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The Effectiveness of Laboratory Strategies in Reducing Analytical Carryover Between Patient Samples

Meshari Sudi M Alanazi[1], Abdullah Hussain Al Edall[2], Abir Ali Mahdi Najmi[3], Marwah Mohammed A Fatani[4], Ohood Obaidullah Abdullah Alsehli[5], Bayan Musa Alzain[6], Omar Farooq Yamani[7], Fawzia Yahya Mohammed Barnawi[8], Sahab Juwaybir M Althobaiti[9], Dalal Hammad Alabdali[10]

[1] Senior Specialist – Laboratory and Blood Bank — Regional Laboratory and Blood Bank – Northern Borders Health Cluster – Ministry of Health – Arar – Northern Borders Region – Saudi Arabia. Email: Mshari9767@gmail.com
[2] Laboratory Technician — Sarat Abidah Hospital – Asir Health Cluster – Ministry of Health – Sarat Abidah – Asir Region – Saudi Arabia.
Email: abdullahhusain1431@gmail.com
[3] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: Abir.najmi@hotmail.com
[4] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: Marwahmafjan@gmail.Com
[5] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: Alsahli.O@kamc.med.sa
[6] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: Alzain.b@kamc.med.sa
[7] Laboratory Specialist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia.
Email: Yamani.o@kamc.med.sa
[8] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: Barnawi.F@kamc.med.sa
[9] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: sachul20@hotmail.com
[10] Phlebotomist — King Abdullah Medical City – Makkah Health Cluster – Ministry of Health – Makkah – Makkah Region – Saudi Arabia. Email: Alabdali.D@kamc.med.sa

ABSTRACT: Analytical carryover—the residual transfer of analyte from a high-concentration sample into a subsequently tested low-concentration specimen—remains a significant source of pre-analytical and analytical error in clinical laboratories. In automated chemistry and immunoassay platforms, carryover can produce clinically misleading results, particularly for analytes such as hormones, tumor markers, and therapeutic drugs where measured concentrations span several orders of magnitude. A single falsely elevated result can trigger unnecessary investigations or inappropriate treatment. Consequently, laboratories have devoted considerable attention to systematically identifying, quantifying, and mitigating carryover through a combination of hardware design, procedural safeguards, and verification studies.Effective carryover mitigation relies on layered strategies rather than a single intervention. Instrument-level solutions—including discrete pipetting with disposable tips, dedicated wash stations, and optimized probe-cleaning protocols using

appropriate wash solutions—form the first line of defense. Procedural measures such as sample ordering (running high-concentration specimens after low ones, or interspersing blanks), rerun algorithms, and the use of carryover-resistant reagent formulations complement these hardware features. Verification through recognized carryover testing protocols, continuous monitoring of quality control data, and appropriate flagging thresholds allow laboratories to detect and correct residual contamination. Ultimately, the evidence supports that a multidisciplinary, systematic approach—combining instrument validation, workflow design, and ongoing surveillance—is most effective at reducing carryover and safeguarding analytical integrity.

INTRODUCTION

Analytical carryover, the transfer of a measurable quantity of an analyte from one patient specimen to a subsequently analyzed specimen, remains one of the most persistent and clinically consequential sources of error in the automated clinical laboratory. Although modern analyzers are engineered to minimize this phenomenon, the expansion of integrated clinical chemistry and immunoassay platforms, the compression of turnaround times, and the increasingly low limits of quantification for many analytes have combined to keep carryover on the quality agenda of every laboratory that reports patient results [1]. The problem is not merely technical. A falsely elevated result attributable to carryover can trigger unnecessary imaging, inappropriate anticoagulation, erroneous staging of malignancy, or the withholding of a needed therapy, and the laboratory that fails to control this risk therefore compromises the central promise of diagnostic medicine: that the number reported on the patient chart corresponds to the concentration in the patient's body [2]. This article examines the effectiveness of laboratory strategies—instrumental, procedural, informatic, and organizational—in reducing analytical carryover between patient samples, with attention to the evidence that supports each strategy and to the gaps that remain [3].

