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Creating an evidence-based economic model for prefilled parenteral medication delivery in the hospital setting

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ABSTRACT

Objectives Prefilled syringes (PFS) may offer clinical and economic advantages over conventional parenteral medication delivery methods (vials and ampoules). The benefits of converting from vials and ampoules to PFS have been explained in previous drug-specific economic models; however, these models have limited generalisability to different drugs, healthcare settings and other countries. Our study aims to (1) present a comprehensive economic model to assess the impact of switching from vials to PFS delivery; and (2) illustrate through two case studies the model's utility by highlighting important features of shifting from vials to PFS.

Methods The economic model estimates the potential benefit of switching to PFS associated with four key outcomes: preventable adverse drug events (pADE), preparation time, unused drugs, and cost of supplies. Model reference values were derived from existing peer-reviewed literature sources. The user inputs specific information related to the department, drug, and dose of interest and can change reference values. Two hypothetical case studies are presented to showcase model utility. The first concerns a cardiac intensive care unit in the United Kingdom administering 30 doses of 1 mg/10 mL atropine/day. The second concerns a coronavirus (COVID-19) intensive care unit in France that administers 30 doses of 10 mg/25 mL ephedrine/day.

Results Total cost savings per hospital per year, associated with reductions in pADEs, unused drugs, drug cost and cost of supplies were £34 829 for the atropine example and €104 570 for the ephedrine example. Annual preparation time decreased by 371 and 234 hours in the atropine and ephedrine examples, respectively.

Conclusions The model provides a generalisable framework with customisable inputs, giving hospitals a comprehensive view of the clinical and economic value of adopting PFS. Despite increased costs per dose with PFS, the hypothetical case studies showed notable reductions in medication preparation time and a net budget savings owing to fewer pADEs and reduced drug wastage.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Globally, most parenteral medications are conventionally supplied via injection with medication dispensed from vials and ampoules, despite evidence that such formats result in unused drugs, increase risk of preventable adverse drug events, significant hospital staff time to prepare, and use of extra supplies.

⇒ Prefilled syringes address the shortcomings of these conventional parenteral medication delivery methods, with benefits for patients, healthcare delivery systems, and hospitals.

WHAT THIS STUDY ADDS

⇒ A novel economic model was developed to estimate the holistic budget impact of switching from vials and/or ampoules to prefilled syringe medication delivery formats for acute care hospital settings based on four key parameters: unused drugs, preventable adverse events, preparation time, and use of supplies.

⇒ Results from two hypothetical case studies illustrate an overall cost offset despite higher prices of ready-to-administer formats with prefilled syringes compared with conventional delivery methods.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Although this study illustrates two hypothetical case studies, the model can be customised using institution specific values to depict the clinical, economic and humanistic impact of prefilled syringes to provide benefits for patients, healthcare delivery systems and hospitals.

INTRODUCTION

Throughout Europe, parenteral medication is predominantly supplied in vials and ampoules (referred to as conventional methods)[1] despite documented limitations that negatively impact patients and healthcare systems.[2–7] Ready-to-administer medication formats, including prefilled syringes (PFS), have the potential to redress conventional delivery shortcomings, yet only 2% of acute liquid injectable small molecule drugs ≤50 mL are currently delivered in such formats, suggesting ample opportunity for improvement.[8] Understanding the economic benefits of PFS vs conventional methods can support broader uptake of this modality.

Conventional methods are associated with many humanistic and economic implications. In fast-paced areas of the hospital where medications must be delivered quickly (e.g., intensive care unit (ICU) or emergency departments), the risk of medication errors is higher.[2–4] A German medical record based study found that on average each adverse

drug event (ADE) results in an additional cost of €970 for the health system and an average additional hospital length of stay of 2.9 days, which may be associated with downstream patient consequences.[5] Furthermore, the criticality of ensuring that we prevent avoidable harm through medication errors has been highlighted by the WHO through their third Patient Safety Challenge Medication Without Harm.[9]

Additionally, dose preparation with conventional methods is complex and time-consuming, placing a substantial burden on healthcare professionals and hospital department resources.[6] Furthermore, conventionally prepared doses are frequently discarded when narrow administration windows or expiration times are not met, resulting in unused drugs and supplies. In fact, one study estimated that 85% of all atropine doses prepared in operating rooms are discarded.[7] As shown above, not only can conventional methods lead to avoidable adverse events for patients, but these delivery methods also yield significant inefficiencies and misallocation of resources, with extra costs for healthcare systems.

