	1	-
	Pharmacist	1	-	-
Hospital E	Chief IT	1	1	1
Medical clinic	Chief pharmacist	2	-	-
		22	**19**	**7**
	External participants			
Government entity	Medical technology director	1	1	1
	Medical project manager	1	1	1
Pharmacists association	President	1	1	1
Technology providers	Project manager	2	1	2
		5	**5**	**5**
	Total	**27**	**24**	**12**

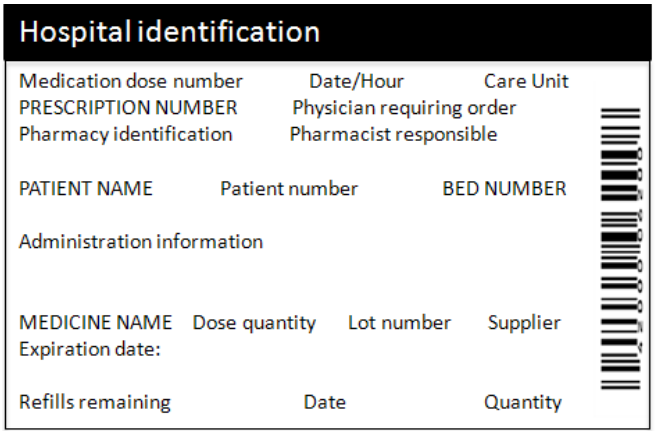

Fig 2. Medication label

The hospital pharmacy has recently adopted new automated distributors and automated unit-dose equipment: McKesson Acudose-Rx and McKesson PACMED. Because these equipments require the identification of medicines and doses using barcode technology, hospital pharmacy is building a barcode infrastructure to control its medicines and doses. Each medication dose is identified by a label containing patient name, medication name, quantity dose, administration instructions and a barcode (see Figure 2). In the short term, this hospital will invest in a barcode medication administration BCMA infrastructure in order to ensure the medication process by identifying patient and doses at the administration point.

IV. The Current Situation

A. The medication process in the emergency department in hospital A

In order to better understand the potential adoption paths for barcode and RFID, the current medication process has been thoroughly analyzed and the underlying processes were mapped using a drilled down approach- i.e. from the most general to the most detailed processes- (Table 2). As displayed in Figure 3, the medication process entails six broad processes namely ordering, transcribing, preparing, distributing, administering and monitoring. Using a drill-down approach, these six medication processes are divided into twenty sub-processes (P1 to P20) which are in turn subdivided into 72 activities (P1.1 to P20).

The first two processes, ordering and transcribing, refer to elements such as selecting the correct medicine and processing the medication order. The physicians write an order by identifying a patient using his or hers healthcare file and bed number (Table 2, sub-processes P1, P2 and P3). Before its transmission by pneumatic service, nurses must validate that medication order cannot be supplied by the emergency department automated distributor (sub-process P4).

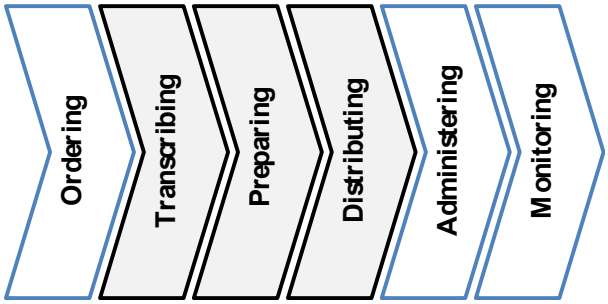

Fig 3. Medication process

At the central pharmacy, the medication order (paper) is transcribed into the Pharmacy Information System and is then validated by the pharmacist (sub-processes P5, P6 and P7). Once the order is validated, medication doses are prepared manually or automatically by using automated uni-dose or smart shelves machines (sub-process P8 and P9). A tag identifies the medication dose (Figure 2) and is placed into the dose container, here in a plastic bag (activity P8.2). Before the distribution to the emergency department, the pharmacist and his or her assistants must ensure the double validation between the medication order, the medication dose and the tag identifying the dose (sub-process P10). The doses can be transmitted to the emergency department by pneumatic service, by scheduled assistant or by special distribution (sub-processes P11, P12, P13 and P14). The pneumatic service is used for regular doses, while the scheduled assistant distributes controlled or "sensitive" medication doses such as morphine or benzodiazepine. Special distribution refers to the distribution of urgent doses by an assistant from the emergency department.