The magnitude of the problem is best appreciated by considering the structural conditions of contemporary laboratory practice. Automated chemistry analyzers employ robotic pipetting and cuvette washing systems as the standard means of processing patient specimens, and these systems are designed to sample continuously while cleaning probes and reaction vessels between aspirations. The obvious concern is that residual analyte from one specimen may be carried into one or more following specimens, falsely increasing the measured concentration in the recipient sample. Specimen carryover is typically addressed through judicious choice of probe material, probe design, and an efficient probe washing system that flushes the probe of residual patient specimen or reagent retained in its bore or clinging to its exterior [4]. Yet these design features operate under assumptions that are not always met in practice. Integrated systems, which combine clinical chemistry and immunoassay modules, introduce an additional pathway: a specimen may be sampled by the reusable chemistry probe, which is washed but not replaced, and then routed to an immunoassay module where the analyte of interest is measured at concentrations several orders of magnitude lower. In such configurations, carryover on the clinical chemistry side can be analytically invisible for chemistry tests while being clinically decisive for the immunoassay that follows [4].

The clinical stakes of carryover are not hypothetical. Immunoassays performed on the chemistry portion of an integrated analyzer have been shown to be vulnerable to carryover from sample probes, and the priority designation of certain assays as "carryover-sensitive" reflects the recognition that a preceding chemistry analysis can lead to an errant result on a subsequently added immunoassay test. Add-on testing, a workflow convenience that prevents additional phlebotomy, is particularly exposed because it routes previously collected specimens back through the system in an order that may contradict the vendor's intended specimen routing [4]. The laboratory that treats carryover as a theoretical instrument specification rather than as a live operational hazard is therefore poorly positioned to defend its results when a discrepant value is challenged.

Mechanisms and Determinants of Analytical Carryover

Carryover arises from the interaction of fluid dynamics, surface chemistry, and assay architecture. At the level of the sample probe, residual volume is retained as a film on the inner and outer surfaces after aspiration and dispensation. The probe is washed between aspirations to reduce carryover, and the wash is performed by pumping a wash fluid through the interior of the probe and over its exterior. The efficiency of this wash depends on the duration and volume of the internal and external wash segments, the timing of their termination relative to one another, and the physical properties of the wash solution [5]. In one representative example, a chemistry sampling protocol employed a one-second external probe wash that ended 100

milliseconds after the internal probe wash, illustrating the level of temporal granularity at which carryover control is engineered [5]. The detergent composition of the wash solution also matters: the addition of detergent to a reagent can decrease the risk of carryover by lowering the surface tension of the reagent and the reaction mixture, thereby reducing adhesion to pipetting needles and reaction vessel walls [6].

Surface chemistry becomes especially important when the analyte itself is adhesive. In a study that used a monoclonal IgG antibody labeled with biotin and ruthenium, a material selected precisely because of its strong adhesiveness, carryover was measurable at levels below 0.04 ppm on one analytical unit and below 0.006 ppm on another, demonstrating that even highly adherent proteins can be controlled by an effective wash procedure [7]. The same principle applies to reagents. Cumulative reagent carryover has been documented in urinary total protein testing on a biochemistry analyzer, where high-concentration quality control materials and pure water were used to distinguish specific sample probe carryover from cumulative reagent effects [8]. Reagent carryover, once confined to the concerns of assay developers, has become a recognized source of error for end-user laboratories that place open-channel reagents on closed systems, and this has driven the development of dedicated guidance for its evaluation [8].

The physical configuration of the analytical system determines which carryover pathways are possible. On analyzers that use disposable pipette tips, sample-to-sample carryover between transfers is eliminated when the tip is changed between every aspiration, and disposable tips are therefore perceived as the most effective single intervention against carryover in liquid-handling workflows [9]. Fixed reusable probes, by contrast, require that cleaning be accomplished entirely by the wash station, and the adequacy of that wash becomes a performance-critical specification. The distinction is not absolute: a system may use disposable tips for immunoassay sampling while retaining a reusable probe for chemistry, which means that a specimen analyzed first on the chemistry module and later on the immunoassay module has already traversed a carryover-prone pathway before it reaches the protected one. This architectural hybridity is the defining technical challenge of the integrated analyzer era [10].

