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# DIGITAL BEDSIDE SPECIMEN IDENTIFICATION AND CLOSED-LOOP TRACKING TO PREVENT LABORATORY SAMPLE ERRORS: A SYSTEMATIC REVIEW

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**Abstract**

**Background:** Specimen misidentification and mislabelling are among the most serious pre-analytical failures in laboratory medicine because they can lead to wrong diagnoses and ABO-incompatible transfusion. Digital bedside identification (barcode or electronic positive patient identification, ePPID) and closed-loop specimen tracking are widely promoted as countermeasures, yet the evidence has not been synthesised with a Saudi and regional focus.

**Objective:** To synthesise evidence on whether digital bedside specimen identification and closed-loop tracking reduce specimen identification and labelling errors, and to compare the Saudi/regional evidence base with international findings.

**Methods:** Systematic review reported according to PRISMA 2020. PubMed (15 queries) and Consensus were searched on 23 November 2026. Records were screened by title and abstract; eligibility was assessed at abstract level by one reviewer. No protocol was registered, no formal risk-of-bias tool was applied, and findings were synthesised narratively (SWiM) with design-based certainty ratings.

**Results:** From 167 records identified (151 screened), 25 studies were included (5 Saudi, 0 other GCC/MENA, 20 international). Large audits place mislabelled ABO samples at about 0.7% to 1.1% and wrong blood in tube (WBIT) at roughly 1 to 4 per 10,000 samples. Before–after and comparative studies of barcode/ePPID systems reported 41% to 90% lower error outcomes (for example, adjusted WBIT 1 in 14,606 with ePPID versus 1 in 3,046 with manual identification), but one multi-site audit found no association with barcoding and residual WBIT persisted where ePPID was bypassed or misused. Evidence on closed-loop tracking was sparse (one RFID pilot; one scan-with-hard-stop study showing an 88.4% reduction in wrong tissue in block). None of the Saudi studies evaluated digital bedside identification; they documented pre-analytical rejection rates of 0.063% to 9.3%, dominated by haemolysis and clotting.

**Conclusions:** International evidence consistently favours digital bedside identification with enforced hard stops, but it is largely observational and of low certainty, and Saudi evidence is limited to baseline error surveillance. Prospective, controlled evaluations in Saudi hospitals are needed.

**Keywords:** specimen identification; wrong blood in tube; barcode; positive patient identification; closed-loop tracking; pre-analytical errors; patient safety; Saudi Arabia

## 1. Introduction

The pre-analytical phase accounts for most laboratory errors, and patient misidentification is among the errors with the worst potential consequences (Lippi et al., 2009). A specimen that carries the right label but the wrong blood, a wrong blood in tube (WBIT) event, may remain undetected and lead to misdiagnosis, inappropriate treatment or an ABO-incompatible transfusion. In the United States, 80 fatalities after ABO-incompatible red cell transfusion were reported to the Food and Drug Administration between 2000 and 2019, and sample collection errors remained among the leading causes (Storch et al., 2020).

Manual identification relies on staff vigilance at the moment of collection, when interruptions, workload and the availability of another patient's labels create opportunities for slips and protocol violations (Dunbar et al., 2022). Digital bedside specimen identification addresses this weakness by scanning the patient wristband, checking the active order and printing labels at the point of care. Closed-loop tracking extends the same principle downstream, so that each tube is scanned at collection, transport and receipt, and cannot progress when a step is missed. These approaches are attractive for Saudi hospitals pursuing national and international accreditation, but regional studies of the pre-analytical phase mostly describe rejection rates and causes rather than evaluating identification technology.

This review therefore asks: **(P)** in patients having laboratory specimens collected in hospitals or clinics, **(I)** does digital bedside identification and/or closed-loop specimen tracking, **(C)** compared with manual identification or no tracking, **(O)** reduce specimen misidentification, mislabelling, WBIT or related rejection? A secondary aim was to compare Saudi and regional evidence with the international evidence base.

## 2. Methods

### *2.1 Design and reporting*

We conducted a systematic review reported according to PRISMA 2020. No protocol was registered. Because designs and outcomes were too heterogeneous for pooling, we used narrative synthesis following the Synthesis Without Meta-analysis (SWiM) approach.

### *2.2 Eligibility criteria*

We included peer-reviewed, English-language studies that reported quantitative specimen-identification, mislabelling, WBIT or rejection outcomes and that either (a) evaluated or compared barcode, ePPID, RFID or scan-based tracking or verification, (b) systematically reviewed interventions against these errors, (c) provided multi-institution or national benchmark data on identification/labelling error rates and consequences, or (d) reported pre-analytical error or rejection data from Saudi Arabia or other GCC/MENA hospitals as a regional baseline. We excluded narrative reviews and commentaries, technical prototypes or algorithms without error outcomes, post-analytical detection methods (delta checks, machine-learning result review), and general pre-analytical studies from outside the Gulf/MENA region without an identification focus.

### *2.3 Information sources and search*

PubMed was searched with 15 queries and Consensus with one query on 23 November 2026 (Table 1). A second Consensus query on digital identification was rate-limited and was not repeated. Broad queries whose Boolean expansion returned very large result sets were limited to the 20 top-ranked records. Three targeted PubMed lookups were used to locate PubMed entries for regional studies surfaced by Consensus; one was found.

