


Impact of pharmacy automation on dispensing efficiency, medication safety, and user satisfaction in hospital pharmacies: A systematic review and meta-analysis of G20 countries

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Abstract

Aim: This study assessed the effects of pharmacy automation on dispensing efficiency, medication safety, and user satisfaction in hospital pharmacies across G20 countries.

Methods: A systematic search of PubMed, Scopus, and ScienceDirect identified studies evaluating dispensing-related automation in hospital settings. Eligible studies were analyzed using Review Manager 5.4. Pooled standardized mean differences (SMDs) with 95% confidence intervals were calculated using a random-effects model, and heterogeneity was assessed with the I^2 statistic.

Results: Twenty-three studies were included, representing hospital pharmacy settings across 10 G20 countries: Saudi Arabia, Australia, France, the United Kingdom, the United States, China, Japan, Germany, Brazil, and Canada. Automation significantly reduced medication administration time (SMD -4.35 ; $p = 0.01$) and dispensing-related medication error rates (SMD -3.89 ; $p < 0.00001$). Improvements were also observed in perceived dispensing efficiency (SMD 0.60 ; $p = 0.04$) and perceived patient safety. However, no statistically significant differences were observed in dispensing time or patient time within the dispensing system. User satisfaction was consistently higher following automation implementation. Substantial heterogeneity was observed across outcomes.

Conclusion: Pharmacy automation in hospital settings is associated with improved dispensing efficiency, reduced medication errors, and increased user satisfaction, supporting its adoption despite variability across studies.

Keywords

Pharmacy automation, dispensing efficiency, medication safety, consumer satisfaction, hospital pharmacy, G20 countries

Introduction

Hospital pharmacies play a crucial role in ensuring patient safety and effective healthcare delivery. Their primary responsibilities include accurate medication dispensing, advising healthcare providers on appropriate drug therapies, and preventing adverse drug events (Schnipper et al. 2006; Mansur 2016; Ahmed and Rahman 2025). The dispensing process is particularly critical in hospital settings, where complex medication regimens and high-risk patients are common. Efficient medication dispensing is key to improving clinical outcomes and enhancing operational efficiency (Sallam 2024). With increasing demands on hospital pharmacy staff, pharmacy automation technologies such as automated dispensing cabinets (ADCs), robotic dispensing systems, and barcode medication administration (BCMA) systems have been increasingly adopted to enhance the dispensing process. These technologies aim to reduce manual errors, improve efficiency, and ultimately enhance patient safety (Sng et al. 2018).

Dispensing efficiency is central to optimizing hospital pharmacy operations. It refers to the speed, accuracy, and effectiveness with which medications are prepared and dispensed (Liou et al. 2023; Hardiyanti et al. 2024). Efficient dispensing ensures that patients receive the correct medications on time, which is essential for effective treatment and positive health outcomes. In hospital settings, where patient turnover is high and medication regimens are complex, improving dispensing efficiency can significantly enhance operational workflows, reduce delays, and enable pharmacists to allocate more time to patient care. The integration of pharmacy automation technologies has the potential to substantially improve dispensing efficiency by streamlining medication distribution, reducing manual input requirements, and minimizing human error. This can lead to reduced patient waiting times, increased throughput, and better management of pharmacy resources (Abu Hagar et al. 2020).

Dispensing-related medication errors are a significant concern in hospital pharmacies. These errors, which can result in adverse drug events, increased patient morbidity, and even mortality, often occur due to human factors such as fatigue, distractions, or miscommunication. Dispensing-related errors remain a global issue, with an estimated 1.6% of dispensed medications affected, and rates as high as 33.5% in some settings (Um et al. 2024). These errors contribute to 5%–41.3% of hospital admissions and 22% of readmissions worldwide, highlighting the clinical burden (National Center for Biotechnology Information 2020). Automation technologies such as ADCs and robotic dispensing systems aim to reduce these errors by improving accuracy and adding a layer of verification during the dispensing process (Liou et al. 2023). This helps to ensure that the correct medication is dispensed, reducing the likelihood of errors that can compromise patient safety. User satisfaction is a key outcome of pharmacy automation. Automation can enhance staff satisfaction by reducing manual tasks, minimizing workload, and enabling pharmacists to focus on more patient-centered duties.

For patients, automation improves dispensing accuracy and speed, which leads to shorter wait times and greater confidence in the medication process. Ultimately, this contributes to overall satisfaction with pharmacy services and enhances the patient experience (Angelo et al. 2005; Alam et al. 2018).

Pharmacy automation technologies have seen widespread adoption globally, with G20 countries leading the charge. These countries, with their well-established healthcare infrastructures and access to advanced technologies, have increasingly turned to automation to improve medication dispensing accuracy and efficiency. The adoption of these systems has been driven by the need to reduce dispensing errors, improve operational workflows, and optimize pharmacy resources (Gupta et al. 2025). However, the rate of adoption and integration of automation technologies in hospital pharmacy practices varies significantly across G20 nations. Factors such as healthcare funding, regulatory environments, and technological infrastructure influence the speed and effectiveness of implementation. For instance, while countries like the United States and Germany have fully integrated automation technologies in many hospitals, other G20 countries face challenges related to cost, staff training, and system compatibility.

Despite the growing adoption of pharmacy automation, there remains a lack of comprehensive, cross-national data assessing its impact on key outcomes such as dispensing efficiency, medication errors, and user satisfaction. Many studies focus on individual institutions or regions, with limited comparison across G20 countries. Therefore, research is necessary to consolidate these findings and evaluate the true effectiveness of pharmacy automation technologies in improving operational workflows and patient safety on a global scale. Furthermore, healthcare systems encounter various challenges in implementing automation, including cost, staff training, and technology integration. These barriers are crucial for hospitals considering adopting automation. By assessing the impact of automation across G20 countries, this review aims to offer valuable insights into the factors that drive successful implementation and the obstacles that must be overcome. This systematic review aims to evaluate the impact of pharmacy automation technologies on dispensing efficiency, dispensing-related medication errors, and user satisfaction.

Materials and methods

This systematic review and meta-analysis were conducted according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al. 2021).

Research question

This review aims to evaluate the impact of pharmacy automation technologies on dispensing efficiency, dispensing-related medication errors, and user satisfaction in hospital pharmacies across G20 countries. To ensure a

structured and transparent study selection process, the research question was framed using the PICOS (Population, Intervention, Comparison, Outcomes, Study design) framework. Eligibility criteria were defined a priori based on this framework and subsequently used to guide the identification of eligible studies.