Table 1 summarizes the principal carryover pathways and the corresponding control points in the analytical process.

Carryover Pathway	Principal Mechanism	Primary Control Point	Typical Acceptance Criterion
Sample-to-sample via reusable probe	Residual specimen film in probe bore and on exterior	Internal and external probe wash; wash duration and sequence	< 0.1 ppm for immunoassay analytes
Sample-to-cuvette/reaction vessel	Incomplete emptying and rinsing of reaction cells	Cuvette wash cycles; detergent concentration	Analyte-specific; often < 3 SD of low-level result
Reagent-to-sample	Reagent probe carries reagent into subsequent specimen	Reagent probe wash; dedicated wash solution	No significant reagent carryover per risk assessment
Reagent-to-reagent	Shared reagent probe or piercer transfers reagent between bottles	Piercer wash after piercing; reagent-specific wash rules	Assay-defined; verified during validation
Add-on testing on integrated systems	Specimen routed from chemistry probe to immunoassay module	Routing rules; disposable-tip immunoassay sampling	Carryover-sensitive assays restricted or flagged

Clinical and Analytical Consequences of Uncontrolled Carryover

The clinical impact of carryover is a function of the analyte, the concentration gradient between donor and recipient specimens, and the clinical decision threshold that the recipient result is meant to inform [11]. For human chorionic gonadotropin, a low-concentration sample near the 5 IU/L pregnancy threshold is clinically interpretable in a way that a sample at 50 IU/L is not, and carryover from a specimen containing 700,000 IU/L can elevate the low-level result across that interpretive boundary [12]. For prostate-specific antigen, the biochemical recurrence threshold after prostatectomy is commonly 0.20 ng/mL, a value at which a small absolute carryover increment may be sufficient to prompt salvage therapy discussions [13]. For procalcitonin, the

reference interval is below 0.09 ng/mL, and a falsely elevated value in a patient with a suspected bacterial infection may influence antibiotic initiation or duration [14]. The clinical significance of carryover is therefore not proportional to the carryover rate alone; it is the product of the carryover rate and the clinical steepness of the decision curve at the recipient's true concentration [14].

Carryover also distorts the analytical performance characteristics that laboratories rely on to assure quality. External proficiency testing and internal quality control programs are designed around the assumption that each measurement is independent of the measurements that preceded it. When carryover is present, the apparent imprecision of low-level materials increases, and the laboratory may misattribute the resulting variability to instrument instability, reagent lot differences, or operator technique [15]. The problem is compounded in integrated systems because the carryover event may occur on one module and be detected on another, so that the module that generated the error is not the module that reports it. The laboratory that investigates a single discrepant result without tracing the specimen's route through the system may therefore fail to identify the true cause [15].

A further consequence is the erosion of trust in add-on testing. Add-on testing prevents additional phlebotomy and reduces turnaround time, but it depends on the premise that a previously collected specimen can be re-entered into the analytical stream without introducing error. When carryover-susceptible assays are added on to specimens that have already been sampled by a reusable chemistry probe, that premise is violated [4]. The laboratory is then forced to choose between restricting add-on testing for certain analytes and accepting a small but nonzero risk of erroneous results. Neither choice is cost-free: restriction increases phlebotomy burden and delays care, while acceptance places the burden of risk on patients whose results happen to fall near a decision threshold [11].

Instrumental and Engineering Strategies

The most durable reductions in carryover have come from engineering changes to the analytical system itself. The first line of defense is the sampling interface. Disposable tips eliminate sample-to-sample carryover when changed between every aspiration, and systems that use them for immunoassay sampling remove the most consequential carryover pathway for low-concentration analytes [9]. Where disposable tips are not feasible because of throughput or cost constraints, probe material and design become critical variables: the choice of probe material, the internal geometry of the probe bore, and the design of the probe tip all influence the residual volume that the wash step must remove [16].

