

Turnaround time in diagnostics, analysing delays and strategic improvements in a tertiary care hospital

Danish Ahmad

Aarogya Hospital

Saumya Sajiv Kumar Sharma

saumyasajivkumarsharma@gmail.com

Santosh Deemed to be University

Manish Sabharwal

Santosh Deemed to be University

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Abstract

Background:

Turnaround time (TAT) is an important indicator of laboratory efficiency and can influence clinical decision-making. Delays may occur during the pre-analytical, analytical, and post-analytical stages. This study assessed laboratory TAT and identified factors associated with delays in biochemistry and haematology investigations.

Methodology:

A Descriptive, cross-sectional, single-centre study was conducted from January to March 2026 in a multispeciality tertiary care hospital in New Delhi. Hospital Information System (HIS) records for routine biochemistry and haematology investigations from outpatient (OPD) and inpatient (IPD) settings were reviewed. Of 4,552 retrieved records, 2,505 complete records met the predefined eligibility criteria, including 1,598 (63.8%) biochemistry and 907 (36.2%) haematology samples. Collection, sample assessing, acceptance, result reporting, and validation timestamps were extracted. Pre-analytical, analytical, post-analytical, and TAT were calculated. Median TAT with 10th and 90th percentiles was assessed. Operational factors were evaluated using structured questionnaires among 238 OPD patients and 80 healthcare workers from inpatient settings.

Results:

The overall median total TAT was 138 minutes, with 139 minutes for biochemistry and 137 minutes for haematology. The analytical phase contributed the highest proportion (57%), followed by pre-analytical (26%) and post-analytical (17%) phases. Significant differences were observed among the TAT phases (Kruskal–Wallis $H = 5897$, $p < 0.001$). Against analytical benchmarks, 1,104 (69%) biochemistry samples met the < 90 -minute criterion, while 204 (22%) haematology samples met the < 60 -minute criterion. Among OPD patients, major reported problems included payment-related delays (76.1%), insufficient manpower for specimen collection (71.8%), patient misdirection/lack of signboards (71.8%), and insufficient billing manpower (71%). In IPD, major issues included pre-analytical processing delays (88%), HIS transcription delays (73%), and specimen transportation delays (70%). A significant association was observed between specimen transport and staff designation ($\chi^2 = 4.490$, $p = 0.034$).

Conclusion:

Laboratory TAT was influenced by multiple workflow-related factors. Although the analytical phase accounted for the largest proportion of TAT, administrative processes, specimen transportation, HIS-related delays, and result validation also contributed to it. Targeted workflow redesign, adequate staffing,

improved transport systems, clear patient navigation, and optimized HIS processes may help reduce delays and improve diagnostic service efficiency.

Introduction

The importance of clinical laboratories in modern medical practice cannot be overstated since they are the basis for evidence-based medicine. According to various sources, up to 60% of clinical decisions about diagnosis, patient management, and treatment are made based on laboratory results. [1–3] Therefore, in addition to the accuracy and quality of laboratory analysis, the timely availability of laboratory results is equally important for effective clinical decision-making and patient care. [4, 5] TAT is one of the most visible performance indicators of laboratory services and is used by many clinicians to evaluate the quality of the laboratory.

Turnaround time (TAT) is widely used as a measure of laboratory efficiency and performance. A review of the literature indicates that a number of different approaches have been taken to draft the definition of TAT. TAT can be categorised by test, priority (urgent or routine), population served (inpatient, outpatient), and the activities included. It is commonly defined as the period from test requisition or sampling to the validation of results. [6, 7] However, TAT is interpreted in several ways. Clinicians often perceive TAT as the total time from ordering a test to receiving the result, whereas laboratories frequently define TAT as the period from sample receipt to result validation or authorisation. [8–10]

The concept of the total testing cycle, also known as the “brain-to-brain loop,” provides a comprehensive understanding of TAT. [11–14] According to ISO 15189:2022, the whole process of laboratory examination process consists of three stages: pre-analytical, analytical, and post-analytical. [15, 16] Despite great progress in automation and quality management systems, which have greatly facilitated accurate results acquisition, up to 70% of laboratory errors take place at the pre-analytical stage. Common causes include improper patient identification, sampling errors, incorrect labelling, inappropriate transport and storage of samples, and incomplete clinical information. [12, 17]

Timely reporting of laboratory results is essential for prompt diagnosis and treatment. Delays in TAT may result in postponed clinical decisions, prolonged hospital stay, emergency department overcrowding, increased healthcare costs, repeat testing, and reduced patient satisfaction. [18, 19] Therefore, TAT is recognized as an important quality indicator and is routinely monitored under laboratory quality management systems. Accreditation standards such as ISO 15189:2022 and NABL require laboratories to establish, monitor, and periodically review TAT criteria to ensure effective and timely laboratory services.