**Table 1.** Search strategy and records retrieved (searches run 23 November 2026).

| Database | Query | Hits | Screened/retrieved |
|---|---|---|---|
| PubMed | (barcode OR positive patient identification) AND specimen labeling AND error | 51 | 20 |
| PubMed | bedside specimen labeling barcode handheld mislabeled | 0 | 0 |
| PubMed | specimen identification error laboratory Saudi Arabia | 0 | 0 |
| PubMed | specimen tracking RFID OR electronic OR barcode laboratory pre-analytical errors | 3,826,393† | 20 |
| PubMed | wrong blood in tube OR mislabelled specimens systematic review | 107 | 20 |
| PubMed | patient identification specimen labeling Saudi OR Riyadh OR Jeddah OR Gulf | 170,538† | 20 |
| PubMed | pre-analytical errors laboratory Saudi Arabia | 10 | 10 |
| PubMed | positive patient identification phlebotomy specimen labeling errors | 2 | 2 |
| PubMed | electronic patient identification blood sample collection wrong blood in tube | 8 | 8 |
| PubMed | specimen collection errors Saudi hospital laboratory rejection | 2 | 2 |
| PubMed | laboratory specimen rejection Gulf OR Qatar OR Kuwait OR Emirates OR Oman OR Jordan | 174,424† | 20 |
| PubMed | barcode specimen collection nurses handheld laboratory errors | 0 | 0 |
| PubMed | RFID specimen tracking laboratory | 11 | 11 |
| PubMed | mislabeled specimens Q-Probes College of American Pathologists | 4 | 4 |
| PubMed | patient misidentification laboratory specimens electronic wristband scanning | 0 | 0 |
| Consensus | specimen labeling and pre-analytical errors in Saudi Arabia or Gulf hospitals | 30 (top results) | 30 |
| Total | | | 167 retrieved |

† Boolean OR expansion by PubMed produced very large sets; only the 20 top-ranked records were retrieved and screened. PubMed yielded 137 retrievals (125 unique) and Consensus 30.

### *2.4 Screening, extraction and appraisal*

One reviewer screened titles and abstracts and assessed eligibility at abstract level; full texts were not retrieved, so extraction is limited to what abstracts report. Records that could not be verified in PubMed (identified through Consensus only) were excluded. For each study we extracted design, setting, sample, digital element, outcomes and key numbers, and tagged each as Saudi, GCC-MENA or International. No formal risk-of-bias instrument was applied; instead, a design-based certainty rating (high, moderate, low, very low) was assigned qualitatively per domain and is not a

formal GRADE assessment. Percentage reductions shown in figures were recalculated from the rates reported in the source abstracts and were not pooled.

## 3. Results

### *3.1 Study selection*

The searches identified 167 records (137 PubMed, 30 Consensus); after removing 16 duplicates, 151 were screened and 59 assessed at abstract level (Figure 1). Twenty-five studies were included. Thirty-four were excluded after assessment: 11 narrative reviews or commentaries, 5 prototypes or algorithms without error outcomes, 10 post-analytical detection studies, 4 of other design, 2 with no abstract or non-English text, and 2 Consensus-only records (one Saudi, one Omani) that could not be located in PubMed.

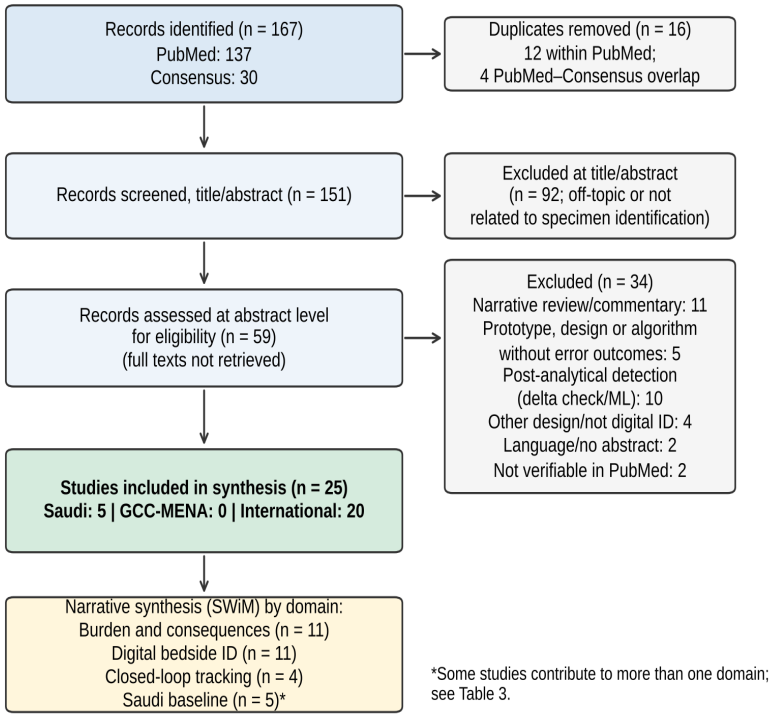


**Figure 1.** PRISMA 2020 flow diagram. Counts come from the search log in Table 1. Eligibility was assessed at abstract level by one reviewer. GCC-MENA = Gulf Cooperation Council and Middle East/North Africa.

