Impact of Implementing Smart Infusion Pumps in an Intensive Care Unit in Mexico: A Pre-Post Cost Analysis Based on Intravenous Solutions Consumption

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Abstract

Background: The use of smart pump technology has shown to be profitable in the intensive care unit (ICU) because it avoids costs from prevented medication errors and allows for savings on disposables and medications by establishing standardized concentrations and dosing units. **Objective:** The objective of the study is to evaluate the economic impact of the implementation of smart infusion pumps in the consumption of intravenous (IV) solutions in an ICU. **Methods:** A retrospective observational study was conducted with a pre-post design. The study occurred in the adult ICU of the Hospital Juárez de México. The pattern of consumption of IV solutions (sodium chloride 9%, Hartmann's solution, dextrose 5% and 10%, sodium chloride 0.9% with dextrose 5%) was analyzed preimplementation and postimplementation of 50 Plum A+™ pumps with Hospira MedNet™ security software. Using the TreeAge Pro 2016 software, deterministic and probabilistic analyses were carried out (10 000 Monte Carlo simulations) to confirm the robustness of the annual consumption comparison and the associated expenses before and after implementing smart technology. **Results:** The implementation of the smart pumps reduced the annual consumption of IV solutions to 8994 units (18%) and 3649 liters (22.3%). In the first year, MXN\$55 850.97 were saved. From an institutional perspective and with a probability of 0.63, the use of MedNet™ technology proved to be a lower cost alternative (17.1% saved) with respect to the conventional infusion systems. **Conclusion:** The implementation of smart infusion pumps allows savings, specifically for the IV solutions used in ICU.

Keywords

smart infusion pumps, intensive care, cost analysis, IV infusions, IV solutions.

Introduction

The use of smart infusion pumps has improved precision in the administration of medication to critical patients.¹ These pumps are a useful tool to reduce errors in the administration of intravenous (IV) medication.^{2,3} More specifically, this system contributes to the prevention of over and under dosing through the standardization of doses, as the limits for each medication established in the drug library restrict the volume, concentration, and rate of infusion of the drug that can be administered, preventing waste and potential accidents.

Smart infusion pumps have shown a positive impact on the safety of patients, the reduction of IV medication errors, the creation of safer work environments for nurses, and the optimization of capital returns, quality control, and the continuous improvement of the processes.⁴⁻¹³ Furthermore, the

use of smart pump technology has shown to be profitable in the intensive care unit (ICU) because it avoids costs from prevented medication errors and allows for savings on disposables and medications by establishing standardized concentrations and dosing units.^{8,9,11,14-16}

Currently, Mexico lacks an evidence-based health technology assessment strategy at the national level that could provide a solid foundation for decision making for the

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introduction and utilization of health technologies at the hospital level. Moreover, budget limitations may still limit the adoption of smart pumps in Mexican hospitals. Thus, the dissemination of best practices and outcomes is still needed for regulatory and advisory bodies to advocate the use of smart IV infusion technology.

Due to the above, the objective of this study is to evaluate the economic impact of the implementation of smart infusion pumps, specifically on the consumption of IV solutions in the ICU of a reference public hospital in Mexico.

Materials and Methods

A retrospective observational study with a pre-post design was carried out in the adult ICU of the “Hospital Juárez de México,” a third-level public hospital in Mexico City. The entire study period was from April 2013 to April 2015.

The ICU has 9 beds. The total number of admissions, average occupancy rate, average mortality rate, and average length of stay in the ICU were 239 patients, 97.3%, 18.5%, and 10.3 days for the preimplementation period, and 311 patients, 85.1%, 13.7%, and 7.6 days for the postimplementation period.

In April 2014, 50 Plum A+™ pumps with safety software Hospira MedNet™ version 5.5 (Hospira Inc., Lake Forest, Illinois) began operating. The security software installed in the pumps monitored in real time all generated programming and alerts, collecting this information as management and usage reports. Before its implementation, a group of experts established the drug library specific for the ICU, comprised by 110 medications, 97% of which were programmed with defined dosing limits.

To evaluate the impact that the implementation of smart infusion pumps had on the consumption of IV solutions in the ICU, 2 study periods were proposed. During the preimplementation time period (April 2013 to April 2014), the number of units used with the conventional infusion systems was calculated, and during the postimplementation time period (April 2014 to April 2015), the consumption of solutions in the first year after the implementation of MedNet™ was determined.