Population (P): Hospital pharmacies operating within G20 countries.

Intervention (I): Pharmacy automation technologies related to medication dispensing, including Automated Dispensing Cabinets (ADCs), Automated Dispensing Devices (ADDs), Robotic Dispensing Systems, and Unit-Dose Dispensing Systems (UDDS).

Comparison (C): Traditional manual dispensing systems, including pre-automation versus post-automation comparisons.

Outcomes (O): Dispensing efficiency (e.g., reduced dispensing time, workflow optimization, time saved in medication preparation or administration), dispensing-related medication errors (e.g., error rates, adverse drug events, missed doses), and user satisfaction (e.g., satisfaction among pharmacy staff, patients, and nurses).

Study design (S): Randomized controlled trials, before-and-after studies, cohort studies, cross-sectional studies, prospective studies, and retrospective studies.

Information sources and search strategy

A comprehensive and systematic literature search was conducted to identify relevant studies published in PubMed (MEDLINE), Scopus, and ScienceDirect, as they provide broad coverage of biomedical, pharmaceutical, and health systems research. To ensure relevance to contemporary pharmacy automation practices, the search included studies published from 1st January 2000 onwards, reflecting the period during which automated dispensing technologies became increasingly implemented in hospital pharmacy settings. Only studies published in peer-reviewed journals were considered eligible. The final search was conducted on 31st January 2026.

The search strategy combined controlled vocabulary terms (where applicable) and free-text keywords related to pharmacy automation and dispensing outcomes. Key search terms included “pharmacy automation”, “automated dispensing”, “Automated Dispensing Cabinet”, “ADC”, “Automated Dispensing Device”, “ADD”, “dispensing efficiency”, “medication dispensing”. These terms were combined using Boolean operators (AND/OR) and adapted appropriately for each database to maximize sensitivity. The full search strategies for each database are provided in Table 1 to ensure reproducibility.

Eligibility criteria

For a study to be considered eligible for inclusion, it had to fulfil the following criteria: (i) evaluate pharmacy operations within hospital settings; (ii) include an intervention involving pharmacy automation technologies directly related to medication dispensing, including ADCs, ADDs,

Table 1. Search strings.

Database	Search strings	Search results
PubMed	(“pharmacy automation” OR “automated dispensing” OR “robotic pharmacy” OR “automated medication systems” OR “automated dispensing cabinets” OR “ADC” OR “ADD” OR “robotic dispensing systems” OR “unit-dose dispensing systems”) AND (“dispensing efficiency” OR “workflow efficiency” OR “medication dispensing” OR “time saved” OR “productivity” OR “medication administration time”) AND (“medication errors” OR “dispensing errors” OR “medication-related errors” OR “wrong drug” OR “wrong dose” OR “missed doses”)	1872
Scopus	(“pharmacy automation” OR “automated dispensing” OR “robotic pharmacy” OR “automated medication systems” OR “automated dispensing cabinets” OR “ADC” OR “ADD” OR “robotic dispensing systems” OR “unit-dose dispensing systems”) AND (“dispensing efficiency” OR “workflow efficiency” OR “medication dispensing” OR “time saved” OR “productivity” OR “medication administration time”) AND (“medication errors” OR “dispensing errors” OR “medication-related errors” OR “wrong drug” OR “wrong dose” OR “missed doses”)	417
ScienceDirect	(“pharmacy automation” OR “automated dispensing” OR “Automated Dispensing Cabinet” OR “ADC” OR “Automated Dispensing Device” OR “ADD”) AND (“dispensing efficiency” OR “medication dispensing”)	1000

robotic dispensing systems, and UDDS; (iii) include a comparison with traditional manual dispensing systems, either through pre- and post-automation evaluations or direct comparisons between automated and manual dispensing workflows; and (iv) report at least one of the predefined outcomes.

Studies conducted outside G20 countries or those focusing on non-hospital pharmacy settings, such as community pharmacies or outpatient clinics, were excluded. Studies evaluating pharmacy technologies not directly related to dispensing, including barcode medication administration systems and other clinical information technologies, were also excluded. Articles focusing solely on clinical outcomes without reporting dispensing efficiency, dispensing-related errors, or user satisfaction were excluded. Finally, reviews, meta-analyses, case studies, and non-peer-reviewed publications were excluded.

Study selection process

All records retrieved from electronic database searches were imported into Zotero, a reference management software, for organization and screening. Duplicate records identified across the databases were systematically removed prior to the screening process. Titles and abstracts were screened independently by two reviewers (FM, ES) to assess eligibility against the predefined inclusion and exclusion criteria. Studies that clearly did not meet the eligibility criteria were excluded at this stage. Full-text articles of potentially relevant studies were then retrieved and independently assessed for eligibility against the same criteria.

Any discrepancies or disagreements arising during either the title and abstract screening phase or the full-text review phase were resolved through discussion and consen-

sus. Where consensus could not be reached, disagreements were resolved by consultation with a third reviewer (MA).

Quality assessment

The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal tools appropriate for each study design (Moola et al. 2020). These tools evaluate the risk of bias at the study level across domains such as selection bias, measurement validity, confounding, and statistical analysis. Each study was classified as low, moderate, or high risk of bias based on predefined JBI scoring criteria, and disagreements were resolved through consensus.

Data extraction

After the study selection process, data extraction was performed independently by three reviewers using a predefined Excel sheet (MA, FM, ES). The extracted data included the first author, year of publication, country, study design, setting, participants, intervention, comparator, and outcomes measured. A second outcomes table was used to extract data related to the predefined outcomes of interest. Extracted outcomes included dispensing efficiency measures (e.g., dispensing time, workflow efficiency), dispensing-related medication errors (e.g., error rates), and user satisfaction. Where studies reported outcomes using different metrics or units, the data were recorded as reported and standardized where appropriate for quantitative synthesis. Any discrepancies identified during the data extraction process were resolved through discussion and consensus between the reviewers, with consultation of a fourth reviewer when necessary (AH).