### *3.2 Characteristics of included studies*

Table 2 summarises the 25 included studies. Twenty were international (United States, United Kingdom, Australia, Taiwan, India and multinational collaborations) and five were Saudi single-centre or regional laboratory studies; no eligible non-Saudi GCC/MENA study was verified. Designs were predominantly observational. The international studies comprised nine audits, benchmarking or multicentre comparisons, five before–after evaluations, two systematic reviews and four others (pilot, policy implementation, case series and fatality review); the Saudi studies were retrospective or quality-improvement studies.

**Table 2.** Characteristics and main findings of included studies (S = Saudi; I = International).

| Study | Setting | Design | Sample | Digital element | Main finding |
|---|---|---|---|---|---|
| Alenezy 2025 | S; Taif | Retrospective, single centre | 3,346,199 test orders; 2,104 errors | None (baseline) | Error rate 0.063%; clotted 32%, insufficient quantity 31%; highest in blood bank (0.4%) |
| Al Saleem 2016 | S; Riyadh | Quality improvement (PDSA) | MOH regional lab, receiving/processing | Process redesign | 2.31 errors per 1,000 samples at baseline; 25% reduction |
| Alonaizan 2026 | S; Riyadh | Retrospective, IFCC indicators | 845,647 tests; 10,783 rejected | None (baseline) | 1.28% rejected; haemolysis 75.9%; ED 38.7% of inpatient rejections |
| Alshaghdali 2022 | S; Hail | Retrospective, 3 years | 95,002 haematology samples | None (baseline) | 9.3% pre-analytical errors; clotted 3.6%; fell from 11.6% to 6.5% |
| Jeraiby 2025 | S; Saudi Arabia | Retrospective cohort | 321,465 samples (2020) | None (baseline) | 2.25% rejected; haemolysis 45.3%; ED misidentification 7.4% (as reported) |
| Booth 2025 | I; UK | National audit, repeat | 179 sites; 23,584 rejected samples | Electronic bedside labelling | Rejection 4.4% (2.99% in 2012); WBIT 1 in 5,882; electronic-only sites 46.9% lower rejection |

| Study | Setting | Design | Sample | Digital element | Main finding |
|---|---|---|---|---|---|
| Bostwick 2013 | I; USA | Pilot | 1,067 prostate biopsies | RFID tracking | 78.3% processed through RFID; dynamic tracking achieved |
| Carmack 2024 | I; mainly USA | Systematic review | 44 studies | Various | Mislabelling in 61.3% of studies; implementation studies reported 70% to 100% error reduction |
| Cottrell 2013 | I; multiple | Systematic review | 9 independent studies | Single/multiple interventions | All interventions reduced WBIT; most effective unclear; sustainability unclear |
| Dunbar 2021 | I; 9 countries | Retrospective multicentre | 39 services; 1,394,862 samples; 143 WBIT | ePPID (some sites) | WBIT 1.03/10,000; ED 1.23 vs wards 0.71 vs clinics 0.24; ePPID OR 0.32 in ED |
| Dunbar 2022 | I; 11 countries | Case series | 36 centres; 331 WBIT | ePPID (some sites) | 53% protocol violations plus slips; 43 WBIT where ePPID not used or misused |
| Goodnough 2009 | I; USA | Policy implementation | Single institution | Two-sample ABO check | Baseline corrected error 1:467 (nurse draws), 1:5,555 (laboratory phlebotomy); 1:630 after (nurse) |

| Study | Setting | Design | Sample | Digital element | Main finding |
|---|---|---|---|---|---|
| Grimm 2010 | I; USA | Q-Probes benchmark | 122 institutions | None | Mislabelled 1.12%; WBIT 0.04% |
| Karcher 2014 | I; USA | Q-Probes benchmark | 78 laboratories | None | Rejection delayed results (median 65 min), often abandoned; relabelling unsafe |
| Kaufman 2019 | I; multicentre | Retrospective comparison plus prospective typing | 20 hospitals (> 2.1 million samples); 2,844 rejected samples | ePPID vs manual | Adjusted WBIT 1:14,606 (ePPID) vs 1:3,046 (manual); WBIT 1:71 among rejected samples |
| Krishna 2025 | I; India | Retrospective root-cause | Hospital blood centre | None | WBIT 4.8/10,000 requests; peak 8 pm to 2 am |
| Layfield 2010 | I; USA | Audit (18 months) | 75 labelling errors | None | 0.25% of cases; 69% occurred in gross room |
| Morrison 2010 | I; USA | Before–after | Inpatient phlebotomy | Barcode PPID | Labelling errors 5.45 to 3.2 per 10,000 (P = .0013) |
| Nakhleh 2011 | I; USA | Q-Probes benchmark | 136 institutions; 1,811 events | None | Per 1,000: cases 1.1, specimens 1.0, blocks 1.7, slides 1.1 |
| Novis 2017 | I; USA | Q-Probes benchmark | 30 institutions; 41,333 ABO samples | Barcoding (exposure) | Mislabelled 7.4/1,000; WBIT 0.43/1,000; barcoding not associated (P = .80, .79) |

| Study | Setting | Design | Sample | Digital element | Main finding |
|---|---|---|---|---|---|
| Passwater 2022 | I; USA | Continuous QI, before–after | Single institution | ePPID + dual verification | More than 10-fold fewer WBIT; 47% fewer mislabelled specimens |
| Spain 2015 | I; Australia | Prospective before–after | 282 ED collections | Armband scanner + education | Armband applied before collection 36% to 90%; no primary misidentification detected |
| Storch 2020 | I; USA | Fatality review (FDA) | 80 deaths, 2000 to 2019 | None | Rate fell from 1 per 2 million to 1 per 7.14 million units; WBIT a leading cause |
| Weaver 2021 | I; USA | Before–after | 38,848 vs 42,411 cases | Scan confirmation + hard stop | Wrong tissue in block 0.043% to 0.005% (−88.4%) |
| Yu 2019 | I; Taiwan | Before–after + survey | 68 perioperative nurses | Barcode labelling | Specimen management errors decreased significantly (magnitude not in abstract) |

ED = emergency department; ePPID = electronic positive patient identification; PPID = positive patient identification; QI = quality improvement; WBIT = wrong blood in tube. Data are as stated in the source abstracts.