PFS provides a convenient solution to many of the shortcomings of conventional methods, with benefits for stakeholders, including healthcare delivery systems, hospitals, and patients. Since the medication is in a ready-to-administer format, PFS utilisation reduces the number of steps required to deliver medication, which translates into a reduction in healthcare professional time spent preparing the injection.[6] Additionally, eliminating preparation steps, such as drawing medication from the vial and switching between the aspiration needle to the injection needle can decrease the contamination risk.[6 10 11] Utilising PFS has fewer steps required to deliver medications, thereby minimising the risk of medication errors associated with conventional methods, including syringe preparation and the potential cascade of preventable ADEs (pADEs) that may follow. In fact, one study demonstrated that dosing errors were 17 times less likely in PFS vs conventional methods.[12] Furthermore, while drugs prepared with conventional drug preparation methods have a limited period for sterile administration, PFS doses remain sterile under correct storage conditions until they are administered and therefore are less likely to be wasted.[11 13 14]

Prior economic models have taken a specific view of the budget impact for an individual drug, hospital, or outcome; however, new evidence is emerging to add potential cost savings of switching from vials to PFS across different hospitals and healthcare delivery systems.[7 15] To facilitate a more comprehensive view of the economic impact of switching to PFS, an economic model incorporating data on pADEs, unused drugs, preparation time, and cost of supplies was developed for use across various hospital departments, drugs, and countries. Through the presentation of two case studies, this study aims to (1) present the holistic nature of the economic model, and (2) illustrate the model's utility by highlighting important and distinct features and impacts of switching from conventional methods to PFS.

METHODS

Model development

The economic model was developed through a multi-step process with adherence to guidelines for budget impact analyses from the International Society for Pharmacoeconomics and Outcomes Research (ISPOR) (online supplemental figure 1). Targeted literature reviews informed the model framework. The initial framework and parameters were reviewed by three advisory boards of pharmacists, doctors, and hospital administrators in France, Germany, and the United Kingdom (UK). The advisory boards discussed and selected the four most pertinent parameters for inclusion in the model. As research continues, the model will be further refined based on the most current literature and findings.

Model structure

The goal of the model is to provide insight into the annual impact of shifting from drug delivered in conventional methods (vials and ampoules) to PFS from a hospital perspective across four outcome areas (figure 1). The Microsoft Excel based economic model includes five user-facing worksheets (Overview, Institution Overview, Input, Results, and References). Model costs and prices are converted to specific country prices via purchasing power parities (PPP). The costs of equipment for PFS are included in the PFS cost per dose. The model allows for inserting institution- and drug-specific inputs, such as cost per vial unit dose, cost per PFS unit dose, and number of doses administered per day.

In addition to the cost of the drug, the model includes calculations for four main parameters: pADEs, unused drug, dose preparation time, and supplies per unit injection. The model input values are based on available peer-review literature sources that were chosen to reflect the situation and drug of interest most accurately.

pADEs are a subset of adverse drug events that result from medication errors and can cause patient harm. The model reference pADE rates are 1.39 (51 pADEs recorded per 3 671 medication administrations) and 0.73 per 100 dose administrations for vials and PFS, respectively, and were derived from a United States (US) study of perioperative medication errors.[16] The PFS pADE rate is calculated assuming that PFS introduction eliminates dosing and labelling errors (47.1% of all errors) and that all error types are equally likely to result in a pADE. The pADE rate can be changed in the model as requested for the specific analysis. A German medical record-based study showed that each ADE results in an incremental average direct hospital treatment cost of €970.[5] The actual costs per ADE will vary from country to country due to conversion via PPP.

Unused drug is described as drug that is prepared but not used and therefore must be discarded.[7] The model allows the user to either enter the percent of prepped doses unused per day or enter the total number of doses prepped per day and the model will calculate the number of unused doses per day. Additionally, the user may select to use reference values that vary by drug and drug dose for vials[13] and a reference value of 3% for PFS.[11] However, unused drug levels associated with conventional method preparation are highly dependent on the drug and type of hospital setting, therefore, reference values should only be used when institution level values are unknown.

Dose preparation time is defined as the total time it takes for hospital staff to prepare a single dose of medication.[6] The preparation time assumptions are based on a time and motion study from two Danish hospitals and assumes 40.3 seconds per vial and 16.9 seconds per PFS.[6] The model user may choose to select from additional options.[6 10 12 17] Preparation time does not factor in monetarily to the cost calculations of the model. Finally, the standard supplies included per unit injection costs of gloves, needles, syringes, and alcohol swabs.

