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Research Article

Impact of Laboratory Turnaround Time on Clinical Decision-Making and Patient Outcomes

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Abstract:

Laboratory Turnaround Time (TAT) is a critical determinant of healthcare quality, acting as the essential bridge between diagnostic science and therapeutic action. Prolonged TAT directly impedes clinical decision-making by forcing clinicians in high-acuity settings like emergency and critical care to operate under diagnostic uncertainty, leading to delays in life-saving interventions, empirical treatments with potential adverse effects, and bottlenecks in patient flow. This delay is conclusively linked to adverse patient outcomes, including increased mortality in time-sensitive conditions like sepsis and acute coronary syndrome, higher rates of hospital-acquired complications, and extended hospital lengths of stay that drive up healthcare costs. Consequently, optimizing TAT through process engineering, automation, and enhanced clinical-laboratory collaboration is not merely an operational goal but a fundamental patient safety imperative, ensuring that the accuracy of laboratory medicine is fully realized through its timeliness.

1. Introduction

The modern healthcare delivery system is an intricate and interdependent network where the seamless flow of information is as critical as the quality of clinical intervention itself. Within this ecosystem, the clinical laboratory occupies a fundamental, yet often understated, position. It functions as the primary source of objective data, translating biological samples into quantitative and qualitative information that forms the bedrock of diagnosis, prognosis, and therapeutic monitoring. The pivotal importance of laboratory tests is universally acknowledged; however, the *timeliness* with which this crucial data is delivered to the clinician—the Laboratory Turnaround Time (TAT)—has emerged as a variable of paramount significance with profound implications for both the process and the outcomes of patient care [1]. Turnaround Time is defined as the total interval between the ordering of a test and the reporting of its results to the responsible caregiver. This metric, far from being a mere operational benchmark, is a critical determinant in the clinical decision-making cascade, influencing everything from initial diagnostic accuracy to the timing and appropriateness of life-saving interventions.

The concept of TAT is deceptively simple but encompasses a complex sequence of pre-analytical, analytical, and post-analytical phases. Each phase—from test ordering and specimen collection, transportation, and processing, to the actual analysis, verification, and final result communication—introduces potential delays. In an era characterized by the pursuit of high-value, patient-centered care, prolonged TAT represents a significant impediment. It can lead to diagnostic uncertainty, compel clinicians to make decisions based on incomplete information, and directly contribute to extended hospital stays, increased resource utilization, and, most critically, adverse patient outcomes [2]. The emergency department (ED), intensive care units (ICUs), and operating theatres are particularly sensitive to delays, where minutes can dictate the difference between recovery and irreversible morbidity or mortality. For instance, the rapid availability of cardiac biomarker results in patients presenting with chest pain is essential for the timely diagnosis of acute myocardial infarction and the initiation of reperfusion therapy, a standard where "time is muscle" [3].

Historically, the focus of laboratory medicine was predominantly on analytical quality—accuracy, precision, and reliability. While these remain non-negotiable pillars, the paradigm has decisively shifted towards a more holistic view that integrates quality with timeliness and clinical utility. The laboratory is no longer seen as an isolated diagnostic facility but as an integral clinical partner. Consequently, TAT has evolved from an internal productivity measure to a key performance indicator (KPI) directly linked to patient safety and institutional efficiency [4]. Studies have consistently demonstrated that delays in laboratory reporting are not merely administrative inconveniences but are associated with tangible negative consequences. These include increased length of stay (LOS) in hospitals, higher rates of hospital-acquired complications, greater likelihood of patient dissatisfaction, and escalated overall cost of care [5].

The impetus for examining TAT has been further amplified by advancements in medical technology and rising patient expectations. The advent of point-of-care testing (POCT) represents a direct response to the need for near-instantaneous results in critical settings, fundamentally challenging the traditional central laboratory model for specific tests. Moreover, the implementation of sophisticated hospital information systems (HIS) and laboratory information systems (LIS) has created both opportunities for streamlining and new

complexities in managing the data flow. In this context, optimizing TAT is a multifaceted challenge requiring a systems-based approach that addresses human factors, process engineering, technological integration, and inter-departmental communication [6].

2. Defining and Measuring Laboratory Turnaround Time

A precise understanding of Laboratory Turnaround Time requires dissecting its timeline and acknowledging the variability in its definition. Clinically, the most relevant TAT is the *total TAT*, perceived by the ordering physician as the time from test order entry to result availability. However, for internal quality improvement, laboratories often break this down into distinct, measurable intervals: the *pre-analytical* phase (order to specimen receipt), the *analytical* phase (specimen processing to result generation), and the *post-analytical* phase (result verification to report delivery) [7- 9].