Several studies have evaluated TAT using routinely requested laboratory investigations to assess laboratory performance and service efficiency. Choosing routinely requested investigations makes TAT assessment more representative of routine laboratory practice. Nevertheless, it is difficult to achieve optimal TAT in spite of all the criteria for quality and the advances in the area of laboratory automation. In developing countries such as India, there have been great improvements in the quality of laboratory

analysis due to the efforts of accreditation bodies such as NABL. Nevertheless, the problems concerning TAT still remain.

While there have been numerous studies done on turnaround time of the laboratories, there are still certain limitations which cannot be overlooked. Although previous studies have evaluated TAT using routinely requested laboratory investigations, important gaps remain in the existing evidence. There is a paucity of studies that comprehensively evaluate TAT across the entire testing cycle using routinely generated Hospital Information System (HIS) data and simultaneously examine workflow- and system-level contributors to delay in both outpatient and inpatient settings. Furthermore, limited institution-specific evidence combines objective HIS-based TAT assessment with stakeholder perspectives to identify operational bottlenecks.

Therefore, there is a need for the systematic evaluation of turnaround time in tertiary care hospitals. In this background, the present study is being conducted in a tertiary care hospital. The purpose of this study is to evaluate the turnaround time in diagnostic analysis delays and strategic improvements in a tertiary care hospital, with the objectives of enhancing laboratory service efficiency by assessing TAT for routine biochemistry and haematology investigations and identifying operational and workflow-related factors influencing turnaround time in Outpatient and Inpatient settings.

Materials and Methods

Study Design:

This was a Descriptive cross-sectional single-centre study.

Study Setting:

The study was carried out in a multispeciality hospital located in New Delhi. The hospital has 110 beds and 18 specialised departments and provides outpatient, inpatient, and emergency care to patients from Delhi and neighbouring states. Laboratory investigations are conducted in a central laboratory comprising biochemistry, microbiology, and pathology sections. The laboratory uses automated equipment for routine diagnostic testing, including EM-200, Nulyte Smart, i-SENS, Abbott, and ARKRAY PocketChem systems for biochemistry-related investigations, ERBA H-560 for haematology, and i-SENS Coag-2 for coagulation testing. For the present study, only routine investigations carried out in the biochemistry and haematology sections were considered, as these investigations constitute a substantial proportion of the laboratory's routine workload.

The study covered a three-month period, from January 2026 to March 2026. During this period, 4,552 laboratory records were obtained from the Hospital Information System (HIS). After reviewing the available records, 2,505 samples containing complete and valid time-stamp information were included in

the analysis. The samples represented patients attending both the outpatient department (OPD) and inpatient department (IPD), and were collected throughout the study period from different hospital units.

Inclusion and Exclusion Criteria:

Inclusion criteria:

- The investigations included in the study were finalized through consultation and consensus with experts from the Departments of Haematology and Biochemistry. Only those investigations for which complete and valid time-stamp information was available were considered for analysis. A detailed list of the selected investigations is provided in Additional file 1.
- Included specimens received in the laboratory between 8:00 AM and 8:00 PM.

Exclusion Criteria:

- Specimens received before 8:00 AM or after 8:00 PM were excluded.
- Specimens were excluded if timestamps were invalid or missing.
- Records showing negative or implausible time intervals were excluded from the analysis, as these were considered to result from inconsistencies in system-generated timestamps.

Procedure:

Blood samples were obtained from patients in accordance with aseptic techniques. Samples received in the laboratory were barcoded, classified based on department and analysed in an automated biochemistry analyser. In calculating laboratory TAT, time stamps that were predefined and automatically captured in the HIS were used. These time stamps are reflective of time stamps at various stages of the preanalytical, analytical and postanalytical stages of laboratory testing. Time stamps recorded in the HIS in relation to each stage of laboratory testing “As shown in Fig. 1”.

Here is the depiction of the sample testing process followed within the study centre, representing the laboratory procedures established at the facility. In the outpatient setting, the pre-analytical process comprises patient registration, medical consultation, test prescription, billing, sample collection, and barcode generation “As shown in Fig. 2”. As the OPD collection centre is attached to the central laboratory, the collected samples are directly transferred to the sample assessing area.

For inpatient setting, test requisition and specimen collection are carried out in the respective wards, after which GDA staff physically transport the specimens to the laboratory assessing area. After the specimen assessment in the assessing area, the specimens for both settings are processed using the same analytical pathway that involves specimen acceptance, testing, electronic results entry in the HIS, and post-analytical procedures such as result validation. TAT measurement was done within the scope of these operational practices specific to the health facility, as the processes in laboratories can vary from one health setting to another.

The first task was to define turnaround time (TAT) in this study. TAT was defined as the time interval starting from sample collection to result validation. Collection, sample assessing, acceptance, result reporting, and validation timestamps were extracted. The definition of Pre-analytical TAT included the time elapsed between the collection of the sample to its reception by the central lab. Analytical TAT covered the time elapsed between the reception of the sample and the entry of results into HIS. Post-analytical TAT covered the time from result entry to result validation.

The TATs were also categorised according to their time (< 60 minutes, 60–90 minutes, and > 90 minutes). The reasons being that there has been no agreement on the best way of reporting TAT in the literature; thus, several metrics have been used.

