Impact of drug storage systems: a quasi-experimental study with and without an automated-drug dispensing cabinet

Sarah Berdot, Cécile Blanc, Delphine Chevalier, Yvonnick Bezie, Laetitia Minh Maï Lê, Brigitte Sabatier

ISQua®

International Journal for Quality in Health Care, 2018, 1–6
doi: 10.1093/intqhc/mzy155
Article

OXFORD

Article

Impact of drug storage systems: a quasi-experimental study with and without an automated-drug dispensing cabinet

SARAH BERDOT[1,2,3,†], CÉCILE BLANC[1,†], DELPHINE CHEVALIER[4], YVONNICK BEZIE[4], LAETITIA MINH MAÏ LÊ[1,5], and BRIGITTE SABATIER[1,2]

[1]Pharmacy Department, Hôpital Européen Georges-Pompidou, APHP, 75015 Paris, France, [2]Equipe 22, Centre de Recherche des Cordeliers, UMR 1138 INSERM, 75006 Paris, France, [3]Faculty of Pharmacy, Clinical Pharmacy Department, Université Paris Sud, EA EA4123, 92290 Châtenay-Malabry, France, [4]Pharmacy Department, Hôpital Paris-Saint Joseph, 75014 Paris, France, and [5]Lip(Sys)[2], EA7357, UFR Pharmacie, U-Psud, Univ. Paris-Saclay, 92290 Châtenay-Malabry, France

Address reprint requests to: Sarah Berdot. Pharmacy Department, Hôpital Européen Georges-Pompidou, APHP, 20 Rue Leblanc, 75015 Paris, France. Tel: +01 56 09 31 51; Fax: +01 56 09 25 59; E-mail: sarah.berdot@aphp.fr
[†]Equal contribution.

Editorial Decision 17 May 2018; Accepted 20 June 2018

Abstract

Objective: To compare the costs and benefits of an automated-drug dispensing cabinet (ADC) versus traditional floor stock storage (TFSS).
Design: A quasi-experimental multicenter study conducted during 2015.
Setting: A teaching hospital (814 beds) equipped with 43 ADCs and a not-for-profit teaching hospital (643 beds) equipped with 38 TFSS systems, in Paris, France.
Participants: All the wards of the two hospitals were included in the study.
Intervention(s): ADC versus TFSS.
Main Outcome Measure(s): A composite outcome composed of cost and benefits.
Results: The total cost with payback period was substantially higher for the ADCs (574 006€ for 41 ADCs) than TFSS (190 305€ for 30 TFSS systems). The mean number of costly drugs and units were significantly higher for ADCs ($P < 0.001$). There was no significant difference in the mean number of overall drugs and units. There were significantly fewer urgent global deliveries with ADCs than TFSS units. Nurses' satisfaction with ADCs was high and the prevalence of medication process errors related to ADCs was low. No event due to storage errors was reported for ADCs and nine events were reported for TFSS units. On the contrary, informatic-related events increased with the use of ADCs, as expected.
Conclusions: Overall, ADCs are well-established in wards and are particularly appreciated by nurses. A significant difference in the initial investment cost was confirmed, but it must be adjusted over time. This difference is offset in the long-term by gains in preparation time and fewer medication process errors, securing the medication process.

Key words: healthcare costs, hospital care, information technology, medication process errors, pharmacy

Introduction

Automated-drug dispensing cabinets (ADC) have been used since the 1980s in North America, but their introduction in France is more recent, dating to the late 1990s. In Canada, 36% of hospitals responding to a survey in 2010 were equipped with ADCs and this rate increased to 50% in 2014 [1]. Pedersen *et al.* estimated that 97% of responding hospitals in the USA were equipped with ADCs in 2014 [2], compared with 58% in 2002 [3]. The floor stock management and rationalization induced by ADCs is important for North American countries where the system of unit billing to the patient is available. In France, the organization of drug dispensing in hospitals is still heterogeneous in terms of equipment (dispensing robot in pharmacy, ADCs, floor stock storage) and stock management (global and unit-dose dispensing, with urgent global deliveries for specific needs). A report by the French hospitalization and care organization directorate (DGOS) in 2009 found that only 2% of French hospitals (any type of healthcare institute) had deployed one or more ADCs [4]. The total number of ADCs in French healthcare institutes represented 0.3% of the total number of pharmacy storage systems. This low rate can be explained by the high unit cost of ADCs, without evaluation of the return on investment and limited manufacturers and products available in France.

