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# HUMAN AND WORKPLACE FACTORS IN PRE-ANALYTICAL LABORATORY ERRORS: A SYSTEMATIC REVIEW WITH SAUDI AND INTERNATIONAL EVIDENCE

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***Abstract***

**Background.** Pre-analytical errors are usually put at 60–70% of all laboratory errors (Lippi et al., 2011; Nordin et al., 2024). A manuscript from Tabuk (Alfaifi et al., unpublished) frames them as failures of systems rather than of individuals.

**Objective.** To synthesize evidence on individual and workplace factors behind pre-analytical errors and on the interventions that reduce them, comparing Saudi and regional data with international data.

**Methods.** Systematic review reported to PRISMA 2020. PubMed and Consensus were searched on 21 November 2026. Screening and extraction were single-reviewer and abstract-level; synthesis was narrative. No protocol was registered.

**Results.** Of 106 unique records, 30 were included: 9 Saudi studies, 1 multi-country Gulf/MENA survey, 4 evidence syntheses and 16 international primary studies. Saudi error or rejection rates ranged from 0.063% to 12.1%, reflecting definitions as much as practice; clotted, insufficient and hemolyzed specimens led. Human factors accounted for 82.8% and 91.1% of contributing factors in two incident-report studies. Workload, time of day and care setting (emergency, inpatient) were linked with higher error rates. Barcode-based patient identification cut mislabeling by 41–97% in uncontrolled before–after studies; education alone gave inconsistent results.

**Conclusions.** The evidence supports a systems approach: identification technology, standardized collection, workload-aware staffing and non-punitive monitoring. Certainty is low, and prospective controlled evaluations from Saudi Arabia are missing.

**Keywords:** pre-analytical errors; specimen rejection; human factors; patient identification; laboratory quality; Saudi Arabia

## *1. Introduction*

Laboratory results drive most diagnostic and treatment decisions, so errors made before analysis (identification, collection, labeling, transport, storage) reach the patient. Pre-analytical errors make up about 60–70% of laboratory errors (Lippi et al., 2011). Most arise outside the laboratory, in steps handled by clinical staff, which is why indicators from the IFCC working group cover the whole path from test request to storage (Plebani, 2012).

Benchmarks vary widely. A meta-analysis of 26 articles and 16,118,499 requests pooled a specimen rejection rate of 1.99%, higher in Asia (2.82%) than in the Americas (0.55%) (Getawa et al., 2022). Saudi audits report error or rejection rates from 0.063% to 12.1% (Alcantara et al., 2022; Alenezy et al., 2025), and it is unclear whether that spread reflects practice or definitions.

A manuscript supplied for this review (Alfaifi et al., unpublished; eight authors at King Salman Armed Forces Hospital, Tabuk) asks which individual and workplace factors drive pre-analytical errors and which interventions reduce them. It sorts drivers into individual factors (training, fatigue, mistakes, communication) and workplace factors (workload, staffing, equipment, organization), lists five interventions, and argues that errors "should not be viewed solely as failures of individual

performance." It poses a review question but reports no search method, so its claims cannot be traced to sources.

This review tests those claims against indexed evidence and asks three questions. Which individual and workplace factors are associated with pre-analytical errors? How large are the error rates in Saudi Arabia compared with other settings? Which interventions reduce errors, and by how much?

## *2. Methods*

**Design.** Systematic review reported to PRISMA 2020. No protocol was registered. The question follows PICO: population, clinical-laboratory, phlebotomy and specimen-collection staff and processes; exposure or intervention, individual or workplace factors, and technology, education, process or quality-improvement interventions; comparator, no intervention, pre-implementation periods or other settings; outcomes, pre-analytical error or rejection rates, mislabeling, hemolysis and patient harm.

**Eligibility.** Included: primary studies, quality-improvement projects and systematic reviews or meta-analyses that reported error or rejection rates, contributing factors or intervention effects for blood and other clinical-laboratory specimens, in English, any year. Excluded: narrative reviews and commentaries, analyte-specific stability or tube-validation studies, surgical-pathology labeling studies, case reports without outcome data, and rate-only descriptive reports from outside Saudi Arabia and the Gulf. Rate-only reports from Saudi Arabia and the Gulf were kept to allow a regional comparison.