### *3.3 Burden and consequences of identification errors*

Eleven studies describe how common identification and labelling errors are and what they cost. In US benchmarking, 1.12% of ABO samples were mislabelled and 0.04% were WBIT (Grimm et al., 2010); a later study reported 7.4 mislabelled and 0.43 WBIT events per 1,000 specimens with no change from 2007 (Novis et al., 2017). Surgical pathology labelling errors were reported at roughly 1 per 1,000 cases, specimens or slides across 136 institutions (Nakhleh et al., 2011), and 0.25% of cases in a single-centre audit (Layfield & Anderson, 2010). Multinational data show WBIT is more frequent in emergency departments (1.23 per 10,000 samples) than wards (0.71) or outpatient clinics (0.24) (Dunbar et al., 2021), and an Indian blood centre reported 4.8 WBIT per

10,000 requests, concentrated in the late evening (Krishna et al., 2025). In the UK, the national sample rejection rate rose to 4.4% from 2.99% a decade earlier (Booth & Davies, 2025).

The consequences are substantial. Rejection of an identification-compromised sample led to a median delay of 65 minutes and frequent test abandonment, and relabelling of incorrectly labelled specimens was associated with later mislabelling (Karcher & Lehman, 2014). Before a two-specimen verification policy, corrected error rates for nurse and laboratory phlebotomy draws were 1 in 467 and 1 in 5,555 (Goodnough et al., 2009).

### *3.4 Digital bedside identification*

Eleven studies address barcode or ePPID systems (Figure 2). A barcode positive-identification system for inpatient phlebotomy reduced labelling errors from 5.45 to 3.2 per 10,000 (Morrison et al., 2010). Across 20 hospitals, electronic identification at pretransfusion sampling was associated with an unadjusted WBIT rate of 1 in 35,806 versus 1 in 10,110 for manual identification, and an adjusted rate of 1 in 14,606 versus 1 in 3,046 (Kaufman et al., 2019). Combining ePPID with independent dual verification produced a more than 10-fold reduction in WBIT and a 47% reduction in mislabelled specimens (Passwater et al., 2022). In emergency departments, ePPID was associated with lower WBIT odds (OR 0.32, 95% CI 0.11 to 0.96), whereas no significant association was found on wards or in clinics (Dunbar et al., 2021). In the UK audit, sites using only electronic labelling had a 46.9% lower rejection rate than hand-labelling sites but still reported WBIT (Booth & Davies, 2025). An Australian emergency department study found that an armband scanner added to education raised armband application before collection from 36% to 90% (Spain et al., 2015), and a Taiwanese barcode implementation reduced specimen management errors (Yu et al., 2019).

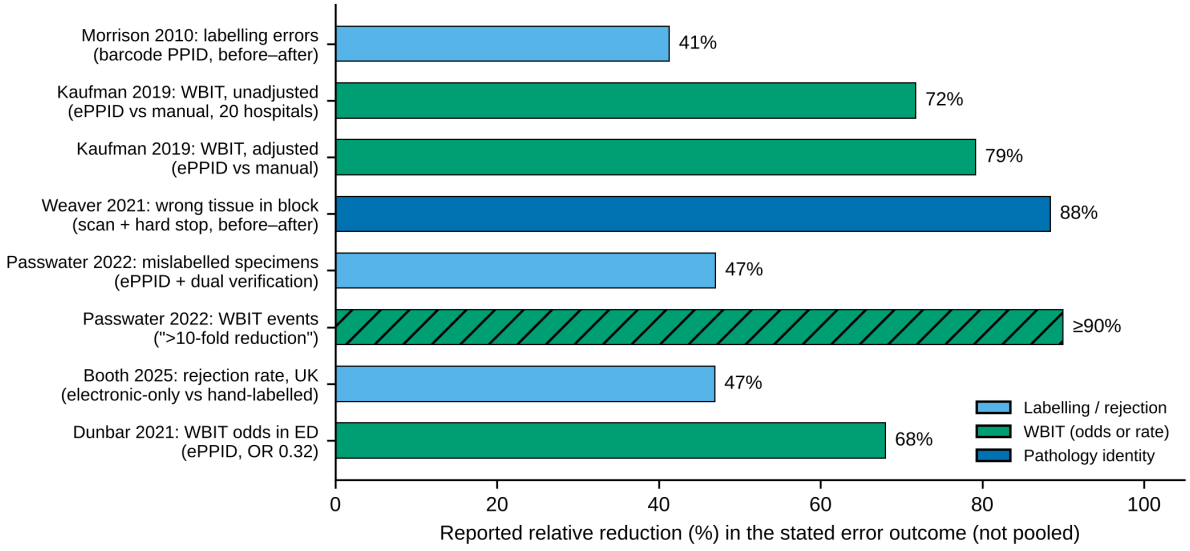


**Figure 2.** Reported relative reductions in specimen error outcomes associated with digital identification. Values are recalculated from rates stated in the source abstracts (Table 2) and are not pooled; outcome definitions and comparators differ. The hatched bar is reported only as a more than 10-fold reduction. Dunbar 2021 shows reduction in odds, not in rate. ePPID = electronic positive patient identification; PPID = positive patient identification; WBIT = wrong blood in tube.