The pre-analytical phase is notoriously prone to delays and errors, accounting for an estimated 60-70% of all laboratory mistakes. This phase includes test ordering, patient identification, specimen collection (phlebotomy), labeling, transportation, and receipt in the lab. Delays here can stem from logistical issues (e.g., inefficient phlebotomy rounds, slow pneumatic tube systems), clerical errors (mislabeling, requiring re-draw), or inappropriate sample collection (hemolyzed, clotted, or insufficient samples) [10]. The analytical phase, while highly automated and controlled, can be affected by equipment downtime, reagent shortages, calibration needs, or the need for repeat testing due to quality control failures. Finally, the post-analytical phase involves result validation by a pathologist or senior technologist (for critical or abnormal values), entry into the LIS, and electronic or manual transmission to the clinician. Delays in this phase, though less common, can occur due to high workload, inefficient alert systems for critical results, or interface problems between the LIS and the hospital's electronic health record (EHR) [11].

Establishing realistic TAT goals is context-dependent. A stat (urgent) troponin test in the ED may have a target TAT of 60 minutes or less, while a routine morning metabolic panel for a stable inpatient might have a target of 3-4 hours. These goals must be established collaboratively between laboratory leadership and clinical departments to align with clinical needs and operational capabilities. Monitoring TAT requires robust data tracking, often facilitated by the LIS, which can generate performance reports identifying bottlenecks. Key metrics include median TAT, the percentage of tests meeting the specified goal (e.g., 95% within target time), and tracking of outliers [12]. Without consistent measurement and benchmarking against agreed-upon standards, efforts to improve TAT are unfocused and ineffective.

3. The Influence of TAT on Clinical Decision-Making Processes

Clinical decision-making is a dynamic, iterative process heavily reliant on diagnostic information. Delays in receiving this information disrupt the clinical workflow, forcing clinicians into a suboptimal decision space characterized by uncertainty, assumption, and potentially unnecessary risk.

In the **Emergency Department (ED)**, time is the most critical resource. Prolonged TAT directly contributes to ED length of stay, which is a major metric of departmental efficiency and patient satisfaction. For patients presenting with non-specific symptoms like abdominal pain, dizziness, or shortness of breath, clinicians often order a battery of tests (e.g., complete blood count, basic metabolic panel, troponin, D-dimer) to narrow the differential diagnosis. Delays in these results leave patients in "diagnostic limbo," occupying valuable bed space while awaiting disposition decisions—admission, discharge, or further observation. This not only creates patient flow bottlenecks but also increases the risk of missed pathologies. For example, a delayed D-dimer result in a patient with a possible pulmonary embolism can postpone a definitive CT angiogram, potentially allowing a clot to propagate with deadly consequences [13]. Similarly, slow turnaround of microbiology cultures (e.g., blood cultures) delays the identification of pathogens and the targeted initiation of appropriate antibiotics, a delay strongly associated with increased mortality in sepsis [14].

In **Critical Care Units (ICUs and CCUs)**, patients are in a physiologically unstable state, requiring continuous data input for moment-to-moment management. Laboratory tests such as arterial blood gases (ABGs), lactate, electrolytes, and coagulation profiles are ordered frequently to guide ventilator settings, inotropic support, fluid therapy, and correction of metabolic derangements. A delayed ABG result can lead to prolonged hypoxemia or hypercapnia in a ventilated patient. A slow potassium result can result in life-threatening arrhythmias going uncorrected. In these environments, the clinical team often makes "best guess" interventions based on trends or clinical signs while awaiting confirmatory data, which may

lead to over- or under-treatment. The availability of rapid point-of-care testing for key analytes in the ICU has been a game-changer, precisely because it collapses the TAT to minutes, enabling real-time titration of therapy [15].

For **Inpatient Ward Management**, TAT impacts the daily progress of patients. Morning rounds are typically planned around the availability of overnight and early morning test results. Delays in routine chemistry or hematology panels can postpone decisions about medication adjustments (e.g., diuretics, insulin, anticoagulants), discharge planning, or the scheduling of procedures. This results in idle time for the clinical team, missed opportunities for timely intervention, and ultimately, a longer average length of stay (ALOS). Research has shown a direct correlation between laboratory TAT and hospital ALOS, where each hour of delay can translate into a significant increase in hospitalization duration and cost [5].