**Search.** PubMed and Consensus were searched on 21 November 2026, and the three references the source manuscript cites for the 60–70% figure were checked in PubMed (Table 1). Consensus returns a ranked top 20 per query, so it is not exhaustive.

**Table 1.** Search strategy and records retrieved

| # | Source | Query | Total hits | Retrieved |
|---|---|---|---|---|
| 1 | PubMed | preanalytical errors laboratory Saudi Arabia | 16 | 15 |
| 2 | PubMed | preanalytical errors human factors review | 13 | 13 |
| 3 | PubMed | patient identification barcode specimen labeling errors intervention | 15 | 15 |
| 4 | PubMed | preanalytical phase quality indicators laboratory GCC OR Gulf OR Middle East | 325,062* | 15 |
| 5 | PubMed | preanalytical errors workload staffing fatigue interruptions phlebotomy | 0 | 0 |
| 6 | PubMed | sample rejection hemolysis education intervention phlebotomy training | 3 | 3 |
| 7 | PubMed | preanalytical errors Riyadh OR Jeddah OR Kuwait OR Qatar OR Emirates OR Oman | 147,381* | 15 |
| 8 | Consensus | pre-analytical errors Saudi Arabia hospital laboratory rejection rate | top 20 | 20 |
| 9 | Consensus | human factors and workplace factors causing pre-analytical errors in clinical laboratory specimen collection | top 20 | 20 |
| 10 | Citation check | References of the source manuscript (Lippi 2011, Plebani 2012, Nordin 2024) | 3 | 3 |

*PubMed parsed the OR operators so that most hits were unrelated; the first 15 records of each were screened and none of those two sets met the criteria. Search date: 21 November 2026.

**Screening and extraction.** One reviewer (Claude, working with the author) screened titles and abstracts; full texts were not read. For each included record the following were extracted: country or setting, design, sample, outcomes, key figures and stated limitations, and each record was tagged Saudi, GCC/MENA or International. Records with identical reported figures were compared for possible duplicate datasets.

**Appraisal and synthesis.** No formal risk-of-bias tool was applied. Certainty was rated qualitatively (moderate, low, very low) from design, consistency and directness. Findings were synthesized narratively by domain (SWiM). A meta-analysis was not attempted because denominators and error definitions differ between studies. Relative reductions were calculated from the before and after values the studies reported.

## *3. Results*

### 3.1 Study selection

The searches returned 119 records, 13 of which were duplicates, leaving 106 to screen. Of these, 41 were off-topic and 65 were assessed at abstract level; 30 met the criteria (Figure 1). One record was excluded because its figures match another study too closely: Kani et al. (2024; PMID 39429359) reports 886 rejected samples, 54.17% insufficient and 0.4% empty or damaged tubes, the same values and near-identical conclusions as Iqbal et al. (2023), yet with a different denominator (56,604 versus 67,892 samples). Its stated 1.3% rate also does not fit its own denominator (886 of 56,604 is 1.57%). The abstracts cannot resolve this, so the discrepancy is flagged for editorial follow-up and only Iqbal et al. was kept.