For the secondary objectives, data were collected to assess factors influencing TAT. Structured questionnaires were developed adapted separately for outpatient participants and healthcare workers working in inpatient departments. The tool was adapted based on the local situation, translated and validated by Naveen K G et al. [20] during the evaluation of the turnaround time of laboratory investigations and factors responsible for delays in a tertiary care teaching hospital in Eastern India.

For OPD, the questionnaire was pilot - tested using 50 patients who visited the hospital randomly in order to check whether all the domains have been covered and the language is clear in the questions. The tool was designed in English and translated into the local language of Hindi. Patients were selected through convenience sampling from the OPD waiting areas.

The tool used to assess the delay factors of OPD (20 items) and IPD (16 items) has been assessed on a Yes/No scale basis. Each item or sub-component of this scale dealt with different phases of TAT delay in OPD as well as IPD departments.

For IPD, data were gathered using structured face-to-face interviews based on convenience sampling. The sample size for the inpatient group comprised 14 out of 19 RMOs and 66 out of 78 nursing staff responsible for requisitioning, collecting and transporting specimens. This questionnaire was pilot-tested to assess clarity and face validity,

The sample size was calculated using Epi Info StatCalc (CDC, version 7.2.7.0), using the Population Survey module. The population size was estimated at approximately 1,000 patients based on the average number of patients/samples received by the laboratory over two months. The calculation assumed an expected frequency of 28.3%, based on the pilot study, a 95% confidence level, a 5% margin of error. Based on these parameters, Epi Info estimated a required sample size of 238 patients. Accordingly, data from 238 patients were included in the final analysis

Data management and analysis

Data were analysed using the Statistical Package for Social Sciences, IBM SPSS Statistics version 27.0 software (IBM Corp, Armonk, NY). The normality of continuous variables was assessed using the Shapiro-Wilk test. Continuous variables were summarised using mean and standard deviation, or median

and interquartile range (IQR), as appropriate, along with minimum and maximum values, and the 10th and 90th percentiles. Comparisons among the pre-analytical, analytical, and post-analytical TAT components were performed using the Kruskal-Wallis test followed by Dunn’s post hoc test with Bonferroni adjustment. Associations between categorical variables were assessed using the Chi-square test.

Ethical Consideration: The study protocol was approved by the Institute Ethics Committee (IEC) of Santosh Deemed to be University (IEC number: RES/IEC SU/2026/CRF/560), Ghaziabad (Uttar Pradesh). The study was conducted according to the Declaration of Helsinki guidelines on ethical conduct involving human subjects. Necessary permissions were sought from the Medical Superintendent and the Director of the institute before initiating the study.

As the primary objective involved analysing TAT for routine biochemistry and haematology investigations, therefore it posed no risk to patients, the requirement for individual patient consent was waived by the IEC. Written informed consent was obtained exclusively for questionnaire-based components, conducted under the secondary objectives, including assessment of factors influencing TAT. Participation in these components was voluntary, and confidentiality of all responses was maintained.

Result

Table 1 Number of Biochemistry and Haematology Test Samples present in the Study.		
Test Name	N`	N
Biochemistry		
RBS	339	307
LFT	899	558
KFT	1330	563
HbA1c	227	170
Total	2795	1598
Haematology		
CBC	1697	851
ESR	60	56
Total	1757	907

N` = Sample retrieved; N = Real number of samples present

Based on the predefined inclusion and exclusion criteria, records retrieved from the Hospital Information System (HIS) were screened before analysis. Laboratory investigations selected through expert consensus from the departments of biochemistry and haematology were considered for the study. Records with complete and valid timestamps for all relevant TAT process steps and specimens received between 8:00 AM and 8:00 PM were included in the analysis. Records with incomplete or invalid timestamps, negative or implausible time intervals resulting from inconsistencies in system-generated timestamps, and specimens received outside the specified time period were excluded. Consequently, of the 2,795 biochemistry test records initially retrieved from the HIS, 1,598 (57.2%) samples were present in the final analysis. Similarly, of the 1,757 haematology test records retrieved, 907 (51.6%) were found in the final analysis. Overall, 2,505 of the 4,552 retrieved records (55.0%) were included in the final analysis. “As shown in Table 1”.

Table 2
Summary evaluation of Different Turnaround Time Stages (N = 2,505)

TAT Stages	Biochemistry Mean (SD)	Biochemistry Median (IQR)	Haematology Mean (SD)	Haematology Median (IQR)
Pre-analytical TAT*	37.4 (10.39)	35 (30–44)	37.5 (9.2)	36 (30–44)
Analytical TAT*	86.8 (34.1)	78 (61–109)	85.0 (32.9)	77 (62–103)
Post-analytical TAT*	23.1 (7.8)	23 (18–26)	22.9 (7.0)	22 (18–26)

* All values are expressed in minutes.