The second line of defense is the wash system. Ultrasonic-assisted probe washing has been shown to reduce sample-to-sample carryover significantly below the design specification of 0.1 ppm, with native analytes such as hepatitis B surface antigen and antibodies to HBsAg found several orders of magnitude below that specification [17]. This is a meaningful advance because it addresses the adhesion problem at the physical level rather than relying solely on chemical solubilization. The timing of the wash is equally important: the termination of the internal wash before the external wash, the duration of each phase, and the volume of wash fluid delivered through and over the probe all interact to determine residual carryover [18].

The third line of defense is the reaction vessel. Cuvette carryover occurs when a previous reaction mixture is not completely removed before the next reaction begins. Here, too, detergent concentration and wash cycle design are the controlling variables, and the addition of detergent to the reagent can reduce adhesion to reaction vessel walls [19]. The cumulative nature of some carryover effects—particularly reagent carryover—means that a single wash cycle may be insufficient, and that the adequacy of cleaning must be assessed over a sequence of measurements rather than in a single donor-recipient pair [19].

Instrument manufacturers have also implemented additional wash cycles before measurements of particular assays, and field safety notices have documented that such cycles can eliminate the risk of carryover without negatively affecting the titers of subsequent samples [20].

Table 2 compares the principal engineering strategies with respect to their mechanism of action and the evidence supporting their effectiveness.

Engineering Strategy	Mechanism	Evidence of Effectiveness	Limitations
Disposable sample tips	Physical replacement of the sampling interface after each aspiration	Eliminates sample-to-sample carryover between transfers when changed every aspiration	Cost per reportable result; throughput penalty; not universally available on chemistry modules

Ultrasonic probe wash	Acoustic energy dislodges adherent residue from probe surfaces	Carryover below 0.1 ppm; IgG-Bi-Ru below 0.04 ppm and 0.006 ppm on respective units	Requires hardware; effectiveness varies with probe geometry
Extended internal/external wash	Increased contact time and volume of wash fluid	One-second external wash ending 100 ms after internal wash reduced carryover	Prolongs cycle time; may reduce throughput
Detergent-modified reagents	Lower surface tension reduces adhesion to probe and cuvette walls	Detergent addition decreases carryover risk	Assay-specific; may affect reagent stability
Additional wash cycle before susceptible assays	Inserts a dedicated cleaning step before the at-risk measurement	Eliminated carryover risk without affecting subsequent sample titers	Consumes analyzer time; requires assay-specific programming

Procedural and Workflow Strategies

Engineering alone does not eliminate carryover, because the conditions that produce carryover are often created by workflow decisions rather than by instrument design. The most important procedural strategy is specimen routing. Vendors design integrated systems to mitigate carryover by routing carryover-susceptible analytes to the immunoassay module, with its disposable pipette tip, before the specimen travels to the chemistry module and its reusable pipette [21]. This "high-priority" routing is effective only if it is respected. Add-on testing, by contrast, may sample a specimen on the chemistry module first and then route it to the immunoassay module, exactly reversing the intended order and creating the conditions for carryover. Laboratories that perform add-on testing must therefore either restrict add-on orders for carryover-susceptible assays or implement a routing override that preserves the intended sequence [21].

A second procedural strategy is the use of an add-on specimen that is sampled only by disposable pipettes, a design that isolates the add-on pathway from the reusable-probe chemistry pathway. This approach preserves the workflow benefit of add-on testing while removing the carryover risk that would otherwise accompany it [21]. The cost is the need to maintain a separate aliquot or a separate sampling route, but for high-volume laboratories with a substantial add-on workload, the trade-off may be favorable. A third strategy is the insertion of empty cycles or dedicated wash cycles between high-concentration and low-concentration analyses. Automated analyzers can be programmed to perform a cleaning process in an empty cycle, thoroughly washing away components related to the preceding analysis before the next analysis begins, thereby reducing the impact of carryover on the subsequent result [22].