Statistical analysis

Statistical analysis was conducted using Review Manager version 5.4. For continuous outcomes reported using different measurement scales, effect sizes were summarized using the standardized mean difference (SMD) with corresponding 95% confidence intervals (CIs). For dichotomous outcomes, pooled effect estimates were calculated using pooled proportions with 95% CIs. A random-effects model was selected a priori due to expected clinical and methodological heterogeneity across studies, including variations in automation technologies, hospital settings, and outcome measurements. Statistical heterogeneity was assessed using Cochran's Q test and quantified using the I^2 statistic, with values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. For objective clinical outcomes (e.g., dispensing time, medication administration time, and dispensing-related medication errors), the pooled effect sizes were calculated using SMD, which compares the difference in means between post-automation and pre-automation measures in standardized units. Dispensing efficiency was not treated as a single pooled outcome. Instead, it was operationalized

using distinct outcome measures, including dispensing time and medication administration time. Each outcome was analyzed and pooled separately using SMDs, rather than combining heterogeneous measures into a single meta-analysis. For subjective perception-based outcomes (e.g., dispensing system efficiency, perceived patient safety), the SMD was also used to compare differences in user perceptions between automated and control systems. User satisfaction and pharmacists' time were analyzed narratively due to heterogeneity in measurement and reporting formats. Subgroup analyses were conducted when data permitted, including stratification by type of automation technology (e.g., robotic dispensing systems versus automated dispensing cabinets). Publication bias was assessed through visual inspection of funnel plots when at least five studies were available for an outcome. Statistical significance was defined as a two-sided p-value < 0.05.

Results

Search results

The database search yielded 2611 non-duplicate articles. Sixty-nine articles were subjected to full-text review, but only 23 were included in the systematic review and meta-analysis. This procedure is shown in Fig. 1.

A total of 23 studies published between 2007 and 2025 were included in the review. The studies were conducted across 10 G20 countries: Saudi Arabia, Australia, France, the United Kingdom, the United States, China, Japan, Germany, Brazil, and Canada. 12 studies used pre-post qua-

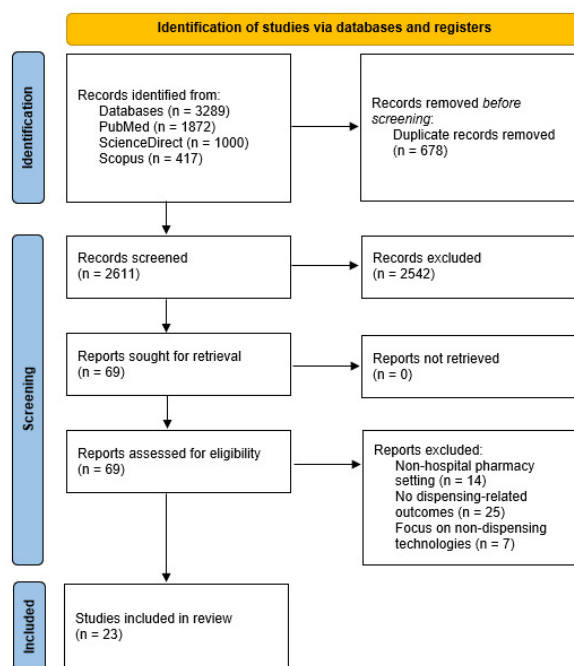


Figure 1. PRISMA flow diagram of study selection. Flow diagram illustrating the identification, screening, eligibility assessment, and inclusion of studies evaluating pharmacy automation in hospital pharmacies across G20 countries.

si-experimental designs, 5 were cross-sectional (including descriptive cross-sectional surveys, analytical cross-sectional comparative, and cross-sectional mixed-method surveys), and 6 were qualitative or mixed-method studies (including qualitative exploratory, descriptive, and mixed observational designs). Study settings were predominantly tertiary hospitals, inpatient hospital wards, and outpatient hospital pharmacy departments. A variety of pharmacy automation technologies were evaluated. These included ADCs, ADDs, robotic dispensing systems, UDDS, and centralized automated dispensing systems. Comparators across studies consistently involved pre-automation workflows or manual dispensing methods such as traditional drug distribution systems.

The methodological quality of included studies was assessed using the JBI critical appraisal tools. Based on this assessment, 19 studies were classified as low risk of bias (high methodological quality), while 4 studies were classified as moderate risk of bias. No studies were excluded based on quality, as all met the predefined inclusion criteria and contributed to the synthesis. The overall risk of bias assessment is presented in Table 1, with detailed study-level appraisal results provided in Appendix 1.

An outcome summary table was developed to synthesize the key findings reported across the included studies (Table 3).

Operational outcomes

Dispensing time

This outcome was reported in two studies (Herrmann et al. 2024; Takase et al. 2022). The pooled SMD was -5.38 (95% CI: -13.49 to 2.72), favoring post-automation dispensing, but the overall effect was not statistically significant ($p = 0.19$) (Fig. 2). Heterogeneity was substantial (I^2

$= 100\%$). Due to this high level of heterogeneity, the results should be interpreted with caution, as the differences between the studies may limit the generalizability of the pooled effect size.

Medication administration time (Pre- and Post-implementation)

This outcome was reported in four studies (Darwesh and Labib 2015; Momattin et al. 2021; Al Nemari and Waterson 2022; Zhao et al. 2025). The pooled SMD was -4.35 (95% CI: -7.72 to -0.98), indicating shorter medication administration times following implementation of pharmacy automation, with a statistically significant overall effect ($p = 0.01$) (Fig. 3). Between-study heterogeneity was considerable ($I^2 = 100\%$). Given the substantial variability, the interpretation of this pooled effect size should be approached with caution.

Dispensing-related medication errors (error rate)

This outcome was reported in eight studies and synthesized using the dispensing error rate as the outcome measure. Studies were grouped by automation type (Oswald and Caldwell 2007; Franklin et al. 2008; Fanning et al. 2015; Berdot et al. 2018b; Momattin et al. 2021; Al Nemari and Waterson 2022; Bagattini et al. 2022; Takase et al. 2022). The overall pooled analysis showed an SMD of -3.89 (95% CI: -4.53 to -3.26), indicating lower dispensing error rates with pharmacy automation, with a statistically significant overall effect ($p < 0.00001$) (Fig. 4). Heterogeneity was substantial ($I^2 = 100\%$). The robotic dispensing systems subgroup had a pooled SMD of -4.44 (95% CI: -6.26 to -2.63 ; $p < 0.00001$; $I^2 = 99\%$). ADCs subgroup pooled and SMD of -3.31 (95% CI: -5.00 to -1.62 ; $p = 0.0001$; $I^2 = 100\%$). Despite the significant effects, the high heterogeneity within each subgroup ($I^2 = 99\%$ and 100%) suggests

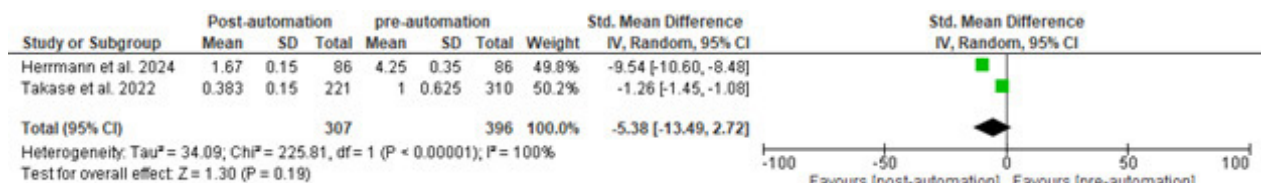


Figure 2. Forest plot comparing dispensing time before and after pharmacy automation. Pooled standardized mean differences (SMD) with 95% confidence intervals (CI) comparing dispensing time (minutes) before and after implementation of pharmacy automation systems. A random-effects model was applied to account for between-study heterogeneity. SMD = standardized mean difference; CI = confidence interval.