At the point of administration, it is the nurse's responsibility to select the correct dose by reading the medication label, to identify the correct patient and to use the correct route of administration (sub-processes P16 and P17). Usually, the nurse verifies patient's identification by reading bed number and verbally confirming their names. Once the doses are administered, the nurse is responsible for documenting the medication service (sub-process P18) and monitoring patient (sub-processes P19 and P20), which represent the last steps of the medication process.

From the information displayed in Table 2, the medication process is complex and prone to errors for three main reasons:

First, it entails a large number of activities. The 72 activities (first column of Table 2) fall mainly under the responsibility of two hospital units, the emergency department (ED) and central hospital pharmacy (CHP) as displayed in the second column of Table 2. As key medication processes are undertaken by both units, the information flows between these units becomes a critical factor for efficiency and quality of the medication service.

Second, the medication process involves healthcare professionals, specialists and technicians, such as physicians, nurses, pharmacists, pharmacy technicians and ED assistants (third column of Table 2) who have to carry out these sometime overlapping activities while relying on different manual, semi-automated and automated procedures and following several medical protocols. Moreover, they must use a variety of medical equipments and devices such as distributors, caskets, robots, automatic shelves, control medicines cabinets, fridges, temperature sensors, etc. These rather repetitive and administrative activities are indeed necessary to accomplish all the processes of the medication service but they prevent healthcare professionals to fully devote their energies and time to patient care activities.

Third, medication errors may arise from any of the 72 activities but occur at different levels of frequency (last column of Table 2), ranging from a low level (42 activities) to a high level (18 activities). For these 18 critical activities, three main sources of errors can be identified:

(i) An incorrect medication order (activities P3.1, P3.2 and P6.1): The lecture or the interpretation of a medication order can trigger critical adverse events. If physician does not specify adequately the medicine in the medication order, the pharmacy staff may encounter several difficulties in the transcribing process. A pharmacist stated that "*sometimes medicines or active components have similar names. If physicians do not write correctly the name of medicine, the pharmacist can easily transcribe in the Pharmacy Information System PIS a different medicine, and so, produced an adverse event*".

(ii) An incorrect identification of patient and limited patient information (activities P1.1, P1.2, P2.1, P3.1, P16.2, P16.3, P17.1 and P17.2): Healthcare professionals stated that they must identify and select information about the patient in different activities of the medication process. Nevertheless, actual processes and equipment do not yet automatically identifying patient or provide patient information. In fact, physicians and nurses usually ask the patient or verify the bed or room number in order to execute the identification. Giving that ED healthcare staff is often overworked and they must execute several activities at the same time, the frequency of potential errors could increase exponentially. A nurse pointed out that *"when several doses arrive at the same time, she takes them all, verifies patient correspondence and takes all the medication profiles with her at the same time"*. Another factor for an inappropriate identification is when medical staff cannot ask the patient for his identity. *"On numerous occasions, the patient is asleep, unconscious or he doesn't want to cooperate with us"*. Therefore, medical staff must rely only on the bed or room number for identification.

(iii) An incorrect identification of medicines or medication doses and limited information (activities P8.2, P9.3, P9.4, P10.1, P10.3, P15.2, P17.2 and P17.3): The pharmacy staff insists that the identification of medicines represents the critical factor for decreasing medication errors. The central pharmacy is undertaking different initiatives such as a more efficient and accurate storage of medicines, using shelves with medicine identification labels and imposing the double verification of medicine name and dose quantity before the dose preparation. However, the identification of medicines is becoming complex because of the variety of medicines in the pharmacy and the similarity between medicines names, formats and packages. A pharmacist stated that *"for a medication order, I can choose between two different medicines that contain the same active component but from different pharmaceutical laboratories. The*