A fourth strategy is the deliberate sequencing of quality control and patient samples. A suggested "1-2-1" control sequence—one low-level sample, two high-level samples, one low-level sample—has been described as a quality assurance tool for measuring carryover within individual assay runs on automated coagulation instruments [23]. The principle generalizes: by placing low-level materials after high-level materials in a defined pattern, the laboratory creates a sentinel for carryover that can be monitored without additional instrumentation. The limitation is that such sequences are practical only when the workflow permits them, and in high-throughput operations the sequencing of patient samples is driven by clinical urgency rather than by carryover surveillance [23].

Verification, Monitoring, and Informatic Strategies

The effectiveness of any carryover reduction strategy depends on the laboratory's ability to verify that it is working. Verification begins with a structured carryover study. The standard experimental design alternates high-concentration and low-concentration samples and quantifies the error in the low-concentration sample that follows the high-concentration donor. The percent carryover can be calculated by subtracting the value of the first low-level sample from the value of the third low-level sample, dividing by the first low-level sample value, and multiplying by 100, or by the equivalent formula that compares the first low-level result with the third low-level result relative to the difference between the third high-level and third low-level results [24]. Acceptance criteria vary by analyte and by clinical application: a carryover rate below 0.1 ppm is a common specification for immunoassay analytes on integrated systems, while some high-sensitivity methods require that the calculated carryover be less

than 25% of the lower limit of quantification. The choice of criterion should be justified by the clinical decision thresholds that the assay informs, not merely by the vendor's specification [24].

Statistical rigor in carryover studies has improved substantially. The simple reporting of carryover in parts per million is not helpful because its uncertainty is not taken into account, and the most commonly used method fails to demonstrate the absence of carryover. A step-by-step guidance based on equivalence testing has been proposed, using a one-sided version of equivalence testing that compares the observed difference with a predefined limit, and experiments using eight to eleven cycles of high- and low-concentration samples have been shown to be appropriate to validate the absence of carryover with 80% to 90% power at an alpha level of 0.05 [24]. This statistical framework allows the laboratory to make a defensible statement that carryover is absent, rather than merely that it was not detected in a small number of pairs.

Ongoing monitoring is the bridge between verification and routine practice. The laboratory information system can embed delta-check rules that highlight sudden clinical changes in a patient's results, and these rules can flag results that are inconsistent with the patient's previous values in a way that suggests contamination or carryover [25]. Structured carryover studies using high-high-high-to-low-low-low sequences can be performed periodically, and laboratory information system flags for hemolysis, icterus, and lipemia interference can be combined with carryover flags to prioritize review before results are reported [25]. The laboratory information system is also the natural repository for the specimen routing history that is needed to investigate a suspected carryover event, because it can link the result to the analytical module, the time of analysis, and the preceding specimen on that module.

Table 3 presents a monitoring framework that links the stage of the analytical process to the informatic tool and the action triggered.

Monitoring Stage	Informatic Tool	Trigger	Laboratory Action
Pre-analytical routing	LIS specimen routing rules; add-on order logic	Add-on order for a carryover-susceptible assay on a specimen previously sampled by a reusable probe	Route to disposable-tip module or restrict add-on
Analytical sequence	Middleware sequence monitoring; analyzer event logs	High-concentration specimen immediately precedes low-concentration specimen	Insert wash cycle or flag result for review
Post-analytical review	LIS delta-check rules; multivariate delta checks	Result exceeds predefined change limit relative to patient's previous result	Hold result; repeat from fresh aliquot; investigate carryover
Periodic verification	Carryover study data capture; QC trend analysis	Scheduled interval or instrument change	Recalculate carryover rate; compare with acceptance criterion
Event investigation	LIS audit trail; analyzer module logs	Clinician query or discrepant result	Reconstruct specimen sequence; identify donor-recipient pair; corrective action