TAT, turnaround time; IQR, interquartile range

Here it presents a summary of the turnaround time stages of biochemistry and haematology investigations, reported as mean (SD) and median and IQR values emphasised. As the TAT data were not normally distributed, the median (IQR) was emphasised for interpretation. The median of pre-analytical TAT in biochemistry was 35 (30–44) and haematology 36 (30–44) minutes. Similarly, the median of analytical TAT was 78 (61–109) minutes for biochemistry and 77 (62–103) minutes for haematology. The median post-analytical TAT was 23 (18–26) minutes for biochemistry and 22 (18–26) minutes for haematology, indicating only minimal differences in TAT stages between the two sections. “As shown in Table 2”.

Table 3
Summary evaluation for Turnaround Time Across Different Stages of Routine Haematology and Biochemical Testing

Investigation	Pre-analytical TAT*		Analytical TAT*		Post-analytical Tat*	
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
OPD						
LFT	41.0 (9.0)	41 (35–48)	73.8 (26.1)	69 (57–83)	22.9 (7.8)	22 (18–26)
KFT	36.8 (10.4)	35 (29–43)	85.3 (32.7)	77 (62–104.7)	22.8 (8.1)	22 (18–26)
RBS	32.4 (12.7)	31 (27–35)	112.0 (31.0)	113 (88–138)	24.2 (10.2)	23 (18–27)
HbA1c	37.4 (9.0)	35 (31–43.7)	84.4 (30.6)	78.5 (62–107.5)	23.0 (7.3)	23 (18.2–26)
CBC	38.7 (9.0)	38 (32–46)	78.1 (29.3)	73 (56–87.2)	22.4 (4.6)	22.5 (19–26)
ESR	37.3 (10.4)	37 (27–45)	88.2 (32.6)	82 (64–109)	23.8 (9.3)	24 (19–27)
IPD						
LFT	38.1 (9.6)	36 (31–45)	84.9 (35.1)	76 (60–105)	22.9 (8.5)	21 (18–26)
KFT	38.5 (8.9)	37 (32–46)	79.0 (31.0)	72 (56–88)	22.8 (4.9)	23 (19–27)
RBS	39.5 (10.3)	36.5 (34.2–40.2)	92.6 (33.8)	85.5 (61.2–124.5)	28.6 (17.6)	23 (18.2–29.2)
HbA1c	38.8 (8.9)	38.5 (32.7–45)	77.2 (31.9)	67 (53.7–87.2)	22.8 (5.2)	24 (18.7–27)
CBC	36.6 (9.3)	35 (30–43)	89.6 (34.5)	88 (63–116)	23.1 (8.2)	22 (18–27)
ESR	31.8 (6.1)	33 (25.5–37.5)	107.8 (42.0)	122 (64–144.5)	22.0 (2.8)	24 (19–24)

* All values are expressed in minutes,

The analytical phase had the highest TAT across most investigations, with RBS showing the highest mean analytical TAT in OPD (112.0 ± 31.0 min) and ESR in IPD (107.8 ± 42.0 min). Pre-analytical TAT was relatively consistent, ranging from 32.4–41.0 minutes in OPD and 31.8–39.5 minutes in IPD. Post-analytical TAT remained comparatively low, generally ranging between 22 and 28.6 minutes. Overall, the

findings indicate that analytical processing was the major contributor to delays in laboratory TAT, while post-analytical processing was relatively stable. “As shown in Table 3”.

Table 4
Comparison of Turnaround Time Across Laboratory Phases Using the Kruskal–Wallis Test.

Variable	Median (min)	Mean Rank	Kruskal–Wallis H	df	p-value
Pre-analytical TAT	36	3653.99	5897.00	2	< 0.001**
Analytical TAT	78	6161.71			
Post-analytical TAT	23	1458.30			

p < 0.001** Highly Significant and p < 0.05 significant.

Table 5
Dunn's Post Hoc Test for Pairwise Comparison of Laboratory Turnaround Time Stages

Comparison	Mean Rank Difference	Z statistic	Adjusted α	Adjusted p-value
Pre-analytical vs Analytical	2507.71	40.91	0.0167	< 0.001**
Pre-analytical vs post-analytical	2195.70	35.82	0.0167	< 0.001**
Analytical vs post-analytical	4703.41	76.74	0.0167	< 0.001**

p < 0.001 ** highly significant, and p < 0.05 significant.

A statistically highly significant difference among the pre-analytical, analytical, and post-analytical TAT (Kruskal-Wallis H = 5897, dr = 2, p < 0.001) “As shown in Table 4”. The analytical phase had the highest mean rank, followed by the pre-analytical and post-analytical phases. Dunn’s post hoc test with Bonferroni adjustment confirmed highly significant pairwise differences among all three TAT phases (p < 0.001), indicating that the analytical phase contributed the greatest proportion to the overall TAT. “As shown in Table 5”.