Numerous studies have been carried out to measure the impact of ADCs on the medication process in clinical wards [5–8]. Most evaluated the impact following implementation in a single hospital. They showed a potential positive impact on the medication process by reducing medication errors at every step of the process, from filling, picking and preparation to administration. Ray *et al.* reported a 32% decrease in refill errors [9]. Administration errors also decreased from 53% to 39% with the use of ADCs [5, 6]. A randomized, controlled study showed a significant decrease in the prevalence of medication errors (18.6% with traditional floor stock storage (TFSS) and 13.5% with ADCs, $P < 0.05$) [7]. However, studies focusing on the economic impact of ADCs are few or outdated [10–12]. In a recent economic analysis in France, Chapuis *et al.* [10] found that the implementation of ADCs was financially profitable, with a positive payback period of 5 years.

The European Georges-Pompidou Hospital has progressively invested in ADCs since its opening in 2000 to optimize and secure the medication process. The benefits of these cabinets in the pharmacy and clinical wards merit evaluation, given their cost. The objective of this study was to compare the cost and benefits of dispensing systems in two hospital settings, one with ADCs and the other with TFSS.

Methods

Population and setting

This study was conducted in two French hospitals. The first, the European Georges-Pompidou Hospital (HEGP), is an 814-bed teaching hospital in Paris, France. HEGP has 43 ADCs (OmniRx; Omnicell, Mountain View, CA, USA). The ADCs were implemented from 2000 to 2014. In each ward, all drugs are stored in the ADCs, and nowhere else. Drugs are stored in a random order. The cabinets are locked, and the nurses have access through passwords or fingerprint identification. They have access to all drugs, narcotics included. After selecting the patient name, nurses select the drug prescribed from the global list. The prescription software is not yet interfaced with the ADC software. The ADC software records the time, the identity of the nurse, the patient's name and the drugs removed. The ADC compartments are refilled weekly by pharmacy technicians and the quantities of drugs determined using the interfaced pharmacy information system to assess the need.

The second hospital is the Paris Saint-Joseph hospital (HPSJ), a 643-bed not-for-profit teaching hospital located in Paris, France. Drugs are stored in 38 TFSS systems from Herman Miller®, which have been in use since 1990. These open floor stock systems consist of one or two cabinets. Storage is in alphabetical order, with a separation between oral and injectable drugs. Narcotic drugs are managed outside the system in locked cabinets. The TFSS units are refilled weekly by pharmacy technicians, as for the ADCs.

Both hospitals are equipped with a patient information system integrating an electronic health record and a computerized physician order entry system (DxCare®, Medasys). The pharmacy software used is Pharma® (Computer Engineering). Global deliveries using Pharma® are scheduled for weekly refilling in both hospitals. This refilling normally satisfies urgent needs. However, it is sometime necessary to complete the stock with punctual urgent global deliveries.

Study design

We conducted a quasi-experimental multicenter study from January to December 2015.

Inclusion criteria

All the wards of the two hospitals were included in the study, including those with an average length of stay above 24 h, emergency departments and intensive care units.

Outcomes

The main outcome was a composite outcome composed of cost and benefits calculated for the study period (Table 1). The cost criteria were derived from Chapuis *et al.* [10] and consisted of (1) the cost of storage, (2) the cost of the immobilized drug stock and (3) the cost to employer of pharmacy technicians. The benefits criteria consisted of (1) the number and quantity of each drug in the storage, (2) the number of refillings and drug lines reloaded, (3) the cumulative refiling time, (4) nurses' satisfaction and (5) medication process errors declared during the study period.