We evaluated the total of the solutions that are used in the ICU: sodium chloride 9%, Hartmann’s solution, dextrose 5%, dextrose 10%, and sodium chloride 0.9% with dextrose 5%. The real pattern of monthly consumption of doses administered intravenously in the ICU—both in number of units and the total volume consumed—was analyzed for both data time periods. The data were obtained from the warehouse drug records, stock, and dispensing records of the hospital. The annual cost associated with the consumption of each IV solution was estimated using as reference the unitary prices reported in the transparency portal of the Mexican Social Security Institute (IMSS for its acronym in Spanish) for the year 2015.¹⁷ The costs were expressed in Mexican pesos (MXN).

With the aforementioned data and from an institutional perspective, a deterministic analysis was carried out, which made it possible to compare the annual consumption of solutions using conventional infusion systems against the consumption using smart infusion pumps. Subsequently, using the same pattern of solution consumption, the analysis was repeated with the prices of 2014 and 2016 to carry out a projection of the expenses with the corresponding costs of those years. These prices were also obtained from the purchasing portal of the IMSS.

Finally, due to the monthly variability in the use of the solutions, a probabilistic sensitivity analysis was carried out to evaluate the robustness of the deterministic analysis and to assess the effect of uncertainty on this result. A Monte Carlo simulation was generated with 10 000 iterations, using a normal distribution and the statistics obtained from the review of the consumption database as reference for all inputs. Table 1 shows the data used as input in the probabilistic analysis. The distribution of the estimated annual costs based on the amount of consumed solutions was considered for both the preimplementation and postimplementation data sets. The prices of 2015 were also used for this analysis.¹⁷ The Monte Carlo probability distribution analysis was developed using the TreeAge Pro 2016 software, version 16.2.1.0-v20160817 (TreeAge Software Inc, Williamstown, Massachusetts).

Results

The results of the calculation of IV solutions consumed in the ICU for the preimplementation and postimplementation study periods are shown in Table 2. These show a reduction in the consumption of IV solutions by the ICU of 8994 units (18%) and 3649.45 L (22.3%).

Table 3 shows the results of the deterministic analysis of the expenses obtained after revising the real pattern of IV solutions consumed preimplementation and postimplementation of the smart infusion pumps. For 2015, the implementation of the technology resulted in MXN\$55 850.97 in savings. The projections for 2014 and 2016 resulted in savings of MXN\$54 960.64 and MXN\$52 205.16, respectively.

The deterministic analysis allowed establishing the differences in the institutional expenses associated with the consumption of IV solutions and, therefore, the percentage of savings generated by the implementation of the smart pumps. A sensitivity analysis was required to simulate the uncertainty and improve the generalization of the study, given that the consumption of IV solutions presents a high monthly variability in the ICU of this study.

Figure 1 shows the results of the probabilistic analysis concerning the distribution of the estimated annual costs for both the preimplementation and postimplementation data sets.

The results of the Monte Carlo simulation show that the mean of the estimated annual costs associated with the use of

Table 1. Consumption Pattern of IV Solutions in the ICU for the Preimplementation and Postimplementation of MedNet™ Study Periods.

Study period	Input	Presentation (mL)	Mean of units used per month	SD	Unitary Price 2015 (MXN) ^{a,b}
Preimplementation of MedNet™	Sodium chloride 9%	50	349.38	313.15	\$5.03
		100	293.38	292.06	\$5.14
		250	951.62	560.60	\$4.94
		500	1257.23	495.14	\$6.91
		1000	168.00	57.85	\$7.13
	Hartmann's solution	250	94.77	100.34	\$6.67
		500	91.08	69.50	\$7.19
		1000	78.31	48.84	\$7.07
	Dextrose 5%	50	133.54	138.28	\$5.89
		100	156.31	153.51	\$6.04
		250	318.46	129.93	\$5.84
		500	25.23	79.72	\$10.56
		1000	20.77	43.17	\$6.73
	Dextrose 10%	500	11.53	28.82	\$7.62
	Sodium chloride 0.9% + dextrose 5%	500	4.62	16.64	\$7.34
Postimplementation of MedNet™	Sodium chloride 9%	50	465.38	341.19	\$5.03
		100	250.00	339.79	\$5.14
		250	723.08	329.53	\$4.94
		500	959.08	346.92	\$6.91
		1000	33.70	32.45	\$7.13
	Hartmann's solution	250	134.62	139.29	\$6.67
		500	121.92	147.00	\$7.19
		1000	63.69	50.53	\$7.07
	Dextrose 5%	50	70.5	117.26	\$5.89
		100	153.85	139.99	\$6.04
		250	186.33	282.32	\$5.84
		500	6.50	15.66	\$10.56
		1000	16.00	26.75	\$6.73
	Dextrose 10%	500	11.00	25.82	\$7.62
	Sodium chloride 0.9% + dextrose 5%	500	5.00	17.32	\$7.34

Note. IV = intravenous; ICU = intensive care unit.