Case studies

To showcase the robustness and utility of the economic model, two hypothetical case study analyses were conducted. Table 1 notes the assumptions and reference values for each case study.

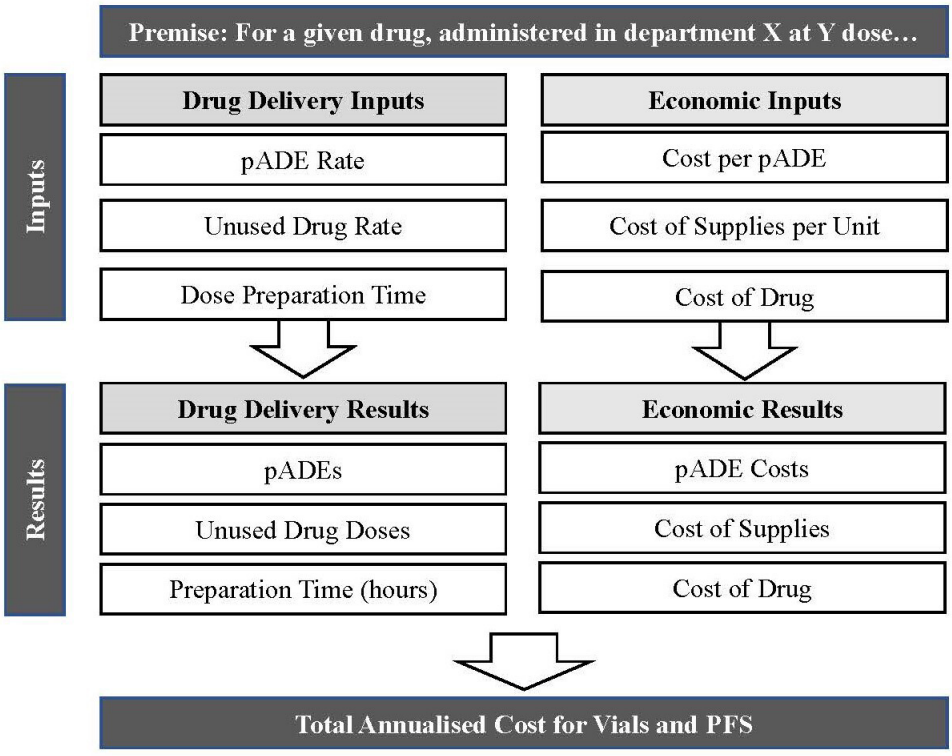

Figure 1 Economic model structure and flow. pADEs, preventable adverse drug events.

To ensure examples are reflective of current situations in hospitals in the UK and France, the assumptions and reference values utilised are based on local expert opinion and best available peer-reviewed literature. Drug costs are based on country-level IQVIA data for list prices from 2019-2021.[8] The costs per dose were converted from United States Dollars ($) to Great British Pounds (£) or euros (€) for case studies 1 and 2, respectively without any discounting.[8]

Table 1 Economic model input: case study values and references for primary analysis and sensitivity Analysis

	Case Study 1 Values		Case Study 2 Values	
Model Input	**Ampoules**	**PFS**	**Vials**	**PFS**
Country	UK		France	
Drug type*	Atropine		Ephedrine	
Dose	1 mg/10 mL		25 mg/10 mL	
Doses administered per day*	30		30	
Cost per dose[8]	£0.83	£5.07	€5.92	€10.37
pADE rate per 100 administrations[16]	1.39	0.73	1.39	0.73
Incremental hospital cost per pADE[5]†	£791.61	£791.61	€914.25	€914.25
Percent wastage for primary analysis[13]	71%	0%	57%	0%
Percent wastage for secondary analysis[7 11]	85%	0%	74%	0%
Preparation time per dose (seconds)[6]	40.3	16.9	40.3	16.9
Supplies per unit injection, n (unit cost) (NHS Tariffs)[21 22] †				
Gloves	2 (£0.07)	2 (£0.07)	2 (€0.06)	2 (€0.06)
Needles	2 (£0.03)	1 (£0.03)	2 (€0.02)	1 (€0.02)
Syringe	1 (£0.16)	0 (£0.16)	1 (€0.13)	0 (€0.13)
Alcohol	2 (£0.02)	1 (£0.02)	2 (€0.02)	1 (€0.02)

*Selection of drug type and doses administered per day based on subject matter expert recommendation.
†NHS tariffs converted to euros (€) with purchasing power parity.
pADE, preventable adverse drug event; PFS, prefilled syringes.