Statistical analysis

Data are expressed as the mean and standard deviation (SD) for quantitative variables and as the number and associated percentage for qualitative variables. Group comparisons were performed using the Wilcoxon test for quantitative variables and the Student test for qualitative variables. Data were analyzed with R software version 3.3.0. Satisfaction was compared with the Chi-square test and exact Fisher test using BioStatgv (http://marne.u707.jussieu.fr/biostatgv/).

Results

For this study, 23 wards in HEGP (41 ADCs) and 21 in HPSJ (30 TFSS systems) were included. The total number of hospitalizations was similar for both hospitals (33 351 for HEGP vs. 37 070 for HPSJ). The average length of stay was 10.2 days (min: 2.7—max: 18, mean of 30 beds/ward) in HEGP and 4.6 days (min: 1.1—max:

8.9, mean of 26 beds/ward) in HPSJ. The mean age of the patients was 61 years for both hospitals.

Cost

We evaluated the costs during the study period, integrating the initial costs of investment with the payback period and those following the payback period (Table 2). The mean cost with and following the payback period for one storage was significantly different between the two systems ($P < 0.001$).For the ADCs, the investment costs were 21 840€ for simple ADCs and 24 340€ for double ADCs, with software, license and annual maintenance costs. The cost of immobilized drug stock was 194 805€ for 2015. For TFSS, the investment costs were 3500€ and 7000€ for one and two cabinets, respectively. There were no associated software or license costs. The maintenance costs could not be evaluated. The cost of immobilized drug stock

Table 1 Description and measurement of the cost and benefits criteria

Criteria	Description/measurement
Cost criteria	
(1) Cost of storage	**Included investment costs, the cost of purchasing software and licenses and annual maintenance costs** For both storage systems (ADCs or TFSS), the manufacturers estimated an amortization period of 5 years, with a repartition of the total investment costs (storage, software, and licenses between the pharmacy department and the ADC computer system) over this period. Thus, during the first 5 years, the cost of storage took into account 20% of the investment costs and the cost of annual maintenance (as storage deployment was continuous). We also evaluated the case after this payback period, in which only annual maintenance costs were considered to calculate the storage costs.
(2) Cost of immobilized drug stocks	**Cost of immobilized drug stocks for 1 year (2015)** The cost of immobilized drug stocks was estimated by floor stock inventories.
(3) Cost of pharmacy technicians	**Cost of pharmacy technicians for 1 year (2015)** The cost of pharmacy technicians on medication-related work activities was calculated, considering an annual cost to employer of 42 000€ per technician.
Benefits criteria	
(1) Number and quantity of each drug in storage	**Number of drugs and unit doses** **Number of costly drugs and unit doses** For each system, the mean number of drugs and unit doses for costly drugs (more than 20€ per unit) and all drugs (costly and not costly) were calculated.
(2) Number of refillings and drugs lines reloaded	**Number of global deliveries and urgent global deliveries** **Mean number of drug lines per global delivery** The number of refillings was calculated by summing the number of global deliveries and urgent global deliveries. The mean number of drug lines per global delivery was also calculated based on all deliveries.
(3) Cumulative time for refilling	**Cumulative time for refilling** The cumulative time for refilling was calculated by multiplying the total number of reloaded lines and the mean time for one reloaded line. The time for refilling one reloaded line was determined simultaneously by a pharmacy technician (self-measurement) and a pharmacist (CB). The average of the two times was used. All stages of refilling (scanning, management, preparation, storage and walks to the ward) were timed to obtain an average time per line.
(4) Nurses' satisfaction	**Nurses' satisfaction** The nurses' satisfaction was evaluated through a self-administered questionnaire derived from a validated questionnaire developed by Palm *et al.* [19, 20]. Four dimensions were estimated (compatibility of the system, usefulness, ease of use and user satisfaction) for the ADC and TFSS systems. A three-point Likert scale was used: satisfied, unsatisfied and not satisfied or unsatisfied
(5) Medication process errors declared in 2015	**Medication process errors** Medication process errors were analyzed using the medication process errors registry available in each hospital, in which every healthcare professional can declare any medication process errors. All events related to the medication process declared during the studied period were evaluated.