^aUnitary prices from the purchasing portal of the Mexican Social Security Institute (IMSS) for the year 2015 were used.¹⁷

^bAs reference, the historical exchange rate of the US dollar and Mexican peso (USD/MXN) reported for the year 2015 was of 15.9753. Currently, the average ratio is of 18.5784 USD/MXN (January-April 2018).¹⁸

Table 2. Units and Total Volume of Solutions Consumed Preimplementation and Postimplementation of the MedNet™ System.

Preimplementation of MedNet™		Postimplementation of MedNet™	
Total units consumed	Total volume consumed (L)	Total units consumed	Total volume consumed (L)
49 935	16 369.25	40 941	12 719.80

Table 3. Expenses Associated With the Consumption of IV Solutions in the ICU Preimplementation and Postimplementation of the MedNet™ System.

Generated costs	With unitary prices from 2014 ^a	With unitary prices from 2015 ^a	With unitary prices from 2016 ^a
Preimplementation of MedNet™	\$295 272.80	\$298 831.48	\$281 595.12
Postimplementation of MedNet™	\$240 312.16	\$242 990.51	\$229 389.96
Savings %	18.61%	18.69%	18.54%

Note. IV = intravenous; ICU = intensive care unit.

^aOfficial public tabulators were used with prices from the corresponding years.¹⁷ All costs are presented in Mexican pesos (MXN).

Figure 1. Monte Carlo simulation.

Note. Probability distribution of annual costs attributable to IV solutions consumption, estimated for the preimplementation of MedNet™ period (a) in comparison with the postimplementation period (b). IV = intravenous.

IV solutions with an administration associated with the use of the smart pumps are lower by 17.1% with respect to the conventional infusion system (Table 4). The simulation showed that, with a 90% probability of occurrence, the postimplementation period was less expensive, while with only a 10% probability, the same data time period would have been more expensive.

In short, the results of the probabilistic analysis show that there is a probability of 0.63 that the use of smart pumps will result in a cheaper alternative with respect to the conventional system. Given that the unitary costs of the IV solutions are very low, the savings in the economic expenses as well as in the total consumed volume are very significant.

Table 4. Results of the Estimation of the Decrease in Consumption of IV Solutions in the ICU, Using a Monte Carlo Simulation With 10 000 Iterations.

Statistic	Preimplementation of MedNet™	Postimplementation of MedNet™
Mean	\$274 471.03	\$227 570.41
SD	\$133 040.48	\$54 711.52
2.5 percentile	\$13 720.78	\$122 282.79
10 percentile	\$104 076.58	\$157 115.97
Median	\$274 448.09	\$228 021.35
90 percentile	\$445 650.69	\$292 752.68
97.5 percentile	\$536 076.32	\$334 477.35
Number of iterations	10 000	10 000

Note. IV = intravenous; ICU = intensive care unit.

Discussion

To the best of our knowledge, this is the first study reporting on actual savings in the consumption of IV solutions generated by smart infusion technology in a hospital setting in Mexico.

Although almost all hospitals in the United States use the smart infusion technology, and more than half have implemented the use of smart pumps with security software,¹⁹ very few hospitals in countries such as Mexico have adopted this type of devices, despite the fact that up to 95% of hospitalized patients receive IV therapy.²⁰

Recently, our group showed the clinical²¹ and economic¹⁶ impact of the prevented errors after implementation of smart pumps in the adult ICU, where the technology intercepted, for insulin alone, at least 32 overdoses that could have presented a high risk of harm to the patients and an annual cost of MXN\$3 331 972.80. Fortunately, the pumps effectively intercepted the infusion errors, thereby avoiding outcomes that would have been catastrophic and costly.

There are many studies determining costs and savings after the implementation of smart pumps; however, savings on IV solutions specifically are poorly detailed or highlighted.^{11,14}

Thus, the present work provides evidence that after the implementation of the smart infusion systems in the studied ICU, savings were generated in the derived costs for the consumption of IV solutions of MXN\$46 900.62 (17.1% of the mean in the preimplementation period, see Table 4).