Regulatory and Quality-System Strategies

Regulatory frameworks have increasingly recognized carryover as a quality-system issue rather than a purely instrumental one. The Clinical and Laboratory Standards Institute has published guidance for planning, performing, evaluating, and documenting reagent carryover experiments, with the goal of establishing that no significant reagent carryover occurs and of promoting uniformity in the evaluation of reagent carryover characteristics across developers, regulatory organizations, and medical laboratories [5]. The scope of this guidance extends to laboratory-developed tests, open-channel reagents placed on closed systems, and the investigation of suspect results, which means that the end-user laboratory is no longer entitled to treat reagent carryover as someone else's responsibility [5]. The guidance provides recommendations for risk assessment criteria, statistically valid study designs, selection of sample and reagent combinations, data analysis and interpretation, and reporting formats. It

does not cover sample carryover in detail, but it establishes the principle that carryover evaluation should be proportionate to risk and documented in a form that supports regulatory review [5].

Accreditation standards reinforce this principle. Laboratories accredited to ISO 15189 are required to demonstrate that their analytical systems are validated for the intended use and that performance is monitored over time. Carryover verification is part of that validation, and the laboratory that cannot produce a documented carryover study for each analytical system and each carryover-susceptible assay is exposed at the time of assessment [24]. The European In Vitro Diagnostic Regulation has added a further layer by requiring performance studies that are sufficient to demonstrate the analytical and clinical performance of devices, and although the regulation does not prescribe a specific carryover protocol, the general requirement for performance evaluation encompasses carryover as a source of analytical error [24]. The practical consequence is that carryover control must be embedded in the laboratory's quality management system, with defined responsibilities, acceptance criteria, review intervals, and corrective-action pathways [25].

A quality-system approach also clarifies the division of responsibility between the manufacturer and the laboratory. Manufacturers must design integrated systems to minimize primary specimen tube carryover and avoid analytical laboratory error that can impact patient safety, and they must continue to develop carryover mitigation on integrated systems outside of specimen routing [21]. Laboratories, in turn, must consider the potential for specimen carryover and its impact on results whether they move primary sample tubes between separate analyzers or use an integrated system, and they must develop internal processes to prevent carryover effects [25]. The effectiveness of the overall strategy therefore depends on both parties fulfilling their roles: a well-designed instrument operated with poor routing discipline will still produce carryover, and a well-disciplined laboratory cannot compensate for an instrument whose wash system is inadequate for the analytes it is asked to measure [21].

Effectiveness of Specific Strategies: A Critical Appraisal

The evidence base for carryover reduction strategies is uneven. Engineering interventions such as ultrasonic probe washing and disposable tips have the strongest evidence, because their effectiveness can be measured directly against a physical specification and because the mechanism of action is well understood [17]. The demonstration that ultrasonic washing reduces carryover of native hepatitis B surface antigen and anti-HBs to levels several orders of magnitude below 0.1 ppm is a clear example of an intervention whose benefit is both large and biologically relevant [17]. Similarly, the finding that disposable tips eliminate sample-to-sample carryover between transfers when changed between every aspiration is supported by the physical logic of the intervention as well as by empirical observation [9].

Procedural interventions have weaker but still meaningful evidence. The effectiveness of routing rules is inferred from the observation that reversing the intended routing sequence produces measurable carryover for human chorionic gonadotropin, procalcitonin, and prostate-specific antigen, which implies that preserving the intended sequence prevents it [21]. The effectiveness of additional wash cycles is supported by field safety notices and by experimental studies showing that a dedicated cycle can eliminate carryover without affecting subsequent results [20]. The effectiveness of empty-cycle insertion is supported by instrument design studies showing that a cleaning process performed in an empty cycle thoroughly washes away components related to the preceding analysis [22]. What is missing is a comparative literature that quantifies the marginal benefit of each procedural intervention across different instrument platforms and assay menus. The laboratory that must choose between, for example, restricting add-on testing and inserting an extra wash cycle has little empirical guidance on which choice produces the greater reduction in patient risk per unit of operational cost [21].