Findings were not uniformly favourable. A US benchmarking study found that barcoding was not associated with lower mislabelling or WBIT rates (Novis et al., 2017). In an international case series, 43 WBIT events occurred where ePPID was available but not used or used incorrectly, and having another patient's labels or tubes available during phlebotomy was the most common

contributing factor (Dunbar et al., 2022). Two systematic reviews support the direction of effect but note that the evidence is limited and the most effective component and its sustainability are unclear (Cottrell et al., 2013), and that published studies are few and largely from Western settings (Carmack et al., 2024).

### *3.5 Closed-loop tracking and downstream verification*

Only four studies informed this domain. A scan-confirmation step for tissue blocks, made mandatory with a hard stop that blocks unconfirmed items from the packing list, cut wrong tissue in block events from 0.043% to 0.005% (Weaver et al., 2021). An RFID pilot of 1,067 prostate biopsies achieved dynamic tracking, with 78.3% of specimens successfully processed through the RFID workflow (Bostwick, 2013). Evidence that operational rules matter comes from the finding that routine relabelling of rejected specimens is hazardous (Karcher & Lehman, 2014), and from the dual-verification component in Passwater et al. (2022).

### *3.6 Saudi and regional baseline*

The five Saudi studies measured pre-analytical error or rejection rather than digital identification (Figure 3). Rates ranged from 0.063% of 3,346,199 test orders in a Taif hospital (Alenezy et al., 2025) to 9.3% of haematology samples in Hail, which fell from 11.6% to 6.5% over three years (Alshaghdali et al., 2022). In Riyadh, 1.28% of 845,647 tests were rejected, with haemolysis accounting for 75.9% of rejections (Alonaizan et al., 2026). A 2020 Saudi study found 2.25% of 321,465 samples rejected and reported misidentification in 7.4% of emergency department rejections (Jeraiby, 2025). A Riyadh quality-improvement project reduced receiving-stage errors by 25% from a baseline of 2.31 per 1,000 samples (Al Saleem & Al-Surimi, 2016). No Saudi study evaluated barcode, ePPID or tracking technology, and identification-specific outcomes were seldom separated from other rejection causes.

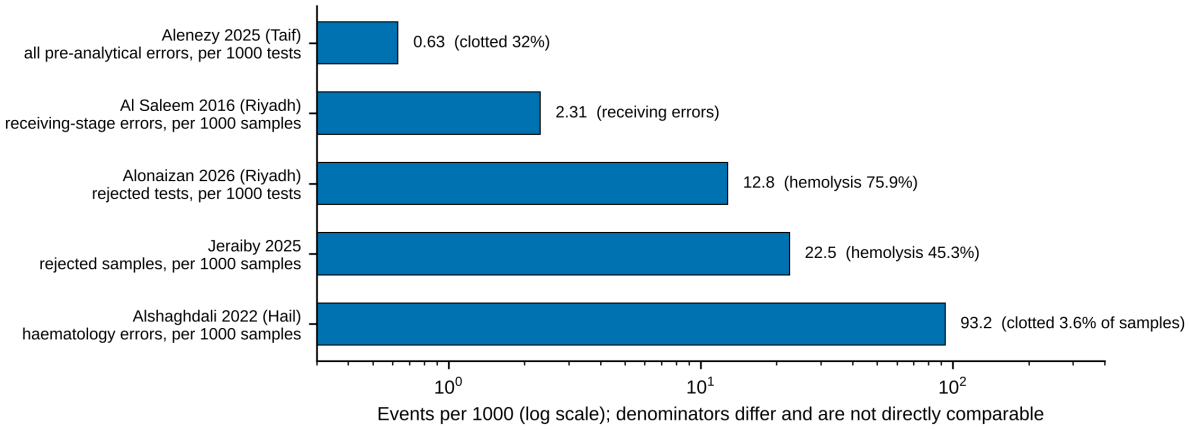


**Figure 3.** Pre-analytical error or rejection rates reported in Saudi studies, expressed per 1,000 and shown on a log scale. Denominators (tests versus samples) and error definitions differ, so bars are not directly comparable. Text in brackets gives the leading cause as reported.

### *3.7 Synthesis and certainty*

Table 3 summarises the four domains. Of nine comparative or before–after evaluations of scan-based identification or verification, eight reported lower error outcomes or better collection behaviour and one found no association (Novis et al., 2017); the association in Dunbar et al. (2021) was significant only in emergency departments. Designs were mainly uncontrolled before–after studies or cross-site comparisons subject to confounding.