In the **Outpatient and Primary Care Setting**, the impact of TAT, while less immediately dramatic, is substantial. Patients leave the clinic awaiting results for cancer screenings, metabolic disease monitoring (e.g., HbA1c for diabetes), or infectious disease tests (e.g., HIV serology). Prolonged TAT extends the period of anxiety for the patient and delays the initiation of necessary treatment or the provision of reassurance. For chronic disease management, slow feedback on parameters like INR for patients on warfarin therapy can lead to subtherapeutic or supratherapeutic periods, increasing the risk of thromboembolic or bleeding events, respectively [16]. Efficient result reporting is thus crucial for continuity of care and effective chronic disease management in the ambulatory population.

4. The Direct Link Between TAT and Patient Outcomes

Beyond influencing the decision-making process, substantial evidence links prolonged laboratory TAT directly to tangible adverse patient outcomes, including increased mortality, higher complication rates, and greater resource consumption.

Mortality and Morbidity: The most severe consequence of delayed diagnostics is increased mortality. This is most clearly demonstrated in time-sensitive conditions. In Acute Coronary Syndrome (ACS), guidelines emphasize door-to-balloon time for ST-elevation myocardial infarction (STEMI) and door-to-needle time for fibrinolysis. The diagnosis hinges on rapid troponin testing. Delays in troponin TAT directly contribute to delays in reperfusion therapy, leading to greater infarct size, more heart failure, and higher mortality [3]. In sepsis, every hour of delay in administering effective antibiotics after onset of hypotension increases mortality by an average of 7.6%. Since antibiotic stewardship requires culture results, delays in blood culture processing, identification, and susceptibility reporting directly impede optimal therapy, contributing to this grim statistic [14]. In stroke management, particularly for ischemic strokes eligible for thrombolysis or thrombectomy, rapid coagulation studies (PT/INR, platelet count) are mandatory before treatment. Any delay in these baseline labs can push the patient beyond the narrow therapeutic window, denying them a potentially disability-sparing intervention [17].

Hospital Length of Stay (LOS) and Costs: Length of stay is a primary driver of hospital costs. Multiple studies have established a causal relationship between laboratory TAT and extended LOS. When test results are delayed, discharge decisions are postponed, consultations are deferred, and necessary treatments are not initiated promptly. This leads to unnecessary additional hospital days. A seminal study demonstrated that improving core laboratory TAT by implementing an automated track system led to a significant reduction in the ED length of stay for patients being admitted, directly freeing up ED beds and reducing inpatient bed occupancy [18]. Longer LOS not only increases direct costs (room charges, nursing care) but also exposes patients to higher risks of hospital-acquired infections (HAIs), falls, and other iatrogenic complications, further degrading outcomes and increasing cost [19].

Patient Safety and Quality of Care: Delayed results contribute to diagnostic errors and patient safety incidents. A clinician may discharge a patient from the ED based on a preliminary assessment, only to receive a critically abnormal result (a "critical value") hours later, requiring an urgent callback and possible readmission—a scenario fraught with medico-legal risk. Furthermore, in busy inpatient settings, a delayed abnormal result might get lost in a flood of later data, leading to a missed finding. Efficient TAT, coupled with robust critical value reporting protocols, is essential for closing the loop on abnormal findings and ensuring they are acted upon [20]. The psychological impact on patients—the anxiety of waiting for results—is also a non-trivial aspect of quality of care that is improved by timely communication.

5. Factors Contributing to Prolonged Turnaround Time

Addressing TAT challenges requires a clear understanding of its root causes, which are often systemic and multifactorial.

Pre-analytical Bottlenecks: This remains the most fertile area for improvement. Inefficient phlebotomy services, whether due to understaffing, poor scheduling, or large geographical distances in a hospital campus, are a primary cause. Manual labeling and order entry are error-prone and slow. Inadequate training of nursing or phlebotomy staff on proper collection techniques leads to a high rate of rejected samples (e.g., hemolysis in chemistry tubes, clotted coagulation samples). Unreliable or congested specimen transportation systems (e.g., pneumatic tubes) further add to delays [10, 21].