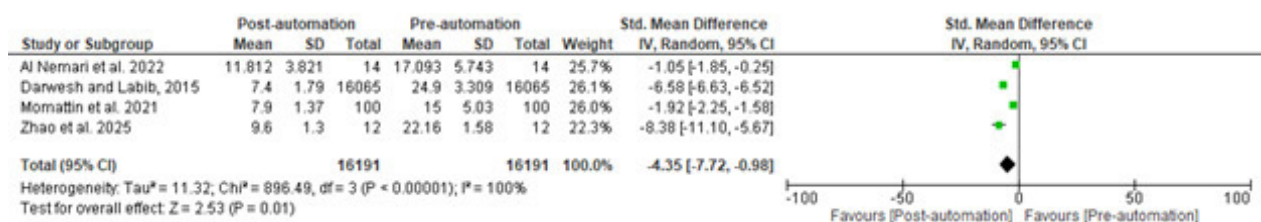


Figure 3. Effect of pharmacy automation on medication administration time. Forest plot presenting pooled SMD with 95% CI for medication administration time (minutes) following implementation of pharmacy automation technologies. Random-effects meta-analysis was performed.

Table 2. Study characteristics.

Reference; ROB*	Year of publication	Country	Study design	Setting	Participants	Intervention	Comparator	Outcome measured
Al Mutair et al. 2025; low	2025a	Saudi Arabia	Qualitative exploratory study	Private tertiary hospital	Pharmacists and nurses	ADCs	Manual dispensing	Efficiency, medication errors, and satisfaction
Al Mutair et al. 2025b; low	2025b	Saudi Arabia	Quantitative cross- sectional survey	Private tertiary hospital	Pharmacists, nurses, and respiratory therapists	ADCs	Pre-ADC	Efficiency, patient safety, and satisfaction
Zhao et al. 2025; low	2025	China	Quasi-experimental pre-post	Tertiary hospital	Nurses	ADC-based intelligent pharmacy system	Pre- implementation ADC workflow	Efficiency, medication errors, and satisfaction
Alomair et al. 2024; low	2024	Saudi Arabia	Descriptive cross- sectional survey	Tertiary hospital	Pharmacists, nurses, technicians	ADCs	Pre-ADC workflow	Satisfaction
Amirthalingam et al. 2024; low	2024	Saudi Arabia	Analytical cross-sectional comparative	Outpatient pharmacies	Patients	ADDs	TDDs	Efficiency and satisfaction
Herrmann et al. 2024; low	2024	Germany	Mixed observational (pre-post + cross- sectional survey)	Inpatient hospital wards	Nurses	UDDs	Pre-UDDs manual dispensing	Efficiency and satisfaction
Almalki et al. 2023; low	2023	Saudi Arabia	Quasi-experimental pre-post	Inpatient hospital wards	Pharmacists and nurses	ADCs	Pre-ADC system	Efficiency, medication errors, and satisfaction
Al Nemari and Waterson, 2022; low	2022	Saudi Arabia	Quasi-experimental pre-post	Outpatient pharmacy department	Pharmacists	Robotic dispensing systems	Pre-automation	Efficiency, medication errors, and satisfaction
Alanazi et al. 2022; low	2022	Saudi Arabia	Analytical cross-sectional comparative	Tertiary hospital	Pharmacists	ADDs	TDDs	Efficiency, medication errors, and satisfaction
Bagattini et al. 2022; low	2022	Brazil	Retrospective pre-post observational	Tertiary hospital	Pharmacists	Robotic dispensing systems	Pre-automation	Efficiency and medication errors
Takase et al. 2022; low	2022	Japan	Quasi-experimental pre-post	Tertiary hospital	Pharmacists	Robotic dispensing systems	Pre-automation	Efficiency and medication errors
Craswell et al. 2021; low	2021	Australia	Qualitative descriptive study	Tertiary hospital	Pharmacists and nurses	ADCs	Pre-automation	Efficiency, medication errors, and satisfaction
Momattin et al. 2021; moderate	2021	Saudi Arabia	Quasi-experimental pre-post	Outpatient hospital pharmacy	Pharmacists, nurses, and patients	Robotic dispensing systems	Pre-automation	Efficiency, medication errors, and satisfaction
Craswell et al. 2020; moderate	2020	Australia	Cross-sectional mixed- method (survey + observation)	Tertiary hospital	Pharmacists and nurses	ADCs	Pre-automation	Medication errors and satisfaction
Berdot et al. 2018a; low	2018a	France	Quasi-experimental comparative	Tertiary hospital	Nurses	ADCs	TFSS	Efficiency, medication errors, and satisfaction
Berdot et al. 2018b; low	2018b	France	Mixed quasi-experimental (pre-post + survey)	Tertiary hospital	Pharmacists	Centralized robotic dispensing + decentralized ADCs	Pre-automation	Dispensing errors, user satisfaction
Darwesh and Labib, 2015; low	2015	Saudi Arabia	Quasi-experimental pre-post	Inpatient hospital wards	Pharmacists and nurses	ADCs	Pre-automation	Medication errors and satisfaction
Fanning et al. 2015; low	2015	Australia	Quasi-experimental pre-post	Tertiary hospital	Nurses and patients	ADCs	Pre-automation	Medication errors
Rochais et al. 2013; moderate	2013	Canada	Descriptive cross- sectional survey	Inpatient hospital wards	Nurses	ADCs	Pre-automation	Efficiency, medication errors, and satisfaction
James et al. 2012; low	2012	United Kingdom	Longitudinal pre-post	Inpatient hospital wards	Pharmacists	ADS	Pre-automation	Efficiency and medication errors
Chapuis et al. 2010; low	2010	France	Quasi-experimental pre-post	Medical intensive care units	Nurses and patients	ADS	Pre-automation	Medication errors and satisfaction
Franklin et al. 2008; low	2008	United Kingdom	Quasi-experimental pre-post	Tertiary hospital	Nurses and patients	Robotic dispensing systems	Pre-automation	Efficiency, medication errors, and satisfaction
Oswald and Caldwell, 2007; moderate	2007	United States	Quasi-experimental pre-post	University hospital	Pharmacists, nurses, and patients	Centralized automated dispensing	Pre-automation	Medication errors

