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Clinical pharmacists' interventions for preventing adverse events in critically ill neonates in Qatar: an economic impact analysis

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ABSTRACT

Objective: This study aimed to assess the overall economic impact of clinical pharmacist interventions in the neonatal ICU (NICU) in Qatar.

Methods: A retrospective review of neonates' records was performed over a 3-month duration in the NICU of Qatar to determine the total economic benefit of clinical pharmacist interventions. The total benefit of interventions was calculated by considering the cost avoidance due to preventable adverse drug events (ADEs) and the cost savings associated with the revised resource use due to interventions. Sensitivity analyses were conducted to ensure the robustness and generalizability of the results.

Results: A total of 513 interventions were analyzed, involving 150 neonates. Most of the drug-related problems were related to therapy dosing, followed by drug choice appropriateness, the addition of prophylactic treatment, and administration frequency. The overall annual benefit was estimated at QAR 4,178,352 (1,147,584), which consisted of cost avoidance of QAR 1,050,680 (USD 288,648) and an overall cost saving of QAR −6091 (USD −1673).

Conclusions: While the clinical pharmacist interventions led to increased resource utilisation and associated costs, when considering the avoided costs of ADEs, the overall clinical pharmacist practices in the NICU setting were economically beneficial.

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Introduction

Healthcare-related costs are rising globally. Many of these costs are attributed to medication use and medication errors (Aspden & Aspden, 2007). Approximately 1.5 million preventable adverse events are reported annually in the United States, incurring a cost of approximately 3.5 billion dollars (Aspden & Aspden, 2007). Later studies suggest that the United States spends about 40 billion dollars per year on patients affected by medication errors and more than 21 billion dollars per year on preventable medication errors (Abushanab et al., 2021; Arredondo et al., 2021). One study found that around 45% of the adverse events were preventable and reported that although medication errors have ranged, to mention a few, from pharmaceutical labelling, route-specific problems due to challenges with medication formulation design, accessibility, and human error (Arredondo et al., 2021), the most serious adverse events happened during ordering the medication or while administering it. In the same study, it was reported that the majority of these adverse events were near misses and slips, rather than stemming from a lack of knowledge (Arredondo et al., 2021). The situation is similar in the intensive care unit (ICU) settings as a systematic review found that the frequencies of medication errors ranged widely, with rates spanning from 8.1 to 2344 occurrences per 1000 patientdays (Wilmer et al., 2010). Similarly, Adverse drug events (ADEs) exhibited variability, ranging from 5.1 to – 87.5 instances per 1000 patientdays (Wilmer et al., 2010).

This is considered more important as neonatal intensive care stays are among the most expensive types of hospitalisation (Congress, 1987).

Several studies have shown the critical role of the pharmacist in reducing medication errors, shortening the duration of stay, and minimising the overall cost in different healthcare settings, including the ICU (Arredondo et al., 2021; Houso et al., 2022; Menezes et al., 2020). Studies have been conducted in Qatar to assess the economic impact of pharmacists' interventions in a general tertiary hospital (Abushanab, Atchan, et al., 2023), cardiology (Al-Badriyeh et al., 2023), and cancer care settings (Abushanab, Gulied, et al., 2023). These studies found that pharmacists' interventions were associated with a positive annual total benefit, including a positive cost avoidance. Although these clinical pharmacist interventions were associated with an increased cost of resource use, this increased cost was overtaken by the cost of avoidance generated. This role has contributed to this as the clinical pharmacist has been involved in several aspects of patient care, from evaluating the efficacy and safety of the administered medication, medication reconciliation, prevention of medication errors, and medical residents' education (Arredondo et al., 2021). There is a lack of data about the economic impact of clinical pharmacist interventions against drug-related problems (DRPs) in neonatal ICUs in Qatar. The availability of such data will assist

decision-makers and policymakers in better judging the need for clinical pharmacy services, including the justification of salaries for personnel.

The study aims to evaluate the economic benefit of clinical pharmacist interventions in preventing adverse drug events (ADEs) in the neonatal intensive care unit (NICU) of Hamad Medical Corporation (HMC) in Qatar.

Materials and Methods

Study setting

The study was conducted at the NICU in HMC. HMC is the main provider of healthcare in Qatar, which incorporates 13 hospitals and is considered one of the leading corporations providing healthcare services in the Middle East region (Abushanab et al., 2021). The HMC tertiary NICU setting includes a total of 120 beds and is the largest and most specialised facility in the country that provides specialised services for neonates who are often admitted within the first 24 h after birth for a variety of reasons, including premature birth, difficulties during delivery, and/or signs of problems during the first few days of life (Abushanab et al., 2021; Heyman et al., 2003).

Study design

The study was a retrospective review of clinical pharmacist interventions, defined as any action a pharmacist took that altered the neonate course of therapy (Dooley et al., 2004). Clinical interventions included in this study were acquired from the clinical intervention forms available in the Cerner medical database. When pertinent information could not be obtained from the clinical intervention sheet, information was directly acquired from the neonate's Cerner medical record.

Study population

The clinical pharmacist interventions examined in this study were related to those performed on neonates admitted to the NICU. The study sample consisted of interventions carried out on neonates during a 3-month follow-up period, encompassing the months of March 2018, 15 July to 15 August 2018, and January 2019.

Ethics approval

The study was approved by the Medical Research Center, HMC (MRC-01-19-110).

Inclusion criteria:

- All clinical pharmacist interventions on neonates admitted to the NICU throughout the specified follow-up durations (in March 2018, from 15 July to 15 August 2018, and in January 2019).
- Clinical pharmacist interventions were for neonates who continuously took at least one medication during their hospitalisation, either for a new indication or for a previous one.
- Interventions recommended by a clinical pharmacist.
- Interventions recommended by a clinical pharmacist and approved by a physician and, hence, implemented.