Case study 1

Case study 1 takes place in a hypothetical cardiac intensive care unit (CICU) in the UK that administers 30 doses of 1mg/10mL atropine per day. In the CICU setting, atropine is frequently used as a first-line therapy for symptomatic bradycardia, as well as a pre- and post-intubation medication. In this example, atropine doses from ampoules cost £0.83 per dose, and PFS format doses cost £5.07 per dose.[8] The incremental cost of a pADE to a hospital system was £791.61.[5] Unused drug levels for prepared doses were set at 71% and 0% for vials and PFS, respectively.[13]

Case study 2

Case study 2 takes place in a hypothetical ICU that has been converted to a coronavirus (COVID-19) unit in France. The drug of interest is ephedrine – a vasopressor commonly used in operating rooms (ORs) and ICUs.[13] This ICU uses 30 doses of 25mg/10mL ephedrine daily. The cost per vial dose is €5.92 and the cost per PFS dose is €10.37.[8] The incremental cost of a pADE was €914.25.[5] Unused drug levels were set at 57% and 0% for vials and PFS, respectively.[13]

Sensitivity analyses

Sensitivity analyses were conducted for both case studies using alternative references for drug waste to showcase model sensitivity. Case study 1 was repeated with the assumption that 85% and 0% of atropine doses were used for vials and PFS, respectively.[7] Case study 2 was repeated with unused drug levels set at

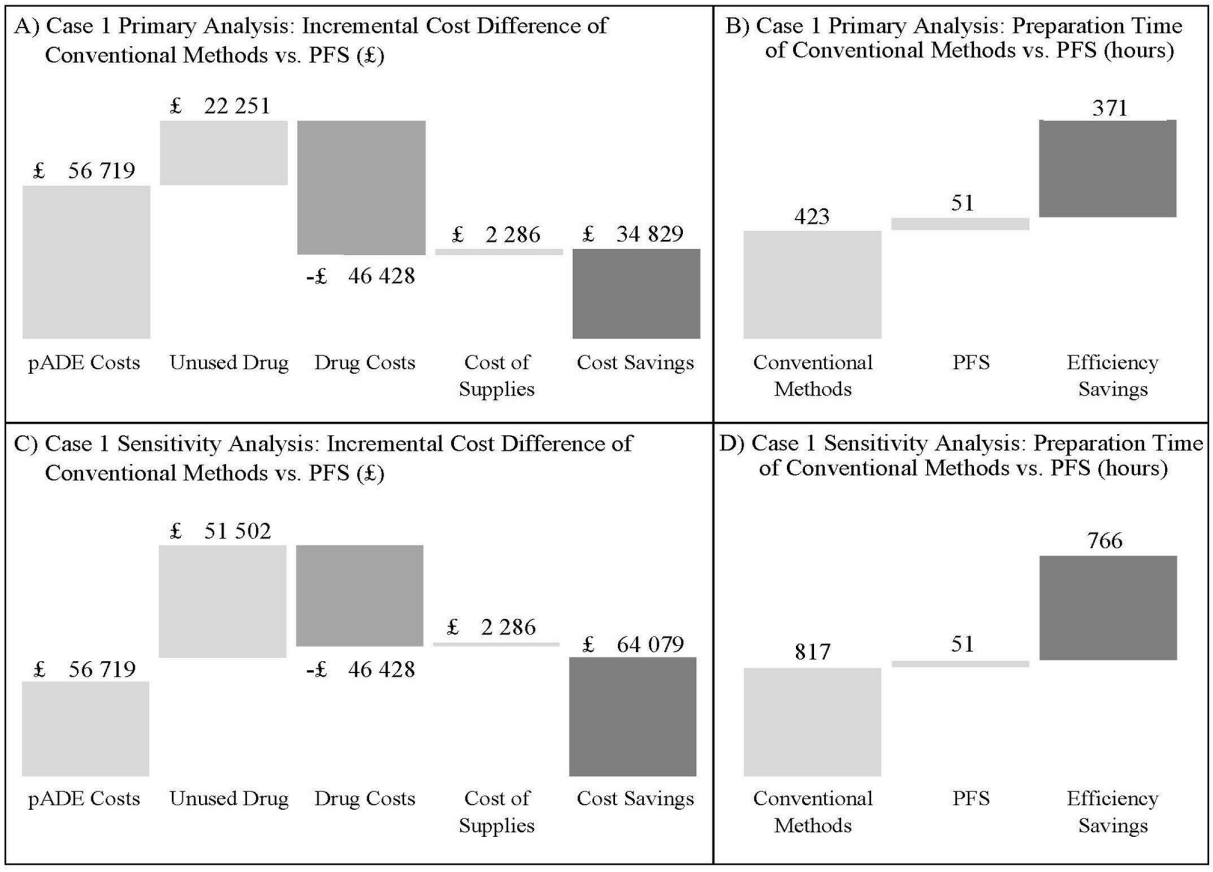

Figure 2 Graphical depiction of case 1 primary analysis and sensitivity analysis results. pADE, preventable adverse drug event; PFS, pre-filled syringes.