**Table 3.** Narrative synthesis by domain with design-based certainty (qualitative, not formal GRADE).

| Domain | Summary of findings | Certainty | Saudi/regional coverage |
|---|---|---|---|
| Burden and consequences (n = 11) | Mislabelling about 0.7% to 1.1% of ABO samples; WBIT about 1 to 4 per 10,000; higher in EDs; rejection delays care and relabelling is unsafe | Moderate (large, consistent audits; observational) | India (Krishna); no Saudi WBIT data |
| Digital bedside identification (n = 11) | Barcode/ePPID associated with 41% to 90% lower error outcomes; null result in one benchmark; residual WBIT when bypassed | Low (uncontrolled or cross-site comparisons; consistent direction) | None evaluated in Saudi Arabia |
| Closed-loop tracking and hard stops (n = 4) | Hard-stop scan confirmation cut wrong tissue in block 88.4%; RFID feasible; relabelling rejected | Very low (one before–after, one pilot) | None |
| Saudi baseline (n = 5) | Rejection 0.063% to 9.3%; haemolysis and clotting dominate; identification errors under-reported | Low (single-centre, retrospective; non-comparable definitions) | Taif, Riyadh, Hail, Saudi Arabia (5) |

Studies contribute to more than one domain (for example, Booth & Davies, Dunbar et al., Novis et al. and Karcher & Lehman).

## 4. Discussion

### *4.1 Principal findings*

This review found consistent but low-certainty international evidence that digital bedside identification lowers specimen identification and labelling errors, with the strongest effects when scanning is enforced by a hard stop and combined with independent verification. Reported reductions ranged from 41% to at least 90%, but they come from heterogeneous outcomes and mostly uncontrolled designs, so the magnitude should not be taken as a pooled estimate. Saudi evidence documents the pre-analytical burden but does not test technological countermeasures.

### *4.2 Saudi versus international evidence*

Saudi laboratories report overall rejection or error rates of roughly 0.06% to 2.3% of tests or samples (9.3% in one haematology laboratory), with haemolysis and clotting dominating, so the visible error burden in Saudi data is collection quality rather than identity. International audits find mislabelling in around 0.7% to 1.1% of ABO samples and WBIT in about 1 to 4 per 10,000. These are not directly comparable, because the Saudi reports aggregate all rejection causes and rarely isolate identification outcomes. The Saudi emergency department signal (misidentification in 7.4% of rejections in one study) parallels the international finding that emergency departments carry higher WBIT risk (Dunbar et al., 2021), but this should be treated as a hypothesis. A Saudi laboratory that does not separately record identity-related rejections and silent WBIT events cannot yet know its own baseline.

### *4.3 A closed-loop model and implementation lessons*

Figure 4 combines the two layers examined here. Bedside identification covers scanning of the wristband, matching to the active order, label printing at the bedside and scanning of the tube at collection. Closed-loop tracking adds scans at transport and receipt with a hard stop, and routes any exception to rejection and re-collection rather than manual relabelling, consistent with the hazard of relabelling (Karcher & Lehman, 2014).

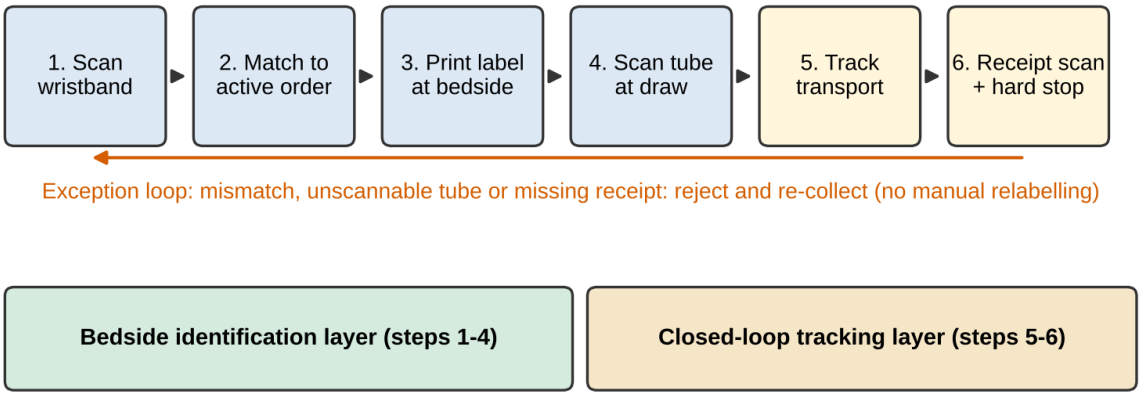


**Figure 4.** Conceptual closed-loop specimen identification and tracking model synthesised from the included evidence (not derived from a dataset). Steps 1 to 4 are supported mainly by barcode/ePPID studies; steps 5 and 6 by the hard-stop and RFID studies.

Three implementation lessons follow. First, technology is not self-executing: WBIT persisted when ePPID was bypassed or misused, and sites with electronic labelling still reported WBIT (Dunbar et al., 2022; Booth & Davies, 2025). Second, the benefit may depend on setting; the association was clearest in emergency departments (Dunbar et al., 2021). Third, costs and workflow matter: in one emergency department the education programme alone and with an armband scanner were reported to cost $5,330 and $104,045 per year respectively (Spain et al., 2015), and a UK audit linked higher rejection to zero-tolerance policies and sampling pressures, urging a human-factors approach (Booth & Davies, 2025). A second ABO check sample remains a useful safety net where ePPID is in place (Dunbar et al., 2022).