Exclusion criteria:

- Interventions carried out by a staff/operational pharmacist (non-clinical), without the clinical pharmacist looking after the neonate.
- Interventions that were rejected by the clinicians. Regardless of the intervention and the evidence behind it, if this is not accepted by the clinician, this will not be implemented.

Economic evaluation

The main objective of this study was to assess the economic impact of clinical pharmacist interventions to prevent ADEs.

Cost savings

The total cost savings from clinical pharmacist interventions were determined by subtracting the cost of after-clinical pharmacy intervention therapy from the cost of before-clinical pharmacist intervention therapy when this is in positive values. Here, the cost of after intervention was based on the original therapy duration until intervention, plus the cost of therapy after the change, based on the duration of its full course. While the cost before intervention was based on the duration of therapy before intervention.

The following equation was used to calculate the cost savings:

Cost savings = cost of therapy resource use before intervention minus cost of therapy resource use after intervention, where positive cost saving represents reduced cost with intervention, while negative cost saving represents added cost with intervention.

Cost avoidance

Cost avoidance refers to the cost that was prevented by eliminating the occurrence of ADEs through clinical pharmacist interventions (Nesbit et al., 2001). The likelihood of an ADE in the absence of the intervention was determined using the method described by Nesbit et al., which categorised the likelihood as 0 (none), 0.01 (very low), 0.1 (low), 0.4 (medium), or 0.6 (high) (Chen et al., 2017).

The cost of an ADE was estimated based on a conservative assumption that it would result in an additional two days of hospital stay in the corresponding unit, in accordance with relevant literature studies (Abushanab, Atchan, et al., 2023; Abushanab, Gulied, et al., 2023; Al-Badriyeh et al., 2023; Chen et al., 2017).

In this study, a 3-month prescription refills cost was used for chronic disease medications, while for acute diseases, we used the duration according to the prescription order or the national HMC guideline.

The total cost avoidance was calculated by multiplying the average of the total probabilities of all ADEs by the total cost of ADEs as shown in the equation below:

Cost avoidance = average probability of avoided ADE with the interventions multiplied by the cost of ADE.

Total benefit analysis

The cumulative benefit of the clinical pharmacist interventions was assessed on a 3-month and a projected annual basis. The monetary value of the interventions' benefit was determined by calculating the sum of the cost savings and cost avoidance achieved through the interventions.

The following equation was used to calculate the total economic impact:

Total economic impact = cost savings

+ cost avoidance due to interventions

Expert panel

Following the approach suggested by Nesbit et al., an expert panel consisting of three clinical pharmacists, each with more than 10 years of clinical experience in the field and one neonatologist, was convened to determine the probabilities of ADEs in the absence of interventions (Nesbit et al., 2001). Each panel member estimated the likelihood of an ADE occurring without an intervention. The average probability of an ADE in the absence of each intervention was then considered. The neonatologist validated the generated probability estimates of ADEs.

Appendix 1 depicts an overall diagram of study.

Perspective

The study was conducted from the perspective of the public NICU in Qatar. Of note, in the Qatari public healthcare system, all medications and non-medication resources are provided free of cost to hospitalised patients (i.e. Qatari citizens and residents).

Cost inputs

To determine the monetary value of resources, the costs associated with medications, non-medication-based resources (such as laboratory and diagnostic tests), and hospital stay were obtained from the pharmacy, finance, and costing departments at HMC ('Qatar Inflation Rate', 2021). All costs were adjusted to the financial year 2023 using the Qatari Health Consumer Price Index. The monetary values were presented in Qatari Riyal (QAR) and the USD. No discounting was applied because outcomes were not projected beyond a 1-year time horizon.

Sample size

This study is not a comparative study, where the sample size used in similar literature studies varies based on factors such as the size of the setting and the prevalence of underlying conditions (Walsh et al., 2017). Local studies in Qatar (Abushanab, Atchan, et al., 2023; Abushanab, Gulied, et al., 2023; Al-Badriyeh et al., 2023), as well as international studies (Gallagher et al., 2014; Malani et al., 2013; Sebaaly et al.), in secondary/tertiary care settings have reported sample sizes ranging from <100 to <2000, but predominantly <500. Considering the anticipated incidence of interventions in the study setting, a preliminary investigation indicated that a 3-month duration would be sufficient to include over 500 interventions for analysis.

In line with our previous studies (Abushanab, Atchan, et al., 2023; Abushanab, Gulied, et al., 2023; Al-Badriyeh et al., 2023), to account for any potential variations in pharmacist vigilance during the institutional review process of pharmacists' performance, the sample size included the first month after the annual staff performance evaluation in the NICU, the last month of the year before the evaluation, and a middle month of the year.

Statistical analysis

Data were tabulated for each neonate and analyzed using the IBM SPSS (Statistical Package for the Social Sciences) version-24. The data were presented as numerical and percentage measures for categorical variables and as mean and

standard deviation measures for continuous variables. Kruskal–Wallis and Chi-Square tests were used to detect any significant differences among the three follow-up months, i.e. March 2018, July/August 2018, and January 2019.

Sensitivity analysis

Sensitivity analyses evaluated the uncertainty surrounding main cost and probability inputs. A one-way sensitivity analysis (OWSA), targeting one uncertain input variable at a time, was performed to assign a ±20% variation range of the base case value of the cost of the ADEs, using a triangular type of random value distribution. A probabilistic sensitivity analysis (PSA), targeting several probabilistic inputs at once, was used to assign an uncertainty range of ±15% of the base case values of the probabilities of ADEs, using a triangular-type distribution, and based on 10,000 simulations. All analyses were performed via Monte Carlo simulation, using @Risk-5.7 (Palisade Corporation, NY). All outcomes were presented as probability curves.