74% and 0% for vials and PFS, respectively.[11] All other model parameters remained the same.

RESULTS

Key results from each case study are described below, with graphical depictions in figures 2 and 3. Complete results are presented in table 2 and table 3.

Case study 1

Economic model primary analysis results indicated that the overall cost impact for switching to PFS delivery in a hypothetical CICU in the UK administering 30 doses/day of atropine is £34 829 in savings per year. pADEs were reduced from 152 to 80 per year, and preparation time for hospital staff reduced from 423 to 51 hours per year (figure 2A,B, table 2).

The sensitivity analysis for case study 1 revealed an overall cost savings of £64 079, with the cost of unused drug doses increasing to £51 502 (compared with £22 251 in the primary analysis). Preparation time savings was 766 hours per year compared with 371 hours per year in the primary analysis (table 2, figure 2C,D).

Case study 2

The overall cost savings for a hypothetical COVID-19 ICU in France administering 30 doses/day of ephedrine is €104 570 per year based on the model results. pADEs were reduced from 152 to 80 per year, and preparation time for hospital staff reduced from 285 hours to 51 hours per year (table 3, figure 3A,B).

The sensitivity analysis for case study 2 showed an overall cost savings of €203 140, with the cost of unused drug doses increasing to €184 499 (compared with €85 929 in the primary analysis). Preparation time savings was 420 hours per year compared with 234 hours per year in the primary analysis (table 3, figure 3C,D).

DISCUSSION

The economic model facilitates estimation of the budget impact of switching to PFS from conventional methods for institutions across four key outcomes associated with parenteral medication administration: pADE, preparation time, unused drug, and cost of supplies. Informed by peer-reviewed literature-based assumptions, hypothetical case studies and sensitivity analyses in two different settings with different drugs highlight the utility and versatility of the model, as well as the potential for hospital cost savings when switching from vials and ampoules to PFS. Despite increased costs per dose with PFS, the analysis in the case studies showed notable reductions in medication preparation time and a net budget savings owing to fewer pADEs and reduced drug waste.

Results from the case studies underscore that drug price significantly impacts model outcomes. The largest drivers of cost savings were found to be related to reductions in unused drug doses and pADEs in PFS versus conventional methods. However, exact prices for drugs cannot always be determined, which is why case studies use official prices without accounting for possible discounts. Despite lower unused drug levels seen in ephedrine compared with atropine, the costs of unused drug doses were higher in case study 2 compared with case study 1 due to higher costs per dose of ephedrine in vials. The cost difference between vial and PFS formats will substantially impact the level of cost savings that could be achieved.