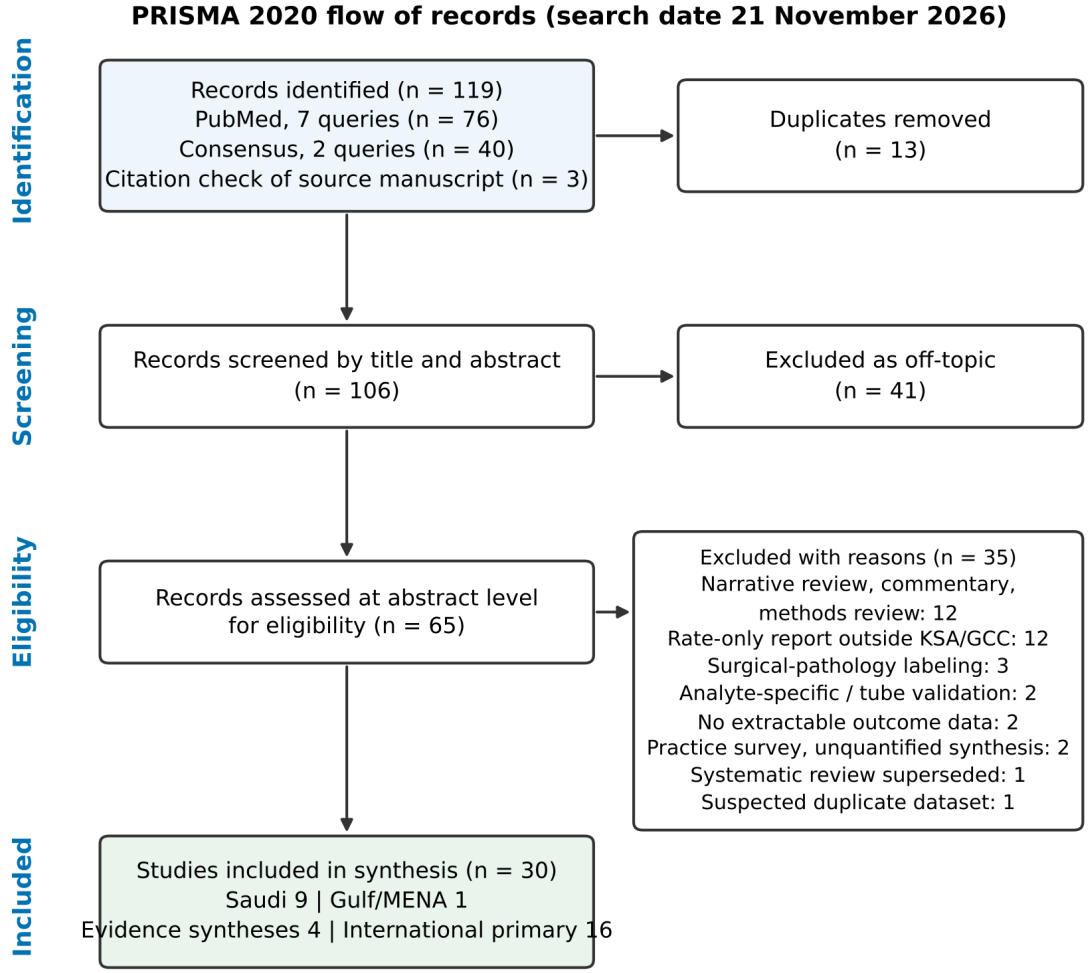


**Figure 1.** PRISMA 2020 flow diagram of study selection. Records come from PubMed and Consensus searches run on 21 November 2026. Screening was single-reviewer and abstract-level. Counts: 119 records identified, 13 duplicates removed, 106 screened, 65 assessed at abstract level, 30 included. PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

### 3.2 Characteristics of included studies

Table 2 lists the ten Saudi and Gulf/MENA studies and Table 3 the 20 international records. Most Saudi studies are single-centre retrospective audits of laboratory-information-system records, and only one tested an intervention.

**Table 2.** Saudi and Gulf/MENA studies (n = 10)

| Study | Setting | Design and sample | Main findings |
|---|---|---|---|
| Ahmed et al., 2026 | KFMC, Riyadh (Saudi) | Retrospective cross-sectional; 89,788 records, Jan–Jun 2025 | 24,200 true errors after removing 33,758 never-received and 31,830 administrative records; insufficient or empty 22.47%, clotted 21.31%, hemolyzed 17.67%; clustered in emergency, neonatal ICU and cardiology |
| Alonaizan et al., 2026 | Riyadh (Saudi) | Retrospective; 845,647 tests, 2024 | 1.28% rejected; hemolysis 75.92%; 3.89 sigma; root-cause analysis named venipuncture technique, needle gauge, workload pressure and prolonged tourniquet |
| Alenezy et al., 2025 | Taif (Saudi) | Retrospective; 3,346,199 orders, 2021 | 2,104 errors (0.063%); clotted 32%, insufficient 31%; rates differed by section, department and shift (all $P < .001$); 58.2% in the morning shift |
| Jeraiby, 2025 | Saudi hospital | Retrospective cohort; 321,465 samples, May–Nov 2020 | 2.25% rejected; hemolyzed 45.3%, clotted 33.6%; inpatient wards 76.2% of rejections; emergency hemolysis 48.1%, misidentification 7.4% |
| Alcantara et al., 2022 | Saudi hospital | Laboratory-system review; 55,345 requests, 2019–2020 | 12.1% errors, 21% in the emergency department; not received 3.7%, hemolysis 3.5%; overall rate rose from 11.3% to 12.9% |
| Alshaghdali et al., 2022 | Hail (Saudi) | Retrospective; 95,002 hematology samples, 2017–2019 | 9.3% errors; clotted 3.6%, not received 3.5%; rate fell from 11.6% to 6.5% |
| Iqbal et al., 2023 | Saudi tertiary centre | Retrospective; 67,892 hematology samples | 1.3% rejected; insufficient 54.17%; pediatric errors mostly insufficient or diluted |
| Zaini et al., 2016 | Hera'a General Hospital, Makkah (Saudi) | Retrospective, 1 year, biochemistry | Hemolysis 35% of rejections; also patient-data mismatch, incomplete data and clotting |
| Al Saleem & colleagues, 2016 | Riyadh Regional Laboratory (Saudi) | Quality-improvement project, PDSA cycles | Baseline 2.31 errors per 1,000 processed samples; 25% fewer errors after interventions |
| Abdelaziz et al., 2026 | Saudi Arabia, other Gulf states, Egypt, Pakistan (Gulf/MENA) | Cross-sectional survey; 300 respondents from CAP-accredited laboratories | Respondents perceived fewer error-related events after CAP accreditation (perception only) |