Table 6
Summary evaluation of total Turnaround Time (N = 2505)

Metrics	Overall TAT (N = 2505)	Biochemistry (N = 1598)	Haematology (N = 907)
Mean (SD)*	146.7 (33.1)	147.4 (33.8)	145.4 (31.9)
Median (IQR)*	138 (122–163)	139 (122–165)	137 (123–160)
10th Percentile*	113	113	113
90th Percentile*	196	197	194

* All values are expressed in minutes,

TAT, turnaround time

Here, it presents an overall median TAT of 138 minutes (2 hours and 18 minutes) for all samples. The median TAT was 2 hours 19 minutes (139 minutes), IQR 122–165 minutes for biochemistry and 2 hours 17 minutes (137 minutes), IQR 123–160 minutes for haematology. The 10th percentile shows that 10% of the recorded TAT values were completed within the specified time, while the 90th percentile shows that 90% of the values were completed within the specified time. Accordingly, 90% of biochemistry samples were completed within 3 hours 17 minutes (197 minutes), and haematology samples were completed within 3 hours 14 minutes (194 minutes). “As shown in Table 6”.

Table 07
Summary evaluation of Overall Turnaround Time for the Investigations Included in the Study.

Investigation	Mean (SD)	Median (IQR)	10th Percentile	90th Percentile
OPD				
RBS	168.2 (35.8)	168 (141–194)	124	211
LFT	145.4 (31.4)	139 (120-162.5)	110	192
KFT	140.6 (33.0)	133 (121.2-151.7)	110.4	179.8
HbA1c	135.6 (18.4)	131 (122–148)	112.5	161
CBC	139.4 (26.8)	134 (121–151)	112	176.3
ESR	149.4 (32.7)	146 (126–164)	111.2	190
IPD				
RBS	160.7 (48.8)	143.5 (121.2-190.7)	116	
LFT	137.7 (27.5)	131 (119–149)	111	175.8
KFT	145.1 (32.9)	137 (120–159)	113	195
HbA1c	151.5 (38.7)	145 (122.7–175)	108.3	203.8
CBC	149.4 (34.5)	139 (125-168.5)	114	199
ESR	161.6 (39.6)	171 (120.5–198)	118	

* All values are expressed in minutes,

In OPD, the highest mean TAT was observed for RBS (168.2 ± 35.8 minutes), followed by ESR (149.4 ± 32.7 minutes), while HbA1c had the lowest mean TAT (135.6 ± 18.4 minutes). In IPD, ESR showed the highest mean TAT (161.6 ± 39.6 minutes), followed by RBS (160.7 ± 48.8 minutes). The 10th–90th percentile values indicate considerable variation in TAT across investigations. Overall, RBS and ESR

demonstrated relatively longer TAT. suggesting greater scope for process improvement. "As shown in Table 7".

TAT: turnaround time

The proportional breakdown of the median turnaround time (TAT = 138 minutes) into its three stages. The analytical stage made up the highest percentage of the total turnaround time at 57% (78 minutes). The pre-analytical stage made up 26% (36 minutes) of the total turnaround time, while the post-analytical stage accounted for 17% (24 minutes). It is clear from the results that the analytical stage contributed the most to the total turnaround time, while the other two stages accounted for 43%. "As shown in Fig. 3".

In biochemistry, 24% of samples (386/1598) completed the analytical phase within 60 minutes, whereas in haematology, 22% of samples (204/907) completed the analytical phase within 60 minutes, "As shown in Figs. 4 and 5", respectively.

Table 8
Patient-Reported Factors Affecting Turnaround Time in the OPD Setting (n = 100)

S. No.	Factors	Count (%)
1.	Long waiting time in the billing area	152 (63.9)
2.	Long waiting time in the sample collection area	76 (31.9)
3.	Insufficient manpower in the billing area	169 (71)
4.	Billing and sample collection areas located far apart	24 (10.1)
5.	Insufficient manpower in the sample collection area	171 (71.8)
6.	Patient misdirection or lack of signboards	171 (71.8)
7.	Staff negligence in the billing area, sample collection area, or laboratory	164 (68.9)
8.	Payment-related issues	181 (76.1)
9.	Insufficient manpower in the laboratory	60 (25.2)
10.	Server, electricity, or network issues affecting the billing system	71 (29.8)
11.	Need for resampling due to insufficient or wasted samples	19 (8)
12.	Misplaced or lost samples	7 (2.9)
13.	Computer or printer breakdown in the report printing area	26 (10.9)
14.	Computer or printer breakdown in the billing area	29 (12.2)
15.	Need for resampling due to indeterminate results	17 (7.1)
16.	Patient name or investigation code misprinted on the bill	10 (4.2)
17.	Laboratory equipment breakdown	21 (8.8)
18.	Vacutainer dispenser failure	12 (5)
19.	Report mismatch	10 (4.2)
20.	Misprinted barcode on the Vacutainer	05 (2.1)

Here, it presents the laboratory TAT delay factors reported by OPD patients. Responses were collected from 100 patients in total. The most frequently reported factors were payment-related issues (76.1%), insufficient manpower in the sample collection area (71.8%), patient misdirection or lack of signboards (71.8%), insufficient manpower in the billing area (71%), and staff negligence in the billing area, sample collection area, or laboratory (68.9%).