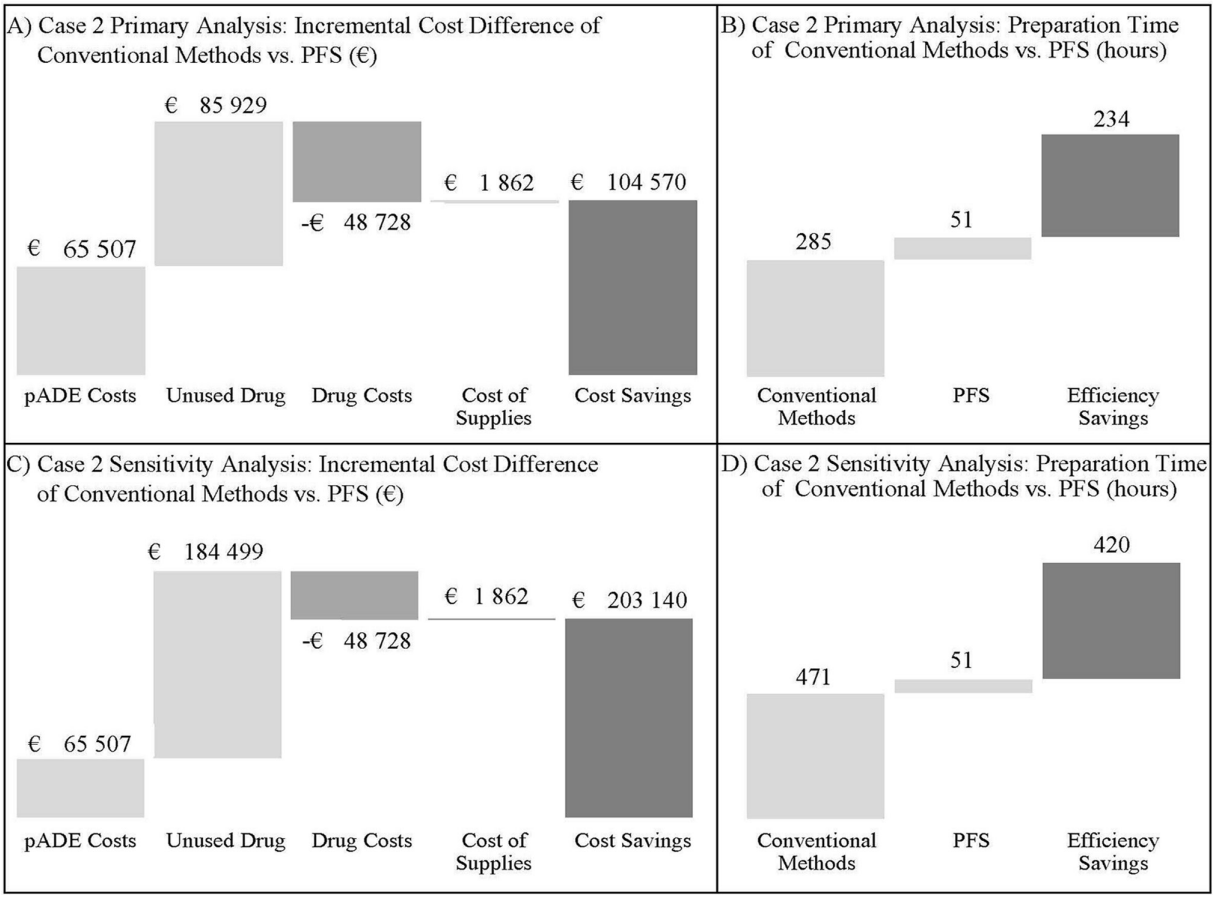

Figure 3 Graphical depiction of case 2 primary analysis and sensitivity analysis results. pADE, preventable adverse drug event; PFS, pre-filled syringes.

The sensitivity analyses we conducted show how much results can change with a single manipulation of the model, showcasing the value of the tool in practical settings. Sensitivity analyses were conducted using varying unused drug levels compared with the primary case studies. Other studies have revealed that different drugs are associated with different unused drug levels.[7 11 13] The specific drugs used in the hypothetical case studies are commonly used in high acuity, fast-paced hospital settings, and due to the impact of unused drug on the model results, lower acuity drugs with lower unused drug rates may have different model outcomes. The primary and sensitivity analyses for both case studies assumed zero waste for PFS; however, it should be acknowledged that there is a potential for discarded doses (e.g., if sterility is broken or if the PFS dose is left unrefrigerated for too long).

Table 2 Economic model output: case study 1, primary analysis and sensitivity analysis results

	Primary Analysis			Sensitivity Analysis		
Model Output	**Ampoules**	**PFS**	**Incremental Difference**	**Vials**	**PFS**	**Incremental Difference**
pADEs (per year)						
Number	152	80	72	152	80	72
Cost	£120 423	£63 704	£56 719	£120 423	£63 704	£56 719
Unused drug (per year)						
Doses	26 809	–	26 809	62 050	–	62 050
Cost	£22 251	–	£22 251	£51 502	–	£51 502
Drug cost of administered doses (per year)						
Cost	£9089	£55 517	-£46 428	£9089	£55 517	-£46 428
Supplies per unit injection (per year)						
Cost	£4332	£2045	£2286	£4332	£2045	£2286
Preparation time (hours per year)						
Hours	423	51	371	817	51	766
Overall cost						
TOTAL	£156 095	£121 266	**£34 829**	£185 345	£121 266	**£64 079**

*Disclaimer: Values are not rounded in any capacity but shown as full numbers without decimals, for this reason value may be off by up to one unit.
pADE, preventable adverse drug event; PFS, prefilled syringes.