**Table 3.** International studies and evidence syntheses (n = 20)

| Study | Setting | Design and sample | Main findings |
|---|---|---|---|
| Gega et al., 2026 | International | Umbrella review (PROSPERO CRD42024540624) ; 15 of 1,201 records | Clotted, hemolyzed, insufficient and mislabeled specimens most common; barcoding named a best practice |
| Getawa et al., 2022 | International | Meta-analysis; 26 articles, 16,118,499 requests | Pooled rejection 1.99% (95% CI 1.73–2.25); Asia 2.82%, America 0.55%; clotted 32.23%, hemolysis 22.87%, insufficient 22.81%, labeling 7.31% |
| Hamithi et al., 2026 | International | Systematic review; 17 studies | Bedside barcode identification, electronic ordering and mobile labeling gave the most consistent reductions; education improved knowledge more than specimen outcomes |
| Sandhu et al., 2017 | International | Systematic review; 12 studies | Communication and collaboration: median change −75.86% (IQI −84.77 to −58.00); standardized labeling protocols −72.45% (IQI −83.25 to −46.50) |
| Lichenstein et al., 2016 | US pediatric emergency network | Incident reports, 2007–2008 | 42.2% of laboratory reports were pre-analytic; human factors in 82.8% of contributing factors; 17.4% of patients harmed |
| Saengpattrachai et al., 2026 | Thailand | 3-year voluntary reports; 5,951,783 samples | 1,031 diagnostic errors, 89.2% pre-analytical; human factors 91.1%; 98% caused no harm; 7.8% delayed diagnosis |
| Guo et al., 2025 | China | Quality-improvement review; 83 laboratory errors | Pre-analytical 51.0% of general errors; 60% originated outside the laboratory; cognitive errors dominated preventable events |
| Fang et al., 2008 | Taiwan | Cross-sectional; 274 specimens | Hemolysis risk 3.35 times higher from non-antecubital sites, 3.7 times with steel needles versus syringes, 8.7 times when delivered by ward assistants |
| Dündar et al., 2023 | Turkey | Record-based; 7,762,981 requests | Pre-analytical rejection 1.28%; inpatients 2.26% versus outpatients 0.02%; higher outside working hours |
| Dündar (Bağnu) et al., 2026 | Turkey | Retrospective; 579,845 specimens | 0.79% rejected; 1.98% at 04:00–08:00 versus 0.45% at 08:00–12:00 (IRR 1.63, 95% CI 1.22–2.19) |
| Sarkar & Sarkar, 2026 | Bangladesh | Cross-sectional; 195 errors, 27 staff surveyed | Workload of 931 or more samples a day linked to errors ($\chi^2 = 121.09$, $P < .001$); morning shifts 65.1% of errors |
| Güner et al., 2025 | University hospital (country not stated) | Mixed methods; 14,290 and 4,220 rejected specimens | Nurses cited weak institutional support, inadequate training, communication gaps and stressful work settings |