TABLE II:
THE MEDICATION PROCESS:
ACTIVITIES, CORRESPONDONG RESPONSABILITIES AND ERROR FREQUENCY

MEDICATION PROCESSES, SUB-PROCESSES AND ACTIVITIES	Unit [1]		Medical staff [2]					Error frequency [2]
	ED	CHP	Phys.	Nurses	Phar.	Tec.	ED ass.	
ORDERING PROCESS								
P1. Pick information patient								
P1.1. Pick patient profile file	√			√			√	***
P1.2. Print patient information tag	√			√			√	***
P1.3. Give patient profile and information tag to the physician	√			√			√	*
P2. Defining medication patient treatment								
P2.1. Identify patient by asking his name or checking the bed number	√		√					***
P2.2. Evaluate patient condition	√		√					*
P2.3. Define medication treatment	√		√					*
P3. Writing medication order								
P3.1. Place patient information tag on a new medication order	√		√					***
P3.2. Write medication order	√		√					***
P3.3. Validate patient medication tag and medication order	√		√					**
P3.4. Place medication order in the medication order carpet for transmission to the pharmacy	√		√					*
Subtotal	10	0	7	3	0	0	3	
TRANSCRIBING PROCESS								
P4. Transmit medication order to the pharmacy								
P4.1. Pick medication order from ED medication order carpet	√			√			√	*
P4.2. Verify if medication order can be supplied at ED automated distributor	√			√			√	*
P4.3. Transmit medication order by pneumatic system	√			√			√	*
P4.4. Contact pharmacy service for urgent medication order	√			√			√	*
P5. Receive medication order								
P5.1. Verify regularly the reception of medication orders by pneumatic system		√				√		*
P5.2. Pick prescription order		√				√		*
P5.3. Write date and hour of reception on medication order		√				√		*
P5.4. Classify medication order by priority, hour and date		√				√		*
P6. Transcribe medication order								
P6.1. Transcribing medication order in the PIS		√				√		***
P6.2. Validate not missing information in the medication order		√				√		**
P6.3. Contact ED in case of missing information		√				√		*
P6.4. Transmit medication order to pharmacist for validation		√				√		*
P7. Validate medication order								
P7.1. Pick medication order in function of it priority		√			√			*
P7.2. Verify medication order in the PIS and in paper		√			√			**
P7.3. Analyze medication order in order to find any pharma-therapy incidence		√			√			*
P7.4. Contact ED physician in case of pharma-therapy incidence		√			√			*
P7.5. Update medication order in the PIS and in paper in case of correction		√			√			*
P7.6. Confirm the validation of medication order in the PIS		√			√			*
P7.7. Print medication dose tags for preparation and distribution		√			√			*
Subtotal	4	15	0	4	7	8	4	
PREPARING PROCESS								
P8. Prepare medication dose bag								
P8.1. Pick tags printed after pharmaceutical validation		√				√		**
P8.2. Place medication dose tags on medication bag		√				√		***
P9. Prepare medication dose								
P9.1. Read medication dose tag information		√				√		**
P9.2. Validate medication dose tag information		√				√		**
P9.3. Select medicine in function of medication dose tag		√				√		***
P9.4. Prepare medication dose		√				√		***
P10. Validate medication dose								
P10.1. Verify correspondence between medication dose and medication tag information (content and packaging)		√				√		***
P10.2. Confirm medication preparation in the PIS		√				√		*

P10.3. Re-verify correspondence between medication dose and medication tag information (double verification)		√			√			***
P10.4. Update medicine stock level control		√			√			**
P10.5. Place medication dose bag in ED distribution casket		√			√			*
P10.6. Print order for distribution		√			√			*
Subtotal	0	12	0	0	4	8	0	
DISTRIBUTING PROCESS								
P11. Prepare for distribution								
P11.1. Pick distribution order from ED distribution carpet		√				√		*
P11.2. Validate the distribution order		√				√		*
P11.3. Classify medication dose bag in function of defined distribution type		√				√		**
P12. Distribution by pneumatic system								
P12.1. Transmit by pneumatic service the medication dose bags		√				√		*
P12.2. Confirm distribution in the PIS		√				√		*
P13. Distribution by assistant (scheduled distribution)								
P13.1. Arrive to the pharmacy service		√					√	*
P13.2. Leave returned medication doses		√					√	*
P13.3. Validate the distribution order		√					√	*
P13.4. Place medication dose caskets in the distribution cart		√					√	*
P13.5. Confirm distribution in the PIS		√					√	*
P13.6. Distribute medication dose casket to the ED	√						√	**
P14. Receive medication doses								
P14.1. Pick medication dose bags from pneumatic service or dose casket	√			√			√	*
P14.2. Place medication dose bags in the ED nurses desk	√			√			√	*
P15. Validate medication dose reception								
P15.1. Verify distribution order	√			√			√	**
P15.2. Verify medication tag information and distribution order	√			√			√	***
P15.3. Place dose bag in returned casket in case of wrong distribution	√			√			√	*
P15.4. Contact pharmacy service in case of missing medication dose	√			√			√	*
P15.5. Confirm reception of medication dose in the PIS	√			√			√	*
Subtotal	8	10	0	7	0	5	13	
ADMINISTERING PROCESS								
P16. Validate medication dose								
P16.1. Pick medication dose bag	√			√				*
P16.2. Identify information of patient in the dose tag	√			√				***
P16.3. Pick patient profile file	√			√				***
P16.4. Verify the validity of medication dose with the medication order of patient	√			√				***
P16.5. Contact pharmacy service in case of error or missing information	√			√				*
P16.6. Return medication doses with errors or missing information	√			√				*
P17. Administer dose								
P17.1. Identify patient by asking his name or by bed number	√			√				***
P17.2. Verify dose tag information in order to validate the 5R for administration	√			√				***
P17.3. Administering medication dose following medication instructions	√			√				***
P18. Document administration								
P18.1. Confirm administration in the profile file	√			√				*
P18.2. Place administration wastes (bag and others) in the waste basket	√			√				**
Subtotal	11	0	0	11	0	0	0	
MONITORING PROCESS								
P19. Supervise patient	√			√				*
P20. Communicate with physician and/or pharmacy service	√			√				**
Subtotal	2	0	0	2	0	0	0	
Total	**35**	**37**	**7**	**27**	**11**	**21**	**20**	