Table 2 Costs for 41 ADCs and 30 TFSS systems

	ADCs ($N = 41$)	TFSS ($N = 30$)
Investment costs with payback period	192 888€	37 100€
Software and license costs with payback period	2400€	
Annual maintenance costs	28 933€	NE*
Cost of immobilized drug stocks	194 805€	52 405€
Annual cost to employer of pharmacy technicians	**154 980€**	**100 800€**
Cost with payback period	**574 006€**	**190 305€**
Cost following the payback period	378 718€	153 205€
Total for one storage (following the payback period)	9237€	5106€

*NE: Not evaluated.

Table 3 Number, refilling and time of refilling for one storage system

Type of storage	ADCs	TFSS	*P*-value
	Mean (SD)	Mean (SD)	
Number and quantity			
Mean number of drugs	228 (86)	233 (64)	0.79
Mean number of costly drugs	3.5 (3.1)	1.4 (1.8)	<0.001
Refilling			
Mean number of global deliveries (refilling)	99 (38)	72 (23)	<0.001
Mean number of lines in global deliveries	3174 (1576)	4038 (1930)	<0.001
Mean number of urgent global deliveries	226 (88)	677 (364)	<0.001
Time of refilling			
Cumulative time for global deliveries	96 h	108 h	
Cumulative time for urgent global deliveries	19 h	56 h	
Total annual time for deliveries	115 h	164 h	

was 52 405€. The mean cost of immobilized drug stock for one storage was significantly lower than the same cost for ADCs ($P < 0.001$). Finally, the total cost, with payback period, was 574 006€ for ADCs and 190,305€ for TFSS systems. Following the payback period, the total cost for one storage system was 9237€ for ADCs and 5106€ for TFSS.

Benefits

There was no significant difference in the mean number of drugs ($P = 0.79$) or drug units ($P = 0.07$) stored in the systems (Table 3). The mean number of costly drugs and units were significantly higher for ADCs ($P < 0.001$). The mean number of global deliveries for ADCs was significantly higher than that for TFSS (99 vs. 72, $P < 0.001$). There were significantly fewer urgent global deliveries with the ADCs than with TFSS. The number of urgent global deliveries represented 70% of the total requests (global deliveries and urgent global deliveries) for ADCs and 90% for TFSS.

Thirty self-measurements were collected at HEGP and 13 at HPSJ. The average time per refilling line obtained was 1.65 min for ADCs and 1.60 min for TFSS. Based on the 2 days of observation performed by the observer (CB), the times were 1.66 min for ADCs and 1.67 min for TFSS. There was no difference between the two systems. The total annual times for dispensing are presented in Table 3.

Fourteen of 23 (61%) wards answered the user satisfaction questionnaire at HEGP and 14 of 21 (67%) at HPSJ. Fifty-six questionnaires from HEGP and 25 from HPSJ were collected. Four nurses in HPSJ had experience with both storage systems and 75% preferred ADCs. In some wards, several nurses and nurse managers participated. Satisfaction rates are presented in Table 4. Overall, user satisfaction was significantly higher with ADCs than TFSS (89% vs. 56%, $P < 0.001$). Despite the perception of comparative compatibility of both storage systems ($P = 0.06$), there were significant differences for the ease of use ($P < 0.001$) and usefulness dimensions ($P < 0.001$), with better perception of the ADC system.