| Study | Setting | Design and sample | Main findings |
|---|---|---|---|
| Kaufman et al., 2019 | US | 16 manual-identification sites versus 4 electronic sites | Wrong-blood-in-tube 1:3,046 (manual) versus 1:14,606 (electronic), adjusted; P < .0001 |
| Morrison et al., 2010 | US (Boston) | Before–after, inpatient phlebotomy | Labeling errors 5.45 to 3.2 per 10,000 (P = .0013); about 108 events prevented a year |
| Brown et al., 2011 | US | Before–after, barcode and bedside printers | Labeling errors 103 to 8 a year (P < .001) |
| Ning et al., 2016 | Taiwan | 10-year retrospective; 3,800-bed centre | Identification errors 0.0511% to 0.0015%, a 97% relative reduction |
| Saathoff et al., 2018 | US | Pre–post; community teaching hospital | Mislabeled specimens 0.020% to 0.003% (P < .001); collection delays over 60 minutes down 27% |
| Spain et al., 2015 | Australia | Before–after; 282 collections in an emergency department | Armband applied before collection 36% to 90%; patient asked to state name 25% to 93%; yearly cost $104,045 with scanner versus $5,330 education alone |
| Gupta et al., 2021 | Setting not stated in record | Quality improvement | Rejected samples 1.43% to 0.47% (P < .001) with education, competency checks and better consumables |
| Mersal et al., 2025 | UK | Two-cycle audit; 399 and 261 INR samples | Rejection 16.5% to 11.1% (P about 0.11); 94% were underfilled tubes |

### 3.3 Size and pattern of errors

Saudi audits report error or rejection rates from 0.063% to 12.1% (Figure 2). The spread follows what is counted. The two highest rates include samples never received, the three studies that count only rejected specimens cluster at 1.28–2.25%, and the lowest rate divides errors by all test orders rather than samples. The rejection-only Saudi figures bracket the pooled global estimate of 1.99% (Getawa et al., 2022). The leading causes match the global ranking: clotted, insufficient and hemolyzed specimens dominate in Saudi and international data alike.

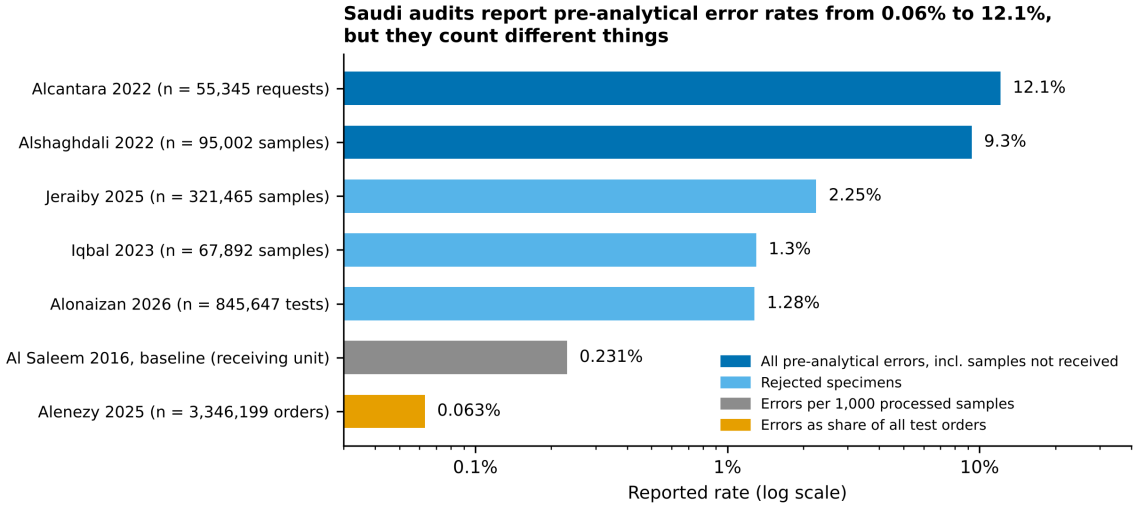


**Figure 2.** Error and rejection rates reported by Saudi audits, from 0.063% to 12.1%. Values come from Table 2. The rates are not directly comparable because the numerators (errors versus rejected

specimens) and denominators (orders, requests, samples) differ between studies. Al Saleem is shown at its baseline of 2.31 errors per 1,000 processed samples (0.231%).