1: Care unit where ED means Emergency Department and CHP Central Hospital Pharmacy.
2:Medical staff where Phy. means physicians, Phar. Pharmacist, Tec. Pharmacy technicians and ED ass. ED assistants..
3: Frequency errors where * means low frequency, ** medium frequency and *** high frequency.

identification is more difficult when we have two different medicines with when pharmacy or ED staff must identify medication doses. If they do not have enough time in order to read all the information containing into the medication dose tag, and thus errors can easily occur.

V. ADOPTION PATHS

Hospitals can consider four different adoption paths (see Figure 1), ***namely full barcode implementation, full RFID implementation, migration*** and ***hybridization***. Each of these

four adoption paths allows to identify patients, medicines and medication doses throughout the medication process but some may be better fitted for certain processes displayed in Table 2. We will attempt to assess, based on the empirical evidence gathered from the field research, which adoption path is more appropriate (Table 3).

A. The relevance of a full barcode implementation

The ***full barcode implementation*** path relies only on barcode technology for the identification of patients, medicines and medication doses. A barcode placed on a wristband carries the patient's ID (Figure 4). Additional information such as patient's name, age, sex, admission date, care unit and allergies, is written directly on the wristband. Medication doses can by identified using a barcode label similar to the actual medication dose tag using in the hospital A (see Figure 2). The medication dose label must carry a barcode representing a unique serial number and can display extra written information, such as medication dose number, date/hour, care unit, prescription number, physician requiring order, pharmacy identification, pharmacist responsible, patient name, patient number, bed number, administration information, medicine name, dose quantity, lot number, supplier, expiration date, refills remaining, date and quantity. Finally, medicines can be identified using a label containing a barcode which holds the pharmaceutical product code (GTIN) or code defined by the hospital. Once again, the medicine label can also hold written information, such as the serial number, the expiry date and the batch code (Figure 5). Written information on either the wristband or on the medicine label can be relied upon when barcode reader is not available or it experiences lecture problems.

Barcodes emerge as the predominant solution to ensure identification in all the steps of the medication process (from activities P1.1 to P20) because of the following reasons. First, the low costs of barcode and readers play an important role in the evaluation of this particular adoption path. Low costs are considered as the most important advantage of the barcode technology by the majority of the interviewed participants. Second, barcode is a mature technology that has been widely used in different healthcare applications and adopted in several industries. It allows to reduce the complexity of the barcode integration in the medication process while its implementation entails limited changes to the actual processes and limited technological upgrades to ensure compatibility with current hospital information systems. Third, the resistance to change may be minimized when using the barcode as data carrier. Giving that healthcare givers, pharmacy professionals, and even, patients know the barcode technology and how it works, they do feel more comfortable when using it or when being identified by it. Fourth, incorporating barcode as a data carrier in the patient's wristband, medication dose label or medicine label is not a complex task as barcode can be directly marked using the available printing technologies on a rather small surface of the actual patient's wristband, medicine package or medication dose label. Fifth, barcode entails high accuracy and current barcode readers report better accuracy lecture rates than RFID readers. Finally, the adoption of barcode technology is supported by external key actors in the pharmaceutical sector, by manufacturers of pharmacy-automated equipment, and by healthcare institutions and government institutions. In fact, there are several financial assistance programs in North America and Europe promoting the barcode utilization.