Keywords: ADCs: Automated Dispensing Cabinets; ADDs: Automated drug dispensing systems; ADS: Automated dispensing system; TDDs: Traditional Drug Dispensing Systems; UDDs: Unit-Dose Dispensing System; TFSS: Traditional floor stock storage; ROB: risk of bias.

Table 3. Outcome summary.

Study	Dispensing efficiency	Dispensing errors	Satisfaction
Al Mutair et al. (2025a)	Improved time efficiency, reduced workload	Reduced medication errors	Positive staff perceptions
Al Mutair et al. (2025b)	87.2% of staff reported improved efficiency	92.1% reported enhanced patient safety Error reduction perceived	High acceptance of ADCs
	ADCs made work more manageable		
Zhao et al. (2025)	Reduced time to retrieve meds; reduced execution time ($P < 0.05$)	Decreased retrieval and administration errors ($P < 0.05$)	86.96% improved efficiency; 97.82% high satisfaction
Alomair et al. (2024)	NR	NR	81.9% high overall satisfaction
Amirthalingam et al. (2024)	Higher satisfaction in the ADDS group for dispensing practice and dispensing system	NR	Overall satisfaction significantly higher in ADDS vs TDDS ($P < 0.05$)
Herrmann et al. (2024)	Time to dispense medications: decreased from 4.52 ± 0.35 min to 1.67 ± 0.15 min/day/patient	NR	Nurses reported high acceptance of UDDS, perceived workload reduction, and improved digitalization and workflow
Almalki et al. (2023)	Turnaround time reduced by 83%, zero delay incidents, and fewer missing medication calls	Medication delay incidents reduced from 7 to 0	64% nurses 67% pharmacists reported an increase in productivity
Al Nemari and Waterson (2022)	Total patient time in pharmacy reduced from 17.093 to 11.812 minutes. Productivity ratio post-automation was 1.26	Incomplete prescriptions reduced from 3.0% to 1.83%, and the dispensing error rate reduced from 1.00% to 0.24%	Increased productivity reported, improved staff satisfaction, improved waiting time, and service flow
Alanazi et al. (2022)	Prescriptions/day increased, and labeling time decreased	Improved medication review time	Higher perception scores with ADDS
Bagattini et al. (2022)	Improved inventory control and waste reduction	Rate-adjusted dispensing errors significantly decreased	NR
Takase et al. (2022)	Dispensing time per prescription reduced from 60 seconds to 23 seconds ($p < 0.001$)	Prevented dispensing errors decreased from 0.204% (324/158,548) to 0.044% (50/114,111)	NR
Craswell et al. (2021)	Work productivity initially disrupted, then improved over time, and workflow changes led to workarounds affecting efficiency	NR	Higher satisfaction for pharmacy assistants at implementation
			Lower initial satisfaction for nurses, but improved over time
Momattin et al. (2021)	Percentage reduction in wait time and percentage increase in productivity	Zero dispensing errors reported post-implementation	Patient satisfaction (wait time) increased by 20%, and the overall pharmacy service satisfaction increased by 22%
Craswell et al. (2020)	NR	Staff perceived ADCs as improving safety and security	Overall high satisfaction
Berdot et al. (2018a)	Gains in preparation time	No storage-related medication errors reported with ADCs	High nurse satisfaction with ADCs
		Nine storage-related errors reported with TFSS	
		Low prevalence of medication process errors with ADCs	
Berdot et al. (2018b)	NR	Significant reduction in dispensing errors; Pre-automation: 2.9%–Post-automation: 1.7% $P < 0.001$	User satisfaction; Mean score: 5.52 ± 1.20
Darwesh and Labib (2015)	Unit saved time and effort with a decrease in personal load	Decrease in possible error	NR
Fanning et al. (2015)	NR	Medication selection & preparation error rate; Pre-ADC: 1.96% and Post-ADC: 0.69%, and 64.7% reduction, $P = 0.017$	NR
Rochais et al. (2013)	90% agreed ADCs made their work easier	81% believed ADCs reduced medication incidents/accidents 91% agreed ADCs helped safely provide patient care	High overall satisfaction with ADCs
	Reported delays in preparation and administration of medication doses (48% dissatisfaction)		
James et al. (2012)	Dispensing workload increased from 9.20 to 13.17 items/person/hour, $P < 0.001$	Prevented dispensing incidents; reduced from 0.64% to 0.28%, $P < 0.0001$	NR
Chapuis et al. (2010)	NR	Overall error rate Before–after from 20.4% to 13.5%, $p < 0.01$	Nurses wishing to continue ADS use: 96.7%
Franklin et al. (2008)	Picking time reduced after automation	Dispensing error rate reduced from 1.2% to 0.6%	Staff satisfaction improved after robot automation
Oswald and Caldwell (2007)	NR	Filling errors and dispensing errors reduced	NR

Keywords: ADCs: Automated dispensing cabinets; TFSS: Traditional floor stock storage; NR: Not reported; ADDS: Automated drug dispensing systems; TDDS: Traditional Drug Dispensing Systems; UDDS: Unit-Dose Dispensing System.

caution in interpreting the results. Publication bias for dispensing-related medication errors was assessed using a funnel plot (Fig. 5). Visual inspection of the funnel plot suggests slight asymmetry, with a concentration of studies

reporting larger negative effect sizes. However, given the small number of studies and the presence of substantial heterogeneity ($I^2 = 100\%$), this asymmetry may reflect between-study variability rather than true publication bias.