“As shown in Table 8”.

Table 9
Healthcare Worker-Reported Factors Affecting Turnaround Time in the Inpatient Setting (N = 80)

Phase of TAT	Sl.NO	Factor	Count (%)	χ^2 (p-value)
Pre-Analytical Phase	1	Server, electricity and network issues of billing and HIS systems	12 (15)	
	2	Transport from ward to laboratory	56 (70)	4.49 (0.034)
	3	Haemolysis and need for repeat sampling	42 (53)	0.459 (0.498)
	4	Waiting at billing area	42 (53)	0.459 (0.498)
	5	Missing or incomplete payment	6 (8)	0.378 (0.539)
	6	Pre-analytical processing delays	70 (88)	
	7	Incorrect entry of patient name or Investigation code	6 (8)	0.378 (0.539)
	8	Delay in analyte testing due to heavy workload	28 (35)	0.137 (0.711)
	9	Specimens misplaced in the laboratory	10 (13)	
Analytical Phase	10	Reagents out of stock/not supplied/expired	0 (0)	
	11	Need for specimen dilution and re-run	6 (8)	
	12	Equipment breakdown	16 (20)	
	13	Delay in transcription from equipment to register and HIS	58 (73)	
	14	Reporting system (HIS) downtime	12 (15)	0.109 (0.742)
Post-Analytical phase	15	Delay in result validation	12 (15)	1.738 (0.187)
	16	Mismatch of reports in HIS	10 (13)	

$p < 0.001$ ** highly significant, and $p < 0.05$ significant.

Here, it presents the laboratory TAT delay factors reported by RMOs and staff nurses (N = 80). The most frequently reported factors were pre-analytical processing delays (88%), delay in transcription from equipment to the Hospital Information System (73%), transport of specimens from the ward to the laboratory (70%), haemolysis requiring repeat sampling (53%), and waiting at the billing area (53%),

Chi-square shows that transport of specimens from the ward to the laboratory was significantly associated with staff designation ($\chi^2 = 4.490, p = 0.034$), being reported more frequently by staff nurses (75.8%; 50/66) than RMOs (42.9%; 6/14). "As shown in Table 9",

Discussion

Factors such as the hospital's workflow, level of automation, staff availability and scheduling patterns, and patient load of the Hospital Information System (HIS/LIS) naturally influence turnaround time (TAT). Consequently, the findings of the present study should be interpreted within the context of a high-volume tertiary care hospital and may not be directly generalisable to other healthcare settings. In accordance with ISO 15189:2022, TAT assessment was performed as an internal quality assurance exercise to establish baseline performance metrics and identify workflow bottlenecks. Previous studies have been cited only to provide context for the observed findings and to explain potential contributors to delays rather than for direct comparison.

A total of 4,552 laboratory records were retrieved during the study period; however, only 2,505 records met the predefined inclusion criteria and were included in the final analysis. Another important operational observation was the limited availability of valid HIS timestamp data points. Only 55% of generated samples were eligible for analysis because final report approval was restricted to between 8:00 a.m. and 8:00 p.m., and many records contained implausible or inconsistent timestamps. An institutional laboratory audit also reported similar problems with reliable time capture and report validation. In the present study, the limited availability of analysable records was attributable primarily to the institution's report validation workflow and the predefined inclusion criteria. In these cases, delayed report validation and incomplete timestamp records made it challenging to accurately evaluate laboratory performance, even when routine laboratory services were being delivered on a regular basis. Naveen K. G. et al.[20] also emphasised that meaningful assessment of turnaround time depends on accurate timestamp recording throughout the testing cycle. Although the exclusion of records with incomplete or inconsistent timestamps, as well as samples outside the predefined study period, may have influenced the overall TAT estimates, the phase-wise findings of the present study are considered reliable because the analysis was restricted to records with chronologically valid timestamps. Moreover, the exclusion of a substantial proportion of retrieved records underscores the importance of accurate timestamp recording and appropriate report validation practices for reliable laboratory performance monitoring.

Results from Phase-wise analysis in the current study revealed that the analytical phase had the highest percentage of contribution to the total TAT at 57%, while pre-analytical and post-analytical phases had contributions of 26% and 17%, respectively. On the contrary, in the findings of Badyal et al.,[21] the combined contribution of pre-analytical and post-analytical phases was between 52.6%-58.4% while that of the analytical phase was between 41.6%-47.4%. Also, in the findings of Bhuyar et al.,[22] the contribution of pre-analytical and post-analytical phases was between 51.7%-51.8%. Naveen K G et al. [20] also found that non-analytical processes dominated the total TAT, with the pre- and post-analytical

phases together contributing approximately 74%. These differences are likely attributable to variations in institutional workflow, including the physical layout of sample collection and laboratory areas, specimen transport systems, degree of automation, and report distribution processes. In the present study, the proximity of the sample collection area to the laboratory likely minimised specimen transportation time, thereby reducing pre-analytical delays and increasing the relative contribution of the analytical phase.