Fig 4. Patient's barcode wristband

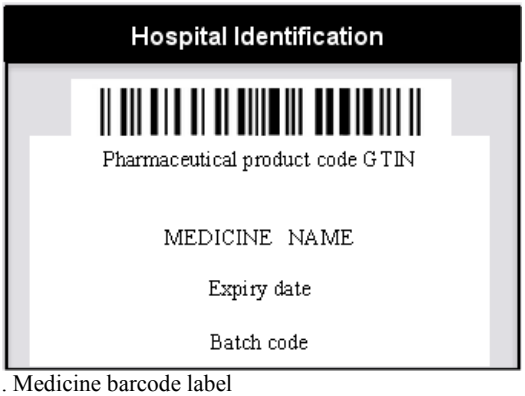

Fig 5. Medicine barcode label

However, the implementation of barcode technology entails new issues for the medication process and new sources of errors. For instance, barcode can increase the workload of healthcare givers and pharmacy professionals, as it requires a direct line of sight for reading the information on the barcode symbol. As observed by one pharmacist, this may have a positive impact on the patient's identification because physicians and nurses must read directly the patient's wristband (activities P2.1 and P17.1). Nevertheless, barcodes are more complex to handle for the pharmacy staff that must manage multiple medication doses and medicines at the same time (activities P9.3, P11.2, P11.3 and P15.2). Several participants added that the one-dimension (1D) barcode has a limited data storing capacity as it can only hold up to 12 characters. Therefore, it can only carry either the patient's id or medication dose id or medicine national code. Other participants mentioned that readers cannot execute accurate lectures when the barcode labels are damaged or dirty. Since patients may receive different treatments, wristbands can be easily damaged. As result, physicians and nurses must read the patient's name or id registered in the wristband in order to execute his identification.

Fortunately, some 1D barcode drawbacks, such as a limited data capacity and lecture problems, have disappeared

TABLE III
FACTORS OF DECISION FOR THE FOUR ADOPTION PATHS

	Full barcode implementation	Full RFID implementation	Migration	Hybridization
Data carrier	Barcode	RFID tag	Barcode (temporary) and RFID	Barcode and RFID
Reader	Barcode reader	RFID reader	Barcode reader (temporary), RFID reader or Barcode and RFID compatible reader	Barcode and RFID compatible reader
Data capacity	Limited with ID barcode	Enough for the medication process	Enough for the medication process	Limited with 1D Barcode
Compatibility with medication process	All processes From P1 to P20	Ordering, administration and monitoring processes From P1 to P3 and from P16 to P20	Ordering, administration and monitoring processes From P1 to P3 and from P16 to P20	All processes From P1 to P20
Compatibility with actual equipment	High	Low	Low	Medium
Compatibility with actual healthcare industry investment	High	Medium	Medium	High
Complexity of implementation	Low	High	Medium	Medium
Cost of implementation	Low	High	Medium	Medium
ROI	Appropriate	Appropriate for patient identification but uncertain for medicines and medication dose identification	Appropriate for patient identification but uncertain for medicines and medication dose identification	Appropriate
Government support	High	Medium	Low	Low
Pharmaceutical industry support	Medium	Medium	Medium	Medium
Technology providers support	Medium	Medium	Medium	High

with two-dimensional (2D) barcodes. For example, the 2D barcode, such as PDF 417, Data Matrix and Aztec, can hold more information than 1D barcode. A 2D barcode can carry up to 3116 digits, 2335 alphanumeric characters, or 1556 bytes [35]. The 2D barcodes can also handle a high degree of information redundancy -i.e. even if barcode is damaged, the reader can execute accuracy lectures. As result, the lecture problems can be reduced or eliminated. Although the 2D barcode requires the purchase of new 2D barcode readers, adopting this data carrier does not entail high costs for the hospital because 2D barcodes are compatible with 1D barcode processes and printing technologies.