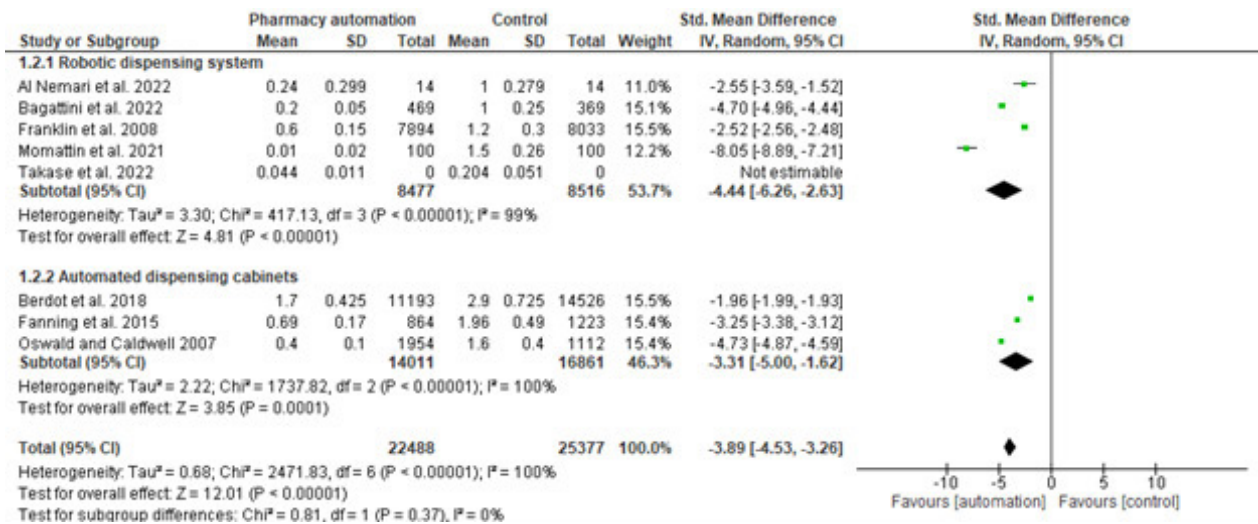


Figure 4. Forest plot of dispensing-related medication error rates stratified by automation type. Pooled effect estimates with 95% CI comparing dispensing-related medication error rates between pharmacy automation systems and control conditions, stratified by type of automation technology. A random-effects model was used.

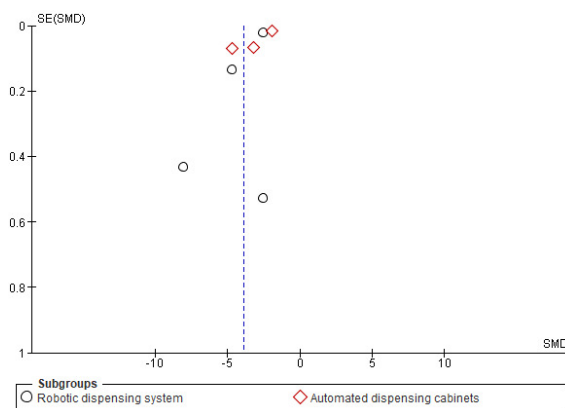


Figure 5. Funnel plot assessing publication bias for medication error outcomes. Funnel plot evaluating potential publication bias among studies reporting dispensing-related medication error rates included in the meta-analysis.

Subjective perception-based outcomes

Dispensing system efficiency

This outcome was reported in two studies (Momattin et al. 2021; Amirthalingam et al. 2024). The pooled SMD was 0.60 (95% CI: 0.01 to 1.18), favoring pharmacy automation, with a statistically significant overall effect ($p = 0.04$) (Fig. 6). Heterogeneity was high ($I^2 = 92\%$). Given the high heterogeneity, the results should be interpreted with caution, as the variability between studies may impact the generalizability of the findings.

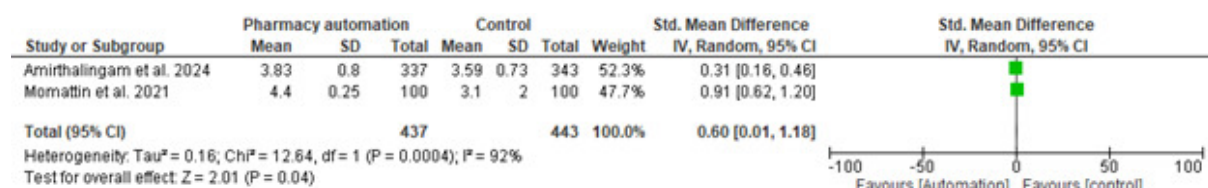


Figure 6. Effect of pharmacy automation on perceived dispensing system efficiency. Forest plot showing pooled SMD with 95% CI for user-reported perceptions of dispensing system efficiency following implementation of automation technologies. Random-effects meta-analysis was conducted.

Patient time in the dispensing system

This outcome was reported in two studies (Amirthalingam et al. 2024; Momattin et al. 2021). The pooled SMD was 3.90 (95% CI: -3.27 to 11.07), indicating no statistically significant difference in patient time between pharmacy automation and control systems ($p = 0.29$) (Fig. 7). Heterogeneity was considerable ($I^2 = 100\%$). Due to the high heterogeneity, the results should be interpreted with caution, as significant variability between studies may affect the reliability of the pooled effect.

Sufficient time to review medications before dispensing

This outcome was reported in two studies (Alanazi et al. 2022; Amirthalingam et al. 2024). The pooled SMD was 0.39 (95% CI: 0.09 to 0.69), indicating greater time available to review medications prior to dispensing with pharmacy automation, with a statistically significant overall effect ($p = 0.01$) (Fig. 8). Heterogeneity was low ($I^2 = 30\%$).

Perceived patient safety

This outcome was reported in two studies (Alanazi et al. 2022; Amirthalingam et al. 2024). The pooled SMD was 0.31 (95% CI: 0.16 to 0.46), indicating higher perceived patient safety associated with pharmacy automation, with a statistically significant overall effect ($p < 0.0001$) (Fig. 9). No heterogeneity was observed between studies ($I^2 = 0\%$).

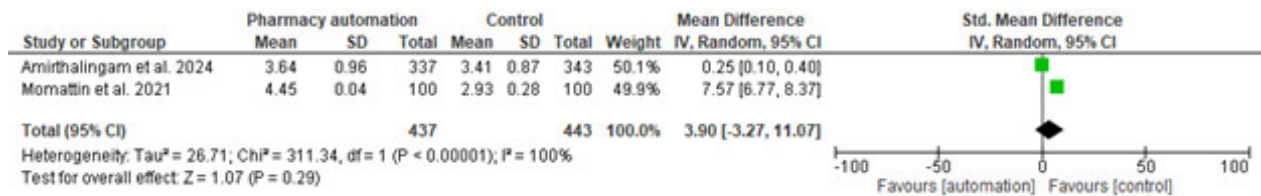


Figure 7. Effect of pharmacy automation on perceived patient time in the dispensing system. Pooled SMD with 95% CI for user perceptions of patient time spent within the dispensing system before and after automation implementation. Random-effects model applied.