Results

Characteristics of neonates and interventions

A total of 150 neonates in the NICU were included in this study, with a total of 513 clinical interventions during the follow-up period of this study. Of the study population, 63 (42.0%) were females and 87 (58.0%) were males. The mean age for both sexes was 3.62 ± 0.51 days. There were no significant differences in baseline characteristics between the three follow-up months. Further details regarding the baseline characteristics of the included population are summarised in Table 1.

Table 1. Neonates' demographics among the study periods.

Variable average (±standard deviation)/ frequency (%)	Total number of neonates ($n = 150$)	March 2018 ($n = 47$)	July–August 2018 ($n = 37$)	January 2019 ($n = 66$)	p value
Sex					
Male	78 (52.0%)	19 (41.7%)	18 (48.6%)	41 (62.1%)	0.09
Female	72 (4.0%)	28 (58.3%)	19 (51.4%)	25 (37.9%)	
Age	3.62 ± 0.51	4.0 ± 0.20	4.0 ± 0.0	3.11 ± 0.31	0.40
Weight	2.65 ± 1.05	3.0 ± 1.2	2.25 ± 0.78	2.59 ± 1.0	0.32
Nationality					
Arab	100 (66.6%)	32 (68.8%)	25 (67.6%)	43 (65.2%)	0.11
Asian (non-Arab)	39 (26.0%)	11 (22.9%)	9 (24.3%)	19 (28.8%)	
African (non-Arab)	4 (2.7%)	1 (2.1%)	1 (2.7%)	2 (3.0%)	
Others	7 (4.7%)	3 (6.2%)	2 (5.4%)	2 (3.0%)	
Ward type					
Inpatient (critical)	149 (99.3%)	47 (100%)	37 (100%)	65 (98.5%)	0.18
Inpatient (non-critical)	1 (0.7%)	0 (0%)	0 (0%)	1 (1.5%)	

The most common intervention intercepted by the clinical pharmacists was related to the medications' dosing (63.2%), followed by interventions related to drug choice appropriateness (26.8%), addition of prophylactic treatment (3.7%), and administration frequency (1.9%). In Table 2, a description of the categories of the interventions is presented with examples, together with the associated average probability of avoided ADEs as per category.

Economic analysis

Cost savings

The overall added cost associated with the interventions was QAR 822,741 (USD 226,028), while the overall reduced cost before the interventions was QAR 816,650 (USD 224,293). Therefore, the overall cost saving, due to the pharmacist-led interventions, was in negative, i.e. QAR −6091 (USD −1673). The added and reduced costs with interventions as per different intervention type categories can be seen in Table 3.

Cost avoidance

The overall cost avoidance due to the interventions over 3 months was QAR 1,050,679 (USD 288,648). Table 3 summarises cost avoidance associated with each intervention type category.

Table 2. Summary of the probability of avoided adverse drug events and categories of the clinical pharmacist interventions.

Probability of avoided adverse drug event	Numbers and categories of the interventions
0.005	3 interventions; 'Increase in medication dose', 'addition of another medication', 'change in medication route'.
0.01	131 interventions; 'Discontinuation of a medication', 'addition of another medication', 'change in medication route', 'increase in medication frequency', 'increase in medication dose', 'decrease in medication duration', 'decrease in medication frequency', 'decrease in medication dose', 'addition of a prophylactic agent'.
0.055	39 interventions; 'Discontinuation of a medication', 'addition of another medication', 'increase in medication dose', 'increase in medication frequency', 'increase in medication duration', 'decrease in medication dose'.
0.1	232 interventions; 'Discontinuation of a medication', 'addition of another medication', 'switching to alternative medication'; 'increase in medication dose', 'increase in medication frequency', 'addition of a prophylactic agent', 'decrease in medication dose'.
0.205	1 intervention; 'Decrease in medication dose'.
0.25	19 interventions; 'Discontinuation of a medication', 'decrease in medication dose', 'increase in medication dose'
0.4	88 interventions; 'Discontinuation of a medication', 'decrease in medication dose', 'addition of lab test',
0.6	1 intervention; 'Switching to alternative medication'

Table 3. Added resource cost, reduced resource cost, and cost of avoidance according to clinical pharmacist intervention types.

Type of interventions	Overall added cost with interventions, QAR (USD)	Overall reduced cost with interventions, QAR (USD)	Overall cost avoidance, QAR (USD)
Addition of another medication	56,471 (15,514)	0 (0)	57,560 (15,813)
Discontinuation of a medication	0 (0)	102,071 (28,034)	110,433 (30,339)
Switching to alternative medication	426 (117)	1253 (344)	20,306 (5579)
Addition of a prophylactic agent during hospitalisation	2262 (621)	0 (0)	5779 (1588)
Change in medication route	0 (0)	11 (3)	1250 (343)
Change in medication strength	3 (1)	9 (2)	2187 (601)
Change in medication dose	761,140 (209,104)	710,462 (195,128)	810,834 (222,757)
Change in medication duration	718 (197)	1093 (300)	12,887 (3540)
Change in medication frequency	1662 (457)	1751 (481)	10,700 (2940)
Addition of a lab test	60 (16)	0 (0)	18,744 (5149)
Total	822,742 (226,028)	816,650 (224,293)	1,050,680 (288,648)

QAR: Qatari Riyal, USD: United States Dollar.

Total benefit analysis

Overall economic benefits in favour of the clinical pharmacist interventions are summarised in Table 4. Considering the sum of cost savings and cost avoidance, the total economic benefit over 3 months was calculated to be QAR 1,044,588 (USD 286,896). In addition, the average total benefit was QAR 6964 (USD 1913) per neonate and QAR 2036 (USD 559) per intervention.