With a full barcode implementation, hospitals have two alternatives, namely 1D or 2D barcodes. On the one hand, if hospitals are opting for the 1D barcode, the barcode readers must get the additional information from the hospital information systems. More specifically, barcode readers must have access by Wi-Fi to the PIS, CPOE and electronic medical records. On the other hand, if hospital implements a 2D barcode, additional information can be held directly in the barcode. Nevertheless, information stored in 2D barcode is static. This means that hospital must reprint the patient's wristband or medication label in case of any change in the patient's information or medication dose information. This results in an additional workload for nurses and pharmacist professionals, as well as new sources of errors.

B. The relevance of a full RFID implementation

The ***full RFID implementation*** path implies the identification of people (here patients) and objects (here medicines and medication doses) with RFID tags. Similar to full barcode implementation, patient must have a wristband with a RFID tag (Figure 6). This tag is able to carry patient's name, id, age, sex, admission date, care unit and allergies. This information must be also registered in characters in case of lecture problems or RFID reader unavailability. The medication doses must hold a label as showed in Figure 2 but, in this case, label has to incorporate a RFID tag which carries all the information regarding the medication dose (Figure 7). Finally, medicines can carry either in their primary and/or secondary package an independent label with a RFID tag containing the medicine information: the pharmaceutical product code (GTIN) or code defined by the hospital, the serial number, the expiry date and the batch code (Figure 8). Similar to the patient's wristband, medication and medicine label must also display the written medication information.