Analytical Limitations: While modern analyzers are fast, bottlenecks occur due to batch testing, where stat samples must wait for the next scheduled run. Equipment failures or maintenance downtime can halt all testing. Tests requiring specialized techniques or send-outs to reference laboratories inherently have long TATs. Furthermore, the need for repeat testing due to instrument flags, abnormal quality control, or verification by a senior technologist for complex results introduces unavoidable delays [22].**Post-analytical Inefficiencies:** The process of reporting is not instantaneous. Manual transcription of results is obsolete but has been replaced by potential digital bottlenecks. Interfaces between LIS and EHR can fail or experience latency. The process of validating and releasing results, especially in microbiology, histopathology, or for complex protein assays, often requires expert review which can be delayed if pathologists are overwhelmed. The protocol for communicating critical values—calling the right clinician, documenting the call—can also be time-consuming if not streamlined [11].**Organizational and IT Factors:** A siloed organizational structure where the laboratory operates in isolation from clinical services leads to misaligned priorities and poor communication. Outdated or poorly configured IT infrastructure is a major impediment. An LIS that cannot handle high volumes efficiently or an EHR that does not display lab results prominently to clinicians negates any gains in analytical speed. Lack of real-time TAT monitoring dashboards for laboratory managers also prevents proactive management of delays [23].

6. Strategies for Optimizing Laboratory Turnaround Time

Improving TAT is a continuous quality improvement endeavor that requires a multidisciplinary approach, combining process engineering, technology, and human resource management.

Lean and Six Sigma Principles: Applying industrial quality management techniques like Lean and Six Sigma to laboratory workflows has proven highly effective. Value stream mapping can be used to visually chart the entire testing process from order to result, identifying every step and quantifying its time contribution. This reveals non-value-added activities (waste) such as unnecessary specimen handling, waiting times, and redundant data entry. By sequentially eliminating these wastes (e.g., reducing handoffs, optimizing workstation layout), the process flow becomes smoother and faster [24]. Kaizen events—focused, short-term projects involving frontline staff—can rapidly address specific bottlenecks like specimen sorting or centrifuge loading.

Automation and Technological Solutions: Automation is a cornerstone of TAT reduction. **Total Laboratory Automation (TLA)** systems, comprising automated tracks, robotic arms, and smart centrifuges, can process specimens 24/7 with minimal human intervention, drastically reducing handling time and pre-analytical errors. **Advanced LIS/EHR Integration** enables computerized physician order entry (CPOE) with built-in decision support, reducing ordering errors and ensuring proper sample collection requirements are communicated. Barcode technology at every step—from patient wristband to sample tube to analyzer—ensures positive sample identification and eliminates manual data entry errors [25]. **Middleware** software acts as an intelligent buffer between analyzers and the LIS, performing automatic validation of results based on predefined rules (delta checks, technical flags), releasing up to 80% of normal results instantly without technologist review, and flagging only those needing attention [26].

Process Re-engineering: Specific processes can be redesigned. Establishing **stat laboratories** or **rapid response teams** within or near high-acuity areas like the ED or ICU can decentralize testing for a select menu of critical tests (e.g., ABG, lactate, troponin), eliminating transportation delays. **Phlebotomy services** can be optimized using dynamic scheduling software and dedicated stat phlebotomists. Implementing **single-piece flow** for stat samples, where they are processed immediately upon arrival rather than batched, is another effective tactic. Standardizing **collection protocols** and investing in continuous training for all staff involved in the pre-analytical phase reduces sample rejection rates [27].

Enhanced Communication and Collaboration: Breaking down silos is essential. Regular meetings between laboratory management and clinical department heads (ED, ICU, Medicine) ensure TAT goals are clinically relevant and

mutually agreed upon. Implementing **auto-escalation protocols** for delayed tests can alert supervisors proactively. The use of **mobile technology**—allowing clinicians to receive critical result alerts on secure smartphones—can accelerate the post-analytical loop. Furthermore, providing clinicians with real-time access to test status (e.g., "sample received," "in analysis," "pending verification") through the EHR can manage expectations and reduce follow-up calls to the lab [28].

7. Future Directions

The future of laboratory TAT optimization lies in further integration of data, advanced analytics, and artificial intelligence (AI). **Predictive analytics** could forecast test ordering patterns based on ED triage level, diagnosis, or time of day, allowing laboratories to pre-emptively allocate resources. **AI-driven validation** software will become more sophisticated, accurately verifying a broader range of complex results and further reducing manual review burdens. The role of **Point-of-Care Testing (POCT)** will continue to expand, particularly for molecular diagnostics (e.g., rapid PCR for influenza, COVID-19, MRSA), bringing the laboratory to the patient's bedside for an increasing number of assays [29]. However, this must be balanced with the need for tight quality control and data integration to avoid creating information silos.