### 3.4 Individual factors

Human performance was the most frequently named cause. Human factors made up 82.8% of contributing factors in pediatric emergency incident reports (Lichenstein et al., 2016) and 91.1% in three years of Thai reports (Saengpattrachai et al., 2026). Specific techniques carry measurable risk: hemolysis was 3.35 times more likely from non-antecubital sites, 3.7 times more likely with steel needles than syringes, and 8.7 times more likely when ward assistants rather than laboratory staff delivered tubes (Fang et al., 2008). A Riyadh root-cause analysis named venipuncture technique, needle gauge and prolonged tourniquet use (Alonaizan et al., 2026). Nurses interviewed in a mixed-methods study described inadequate training and communication gaps (Güner et al., 2025), and a Chinese review judged most preventable errors to be cognitive slips (Guo et al., 2025). Fatigue and interruptions, which the source manuscript lists, were not measured in any included study. The dedicated PubMed query (Table 1, #5) returned no records, so the claim is plausible but untested here.

### 3.5 Workplace and system factors

Workload showed the clearest association. Days with 931 or more samples had more errors in a Bangladeshi centre (Sarkar & Sarkar, 2026), and the Riyadh root-cause analysis listed workload pressure (Alonaizan et al., 2026). Timing mattered: rejection was 1.98% at 04:00–08:00 against 0.45% at 08:00–12:00 (Dündar et al., 2026), and rates were higher outside working hours (Dündar et al., 2023), although the authors note the link to workload is not linear. Care setting mattered too. The emergency department had 21% errors in one Saudi audit (Alcantara et al., 2022), and inpatient wards produced 76.2% of rejections in another (Jeraiby, 2025). In Taif, errors differed by laboratory section, department and shift (Alenezy et al., 2025), but the abstract gives no shift-level volumes, so a busier morning shift cannot be separated from a worse one.

System design also contributed. Before barcode identification, a manual label-printing step carried possible labeling errors in about a quarter of draws (Morrison et al., 2010), and 60% of errors in one hospital originated outside the laboratory (Guo et al., 2025). None of the included studies measured staff shortages or a punitive reporting culture directly.

### 3.6 Interventions

Barcode and electronic identification gave the largest and most consistent effects. In before–after studies, labeling or identification errors fell by 41% (Morrison et al., 2010), 85% (Saathoff et al., 2018), 92% (Brown et al., 2011) and 97% (Ning et al., 2016) (Figure 3). Sites with electronic identification had an adjusted wrong-blood-in-tube rate of 1:14,606 against 1:3,046 at manual sites (Kaufman et al., 2019). A systematic review of 12 studies found median reductions of 76% for communication and collaboration between laboratory and clinical staff and 72% for standardized labeling protocols (Sandhu et al., 2017).

Education-led programmes were less consistent. Phlebotomy education with direct competency checks and better consumables cut rejection from 1.43% to 0.47% (Gupta et al., 2021), but education plus a discard tube lowered INR rejection from 16.5% to 11.1% without reaching significance (Mersal et al., 2025). In one emergency department, education alone improved identification behaviours at $5,330 a year, and adding an armband scanner pushed them further at $104,045 (Spain et al., 2015). Syntheses report that education improved knowledge more than specimen outcomes (Hamithi et al., 2026) and that evidence for training alone is insufficient (Sandhu et al., 2017). The one Saudi intervention, improvement cycles in a Riyadh receiving unit, cut errors by 25% (Al Saleem & colleagues, 2016), and respondents in Gulf laboratories perceived fewer error events after CAP accreditation (Abdelaziz et al., 2026). Every effect size here comes from an uncontrolled before–after design (Table 4).