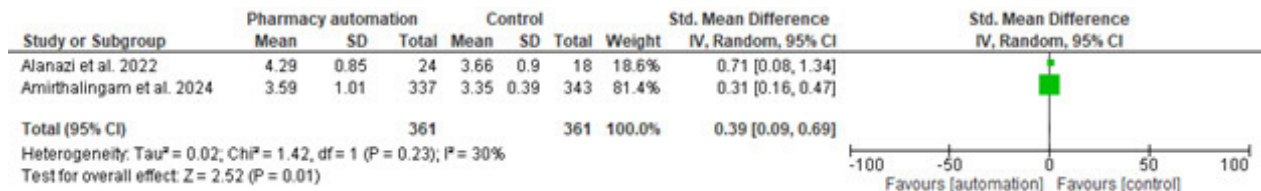


Figure 8. Effect of pharmacy automation on perceived sufficient time for medication review. Forest plot presenting pooled SMD with 95% CI assessing perceived adequacy of time available to review medications prior to dispensing after automation implementation. Random-effects meta-analysis performed.

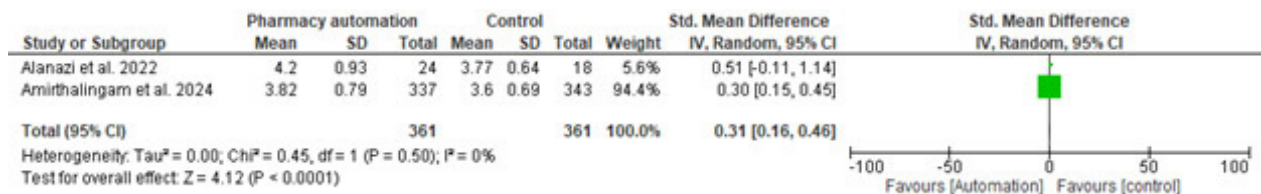


Figure 9. Effect of pharmacy automation on perceived patient safety. Forest plot showing pooled SMD with 95% CI for perceived patient safety following implementation of pharmacy automation systems. Random-effects model applied.

Pharmacists' time in the dispensing system

Two studies examined the impact of pharmacy automation on pharmacists' time in the dispensing process (Rochais et al. 2013; Zhao et al. 2025). Both studies found a consistent reduction in the time pharmacists spent on dispensing medications after the introduction of automation. The time savings were attributed to the system's ability to streamline medication picking and improve workflow.

User satisfaction

Seven studies reported on user satisfaction with pharmacy automation (Chapuis et al. 2010; Berdot et al. 2018a; Craswell et al. 2020; Almalki et al. 2023; Alomair et al. 2024; Al Mutair et al. 2025b; Zhao et al. 2025). Across all studies, user satisfaction was consistently higher in settings where pharmacy automation was implemented.

Discussion

Pharmacy automation has the potential to enhance the efficiency and safety of hospital dispensing processes significantly. This systematic review and meta-analysis examined the impact of pharmacy automation technologies on dispensing efficiency, dispensing-related medication errors, and user satisfaction across hospital pharmacies in G20 countries. Our findings suggest that pharmacy automation is associated with improvements in several workflow-related metrics, such as dispensing system efficiency and medication administration time, as well as re-

ductions in dispensing-related error rates. In addition, the perceived patient safety and user satisfaction were notably higher in automated systems. However, the magnitude and consistency of these effects varied significantly across outcomes and studies, leading to substantial heterogeneity in most pooled analyses.

The results of this systematic review and meta-analysis provide valuable insights into the impact of pharmacy automation technologies on dispensing efficiency, medication errors, and user satisfaction within hospital pharmacies across G20 countries. While overall trends indicate that pharmacy automation can improve several key outcomes, the magnitude and consistency of these effects varied significantly across studies. Regarding dispensing efficiency, the results revealed a statistically significant improvement in dispensing system efficiency, suggesting that automation systems can enhance overall workflow efficiency in hospital pharmacies (Fanning et al. 2015; Al Nemari and Waterson 2022; Takase et al. 2022). However, the lack of statistical significance in dispensing time, despite a favorable trend, highlights the complexity of measuring efficiency across different automation technologies and contexts. The substantial heterogeneity observed underscores the importance of considering factors such as the specific type of automation system, the scale of hospital operations, and regional healthcare infrastructure when interpreting these results. Similarly, medication administration time showed a significant reduction following the implementation of pharmacy automation, suggesting that automation can streamline the medication administration

process. This aligns with previous findings that automation systems can reduce time-consuming manual tasks, thus freeing up time for other critical activities (Darwesh and Labib 2015; Zhao et al. 2025).

The availability of time to review medications before dispensing was significantly higher with pharmacy automation, suggesting that automation provides pharmacists with more time to verify medications, which can enhance safety and reduce errors. This finding aligns with the broader expectation that automation can support pharmacists in making more accurate and informed decisions, thereby improving overall medication management (James et al. 2012; Sng et al. 2018). However, when examining patient time in the dispensing system, the results indicated no statistically significant difference between automation and control systems. This suggests that while automation improves internal efficiency, it may not directly reduce the time patients spend in the system. Several factors could contribute to this, including wait times in other parts of the hospital or patient flow dynamics that are unaffected by automation at the dispensing stage.

In terms of dispensing-related medication errors, automation technologies demonstrated a robust effect in reducing error rates, supporting the hypothesis that automated systems can enhance medication safety by minimizing human error. This finding is consistent with the broader literature, which suggests that automation can significantly reduce dispensing errors (Fanning et al. 2015; Bagattini et al. 2022). Notably, robotic dispensing systems and ADCs both showed substantial reductions in error rates, with robotic systems showing a more pronounced effect (Oswald and Caldwell 2007; Franklin et al. 2008; Momattin et al. 2021). The consistent finding of error reduction across multiple studies supports the notion that automation improves patient safety, particularly in high-volume pharmacy environments where errors are more likely to occur. Finally, subjective perception-based outcomes, such as user satisfaction and perceived patient safety, consistently showed high levels of positive feedback, indicating that both healthcare providers and patients generally view automation favorably. It's important to note that subjective outcomes like satisfaction and perceived safety are based on individual perceptions and are not direct measures of clinical efficacy. While these outcomes provide valuable insights into how automation is viewed by users, they should be interpreted with caution as they do not directly reflect the operational impact of automation on processes like dispensing accuracy or time.