Table 3 Economic model output: case study 2, primary analysis and sensitivity analysis results

	Primary Analysis			Sensitivity Analysis		
Model Output	**Ampoules**	**PFS**	**Incremental Difference**	**Vials**	**PFS**	**Incremental Difference**
pADEs (per year)						
Number	152	80	72	152	80	72
Cost	€139 081	€73 574	€65 507	€139 081	€73 574	€65 507
Unused drug (per year)						
Doses	14 515	–	14 515	31 165	–	31 165
Cost	€85 929	–	€85 929	€184 499	–	€184 499
Drug cost of administered doses (per year)						
Cost	€64 824	€113 552	-€48 728	€64 824	€113 552	-€48 728
Supplies per unit injection (per year)						
Cost	€3614	€1752	€1862	€3614	€1752	€1862
Preparation time (hours per year)						
Hours	285	51	234	471	51	420
Overall cost						
TOTAL	€293 447	€188 877	**€104 570**	€392 017	€188 877	**€203 140**

*Disclaimer: Values are not rounded in any capacity but shown as full numbers without decimals, for this reason value may be off by up to one unit.
pADE, preventable adverse drug event; PFS, prefilled syringes.

Notably, as demonstrated through the case studies, PFS drug administration is projected to nearly halve the estimated pADEs, which has critical implications for individual patient safety and related costs, including reducing excess hospitalisations and length of hospital stays.[5 18] Ultimately, the case studies show that the higher upfront costs of PFS may be offset by reductions in pADE and unused drug, potentially leading to overall reduced costs.

Results revealed that preparation time savings were higher for atropine compared with ephedrine. One reason for higher preparation time savings is due to higher levels of unused drug doses in atropine. All prepared doses contribute to staff time, and the higher the levels of unused drugs, the more staff time is used preparing drugs that are ultimately wasted. Therefore, preparation time, for a drug that is both used and unused, is higher for atropine compared with ephedrine. Similarly high preparation time savings would be expected for other high-acuity drugs, such as epinephrine and midazolam, which are often prepared in advance of administration and must frequently be discarded.[13] For drugs similar to ephedrine that are commonly used and prepared in advance, the preparation time savings from shifting from vials to PFS are expected to be lower. Additionally, while there may not be direct economic savings from time savings, it may have an impact on how healthcare worker time is efficiently used to provide care, as hospitals across Europe are currently experiencing increased staff shortages due to factors such as the aging healthcare workforce and burnout related to the COVID-19 pandemic.[19 20]

Limitations

There are several limitations of the model and analysis. The complexity of switching from conventional methods to PFS is simplified in the economic model to include four main domains that were chosen based on availability of evidence and amenability to modelling. The underlying data that drives the model is specific but may not adequately reflect the individual setting of interest because it assumes that conditions are similar at the user site and the reference site. Published data on pADE rates and unused drug levels are scarce, however, we utilised the best currently available peer-reviewed literature to inform model estimates. Users can also customise reference values for a specific institution. While the objective of our study was to validate the utility of the economic model using existing data, future prospective studies at hospitals may provide more robust real-world values for these parameters.

Given variation in dose preparation time in the literature, the model utilises a conservative lower-end estimate, which may lead to an underestimated result. The effect of underestimation is minimised due to the model examining changes before and after switching from conventional methods to PFS methods; however, the difference between conventional methods preparation and PFS preparation may be significantly greater than the model estimates. Further, the outcomes modelled may not be applicable to all drug uses and may not reflect all benefits and costs of PFS. Finally, the model does not account for certain factors that may influence the costs of switching from conventional methods to PFS from a global perspective, including microbial contamination risks, costs of sharps disposal, and storage costs and requirements for PFS.

CONCLUSION

Throughout the COVID-19 pandemic, shortages of hospital staff, especially ICU nurses, impacted the efficiency of care and overall health system burden. Challenges in healthcare delivery during the past two years highlight the importance of dissemination of existing innovations into new territory, including the adoption of PFS, to improve efficiency and patient safety for now and as we look to future challenges and additional potential pandemics.

Results from the two case studies reinforce the finding that relevant cost savings can be realised across various drugs with differing use-cases, settings, and practice patterns when switching from vials and ampoules to PFS. Our model shows important financial, clinical, and humanistic implications for various stakeholder groups, highlighting its utility for decision makers. While the examples included in our study were intended to mimic real-world acute care settings, future model users are encouraged to use individualised hospital or department data, where possible, to increase the accuracy of the model and the relevance of findings.

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Contributors MW accepts full responsibility for content, study, and decision to publish. MW, HG, BJL, and KAC designed the study. MW, AT, HG, BJL and KAC led the analysis and interpretation of data. JFHE and MP provided additional clinical and economic interpretation of data. BJL and KAC drafted the manuscript. All authors (JFHE, MW, AT, TE, HG, BJL, KAC, and MP) have read, revised, and approved the final manuscript.