Furthermore, the concept of **"Clinical Turnaround Time"** is gaining traction, which encompasses not just the lab's work but the entire clinical action cycle—from the clinician's decision to order a test, through the TAT, to the clinician's action upon receiving the result. This holistic view reinforces the laboratory's role as a partner in the care pathway rather than just a service provider [30].

8. Conclusion:

In conclusion, Laboratory Turnaround Time is a critical quality metric that sits at the intersection of diagnostic science and clinical efficacy. It is not merely a measure of laboratory efficiency but a vital component of patient safety and healthcare quality. Prolonged TAT directly impedes clinical decision-making, fostering uncertainty and delay in every care setting, from the frantic emergency room to the managed outpatient clinic. The evidence convincingly links slow TAT to worse patient outcomes, including higher mortality, increased complication rates, longer hospital stays, and greater overall costs. While the challenges to achieving optimal TAT are multifaceted—spanning pre-analytical logistics, analytical throughput, and post-analytical communication—a toolkit of effective strategies exists. By embracing lean management principles, investing in automation and sophisticated informatics, re-engineering core processes, and fostering a culture of collaboration between the laboratory and clinical teams, healthcare institutions can significantly improve this key performance indicator. The ultimate goal is unambiguous: to ensure that the invaluable data generated by the modern clinical laboratory is delivered with a speed that matches its clinical urgency, thereby enabling timely, informed, and life-saving decisions for every patient. In the pursuit of excellence in healthcare, time is indeed of the essence.

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References

[1] McCarthy ML, Zeger SL, Ding R, Levin SR, Desmond JS, Lee J, Aronsky D. Crowding delays treatment and lengthens emergency department length of stay, even among high-acuity patients. Ann Emerg Med. 2009;54(4):492–503.e4.

[2] ten Berg MJ, Huisman A, van den Bemt PM, Schobben AF, Egberts AC, van Solinge WW. Linking laboratory and medication data: new opportunities for pharmacoepidemiological research. Clin Chem Lab Med. 2007;45(1):13–19.

[3] Kendall J, Reeves B, Clancy M. Point of care testing: randomised controlled trial of clinical outcome. BMJ. 1998;316(7137):1052–1057.

[4] Florkowski C, Don-Wauchope A, Gimenez N, Rodriguez-Capote K, Wils J, Zemlin A. Point-of-care testing (POCT) and evidence-based laboratory

medicine (EBLM) – does it leverage any advantage in clinical decision making? Crit Rev Clin Lab Sci. 2017;54(7–8):471–494.

[5] Hawkins RC. Laboratory turnaround time. Clin Biochem Rev. 2007;28(4):179–194.

[6] Jensen K, Haniff R, Kamarinos A, Rosenberg A, Santiago M, Laser J. Improving turnaround times through a process improvement initiative involving barcoding, floorplans, dual measuring cells, chemistry analyzers, and staff shifts. J Appl Lab Med. 2019;4(3):311–322.

[7] Carter EJ, Pouch SM, Larson EL. The relationship between emergency department crowding and patient outcomes: a systematic review. J Nurs Scholarsh. 2014;46(2):106–115.

[8] Ha JY, Sung WY. Impact of COVID-19 pandemic on emergency department length of stay and clinical outcomes of patients with severe pneumonia: a single-center observational study. Med (Baltimore) 2022;101(38):e30633.

[9] Lewandrowski K, Flood J, Finn C, Tannous B, Farris AB, Benzerx TI, Lee-Lewandrowski E. Implementation of point-of-care rapid urine testing for drugs of abuse in the emergency Department of an Academic Medical Center: impact on test utilization and ED length of stay. Am J Clin Pathol. 2008;129(5):796–801.

[10] Brouns SH, Stassen PM, Lambooij SL, Dieleman J, Vanderfeesten IT, Haak HR. Organisational Factors Induce Prolonged Emergency Department Length of Stay in Elderly Patients--A Retrospective Cohort Study. PLoS One. 2015;10(8):e0135066.

[11] Wuerz RC, Milne LW, Eitel DR, Travers D, Gilboy N. Reliability and validity of a new five-level triage instrument. Acad Emerg Med. 2000;7(3):236–242.

[12] Li L, Georgiou A, Vecellio E, Eigenstetter A, Toouli G, Wilson R, Westbrook JI. The effect of laboratory testing on emergency department length of stay: a multihospital longitudinal study applying a cross-classified random-effect modeling approach. Acad Emerg Med. 2015;22(1):38–46.