The present study identified several operational factors contributing to delayed TAT in the outpatient setting. Patients most frequently reported payment-related issues, insufficient manpower in the billing and sample collection areas, lack of signboards, staff negligence, and prolonged waiting in the billing area as the major contributors to delay. Similar workflow-related challenges have been reported by Naveen K. G. et al.[20] also reported that prolonged waiting time, inadequate manpower, and patient flow-related issues were important factors affecting laboratory TAT, while Rathva et al.[5] highlighted that workflow inefficiencies and specimen transport delays adversely affected laboratory TAT. The results indicate that the administrative procedures and patient flow can have a significant impact on the laboratory turnaround time even before the analytical phase begins.

In the inpatient setting, healthcare workers identified delays in pre-analytical processing, specimen transport from the ward to the laboratory, delay in transcription from laboratory equipment to the HIS and haemolysis requiring repeat sampling as major contributors to delayed TAT. Similar results were reported by Zaffar et al.[23] who found that the largest proportion of total TAT was due to delays in specimen collection, transportation and pre-analytical processing. Kaur et al.[24] observed that manual specimen transport and manual report dispatch prolonged the pre- and post-analytical phases compared with the analytical phase.

Among all evaluated factors, only transport from the ward to the laboratory showed a statistically significant association with delayed TAT ($\chi^2 = 4.490$, $p = 0.034$), highlighting specimen transport as an important operational bottleneck in the inpatient setting. Cherie et al.[25] demonstrated that Lean-based process optimisation can substantially decrease laboratory TAT by improving workflow efficiency. Cai et al.[26] reported that real-time digital monitoring and Lean Six Sigma helped to identify workflow bottlenecks early and improve laboratory performance. The results emphasise the need for focused interventions on the preanalytical workflow, particularly specimen transport and process monitoring, to improve the overall laboratory efficiency.

The analytical phase was evaluated using the turnaround time (TAT) benchmarks recommended by Hawkins et al.[27] which suggest an analytical TAT of ≤ 60 minutes for haematology and ≤ 90 minutes for biochemistry. When these benchmarks were applied to the overall TAT, only 0.12% of biochemistry samples and none of the haematology samples met the recommended target. However, when only the analytical phase was considered, 69% of biochemistry samples met the recommended benchmark, whereas 22% of haematology samples were processed within 60 minutes. These findings suggest that delays in the overall TAT were mainly due to non-analytical processes rather than the analytical testing itself. Compared with the findings of Naveen et al.[20] the present study demonstrated lower compliance

with the recommended analytical TAT, particularly for haematology (22%), while 69% of biochemistry samples achieved the recommended ≤ 90 -minute benchmark. This difference may reflect variations in laboratory workload, workflow, instrumentation, and operational practices across study settings.

The analytic phase was measured based on the TAT benchmarks as outlined by Hawkins et al.²³, which state that the TAT for haematology should be less than or equal to 60 minutes, while that of biochemistry should be less than or equal to 90 minutes. While the application of these benchmarks to the TAT as a whole showed that just 0.12% of biochemistry samples and no haematology samples fulfilled the benchmark, taking into account just the analytic phase, 69% of biochemistry samples reached the benchmark, compared to only 22% of haematology samples being processed in 60 minutes. Compared with the findings of Naveen et al.^[20] The present study demonstrated lower compliance with the recommended analytical TAT, particularly for haematology (22%), while 69% of biochemistry samples achieved the recommended ≤ 90 -minute benchmark. This difference may reflect variations in laboratory workload, workflow, instrumentation, and operational practices across study settings.

The present study identified post-analytical factors that contributed to delayed laboratory turnaround time (TAT). Similar findings have been reported by Alain et al.^[8] who observed that result verification and reporting workflow were important contributors to post-analytical delays. In the present study, delays related to result validation, report verification, and the Hospital Information System (HIS) were identified as factors affecting the post-analytical phase. However, samples that had been processed past 8:00 PM were not included in the post-analytical review since, in accordance with the laboratory's reporting guidelines, regular reports issued during the night shift would be checked by the senior technical staff through delta check and would then be reported as provisional reports, with the final approval done by the pathologist the next day. Therefore, this routine reporting practice was not considered a true post-analytical delay in the present study.

Several operational factors contributing to laboratory turnaround time (TAT) delays were identified across the testing cycle. In the outpatient setting, patients most frequently reported payment-related issues, insufficient manpower in the billing and sample collection areas, lack of signboards leading to patient misdirection, staff negligence, and prolonged waiting in the billing area as the major contributors to delayed TAT. In the inpatient sector, healthcare practitioners found specimen pre-analysis delay, specimen transport from the ward to the laboratory, haemolysis necessitating recollection of specimens, and analyte analysis delay caused by work overload as factors that impact TAT. In the analytical and post-analytical stages, factors such as result transcription from laboratory machines to the Hospital Information System (HIS), result validation, HIS downtime, and result reporting mismatch were cited as major operational challenges. These results clearly show that there is more than just analysis that impacts TAT in laboratories.