Sensitivity analysis

The results of OWSA demonstrated robustness against the uncertainty in the cost of the ADE, as reported in Table 5 and Figures 1 and 2. The PSA also showed that there is a 100% probability that the pharmacist-led intervention

Table 4. Outcomes of total benefit analysis.

Outcome	Value, QAR (USD)
Overall added cost after interventions per 3 months	822,741 (226,028)
Overall reduced cost before therapy interventions per 3 months	816,650 (224,293)
Overall cost saving per 3 months	−6091 (−1673)
Overall cost avoidance per 3 months	1,050,680 (288,648)
Total benefit per 3 months	1,044,588 (286,896)
Projected total benefit per 1 year	4,178,352 (1,147,584)

QAR: Qatari Riyal, USD: United States Dollar.

Table 5. Outcomes of one-way sensitivity analysis with their uncertainty distributions.

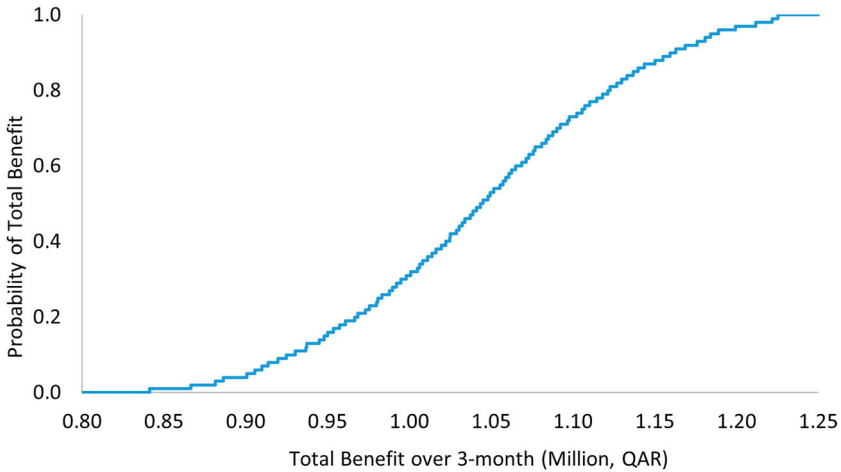| Variable	Point estimate, QAR (USD)	Variation range	Projected total benefit per 1-year range, QAR (USD)	Total benefit per 3-month, QAR (USD)
Cost of adverse drug event	7810 (2146)	Triangular distribution, QAR 6248, 7810, 9372 (USD 1716, 2146, 2575)	Mean: 4,178,410 (1,147,600), 95% CI 3,392,196 to 4,951,184 (931,666 to 1,359,842)	Mean: 1,044,278 (286,811), 95% CI 841,334 to 1,225,348 (231,072 to 336,542)

Figure 1. Total benefit probability curve over a 3-month period (one-way sensitivity analysis).
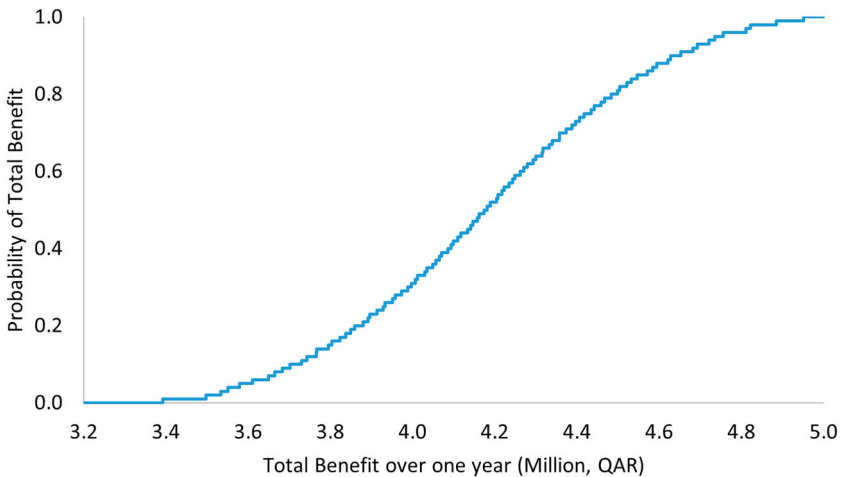

Figure 2. Total benefit probability curve over a 1-year period (one-way sensitivity analysis).

is associated with positive total benefit with a mean of QAR 1,084,895 (297,966), 95% CI 880,264–1,287,332 (241,764–353,565) over 3 months (Table 6 and Figure 3), and with a mean of 4,339,020 (1,191,711), 95% CI 3,581,233–5,104,675 (983,585–1,401,998) annually (Table 6 and Figure 4).

A regression Tornado analysis demonstrated that the main contributor to the outcome was the cost of ADE, followed by 0.1 and 0.01 probabilities of avoided ADE (Figure 5). Table 5 shows the results of sensitivity analyses with their uncertainty distributions.

Discussion

This is the first study to demonstrate the economic impact of clinical pharmacist interventions in the NICU setting in Qatar. A study conducted in a general tertiary hospital in Qatar by our group found that clinical pharmacists' interventions led to a total of USD 621,106 annual benefit, including a positive cost avoidance of USD 203,260 (Abushanab, Atchan, et al., 2023). Similarly, a study conducted in cardiology settings in Qatar found that pharmacists' interventions led to cost savings and cost avoidance of USD −3169 and USD

Table 6. Outcomes of probabilistic sensitivity analysis with their uncertainty distributions.