### *4.4 Strengths and limitations*

Strengths include the explicit PRISMA flow, a search log, verification of every included record in PubMed, and side-by-side coverage of Saudi and international evidence. The main limitations are methodological. Only PubMed and one Consensus query were completed (a second Consensus query was rate-limited), broad queries were truncated to the top 20 records, screening was by a single reviewer, eligibility was judged at abstract level without full texts, no protocol was registered, and no formal risk-of-bias tool or GRADE assessment was used. Heterogeneous outcomes prevented meta-analysis, publication bias is likely, and most included studies are from the United States. An Omani study identified through Consensus could not be located in PubMed, so the verified regional evidence is effectively Saudi.

## 5. Conclusion

Digital bedside identification with enforced scanning and closed-loop verification is associated with fewer specimen identification and labelling errors in international studies, but the evidence is observational and of low certainty. Saudi studies describe the pre-analytical burden without evaluating these tools. We recommend prospective, controlled before–after or stepped-wedge

evaluations in Saudi hospitals that record identity-specific outcomes (mislabelling per 10,000 samples, WBIT, recollection time) alongside scan-compliance rates.

## Declarations

**Ethics approval and consent:** Not applicable; this review used published literature only. **Funding:** Not Applicable. **Conflicts of interest:** Not Applicable. **Data availability:** All data are from the cited published studies; the search log is in Table 1. **AI transparency:** Literature retrieval, data extraction, figure generation and drafting were assisted by an AI model (Claude, Anthropic). The authors must verify all extracted figures against full texts and take responsibility for the final content.

## References

Alenezy, N. T., Arain, S. A., Omair, A., Afnan, R., Nadheef, A., Ahmed, A. F., & Sindi, H. M. (2025). Frequencies and causes of pre-analytical errors in a tertiary care hospital laboratory in Saudi Arabia. *Annals of Saudi Medicine*, *45*(6), 381–387. https://doi.org/10.5144/0256-4947.2025.381

Alonaizan, S. A., Alenaizan, N. A., Binjomah, A. Z., Aldosari, S., & Arain, S. A. (2026). Evaluation of pre-analytical performance using IFCC quality indicators, Six Sigma metrics and root cause analysis in a biochemistry laboratory: A retrospective study. *Diagnostics*, *16*(15), Article 2357. https://doi.org/10.3390/diagnostics16152357

Al Saleem, N., & Al-Surimi, K. (2016). Reducing the occurrence of errors in a laboratory's specimen receiving and processing department. *BMJ Quality Improvement Reports*, *5*(1), Article u211474.w4624. https://doi.org/10.1136/bmjquality.u211474.w4624

Alshaghdali, K., Alcantara, T. Y., Rezgui, R., Cruz, C. P., Alshammary, M. H., Almotairi, Y. A., & Alcantara, J. C. (2022). Detecting preanalytical errors using quality indicators in a hematology laboratory. *Quality Management in Health Care*, *31*(3), 176–183. https://doi.org/10.1097/QMH.0000000000000343

Booth, C., & Davies, P. (2025). Transfusion sample mislabelling and wrong blood in tube in the UK: Insights from the national comparative audits of blood transfusion in 2012 and 2022. *Transfusion Medicine*, *35*(1), 41–47. https://doi.org/10.1111/tme.13092

Bostwick, D. G. (2013). Radiofrequency identification specimen tracking in anatomical pathology: pilot study of 1067 consecutive prostate biopsies. *Annals of Diagnostic Pathology*, *17*(5), 391–402. https://doi.org/10.1016/j.anndiagpath.2013.04.007

Carmack, H. J., Lazenby, B. S., Wilson, K. J., Bakkum-Gamez, J. N., & Carranza, L. (2024). Lost, mislabeled, and mishandled surgical and clinical pathology specimens: A systematic review of published literature. *American Journal of Clinical Pathology*, *162*(4), 349–355. https://doi.org/10.1093/ajcp/aqae055

Cottrell, S., Watson, D., Eyre, T. A., Brunskill, S. J., Dorée, C., & Murphy, M. F. (2013). Interventions to reduce wrong blood in tube errors in transfusion: a systematic review. *Transfusion Medicine Reviews*, *27*(4), 197–205. https://doi.org/10.1016/j.tmrv.2013.08.003

Dunbar, N. M., Delaney, M., Murphy, M. F., Pagano, M. B., Saifee, N. H., Seheult, J., Yazer, M., Kaufman, R. M., & WBIT Study Investigators on behalf of the Biomedical Excellence for Safer Transfusion (BEST) Collaborative (2021). Emergency departments are higher-risk locations for wrong blood in tube errors. *Transfusion*, *61*(9), 2601–2610. https://doi.org/10.1111/trf.16588

Dunbar, N. M., Kaufman, R. M., & WBIT Study Investigators, The Biomedical Excellence for Safer Transfusion (BEST) Collaborative (2022). Factors associated with wrong blood in tube

errors: An international case series—The BEST collaborative study. *Transfusion*, *62*(1), 44–50. https://doi.org/10.1111/trf.16716

Goodnough, L. T., Viele, M., Fontaine, M. J., Jurado, C., Stone, N., Quach, P., Chua, L., Chin, M. L., Scott, R., Tokareva, I., Tabb, K., & Sharek, P. J. (2009). Implementation of a two-specimen requirement for verification of ABO/Rh for blood transfusion. *Transfusion*, *49*(7), 1321–1328. https://doi.org/10.1111/j.1537-2995.2009.02157.x