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Provenance and peer review Not commissioned; externally peer reviewed.

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REFERENCES

1 Schaut RA, Weeks WP. Historical review of glasses used for parenteral packaging. *PDA J Pharm Sci Technol* 2017;71:279–96.
2 Keers RN, Williams SD, Cooke J, *et al*. Prevalence and nature of medication administration errors in health care settings: a systematic review of direct observational evidence. *Ann Pharmacother* 2013;47:237–56.
3 Berdot S, Gillaizeau F, Caruba T, *et al*. Drug administration errors in hospital inpatients: a systematic review. *PLoS One* 2013;8:e68856.
4 Leendertse AJ, Egberts ACG, Stoker LJ, *et al*. Frequency of and risk factors for preventable medication-related hospital admissions in the Netherlands. *Arch Intern Med* 2008;168:1890–6.
5 Rottenkolber D, Hasford J, Stausberg J. Costs of adverse drug events in German hospitals--a Microcosting study. *Value Health* 2012;15:868–75.
6 Subhi Y, Kjer B, Munch IC. Prefilled Syringes for intravitreal injection reduce preparation time. *Dan Med J* 2016;63:A5214.
7 Benhamou D, Piriou V, De Vaumas C, *et al*. Ready-to-use pre-filled Syringes of atropine for anaesthesia care in French hospitals - a budget impact analysis. *Anaesth Crit Care Pain Med* 2017;36:115–21.
8 IQVIA. Injectable drug universe data in IQVIA smart MIDAS 2019; 2019-2021.
9 World Health Organization. Medication without harm; 2017. Available: https://www.who.int/publications/i/item/WHO-HIS-SDS-2017.6
10 Souied E, Nghiem-Buffet S, Leteneux C, *et al*. Ranibizumab prefilled syringes: benefits of reduced syringe preparation times and less complex preparation procedures. *Eur J Ophthalmol* 2015;25:529–34.
11 Atcheson CLH, Spivack J, Williams R, *et al*. Preventable drug waste among anesthesia providers: opportunities for efficiency. *J Clin Anesth* 2016;30:24–32.
12 Adapa RM, Mani V, Murray LJ, *et al*. Errors during the preparation of drug infusions: a randomized controlled trial. *Br J Anaesth* 2012;109:729–34.
13 Barbariol F, Deana C, Lucchese F, *et al*. Evaluation of drug wastage in the operating rooms and intensive care units of a regional health service. *Anesth Analg* 2021;132:1450–6.
14 Weinger MB. Drug wastage contributes significantly to the cost of routine anesthesia care. *J Clin Anesth* 2001;13:491–7.
15 Larmené-Beld KHM, Spronk JT, Luttjeboer J, *et al*. A cost Minimization analysis of ready-to-administer prefilled sterilized syringes in a Dutch hospital. *Clin Ther* 2019;41:1139–50.
16 Nanji KC, Patel A, Shaikh S, *et al*. Evaluation of perioperative medication errors and adverse drug events. *Anesthesiology* 2016;124:25–34.
17 Moreira ME, Hernandez C, Stevens AD, *et al*. Color-coded prefilled medication Syringes decrease time to delivery and dosing error in simulated emergency department pediatric resuscitations. *Ann Emerg Med* 2015;66:97–106.
18 Amelung S, Meid AD, Nafe M, *et al*. Association of preventable adverse drug events with inpatients' length of stay-A propensity-matched cohort study. *Int J Clin Pract* 2017;71:10.
19 NHS. NHS vacancy Statistics England April 2015 – September 2022 experimental statistics. 2022. Available: https://digital.nhs.uk/data-and-information/publications/statistical/nhs-vacancies-survey/april-2015---september-2022-experimental-statistics [Accessed 05 Jan 2023].
20 World Health Organization (WHO). Health and care workforce in Europe: TIME TO ACT. 2022. Available: https://www.who.int/europe/publications/i/item/9789289058339 [Accessed 05 Jan 2023].
21 National health service England and Wales: electronic drug tariff. (2021, May). 2021. Available: https://www.https://www.drugtariff.nhsbsa.nhs.uk/#/00803325-DC/DC00803258/Part%20IXA-Appliances
22 Health care prices - brief - OECD. Available: https://www.oecd.org/health/health-systems/Health-Care-Prices-Brief-May-2020.pdf [Accessed 23 Feb 2022].