Variable	Point estimate, QAR (USD)	Variation range	Projected total benefit per 1-year range, QAR (USD)	Total benefit per 3-month, QAR (USD)
Very low probability for ADE	0.01	Triangular distribution, 0.009, 0.01, 0.012	Mean: 4,339,020 (1,191,711), 95% CI 3,581,233 to 5,104,675 (983,585 to 1,401,998)	Mean: 1,084,895 (297,966), 95% CI 880,264 to 1,287,332 (241,764 to 353,565)
Low probability for ADE	0.1	Triangular distribution, 0.09, 0.1, 0.12		
Low to moderate probability for ADE	0.2	Triangular distribution, 0.17, 0.2, 0.23		
Low to moderate probability for ADE	0.3	Triangular distribution, 0.26, 0.3, 0.35		
Moderate probability for ADE	0.4	Triangular distribution, 0.34, 0.4, 0.46		
Moderate to high probability for ADE	0.5	Triangular distribution, 0.43, 0.5, 0.58		
High probability for ADE	0.6	Triangular distribution, 0.51, 0.6, 0.69		

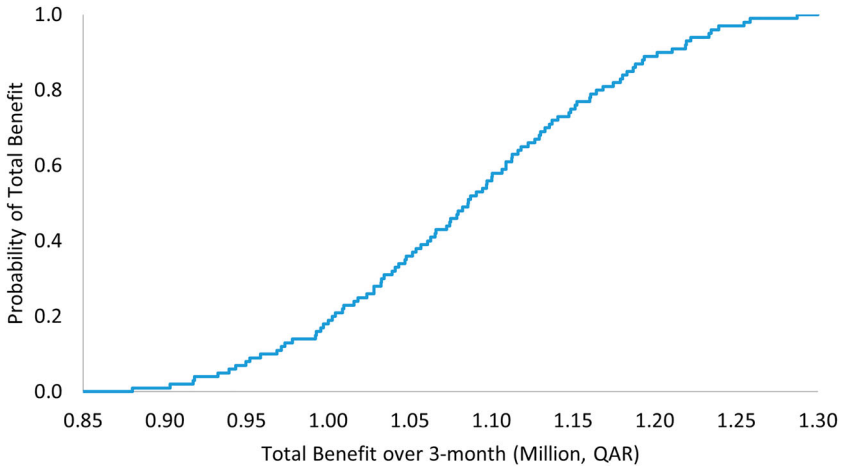QAR: Qatari Riyal, USD: United States Dollar, CI: confidence interval.

Figure 3. Total benefit probability curve over a 3-month period (probabilistic sensitivity analysis).
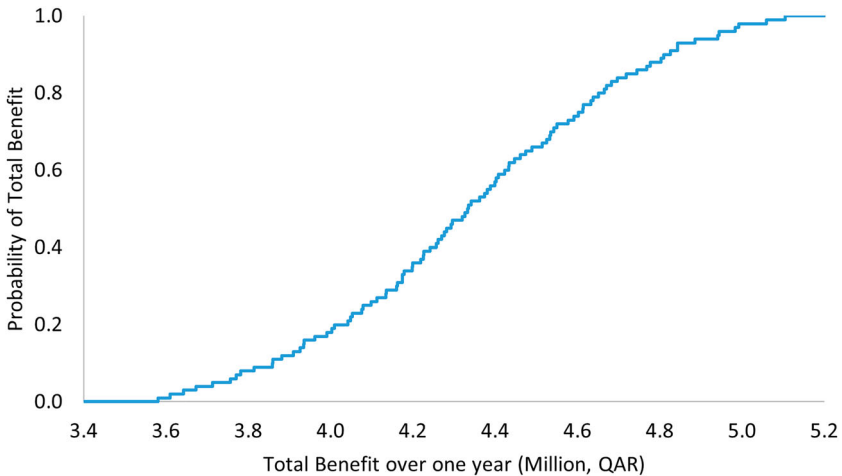
Figure 4. Total benefit probability curve over a 1-year period (probabilistic sensitivity analysis).

441,616, respectively, yielding a total benefit of USD 1,753,789 per year (Al-Badriyeh et al., 2023).

The results of the current study showed that the clinical pharmacist interventions reduced the cost of resource consumption, leading to cost savings and cost of ADEs avoidance, with a yearly overall monetary value of QAR 4,178,352 (USD 1,147,584).

The interventions that added to the cost of resource use the most were the addition of other medications and the switch to alternative medication. The

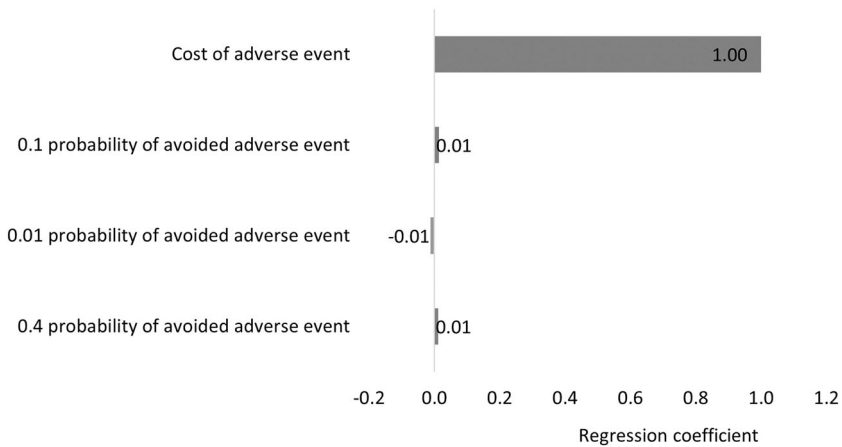**Figure 5.** A regression tornado diagram of elements and their effect on the outcome.

cost avoidance that drove the overall economic benefit was primarily based on the addition of medications, discontinuation of medications, and addition of prophylactic agents.