[13] Singh G, Savage NM, Gunsolus B, Foss KA. Requiem for the STAT test: automation and point of care testing. Lab Med. 2020;51(2):e27–e31.

[14] Driesen BEJM, van Riet BHG, Verkerk L, Bonjer HJ, Merten H, Nanayakkara PWB. Long length of stay at the emergency department is mostly caused by organisational factors outside the influence of the emergency department: a root cause analysis. PLoS One. 2018;13(9):e0202751.

[15] Morley C, Unwin M, Peterson GM, Stankovich J, Kinsman L. Emergency department crowding: a systematic review of causes, consequences and solutions. PLoS One. 2018;13(8):e0203316.

[16] Parvin CA, Lo SF, Deuser SM, Weaver LG, Lewis LM, Scott MG. Impact of point-of-care testing on patients' length of stay in a large emergency department. Clin Chem. 1996;42(5):711–717.

[17] Andersson J, Nordgren L, Cheng I, Nilsson U, Kurland L. Long emergency department length of stay: a concept analysis. Int Emerg Nurs. 2020;53:100930.

[18] Asha SE, Chan ACF, Walter E, Kelly PJ, Morton RL, Ajami A, Wilson RD, Honneyman D. Impact from point-of-care devices on emergency department patient processing times compared with central laboratory testing of blood samples: a randomised controlled trial and cost-effectiveness analysis. Emerg Med J. 2014;31(9):714–719.

[19] Angeletti S, De Cesaris M, Hart JG, Urbano M, Vitali MA, Fragliasso F, Dicuonzo G. Laboratory automation and intra-laboratory turnaround time: experience at the university hospital campus bio-medico of Rome. J Lab Autom. 2015;20(6):652.

[20] Ialongo C, Porzio O, Giambini I, Bernardini S. Total automation for the Core Laboratory: improving the turnaround time helps to reduce the volume of ordered STAT tests. J Lab Autom. 2016;21(3):451–458.

[21] Gardner RL, Sarkar U, Maselli JH, Gonzales R. Factors associated with longer ED lengths of stay. Am J Emerg Med. 2007;25(6):643–650.

[22] Bernstein SL, Aronsky D, Duseja R, Epstein S, Handel D, Hwang U, McCarthy M, John McConnell K, Pines JM, Rathlev N, et al. The effect of emergency department crowding on clinically oriented outcomes. Acad Emerg Med. 2009;16(1):1–10.

[23] Kreindler SA, Cui Y, Metge CJ, Raynard M. Patient characteristics associated with longer emergency department stay: a rapid review. Emerg Med J. 2016;33(3):194–199.

[24] Lee EJ, Shin SD, Song KJ, Kim SC, Cho JS, Lee SC, Park JO, Cha WC. A point-of-care chemistry test for reduction of turnaround and clinical decision time. Am J Emerg Med. 2011;29(5):489–495.

[25] Casalino E, Wargon M, Peroziello A, Choquet C, Leroy C, Beaune S, Pereira L, Bernard J, Buzzi J-C. Predictive factors for longer length of stay in an emergency department: a prospective multicentre study evaluating the impact of age, patient's clinical acuity and complexity, and care pathways. Emerg Med J. 2014;31(5):361–368.

[26] Goodacre S, Bradburn M, Fitzgerald P, Cross E, Collinson P, Gray A, Hall AS. The RATPAC (randomised assessment of treatment using panel assay of cardiac markers) trial: a randomised controlled trial of point-of-care cardiac markers in the emergency department. Health Technol Assess. 2011;15(23):1–102.

[27] Ellison TL, Alharbi M, Alkaf M, Elimam S, Alfaries M, Nounou RA, Nasr R, Owaidah T. Implementation of total laboratory automation at a tertiary care hospital in Saudi Arabia: effect on turnaround time and cost efficiency. Ann Saudi Med. 2018;38(5):352–357.

[28] Lee-Lewandrowski E, Corboy D, Lewandrowski K, Sinclair J, McDermot S, Benzer TI. Implementation of a point-of-care satellite Laboratory in the Emergency Department of an Academic Medical Center. Arch of Pathol & Lab Med. 2003;127(4):456–460.

[29] Kaushik N, Khangulov VS, O'Hara M, Arnaout R. Reduction in laboratory turnaround time decreases

emergency room length of stay. Open Access Emerg Med. 2018;10:37–45.

[30] Murray RP, Leroux M, Sabga E, Palatnick W, Ludwig L. Effect of point of care testing on length of stay in an adult emergency department. The J Emerg Med. 1999;17(5):811–814.