Based on the census data of the ICU for both study periods, it is possible to ask whether the results found are truly associated with the implementation of the smart pumps as compared with a decrease of overall patient loads or a decrease in patients admitted with conditions that warrant use of less fluids. Both, the preimplementation and postimplementation data sets showed a high monthly variability in terms of IV solutions consumption. Variables and factors that cause such variability are many, including ICU occupancy, inpatient mortality, patients undergoing septic shock, length of stay, prescription patterns, patients' conditions, and fluid management needs and practices, among others. Due to the above, the probabilistic sensitivity

analysis carried out in this study aimed to include all types of uncertain or stochastic effects that could result from the observations. This type of analysis improves the generalization of our study results as well. In addition, the number of observations that were simulated through the Monte Carlo Simulation (10 000 iterations) can be considered a large enough sample size to support the reported results. Therefore, all possible variations are implicit in the analysis, which confirms the robustness of the conclusions.

One of the main attributes of smart IV infusion systems is that they make it possible to standardize doses, an aspect that in addition to contributing to the safety of the patient and the economic impact also suggests a potential logistical impact related to the reduction in the consumption of IV solutions.^{7,16,21}

In terms of organization and administration of hospital consumables, the use of lower quantities of IV solutions could have a positive impact on the management of storage spaces, internal registration and verification processes, and on the correct conservation and supply of IV solutions.

In the studied ICU, infusion concentrations for 107 medications were standardized and dosage limits were set for each drug included in the customized library of the safety software of the pumps. Dosing standardization led to a reduction in dissolution volumes for most drugs.

Certainly, there were also savings in medications and very significant. However, the records of drug consumption of the hospital were incomplete and disorganized, so it was not possible to include them in the present analysis.

Although the impact on savings can be much greater when analyzed from the perspective of drugs, IV solutions can be considered a good marker of consumption precisely because they are relatively inexpensive compared with medications in general.

The costs analysis provides a point of reference for the strategic planning of the critical care medical services of the health systems. Normally, the costs analyses of IV or fluid solutions are included within the concept of medications or consumables. In this regard, it has been described that within other pharmaceutical products, the solutions for hydration generate high costs in the ICUs due to the fact that all patients reported as critical have a hydration scheme for however long they remain in a critical condition, be it to maintain a proper intravascular volume and to serve as diluents of drugs for IV infusion or as a complement for artificial nutrition schemes.^{22,23} Thus, medications or consumables generate high expenses, as they are considered one of the areas with a greater financial load in ICUs.²⁴⁻²⁷

Finally, as part of *smart pump* implementation, the adoption of standardized concentrations for IV medications has been known to enhance patient safety.²⁸⁻³⁰ This work also demonstrates its impact in reducing the consumption of IV solutions and thus in reducing costs.

Hence, the purpose of this study was to generate interest in the subject and contribute to the existing literature on the benefits, both clinical and economical, of optimizing the use and IV administration of medications for critical care.³¹

Limitations of the Study

As it was not possible to access the information of the hospital regarding the consumption and real costs of the medications used in the ICU before and after the implementation of MedNet™, the present study could only compare the total of the IV solutions used in the ICU for both data time periods. In this manner, the estimation presented here of the savings generated in IV solutions provides partial evidence on the additional strategies for cost saving for ICUs (eg, savings on medications, savings on consumables, cost avoidance for prevented errors).

On another topic, it is worth noting that despite the limitation of not having used the real unitary prices of the inputs of the hospital in this study, the use of the public prices of the IMSS for our analyses was validated when comparing the preimplementation and postimplementation study samples.

Conclusions

The implementation of smart infusion pumps in the ICU under study allowed an annual savings of 17.1% in the cost of IV solutions used, as well as reductions in the number of units (18%) and liters (22.3%) of solutions used.

From an institutional perspective, the use of the MedNet™ technology proved to be a lower cost alternative with respect to the conventional infusion systems.

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Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Erika Palacios-Rosas, Isaac F. Soria-Cedillo, Fabiola Puértolas-Balint, Rebecca Ibarra-Pérez, Sergio E. Zamora-Gómez, Elizabeth Lozano-Cruz, Marcos A. Amezcua-Gutiérrez, and Lucila I. Castro-Pastrana have no conflicts of interest that are directly relevant to the content of this article.

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Ethics Approval

This work was approved by the Research Ethics Committee of our institution with the number 060 on September 21, 2016. This research was observational and, therefore, noninterventive.

Consent to Participate

The *study* involved an intravenous (IV) solution consumption pattern analysis from data obtained from the hospital warehouse drug records. *Written consent was not required* as the patients hospitalized in the intensive care unit (ICU) during the study period could *not* be identified nor their treatments or medical procedures were intervened.

Supplementary Materials

Data sets and analysis will be available upon request.

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