Grimm, E., Friedberg, R. C., Wilkinson, D. S., AuBuchon, J. P., Souers, R. J., & Lehman, C. M. (2010). Blood bank safety practices: Mislabeled samples and wrong blood in tube—A Q-Probes analysis of 122 clinical laboratories. *Archives of Pathology & Laboratory Medicine*, *134*(8), 1108–1115. https://doi.org/10.5858/2009-0674-CP.1

Jeraiby, M. A. (2025). Preanalytical phase: Evaluation of specimen rejection rates and reasons from different hospital units during coronavirus disease 2019 pandemic in Saudi Arabia. *Annals of African Medicine*, *24*(3), 643–648. https://doi.org/10.4103/aam.aam_132_24

Karcher, D. S., & Lehman, C. M. (2014). Clinical consequences of specimen rejection: a College of American Pathologists Q-Probes analysis of 78 clinical laboratories. *Archives of Pathology & Laboratory Medicine*, *138*(8), 1003–1008. https://doi.org/10.5858/arpa.2013-0331-CP

Kaufman, R. M., Dinh, A., Cohn, C. S., Fung, M. K., Gorlin, J., Melanson, S., Murphy, M. F., Ziman, A., Elahie, A. L., Chasse, D., Degree, L., Dunbar, N. M., Dzik, W. H., Flanagan, P., Gabert, K., Ipe, T. S., Jackson, B., Lane, D., Raspollini, E., . . . BEST Collaborative (2019). Electronic patient identification for sample labeling reduces wrong blood in tube errors. *Transfusion*, *59*(3), 972–980. https://doi.org/10.1111/trf.15102

Krishna, A., Pandey, H. C., Coshic, P., Kumar, R., & Jain, R. (2025). Analysis of wrong blood in tube events at a hospital-based blood centre in a tertiary care referral hospital: A perspective from a lower middle-income country. *Vox Sanguinis*, *120*(2), 155–162. https://doi.org/10.1111/vox.13767

Layfield, L. J., & Anderson, G. M. (2010). Specimen labeling errors in surgical pathology: an 18-month experience. *American Journal of Clinical Pathology*, *134*(3), 466–470. https://doi.org/10.1309/AJCPHLQHJ0S3DFJK

Lippi, G., Blanckaert, N., Bonini, P., Green, S., Kitchen, S., Palicka, V., Vassault, A. J., Mattiuzzi, C., & Plebani, M. (2009). Causes, consequences, detection, and prevention of identification errors in laboratory diagnostics. *Clinical Chemistry and Laboratory Medicine*, *47*(2), 143–153. https://doi.org/10.1515/CCLM.2009.045

Morrison, A. P., Tanasijevic, M. J., Goonan, E. M., Lobo, M. M., Bates, M. M., Lipsitz, S. R., Bates, D. W., & Melanson, S. E. (2010). Reduction in specimen labeling errors after implementation of a positive patient identification system in phlebotomy. *American Journal of Clinical Pathology*, *133*(6), 870–877. https://doi.org/10.1309/AJCPC95YYMSLLRCX

Nakhleh, R. E., Idowu, M. O., Souers, R. J., Meier, F. A., & Bekeris, L. G. (2011). Mislabeling of cases, specimens, blocks, and slides: A College of American Pathologists study of 136 institutions. *Archives of Pathology & Laboratory Medicine*, *135*(8), 969–974. https://doi.org/10.5858/2010-0726-CPR

Novis, D. A., Lindholm, P. F., Ramsey, G., Alcorn, K. W., Souers, R. J., & Blond, B. (2017). Blood bank specimen mislabeling: A College of American Pathologists Q-Probes study of 41,333 blood bank specimens in 30 institutions. *Archives of Pathology & Laboratory Medicine*, *141*(2), 255–259. https://doi.org/10.5858/arpa.2016-0167-CP

Passwater, M., Huggins, Y. M., Delvo Favre, E. D., Mukhtar, F., & Pelletier, J. P. R. (2022). Adding automation and independent dual verification to reduce wrong blood in tube (WBIT) events. *American Journal of Clinical Pathology*, *158*(2), 212–215. https://doi.org/10.1093/ajcp/aqac031

Spain, D., Crilly, J., Pierce, J., Steele, M., Scuffham, P., & Keijzers, G. (2015). Can a barcode scanner for blood collection improve patient identification integrity in the emergency department? A prospective before-and-after study. *Emergency Medicine Australasia*, *27*(1), 47–54. https://doi.org/10.1111/1742-6723.12334

Storch, E. K., Rogerson, B., & Eder, A. F. (2020). Trend in ABO-incompatible RBC transfusion-related fatalities reported to the FDA, 2000–2019. *Transfusion*, *60*(12), 2867–2875. https://doi.org/10.1111/trf.16121

Weaver, K. D., De Los Santos, Y., Gaffar, M., Zona, M. C., Gennaro, T., Shenoy, A., Flax, S., Chamala, S., Seifert, R. P., & Esnakula, A. K. (2021). Wrong Tissue in Block. *American Journal of Clinical Pathology*, *156*(4), 700–707. https://doi.org/10.1093/ajcp/aqab011

Yu, M. H., Lee, T. T., & Mills, M. E. (2019). The effect of barcode technology use on pathology specimen labeling errors. *AORN Journal*, *109*(2), 183–191. https://doi.org/10.1002/aorn.12585