Informatic and monitoring interventions are the least well studied, despite their intuitive appeal. Delta-check rules are widely used and are recommended for detecting sudden clinical changes that may indicate contamination, but their sensitivity and specificity for carryover specifically, as opposed to specimen mix-up or other pre-analytical errors, have not been rigorously established [25]. The use of laboratory information system flags for potential carryover is a promising development, but it depends on the availability of routing history and on the willingness of the laboratory to hold results pending review, which may conflict with turnaround-time targets [25]. The development of multivariate delta checks that consider multiple analytes simultaneously may improve detection of subtle contamination, but these methods require validation in the specific populations and assay menus to which they are applied [24].

A further limitation of the evidence base is that most published carryover studies are performed under controlled conditions with spiked or contrived samples, and the extent to which the results generalize to native patient specimens with complex matrices is uncertain [7]. The study that used a strongly adhesive monoclonal IgG labeled with biotin and ruthenium is valuable

precisely because it moves beyond contrived materials, but such studies are the exception rather than the rule [7]. The laboratory that relies on vendor specifications alone may therefore underestimate carryover for analytes that behave differently in native matrix. This argues for periodic verification with patient-derived materials, particularly when a new assay is introduced or when the analyzer's specimen routing is changed [24].

Synthesis and Practical Recommendations

The cumulative evidence supports a layered strategy rather than a single intervention. The first layer is instrument selection and configuration: laboratories should prefer systems with disposable tips for immunoassay sampling and should verify that the wash system has been validated for the specific analytes and concentration ranges that the laboratory reports [9]. The second layer is routing discipline: add-on testing for carryover-susceptible assays should be either routed through a disposable-tip pathway or restricted, and the laboratory should audit compliance with routing rules rather than assume that the vendor's intended sequence is being followed [21]. The third layer is sequence management: additional wash cycles and empty cycles should be used strategically for the specimen pairs and assay combinations that present the greatest risk, and the effectiveness of these cycles should be verified rather than assumed [22]. The fourth layer is monitoring: delta-check rules and carryover-specific flags should be configured in the laboratory information system, and the results of periodic carryover studies should be reviewed as part of the quality management system [25]. The fifth layer is documentation: every carryover study, acceptance criterion, and corrective action should be recorded in a form that supports accreditation review and regulatory inspection [24].

The effectiveness of these layers is not merely additive. Instrumental improvements reduce the baseline carryover rate, which makes procedural and informatic interventions more sensitive because they are detecting a smaller signal against a lower background [17]. Procedural discipline ensures that the instrumental improvements are actually realized in practice, because an analyzer that is capable of low carryover will not achieve it if specimens are routed in the wrong order [21]. Informatic monitoring closes the feedback loop by identifying failures before they reach the patient record [25]. The laboratory that invests in only one layer—typically the instrumental layer—will have a system that performs well under controlled conditions but that remains vulnerable to the workflow contingencies that characterize real clinical operations [24].

CONCLUSION

Analytical carryover between patient samples is a controllable source of laboratory error, but its control requires a strategy that is broader than any single instrument feature or procedural rule. The evidence reviewed here shows that engineering interventions such as disposable tips and ultrasonic probe washing can reduce carryover to levels well below clinically relevant thresholds, that procedural interventions such as routing discipline and additional wash cycles can prevent the conditions under which carryover occurs, and that informatic interventions such as delta-check rules and carryover flags can detect failures before they are reported. What the evidence does not support is complacency. Carryover effects are generally minor, but they can cause significant errors in specific situations, particularly with high analyte concentrations or reactive reagents, and rigorous evaluation during instrument validation and ongoing monitoring are essential to mitigate these effects. The laboratory that treats carryover as a specification on a vendor datasheet rather than as a property of its own workflow will eventually report a result that is wrong for reasons it cannot explain. The laboratory that layers instrumental, procedural, and informatic controls, and that verifies each layer with statistically defensible studies, is in a position to state with confidence that the results it reports reflect the specimens it received.

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