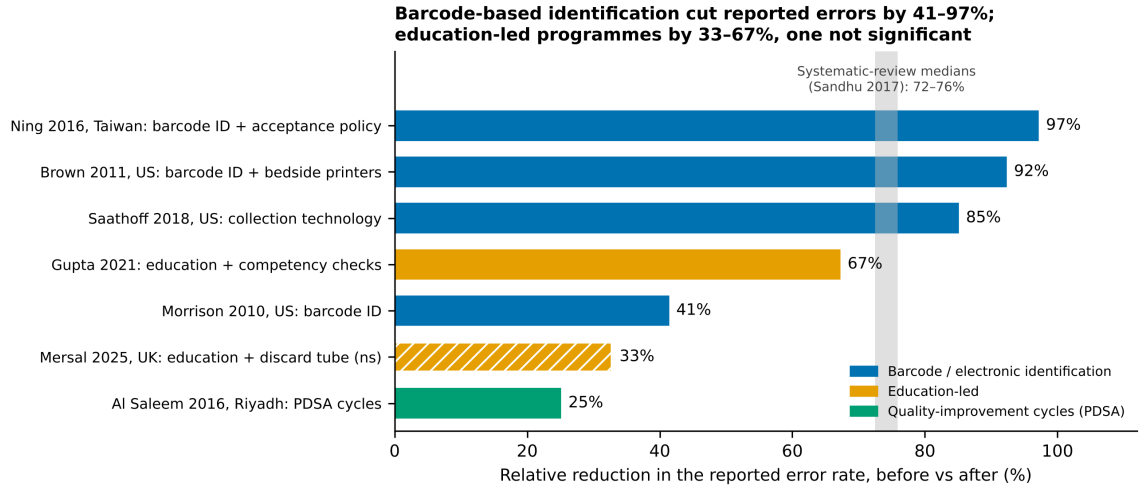


**Figure 3.** Relative reduction in reported errors after barcode-based identification and education-led programmes. Values come from Tables 3 and 4: Ning 97.1%, Brown 92.2%, Saathoff 85.0%, Gupta 67.1%, Morrison 41.3%, Mersal 32.7% (hatched, not significant) and Al Saleem 25% (as reported). All studies were uncontrolled before–after designs, so the reductions are descriptive. The Sandhu systematic review reports median reductions of 72.45–75.86% for communication and labeling practices.

**Table 4.** Synthesis by domain and certainty of the evidence

| Domain | Direction of the evidence | Main sources | Certainty |
|---|---|---|---|
| Size and pattern of errors | Clotted, insufficient and hemolyzed specimens dominate in Saudi and global data | Getawa 2022; Gega 2026; Table 2 | Low (definitions differ) |
| Individual factors | Technique and human factors most often named; training gaps reported | Lichenstein 2016; Saengpattrachai 2026; Fang 2008; Güner 2025 | Low |
| Workload and time | More errors at high workload and outside working hours; link not linear | Sarkar 2026; Dündar 2023, 2026; Alonaizan 2026 | Low |
| Care setting | Emergency and inpatient areas carry the largest burden | Alcantara 2022; Jeraiby 2025; Alonaizan 2026 | Low |
| Barcode and electronic identification | Consistent 41–97% fewer identification errors | Morrison 2010; Brown 2011; Ning 2016; Saathoff 2018; Kaufman 2019 | Moderate for direction, low for size |
| Communication and standard labeling protocols | Median reductions of 72–76% | Sandhu 2017 | Low to moderate |
| Education and competency programmes | Mixed; knowledge improves more than outcomes | Gupta 2021; Mersal 2025; Spain 2015; Hamithi 2026 | Low |
| Improvement cycles and accreditation | 25% fewer errors in Riyadh; perceived fewer events after accreditation | Al Saleem 2016; Abdelaziz 2026 | Very low |

### 3.7 Appraisal of the source manuscript

Table 5 sets each contribution of the supplied manuscript (Alfaifi et al., unpublished) against the evidence above.

**Table 5.** Contributions of the source manuscript and the evidence found

| Contribution in the source manuscript | Evidence in this review | Verdict |
|---|---|---|
| Pre-analytical errors cause 60–70% of laboratory errors; a later section gives 46–70% and up to 80–90% for sample quality | Lippi et al. (2011) give nearly 60–70%; the wider ranges are not traced to a source | Supported; ranges need sources |
| Individual factors: training, fatigue and stress, mistakes, communication; later, closed identification questions and technique lapses | Human factors in 82.8–91.1% of contributing factors; technique, tourniquet and training gaps documented; fatigue and closed questions not measured | Largely supported |
| Workplace factors: heavy workload, staff shortages, inadequate equipment, poor organization | Workload and time-of-day associations; manual labeling steps; staffing shortage not measured | Partly supported |
| Five interventions: training, standard procedures, barcodes, workload management, quality monitoring | Barcodes and standard protocols strongly supported; training mixed; workload management and monitoring supported only indirectly | Partly supported |
| Errors "should not be viewed solely as failures of individual performance"; a systems approach "shifts the focus from blaming individuals" | 60% of errors originated outside the laboratory; nurses cite institutional factors; no study compared punitive and non-punitive cultures | Supported in principle; culture claim untested |
| Technology: positive patient identification, order entry with decision support, automation | Positive patient identification supported; decision support and automation not evaluated in included studies | Partly supported |