During the study period, 75 medication process errors related to a 'drug event: medication error process/dysfunction' were reported at HEGP. Among these, 12 were related to ADCs (16%). At HPSJ, there were 40 errors related to TFSS among 99 events reported (40%). Four types of medication process errors were identified: storage refill management, informatics problems, administration errors and other types of events (Fig. 1). Storage refill management events were reported five times more often for TFSS than for ADCs. There were seven events reported at HEGP (six due to treatment supply failure and one due to an expired drug present in the ADC). At HPSJ, there were 19 events due to treatment supply failure, one to the presence of an expired drug, four linked to the lack of drug storage by pharmacy technicians, nine to storage of the wrong drug and six to delivery of the wrong drug. There were four events related to informatics problems, such as the lack of a nurse password or an error in the password to enter the ADC. Finally, there was one event reported at HEGP which generated a wrong administration error due to confusing one drug with another. The other event at HPSJ concerned a problem with refrigerator temperature.

Table 4 Perception of drug storage (ADCs or TFSS) for the four dimensions of the user questionnaire—percent of satisfaction

	ADCs $N = 56$	TFSS $N = 25$	*P*-value
Compatibility*	93%	76%	0.06
Usefulness*	98%	64%	<0.001
Ease of use*	98%	66%	<0.001
User satisfaction**	89%	56%	<0.001

Statistical analyses were performed using the exact Fisher test (*) or Chi-square test (**).

Discussion

The total cost, with payback period, was 574,006€ for 41 ADCs and 190,305€ for 30 TFSS systems. The mean number of costly drugs and units were significantly higher for ADCs ($P < 0.001$). However, there was no significant difference in the mean number of stored drugs or units. There were significantly fewer urgent global deliveries with ADCs than TFSS. The total annual time for deliveries was 115 h for ADCs and 164 h for TFSS. Nurses' satisfaction with ADCs was high and the prevalence of medication process errors related to ADCs lower than that for TFSS. No medication process error due to storage errors was reported for ADCs, whereas nine were reported for TFSS. On the contrary, informatics-related events increased with the use of ADCs, as expected.

Some of our results are consistent with those found in the literature [13]. The use of ADCs at Robert Ballanger Hospital Center (France) resulted in fewer urgent global deliveries with a 75% decrease of demands during daytime care and 50% during night-time care [14]. Chapuis *et al.* reported a 43–57% decrease in treatment failures in the two wards equipped with ADCs [15]. User satisfaction with the use of ADCs has been evaluated in several studies [16].

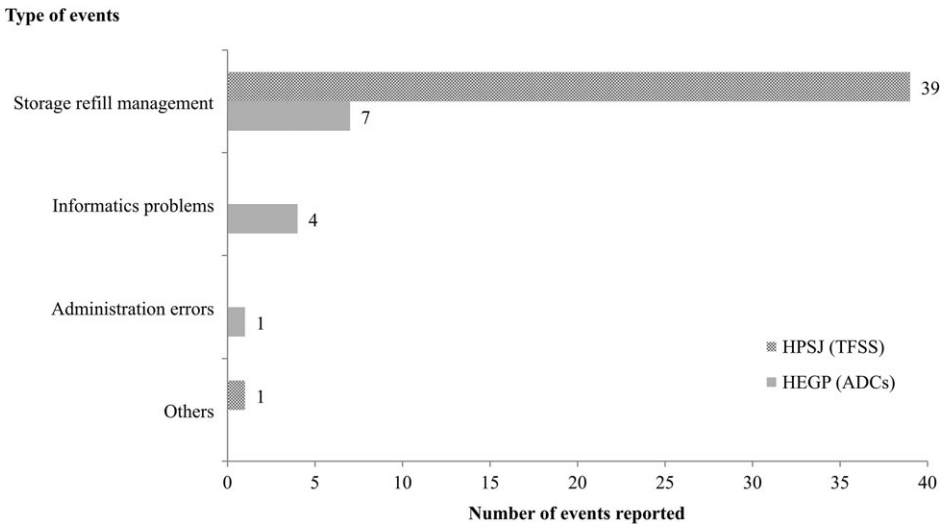

Figure 1 Medication process errors reported during the study period.