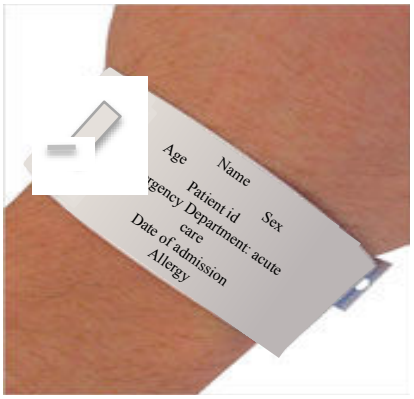

Fig 6. Patient's RFID wristband

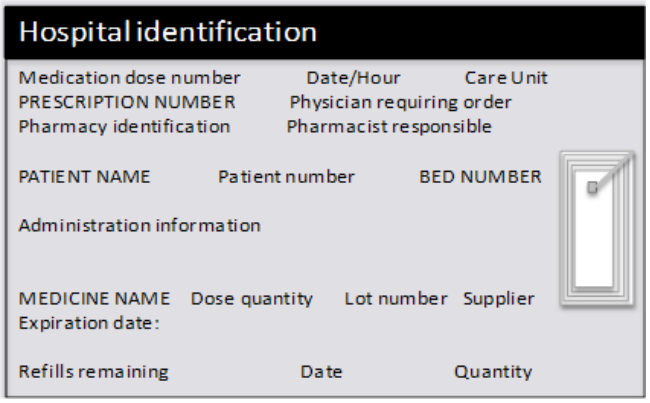

Fig 7. Medication dose label furnished with a RFID tag

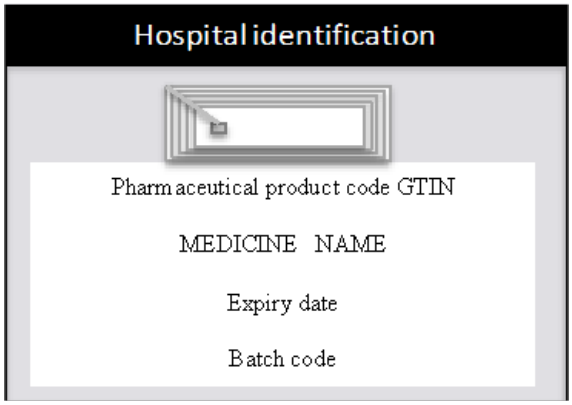

Fig 8. Medicine label furnished with a RFID tag

In spite of these benefits, the participants identified several drawbacks. The most important drawback deals mainly with an uncertain ROI (return on investment). Hospitals tend to tag high value and high cost assets with this data carrier. Therefore, a full RFID implementation for medication doses and medicines would not yield an appropriate ROI. Participants to the field research were also concerned by potential problems with reading accuracy. In fact, liquid and metal products can produce incorrect lectures of RFID tags. As a third drawback, participants felt that current processes and technological systems are not ready for getting RFID information. Collisions may happen when multiple tags are read simultaneously. A pharmacist stated that *"pharmacists and current information systems are not able to manage all the information getting from multiple readings"*. He added *"Since several medicines and doses are stored and handled in a small cabinet, pharmacist can easily get the information of an incorrect medicine when he's preparing the medication doses. This can result in several errors"*. Even if anti-collision schemes have been developed, this problem remains to be resolved. Finally, patient's RFID identification raises several privacy concerns. Information concerning the patient can be detected and modified by unauthorized readers. Several participants in our research work mentioned *"hospitals would not opt for RFID adoption if patients' information remains unprotected"*. Encryption schemes have been also developed in order to ensure the security and integrity of information registered in the RFID tag. Nevertheless, healthcare givers and specially patients are still feeling that information is not adequately protected.

C. The relevance of coexistence: Migration from barcode to RFID

The ***migration from barcode to RFID*** is appropriate for hospitals that already have a barcode infrastructure for their medication process and wish to upgrade their data carrier. In fact, it allows a progressive implementation of RFID into the medication process since barcode basically serves as a support mechanism for ensuring the operability of medication process during RFID implementation, while technological problems with the new technology are solved or while the organization adapts itself to the new RFID system. This adoption path is considered as temporary because the final objective is to achieve the full RFID implementation. When the RFID system reaches successful implementation and organization acceptance, the barcode technology could be progressively removed from the medication process. During the migration phase, patient must hold a wristband with a barcode and a RFID tag. Similar to the wristband used for the full implementation of RFID or barcode, the wristband must hold additional information in characters (Figures 4 and 6). The medication doses, as well as medicines, are identified using a label incorporating both data carriers. Additional information concerning the medication doses and medicines must also be registered in characters (Figures 2, 5, 7 and 8). Once the migration is completed, only the RFID tag will be placed on the wristband and the label. This entails several changes in the label and the wristband, in the printing process, and in the medication process. These changes will result in extra costs and may induce further resistance.

The characteristics of the readers have to be also considered for the evaluation of this adoption path. Before the migration, readers are only able to recognize the barcode nomenclature. During the migration, the hospital has two alternatives for executing lecture from the two data carriers. On one hand, the hospital could purchase new RFID readers, which implies that healthcare professionals must rely on both barcode and RFID readers for identification of patients, medication dose and medicines. Obviously, this makes the medication process more complex. On the other hand, hospital could purchase readers that are compatible with both data carriers. Nevertheless, once the RFID technology is fully implemented, this reader will not be used to its full capacity (and therefore this investment will not be well-spent),

because the barcode lecture will be no longer be required. This can again translate into an inappropriate ROI.

The migration adoption path seems particularly fitted for the patient identification in ordering, administering and monitoring phases (activities from P1 to P3 and from P16 to P20). In fact, the patient can be always identified because of the RFID tag, even if his wristband is not visible. This migration could be achieved in a short time if the hospital invests resources to resolve privacy concerns. With respect to identification of medication doses and medicines during the preparing, distributing and administering stages (activities from P8 to P18), the migration could take a longer period due to the high RFID costs and some technology limits. As result, the use of both technologies could become a de-facto standard for the medication process.

D. The relevance of coexistence: hybridization

The ***hybridization path*** relies on barcode and RFID for the identification of patients, medication and medicines. This path capitalizes on the relative advantages of both technologies. *Hybridization* could be achieved in two different ways, namely integration and combination.

Hybridization by integration requires using a label holding RFID and barcode technology for identifying medication doses and medicines, and a wristband containing both data carriers for patient's identification. *Hybridization by integration* could occur for all the steps of the medication process. At the preparing and the distributing processes (activities from P8 to P15), this path could be preferable to ensure the performance of automated equipment. Solutions such as Fulfill Rx, IntelliShelf-Rx of McKesson rely on RFID for the identification of each medicine container and on barcode for identification of doses. If this hybridization solution is adopted for the preparation stages, other automated equipment such as automated distributors or robots could operate with both technologies. This particular adoption path could combine both technologies in order to support the medication process and improve logistic management activities. While barcode can be used for identifying medicines and doses in the medication process, RFID can be used for executing logistic process. Hence, the hospital could get a more profitable ROI. *Hybridization by integration* could also have a positive impact for the ordering, administering and monitoring phases (activities from P1 to P3 and from P16 to P20). In fact, double validations can be incorporated by reading both carriers in order to improve the identification of patients. Despite these benefits, the hospital must evaluate the cost of double tagging the patient, the medication dose and the medicines with barcode and RFID technology.