Two reporting issues need attention before submission. The second half of the manuscript carries unmarked fragments of source text (for example "Testing, Psychometri…" and a bare "National Institutes of Health (NIH)" line) and statistics without citations, and the reference lists are numbered separately. The authors should replace these with primary citations.

### *4. Discussion*

Pre-analytical errors in the evidence reviewed cluster by specimen type, care setting, time of day and workflow, not at random, and the interventions with the clearest effect act on the system (identification technology, standard protocols) rather than on individual vigilance alone. This agrees with the source manuscript's systems framing, though most of its supporting claims rest on indirect evidence.

**Saudi and international pictures.** Saudi rejection-only rates of 1.28–2.25% bracket the pooled global rate of 1.99% (Getawa et al., 2022), so the headline burden is not unusual. The very high Saudi figures of 9.3% and 12.1% count samples never received, and the very low 0.063% divides by all orders; comparing them with rejection rates would mislead. The cause mix differs by section. Hemolysis led in Saudi biochemistry (45.3% in Jeraiby, 2025; 75.92% in Alonaizan et al., 2026), above the pooled global share of 22.87%, while clotting and insufficient volume led in hematology (Alshaghdali et al., 2022; Iqbal et al., 2023). Hemolysis is largely a collection-technique problem, which fits the Riyadh root-cause findings on needle gauge and tourniquet time.

**Evidence gap.** Saudi studies describe errors well but test little. Only one (Al Saleem & colleagues, 2016) evaluated an intervention, whereas the barcode evidence comes from the United States, Taiwan and Australia. Those settings differ from Saudi laboratories in staffing and information systems, so effect sizes may not transfer, although the direction was consistent across five designs.

**Practical reading.** The evidence supports four actions: bedside positive patient identification with printed labels; standard collection kits with competency checks on technique; monitoring of

rejection by unit and time of day using common definitions such as the IFCC indicators (Plebani, 2012); and non-punitive error reporting. The last is supported only by qualitative accounts (Güner et al., 2025) and by the logic of root-cause analysis, not by a controlled comparison.

### *5. Strengths and limitations*

**Strengths.** The review draws on Saudi, Gulf and international sources and tags each; every figure is generated from the tables; a possible duplicate dataset was detected and excluded; and the supplied manuscript was appraised claim by claim.

**Limitations.** Screening and extraction were single-reviewer and abstract-level, so numbers were not checked against full texts and no risk-of-bias tool was applied. No protocol was registered. Only PubMed and Consensus were searched, Consensus returns a ranked top 20 per query, and two PubMed queries were mis-parsed, so relevant studies may be missing. Only English records were sought. Saudi studies are mostly retrospective single-centre audits with differing definitions, intervention effects come from uncontrolled before–after designs, and the Gupta et al. record does not state its country. Fatigue, interruptions, staffing and reporting culture could not be assessed.

### *6. Conclusion*

Pre-analytical errors in Saudi and international laboratories arise mainly at collection and identification and are shaped by workload, timing and setting. Barcode-based identification and standard protocols reduced errors most consistently, education alone less so. Saudi laboratories need common error definitions and prospective, controlled evaluations of these measures.

### *Declarations*

**Ethics approval and consent.** Not required. The review used published literature and no patient data. Consent to participate does not apply.

**Funding.** Not Applicable

**Conflicts of interest.** The included study by Ahmed et al. (2026) comes from a Riyadh centre, so authors affiliated with that institution should declare any overlap.

**Data availability.** All records were retrieved from PubMed and Consensus on 21 November 2026. The search queries are in Table 1, and the extracted values are in Tables 2, 3 and 5.

**AI transparency.** This manuscript was drafted with the help of Claude. Screening and extraction were abstract-level and single-reviewer, so the authors must check every value against the full texts before submission.

**Attribution.** Bibliographic records for items with a DOI come from PubMed. Entries marked † come from Consensus records and lack volume, pages or DOI.

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