In France, 78% of nurses have been reported to be satisfied or very satisfied with the daily use of ADCs [14]. They appreciated the fact that the ADCs indicated the equivalents between brand name drugs and their generic term on the ADC screen and redirected them to the correct reference available in the system.

Our findings on reported medication process errors related to the storage system are consistent with the literature. Studies showed a decrease in the number of drug errors with ADCs, both in the refilling [9] and administration steps [5, 6]. In addition, three times fewer events due to treatment supply failures have been reported with ADCs. This observation is consistent with the higher number of urgent deliveries in HPSJ due to treatment failure.

In contrast, some of our results differ from those of the literature. Savings in the cost of immobilized drug stocks have been observed after implementing ADCs. These savings ranged from 29 to 56% [10, 17, 18]. At HEGP, costly drugs were stored in the ADC, probably explaining this difference. The traceability and accuracy afforded by informatics has allowed the drugs stored in ADCs to be tracked, facilitating the storage of costly drugs and blood-derived drugs requiring patient traceability. Indeed, narcotics and blood-derived drugs were only stored in ADCs. Unlike in our study, several studies have reported an increase in the time of pharmacy technicians dedicated to ADC management [10, 13, 18]. Some functions of ADCs allow better management and optimization of stocks. Urgent global deliveries were three times higher with TFSS when refilling drug stocks. This shows that the refilling planning is not adapted to a ward's needs and results in functional disorganization, even when a similar process is used by the two hospitals. The automation of the scanning step during the refilling process avoided a visit to the ward by pharmacy technicians and removed the need of transcriptions. Hospital stock visibility is especially appreciated during supply shortages, and the ADC itself avoided drug overstorage due to finite physical space allocated for a given drug. The risk of informatics failure should not be ignored. An override mode must be made available. Team training is essential for optimal use of ADCs, but it is more elaborate than that for TFSS.

This is the first study to compare traditional storage and ADCs with a quasi-experimental design. Most studies have used a 'before-after' design to evaluate the implementation of ADCs within one or more wards. Our study has some limitations. The time-saving for nurses was not evaluated, but was predictable. Studies show a reduction in nurses' time spent on acquisition of a single narcotic dose and drug inventory, allowing more time spent with patients [13]. There were two times fewer pharmacy technician self-measurements returned from HPSJ than HEGP. This difference can be explained by the less frequent presence of the pharmacist at HPSJ. More self-measurements and, more importantly, more observations would have made the results for refilling time even more robust. The medication process error reporting system is based on declarative reports. Underestimation of the prevalence of events is known for both storage systems. It would have been informative to directly observe users to evaluate medication errors using the two systems. Finally, it would have been informative to assess the loss of drug due to professional and personal consumption.

Overall, ADCs are well-established in wards and particularly appreciated by nurses. A significant difference in the initial investment cost was confirmed, which is offset in the long-term by gains in preparation time and fewer medication process errors, securing the medication process. The time of pharmacy technicians and nurses can be saved by minimizing urgent global deliveries and controlling their frequency, and functional disorganization may be avoided. The time saved can be used for ADCs maintenance by pharmacy technicians and patient care by nurses.

Acknowledgements

The pharmacy technicians, pharmacy technician managers and nurse managers of both hospitals.

Funding

This study received no external funding.

References

1. The Hospital Pharmacy in Canada Editorial Board. Hospital Pharmacy in Canada 2013/2014 Report (20th edition). 2015.
2. Pedersen CA, Schneider PJ, Scheckelhoff DJ. ASHP national survey of pharmacy practice in hospital settings: Dispensing and administration—2014. *Am J Health-Syst Pharm AJHP Off J Am Soc Health-Syst Pharm* 2015;**72**:1119–37.