Hybridization by combination requires using barcodes for identifying medication doses and medicines while the RFID wristband identifies patients. Both hybridization alternatives rely on using readers that are able to recognize the two data carriers. This means that the same reader can be used for identifying objects and people, even if they have a barcode or an RFID tag. As result, the medication process becomes less complex and the hospital realizes some savings. *Hybridization by combination* could also be favorable for all the stages of the medication process. This adoption path is based on the fact that hospitals are looking for the most effective solution while respecting strict financial constraints. For ordering, administering and monitoring processes (activities from P1 to P3 and from P16 to P20), it seems that patient's identification by RFID technology entails an appropriate and attractive ROI. In fact, ensuring the identification of patient even if his wristband is no totally visible allows the reduction of several medication errors resulting in important savings for the hospital. Moreover, hospital could obtain more financial benefits if RFID wristband is combined with other capabilities, such as temperature monitoring, movement control and patient localization. In the case of preparing and distributing processes (activities from P8 to P15), the cost, the complexity and the technical problems of tagging medication doses and medicines seem to be the main obstacle for RFID adoption. Considering that a short-term solution must be undertaken to ensure the safety of medication process, the hospital could opt for using barcode to support the preparation and distribution of medication doses. For the administering process (from P16 to P18), nurses could ensure the identification by tracking patient's RFID wristband and medication doses barcode label.

VI. Conclusion

This paper has explored four different adoption paths for improving the medication process of an emergency department, namely full barcode implementation, full RFID implementation, migration and hybridization. The analysis of the empirical evidence obtained from the field research took into account several key dimensions, namely the characteristics of the medication process, the relative advantages and drawbacks of barcode and RFID technologies, the organizational characteristics of hospitals, and the influence of external actors.

Based on the results from the field research, it seems more likely that hospitals will opt for the coexistence of both barcode and RFID, either through hybridization or migration adoption strategies for several reasons. First, hospitals can capitalize on the potential benefits of barcode and RFID while respecting strict financial constraints. Second, the current processes and available equipment such as automated medication preparing equipment, dose distributors and readers are compatible with either barcode technology or RFID technology. Third, the coexistence path offers a broader potential, apart from the medication process, for improving pharmacy logistics activities and the compatibility with industry regulations.

The selected path should be aligned with the organizational characteristics of hospitals, including the in-house acquired knowledge of barcode and RFID technologies, the existing information technologies and legacy systems (CPOE, PIS, HIS or Wi-Fi,), and the projects and pilot projects using any data carrier undertaken within or outside the hospital pharmacy.

Resistance to change can also modify the direction of the adoption path. The hospitals could include in the evaluation

of adoption path a thorough assessment of the anticipated impacts on their organization and on healthcare professionals, technicians and staff. Process mapping (Table 2) seems useful to identify and analyze the impacts of a selected adoption path on individuals, activities, and potential improvements, especially with respect to the reduction of adverse events in the medication process. Once validated and accepted by the individuals involved in the medication process, process mapping may actually reduce the resistance to change.

Finally, external actors such as government institutions, the pharmaceutical industry and technology developers play an important role in the evaluation of the four adoption paths. The hospitals will tend to select the data carrier that obtains more governmental and industry support, even if the technology is not the most appropriate. When the healthcare system is publicly funded, the governmental support is indeed a key factor. Moreover, companies from the pharmaceutical industry currently locate and track the medicines throughout the supply chain with either barcode or RFID. Since hospitals receive from the pharmaceutical producers medicines tagged with either technology, they will be inclined to wait and postpone their choice for a specific data carrier.

This paper offers some important contributions. First, it demonstrates that technology implementation in hospital is complex and multifaceted. Several key dimensions, in particular the characteristics of the medication process, the relative advantages and drawbacks of barcode and RFID technologies, the organizational characteristics of hospitals, and the influence of external actors, have to be thoroughly evaluated. Second, the improvement of the medication process cannot be summed to a simple model - i.e. adopting either the barcode technology or the RFID technology. Rather, it is based on a new model for identifying patient, medicines and medication process, namely coexistence. Third, healthcare managers and technology managers could use the research framework as a reference in order to plan their implementation projects. To what extent the coexistence model influences the dynamics of the "interregnum" between an old and a new technology in general and the emergence of a dominant design in particular remains to be investigated in the future.

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