While few studies have examined the impact of pharmacy automation in hospital settings, this review adds new insights by synthesizing data from multiple countries and various automation technologies. Existing literature generally supports the idea that automation can improve medication safety and dispensing efficiency, but often focuses on isolated aspects, such as error rates or dispensing time, without examining a broad range of dispensing-stage outcomes (Oswald and Caldwell 2007; Franklin

et al. 2008; Chapuis et al. 2010; James et al. 2012). Several studies have also found significant reductions in medication errors following the implementation of pharmacy automation. For example, a study by Zaidan et al. found that ADCs significantly reduced medication errors in a hospital pharmacy setting (Zaidan et al. 2016). Similarly, our findings show a robust reduction in dispensing-related medication errors, further supporting the notion that automation can play a critical role in enhancing medication safety. The more pronounced decrease in errors with robotic dispensing systems in this review also aligns with previous findings, including those from Boyd and Chaffee (2018), who highlighted the superior performance of robotic systems in reducing dispensing errors.

Implications for practice

This review highlights the potential of pharmacy automation to improve dispensing efficiency, reduce medication errors, and enhance user satisfaction. Hospitals should consider implementing robotic dispensing systems and ADCs, as these have shown significant benefits in medication safety and workflow efficiency. However, successful integration of automation depends on effective staff training and seamless integration into existing pharmacy workflows. The variability in outcomes suggests that hospitals should tailor automation solutions to their specific needs, considering factors such as hospital size and existing infrastructure. Additionally, while automation improved medication administration time, it did not reduce patient time within the dispensing system, indicating that broader hospital flow optimization may be needed. Finally, continuous evaluation and further research are essential to assess the long-term impacts and cost-effectiveness of automation technologies across diverse settings.

Limitations of the study

This review's strengths include its comprehensive scope, incorporating studies from multiple G20 countries, and its rigorous meta-analytic approach, which synthesizes diverse outcomes related to pharmacy automation. By evaluating a broad range of dispensing-related processes, this review provides a more holistic understanding of the effects of automation compared to previous studies. However, several limitations should be considered. High heterogeneity across studies, particularly in dispensing time, medication administration, and dispensing-related medication errors, suggests considerable variability in implementation and context, such as differences in automation types, healthcare settings, and patient populations. This variability limits the generalizability of our findings and suggests caution in interpreting the pooled effect sizes. While pharmacy automation appears to have a positive impact on dispensing efficiency and medication error rates, the substantial differences between studies highlight the need for further research with more consistent methodologies and settings.

Recommendations for future research

Future research should focus on exploring the long-term impacts of pharmacy automation on both operational efficiency and patient outcomes. Studies assessing the cost-effectiveness of different automation technologies, including robotic dispensing systems and ADCs, are needed to guide healthcare administrators in making informed investment decisions. Further investigation into the contextual factors, such as hospital size, staff training, and technology integration, will help identify best practices for successful implementation. Finally, longitudinal studies that track the effects of automation over time, particularly on patient safety and staff workflow, are also crucial.

Conclusion

This review suggests that pharmacy automation is associated with improvements in dispensing efficiency, reductions in dispensing-related medication errors, and enhancements in user satisfaction in hospital pharmacies across G20 countries. Specifically, significant improvements were observed in medication administration time, dispensing-related medication error rates, perceived dispensing efficiency, and perceived patient safety. However, not all operational outcomes demonstrated consistent benefits, as no statistically significant differences were observed in dispensing time or patient time within the dispensing system. The magnitude of these associations varies according to automation technology type, institutional context, and the degree of system integration within existing medication-use processes. High heterogeneity across studies, particularly in terms of implementation contexts, outcome measurement, and automation types, suggests that the findings should be interpreted with caution, as they may not be fully representative of all hospital pharmacies.

These findings underscore the importance of strategic, context-specific implementation to maximize the operational and safety benefits of pharmacy automation in health-system practice. Future research should prioritize standardized outcome reporting, long-term effectiveness, cost-effectiveness, and workforce implications to inform

sustainable adoption and optimize the role of automation in supporting patient safety and efficient hospital pharmacy operations.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statements

The authors declared that no clinical trials were used in the present study.

The authors declared that no experiments on humans or human tissues were performed for the present study.

The authors declared that no informed consent was obtained from the humans, donors or donors' representatives participating in the study.

The authors declared that no experiments on animals were performed for the present study.

The authors declared that no commercially available immortalised human and animal cell lines were used in the present study.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.

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Author contributions

The authors declare that they have not used any generative artificial intelligence for the writing of this manuscript, nor for the creation of images, graphics, tables, or their corresponding captions.

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Data availability

All of the data that support the findings of this study are available in the main text.

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Appendix 1

Table A1. Quality assessment.

Study	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Overall
Al Mutair et al. (2025a)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	High
Al Mutair et al. (2025b)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Zhao et al. (2025)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Alomair et al. (2024)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Amirthalingam et al. (2024)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Herrmann et al. (2024)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Almalki et al. (2023)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	High
Al Nemari and Waterson (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Alanazi et al. (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Bagattini et al. (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Takase et al. (2022)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	High
Craswell et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Momattin et al. (2021)	Yes	No	Yes	Yes	No	No	Yes	Yes	Moderate
Craswell et al. (2020)	Yes	Yes	NA	Yes	No	No	Yes	Yes	Moderate
Berdot et al. (2018a)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Berdot et al. (2018b)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Darwesh and Labib (2015)	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	High
Fanning et al. (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Rochais et al. (2013)	Yes	Yes	No	Yes	No	No	Yes	Yes	Moderate
James et al. (2012)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	High
Chapuis et al. (2010)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	High
Franklin et al. (2008)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Oswald and Caldwell (2007)	Yes	No	Yes	Yes	No	No	Yes	Yes	Moderate

Item 1: Were the criteria for inclusion in the sample clearly defined? Item 2: Were the study subjects and the setting described in detail? Item 3: Was the exposure measured in a valid and reliable way? Item 4: Were objective, standard criteria used for measurement of the condition? Item 5: Were confounding factors identified? Item 6: Were strategies to deal with confounding factors stated? Item 7: Were the outcomes measured in a valid and reliable way? Item 8: Was appropriate statistical analysis used?