Only a few studies have evaluated the economic value of the clinical interventions in the ICU settings. Menezes et al. (2020) have estimated the economic impact of clinical pharmacists in pediatric intensive care units (PICU). In their study, savings were measured over 1-year duration based on (i) clinical pharmacist interventions from prescription checking, (ii) individualised doses of four antibiotics, and (iii) comparison of drug dispensing systems before and after the decentralisation of pharmacy services. In the study, a total of 73 clinical pharmacist interventions were conducted, out of which 13 enabled the assessment of their economic impact, resulting in a yearly saving of USD 633.38. The personalised dosing of four antibiotics resulted in cost savings of USD 8754.46 per year, and the decentralisation of pharmacy services led to annual savings of USD 28,770.52. Here, unlike our study, the cost of ADEs was not the key driver of the study outcome. In another study, by Kim et al. (2019), the authors evaluated the economic impact of pharmacist interventions in the NICU. The study showed that, over 6 months, the total cost avoidance was USD 135,419.30, and the total cost saving was USD 57.78. Unlike our study, pharmacists, not clinical pharmacists, were involved in the Kim et al study. Moreover, the economic evaluation was conducted by analyzing clinical interventions from prescription reviews, total parenteral nutrition consults, and clinical pharmacokinetic consultation service reports delivered by pharmacists in a tertiary hospital, and not by analyzing the cost of ADEs as the case in our current study. Despite these differences,

and consistent with our results, noting the lesser extent of impact, the pharmacist interventions led to a positive cost avoidance and a positive cost saving. The observed variation in economic impact between the studies could be attributed to variances in clinical practice approaches and the cost structure of medical services.

Despite that our findings provide valuable insights into the overall economic impact of clinical pharmacist interventions, supported by sensitivity analyses, it is crucial to interpret these results within the context of the specific setting and sample characteristics. The neonatal population, the nature of drug-related problems identified, and the nature of health care system and resource use may differ in other NICU settings.

The current study has several limitations. The nature of the retrospective research design, which has the inherent disadvantage of bias, may cause the overall benefit to be overestimated or underestimated. This is especially true given that daily reporting of clinical interventions is advised but not mandatory and not necessarily documented in a timely manner. Moreover, for the cost of avoided ADEs, it is impossible to follow up neonates until ADEs that did not take place as results of interventions, and then have these accurately estimated, differently with different interventions. Thus, it was assumed that the cost of ADEs would be the same for all ADEs, leading to an additional two days stay in the hospital. This assumption is consistent with previous literature studies, where sensitivity analyses accounted for the uncertainty (Abushanab, Atchan, et al., 2023; Abushanab, Gulied, et al., 2023; Al-Badriyeh et al., 2023; Chen et al., 2017). In addition, a 3-month follow-up period in our study may not accurately reflect the actual economic gains throughout the whole year. Based on the available information, however, there is no compelling rationale to anticipate any significant deviations in observations based on other months, particularly given how the 3-month follow-up was chosen as a sample size, in addition to the lack of significant differences in neonates' characteristics between the 3 months of the follow-up duration. Finally, generalizability-wise, despite that our findings provide valuable insights into the overall economic impact of clinical pharmacist interventions, the results of this analysis are specific to the Qatari setting and should not be extrapolated to neonates in different settings given the variations in the drug-related problems identified, nature of health care systems, and resource utilisation.

In conclusion, the clinical pharmacists' interventions toward the rational use and management of medications in the NICU at HMC resulted in a positive overall economic benefit. The result strongly supports the notion that extending the role of clinical pharmacists in the NICU, and possibly other medical specialties would deliver a noteworthy economic advantage to healthcare systems.

Acknowledgment

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Author contributions

DA-B and DA contributed to the study conception and design, led data validation, data analysis and interpretation, and revised the manuscript. OY contributed to analysis and writing the first draft of manuscript. MR, MA, OA, RK, MA, PA, WE, and FA contributed to the data collection. MA, PA, and WE facilitated the planning and carrying out of the study. All authors contributed to the final version of the manuscript.

Notes on contributors

Ola Yakti is a dedicated clinical pharmacist working at Hamad Medical Corporation, a governmental healthcare organization in Doha, Qatar. She possesses a solid educational background and diverse clinical training experiences. Ola earned her Doctor of Pharmacy (PharmD) degree and Bachelor of Science in Pharmacy (BSc (Pharm)) degree from Qatar University, College of Pharmacy, both accredited by the Canadian Council for Accreditation of Pharmacy Programs (CCAPP) in 2021 and 2020, respectively. Throughout her academic journey, Ola excelled in various clinical training sites, including the Drug Information Center, Intensive Care Unit (ICU), Home Health Care Services, Internal Medicine, Women's Health, Oncology, Infectious Diseases, and Cardiology. Before assuming her role as a clinical pharmacist, Ola served as a research assistant at Qatar University, contributing significantly to multiple projects and gaining valuable insights into the fields of pharmaceutical and health research. In her capacity as a research assistant, she had the opportunity to work on multiple projects, and she successfully published some of them. Currently, Ola actively contributes to ongoing projects and is engaged in interprofessional education sessions and continuing professional pharmacy development, demonstrating her commitment to lifelong learning.

Dr. Daoud Al-Badriyeh completed an honors degree in pharmacy at the University of Sydney (Sydney, Australia) and then received his PhD in pharmacoeconomics from Monash University (Melbourne, Australia). Dr. Daoud also completed specialized training in healthcare analytics, patient safety and medical errors, and medical statistics. Currently, Dr. Daoud is a Professor of Pharmacoeconomics and Outcomes Research

at the College of Pharmacy of Qatar University, Qatar. Dr. Daoud has hundreds of publications and conference presentations. He supervised over a dozen postgraduate students so far and has accumulated research funds in millions of dollars. Dr. Daoud's research focuses on pharmacoeconomics, health economics, decision-analytic simulation, comparative effectiveness research, and the economic impact of hospital services. Underlying populations of interest vary, from neonatal intensive care illnesses, cardiovascular disease, cancer, diabetes, mental health, and infectious diseases to healthcare services research concerning genotype testing, clinical and technology interventions, and stewardship programs. Dr. Daoud is also the Founder and current President of the Qatar Chapter of the International Society of Pharmacoeconomics and Outcomes Research (ISPOR, USA).