3. Pedersen CA, Schneider PJ, Scheckelhoff DJ. ASHP national survey of pharmacy practice in hospital settings: dispensing and administration—2002. *Am J Health Syst Pharm* 2003;**60**:52–68.
4. Ministère de la Santé et des Sports. Direction de l'hospitalisation et de l'organisation des soins (DGOS). Etude d'impact organisationnel et économique de la sécurisation du médicament dans les établissements de santé. 2009.
5. Borel JM, Rascati KL. Effect of an automated, nursing unit-based drug-dispensing device on medication errors. *Am J Health Syst Pharm* 1995; **52**:1875–9.
6. Cousein E, Mareville J, Lerooy A *et al*. Effect of automated drug distribution systems on medication error rates in a short-stay geriatric unit. *J Eval Clin Pract* 2014;**20**:678–84.
7. Chapuis C, Roustit M, Bal G *et al*. Automated drug dispensing system reduces medication errors in an intensive care setting. *Crit Care Med* 2010;**38**:2275–81.
8. Risør BW, Lisby M, Sørensen J. Complex automated medication systems reduce medication administration errors in a Danish acute medical unit. *Int J Qual Health Care J Int Soc Qual Health Care* 2018. doi: 10.1093/intqhc/mzy042. [Epub ahead of print]
9. Ray MD, Aldrich LT, Lew PJ. Experience with an automated point-of-use unit-dose drug distribution system. *Hosp Pharm* 1995;**30**:18. 20–3, 27–30.
10. Chapuis C, Bedouch P, Detavernier M *et al*. Automated drug dispensing systems in the intensive care unit: a financial analysis. *Crit Care Lond Engl* 2015;**19**:318.
11. Lee LW, Wellman GS, Birdwell SW *et al*. Use of an automated medication storage and distribution system. *Am J Hosp Pharm* 1992;**49**:851–5.
12. Schwarz HO, Brodowy BA. Implementation and evaluation of an automated dispensing system. *Am J Health-Syst Pharm AJHP Off J Am Soc Health-Syst Pharm* 1995;**52**:823–8.
13. Tsao NW, Lo C, Babich M *et al*. Decentralized automated dispensing devices: systematic review of clinical and economic impacts in hospitals. *Can J Hosp Pharm* 2014;**67**:138–48.
14. Chedhomme FX Apport des armoires robotisées dans la sécurisation et l'optimisation du circuit du médicament. Exemple de l'hôpital Robert-Ballanger d'Aulnay-sous-Bois. These Pharmacie. DES Pharmacie Industrielle et Biologie Médicale. 2005.
15. Chapuis C Impact d'une armoire à pharmacie sécurisée en réanimation médicale sur l'iatrogénèse médicamenteuse, la gestion des médicaments et la perception des utilisateurs. Thèse de doctorat. 2009.
16. Ottino G, Rochais E, Bussières J-F. Impact des cabinets automatisés décentralisés sur la diminution des erreurs de médication en soins intensifs. *Qué Pharm* 2011;**58**:44–5.
17. Sabatier B, Goudou-Sinha C, Pineau J *et al*. La mise en place d'un automate décentralisé dans une unité de réanimation médicale. *Gest Hosp* 2001;**405**:264–9.
18. Kheniene F, Bedouch P, Durand M *et al*. [Economic impact of an automated dispensing system in an intensive care unit]. *Ann Fr Anesth Reanim* 2008;**27**:208–15.
19. Palm JM, Colombet I, Sicotte C *et al*. Determinants of user satisfaction with a Clinical Information System. *AMIA Annu Symp Proc* 2006: 614–8.
20. Palm J-M, Grant A, Moutquin J-M *et al*. Determinants of clinical information system post-adoption success. *Stud Health Technol Inform* 2010; **160**:213–7.