Dr. Mohammed Rijims is an empathetic, solution-oriented health care professional with an exceptional blend of clinical expertise, ingenuity, and compassion. Dr. Mohammed earned his Masters in Clinical Pharmacy Practice from Annamalai University in India in 2005. Presently, he is engaged in the pursuit of his Ph.D. in Clinical Pharmacy. He has demonstrated exceptional performance in various positions, such as clinical pharmacist, community pharmacist, and clinical pharmacist specialist in the neonatal intensive care unit at Women's Wellness and Research Centre, Hamad Medical Corporation-Qatar. At present, he holds this position. Approximately fifteen research initiatives and publications had been his work. He holds the positions of adjunct clinical lecturer and preceptor for the pharmacy residency program at Hamad Medical Corporation in Doha, and Qatar University's Pharm D program.

Mohammed Abdelaal is a pharmacist holding a master's degree in Pharmacoeconomics and Outcome Research from Qatar University with more than 14 years' experience in the pharmaceutical field. With a passion for patient safety, he passed the Qualified Person Responsible for Pharmacovigilance (QPPV) Advanced Training Program on Good Pharmacovigilance Practice (GPV), Pharmacoepidemiology & Biostatistics. This is in addition to multiple tailored programs organized by WHO in relation to bioequivalence and medicines quality assessment. His experience covers clinical practice aspects through working in community pharmacies in Egypt and Saudi Arabia during the period from 2009 – 2012, as well as drugs registration files assessment in CTD, Nees and eCTD format, covering all aspects of quality, safety and efficacy, from both industrial and governmental perspectives, with extensive knowledge of ICH and GCC policies and guidelines through working in national drug authority of both Egypt & Qatar, and a private pharmaceutical company in Egypt. Mohammed joined the Ministry of Public Health in Qatar as a member for Pharmacy & Drug Control Department team in 2014. He is holding the title of Supervisor, Pharmaceutical Regulatory Compliance – in Registration & Pricing section, with all responsibilities of ensuring smooth process flow of registration requests for pharmaceutical and biological products along with supervising any related activity, as well as liaising with different stakeholders in relation to strategic projects.

Omar Alsoukhni is a highly skilled and accomplished pharmacist with a strong background in clinical pharmacy, pharmacy technology and pediatric care. He received his PharmD degree from Jordan University of Science and Technology in 2008, followed by American board certification in 2012. In 2017, Omar completed a Master's degree in Pharmacoeconomics and Health Economy from UPS Pompeu Fabra University. With a passion for patient safety, Omar holds a certification in medication safety in 2022, demonstrating his commitment to ensuring optimal medication management practices. He has amassed valuable experience throughout his career, having served as

a Clinical Pharmacist in Saudi Arabia from 2008 to 2013. Following this, he worked as a Clinical Pharmacy Specialist and Adjunct professor in Pediatric Care in Qatar from 2013 to 2018, where he developed expertise in providing specialized pharmaceutical care to young patients. In addition to his clinical practice, Omar serves as an Adjunct Professor at multiple prestigious institutions including MBRU, Qatar University, Sharjah University, and DPCG. In 2018, Omar joined the prestigious Al Jalila Children's Hospital as a Clinical Pharmacy Specialist and Head of Pharmacy. In this role, he leads a team of professionals, world class pharmaceutical operations, and contributes to the development and implementation of evidence based pharmacy programs.

Dr. Moza Al Hail is the Executive Director of Pharmacy at Hamad Medical Corporation. She has a distinguished career, serving in various clinical and administrative roles.Dr. Al Hail has been instrumental in initiating key projects, including establishing different units at Women's Hospital, such as the Unit Dose system, IV unit, and Clinical Pharmacy services. Her contributions extend to various Corporate Pharmacy activities, where she played a pivotal role in establishing the Medication Safety and Quality Office and the Office of Continuing Professional Development (CPPD) at HMC. Noteworthy achievements include securing international and national accreditations for the Pharmacy Department from organizations like the Accreditation Council for Pharmacy Education (ACPE) and Qatar Council for Healthcare Practitioners (QCHP). Dr. Al Hail has also introduced the Pharmacy Residency Program, aligning its quality with international medical training programs. In addition to her administrative roles, Dr. Moza Al Hail is a prolific researcher, authoring over 50 research articles. Her professional interests encompass interprofessional education, medication safety, pharmacovigilance, leadership development, and mentorship within the pharmaceutical profession. Dr. Al Hail actively participates in various national and international committees, chairing some of them. Her current research strategy focuses on pharmaceutical care, safe medication use, effectiveness, and safety. She collaborates strongly with national and international universities, significantly advancing pharmacy practice and research.

Dr. Palli Valapila Abdulrouf is the Assistant Director of Pharmacy Department Corporate Pharmacy services-HMC. He received both B.Pharma & M.Pharma degrees from K.L.E's Dharwad University India and the MSc Clinical Pharmacology and Ph.D. from the University of Aberdeen, U.K. and received hands on training in Pharmacovigilance from Uppsala Monitoring Center - WHO, Sweden. He underwent certification programs related to Epidemiology and Biostatistics (UK), Research to Publication (BMJ-UK), and Drug Information & Toxicology (USA and MENA). In addition to his extended role, he specializes in Medication safety practices including Adverse Drug Reactions, Medication Error. Dr. Abdul Rouf has authored in several publications and serves as reviewer for the numerous international high impact journals. He served as a speaker, presenter and scientific committee member in several conferences. He also supervises PhD students based in both India and the UK. Currently, he is involved in research related to Pharmacy prescribing, antimicrobial stewardship, Patients reporting ADR's, Medication waste, COVID19 Vaccination advocacy, Pregnancy registry relayed to COVID19, Formulary adherence, Toxicology and Poison epidemiology and registries, and few quality projects looking at medication safety.

Dr. Wessam El-Kassem is a highly accomplished and devoted healthcare professional. In 2015, he completed a Doctor of Pharmacy (PharmD) degree from Qatar University in Doha, Qatar. This accomplishment was preceded by completing a Master of Business Administration (MBA) program at the same institution in 2008. With a robust

foundation in pharmacy, Dr. Wessam has undertaken diverse roles and responsibilities throughout his career. Presently, he serves as the pharmacy assistant director at HMC Corporate Pharmacy. Additionally, he holds the positions of Co-Head of the Medication Safety and Quality Center and HMC Pharmacy Residency Coordinator. Dr. Wessam has an extensive publication record, with over 40 peer-reviewed publications, and contributed to two book chapters. Furthermore, he has actively participated in several regional and international conferences.

My name is *Fouad Abounahia*, currently working as attending neonatologist in the Neonatal Intensive Care Unit (NICU) of Women's Wellness and Research Center (WWRC), Qatar. I graduated from college of medicine at Aleppo university in Syria 1996, then worked as GP in private hospitals for one year. Jan 1st, 1997, I joined HMC as medical intern, completed my residency in Pediatrics, and then became NICU specialist until May 2006. Jun 2006, I went to Canada as neonatal fellow and neonatal transport fellow. In which both were completed the year of 2010. Since then, rejoined HMC and I am leading Qatar's neonatal transport program as well as an attending neonatologist. After the completion of my residency and neonatology fellowship training, I became an attending neonatologist that can lead and conduct clinical rounds. I lead the neonatal neurodevelopmental follow up program between 2012 – 2020 that helped to follow high risk neonates after NICU discharge. Since 2010 I began to prepare for the neonatal transport program which was launched officially on October 2014. As a director of the Qatar neonatal transport program, my focus was to have the program be a model for the region and Middle East (in which is in the process). Currently leading and directing Qatar Neonatal Transport simulation workshop that provides an extensive training for NICU healthcare professionals to become transport experts. (a full day workshop that includes practical stations). I had worked in many research projects as primary investigator or Co-author that published as an abstracts or full paper. In many research activities, some of my research work was presented as a poster and oral presentation.

Rasha Kaddoura, MSc (Pharm), Pharm D, is a clinical pharmacy specialist at the Heart Hospital, serving in the in-patient and out-patient settings including acute and intensive care units, Advanced Heart Failure Clinic and Anticoagulation Clinic. In addition to COVID-19 facilities during the pandemic. Rasha received her Post-Graduate Doctor of Pharmacy degree from the University of Toronto and her Masters Degree in Clinical Pharmacy from Albert Saint Gyorgyi Medical University – Faculty of Pharmacy – Hungary. Currently, a Master's study candidate to pursue a degree in clinical research. Licensed and practised in Hungary, Canada and Qatar. In addition to being a pharmacy board-certified in Lebanon. Her practice expertise also includes drug information, drug utilization review, and medication therapy management. Served in three hospital committees, involved in preparing, updating and reviewing clinical practice guidelines, and variety of pharmacy and non-pharmacy related projects. She has many published papers and served as a preceptor for pharmacy undergraduate, Masters' and Pharm D students, as well as a preceptor for PGY-1 pharmacy residents.

Dina Abushanab is a Drug Information Pharmacist at the Corporate Hamad Medical Corporation. She completed her bachelor in Pharmacy and Master in Pharmacoeconomics and Outcomes Research from the College of Pharmacy (CPH) at Qatar University (QU). She is also a Board-Certified Pharmacotherapy Specialist, a Pharmacy Preceptor for Doctor of Pharmacy Students, and an invited instructor at CPH-QU. Currently, Ms. Dina is a PhD Candidate in Health Economics and Epidemiology at Monash

University, Australia. To date, she has published over 35 peer reviewed research papers, received several competitive grants as principal investigator, and supervised several research assistants. She also serves as member of master supervisory committees at CPH-QU and subcommittee member of the ISPOR Victoria and Tasmania Student Chapter. She is the current Secretary/Treasurer of the Qatar Chapter of ISPOR. Her research focuses on: health economics, including cost-effectiveness, cost-benefits and modellings, burden of diseases, epidemiology, and meta-analyses.

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Appendix 1

Total economic impact= cost savings + cost avoidance

Cost savings=cost of therapy resource use before intervention minus cost of therapy resource use after intervention

Cost avoidance=average probability of avoided ADE with interventions multiplied by ADE cost

Clinical pharmacy intervention

Identified DRPs as per intervention sheet:
- Appropriate therapy
- Contraindication/safety
- Dosing/administration
- Drug interaction
- Duplicate therapy

Interventions:
- Addition of a medication/prophylactic ↑
- Discontinuation of a medication ↓
- Switching to alternative ↑↓
- Change in route ↓
- Change in strength ↑↓
- Change in dose ↑↓
- Change in duration ↑↓
- Change in frequency ↑↓
- Addition of a laboratory test ↑

Expert panel to estimate the probability of ADEs without an intervention by (Nesbit et al. method)

DRP: drug-related problem; ADE: adverse drug event; ↑ refers to added cost with intervention; ↓ refers to reduced cost with intervention