Strengths and limitations of the study

The present study has several notable strengths. First, laboratory turnaround time was assessed across all three stages of the testing process, namely the pre-analytical, analytical, and post-analytical stages, allowing identification of phase-specific workflow bottlenecks rather than assessing only the overall TAT. Second, the study had the advantage of having investigations for biochemistry and haematology performed routinely for both in-patient and out-patient patients at a busy tertiary care hospital. The third aspect of the study is that TAT analysis was done using HIS (Health Information System) generated system time stamps which helped avoid bias due to recall. The last strength of the study was that not only laboratory but also patient- and healthcare worker-reported process factors were included.

The study was conducted in only one tertiary care hospital and for a period of three months, so the results may not be the same in other hospitals or during other periods. Also, many records available in the Hospital Information System did not have complete or correct time information. Because of this, some records had to be removed from the study. The study also included only routine biochemistry and haematology tests and did not include other laboratory sections. In addition, the factors affecting TAT were collected from patients and healthcare workers using questionnaires, so the responses were based on their own experience and may not represent every delay occurring in the laboratory.

Conclusions and recommendations

The current study analyzed the turnaround time of laboratory analysis for the common biochemistry and haematology investigations in a tertiary healthcare center and determined the key operational barriers to this process. According to the results, the analytical phase comprised the biggest part of TAT. However, the overall delay in TAT was not related only to the analytical phase. The pre-analytical and post-analytical operations, such as prolonged waiting time at the billing department, prolonged waiting time at the sample collection department, lack of staff at the billing department, payment issues, negligence of the staff at the billing department, manual recording of the results in the Hospital Information System (HIS), and results validation, were found to be the important operational barriers. The transportation of the samples from the ward to the lab in the inpatient setting was associated with significantly higher chances of TAT delay, haemolysis, and re-sampling needs. Delay in the transcription of the results using equipment to register in the HIS.

An automated delta check system that integrates with the Hospital Information System would be ideal for this laboratory. This would enable comparison of current test results and those of previous tests and detect any differences. The introduction of this system will also make it possible to release reports more quickly both day and night. Delta check and quality control systems can be automated to save on effort and enable fast reporting.

The time interval between wards and the laboratory should be reduced by instituting an inpatient specimen transport system or scheduled transport rounds. There should be enough staff in the billing and sample collection areas. Proper patient guidance, clear signboards and regular staff training should be provided to reduce waiting time, haemolysis and repeat sampling. Laboratory workload should be

balanced, regular preventive maintenance of analysers should be performed, and backup arrangements should be available to reduce interruptions during the analytical phase. Create a real-time digital dashboard showing phase-by-phase TAT, late samples, validation pending and critical alerts to allow lab personnel to detect bottlenecks in advance and optimize the process flow. Internal audits should be conducted regularly, and staff should be assessed for their competency to review compliance with ISO 15189:2022 and to identify areas of continuous quality improvement.

List of Abbreviation

CBC, Complete Blood Count; CDC, Centers for Disease Control and Prevention; ESR, Erythrocyte Sedimentation Rate; GDA, General Duty Attendant; HbA1c, Glycated Haemoglobin; HIS, Hospital Information System; IQR, Interquartile Range; IPD, Inpatient Department; KFT, Kidney Function Test; LIS, Laboratory Information System; LFT, Liver Function Test; NABL, National Accreditation Board for Testing and Calibration Laboratories; OPD, Outpatient Department; RBS, Random Blood Sugar; RMO, Resident Medical Officer; SD, Standard Deviation; TAT, Turnaround Time.

Declarations

- **Ethical Consideration:** The study protocol was approved by the Institute Ethics Committee (IEC) of Santosh Deemed to be University (IEC number: RES/IEC SU/2026/CRF/560), Ghaziabad (Uttar Pradesh). The study was conducted according to the Declaration of Helsinki guidelines on ethical conduct involving human subjects. Necessary permissions were sought from the Medical Superintendent and the Director of the institute before initiating the study.

As the primary objective involved analysing TAT for routine biochemistry and haematology investigations, therefore it posed no risk to patients, the requirement for individual patient consent was waived by the IEC. Written informed consent was obtained exclusively for questionnaire-based components, conducted under the secondary objectives, including assessment of factors influencing TAT. Participation in these components was voluntary, and confidentiality of all responses was maintained.

- **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue.

Consent for Publication:

- Informed consent for publication was provided by the participants.

Competing interests:

- The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Author Contribution

DA - Conception/design; data acquisition, analysis or interpretation; drafting or substantive revision of the manuscript. SS - Conception/design; interpretation; drafting or substantive revision of the manuscript. MS - Substantive revision of the manuscript; Investigation and reviewing & Editing. All authors read and approved the final Manuscript.

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Data Availability

The datasets generated during the current study are not publicly available but are available from the corresponding author on reasonable request.

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Figures

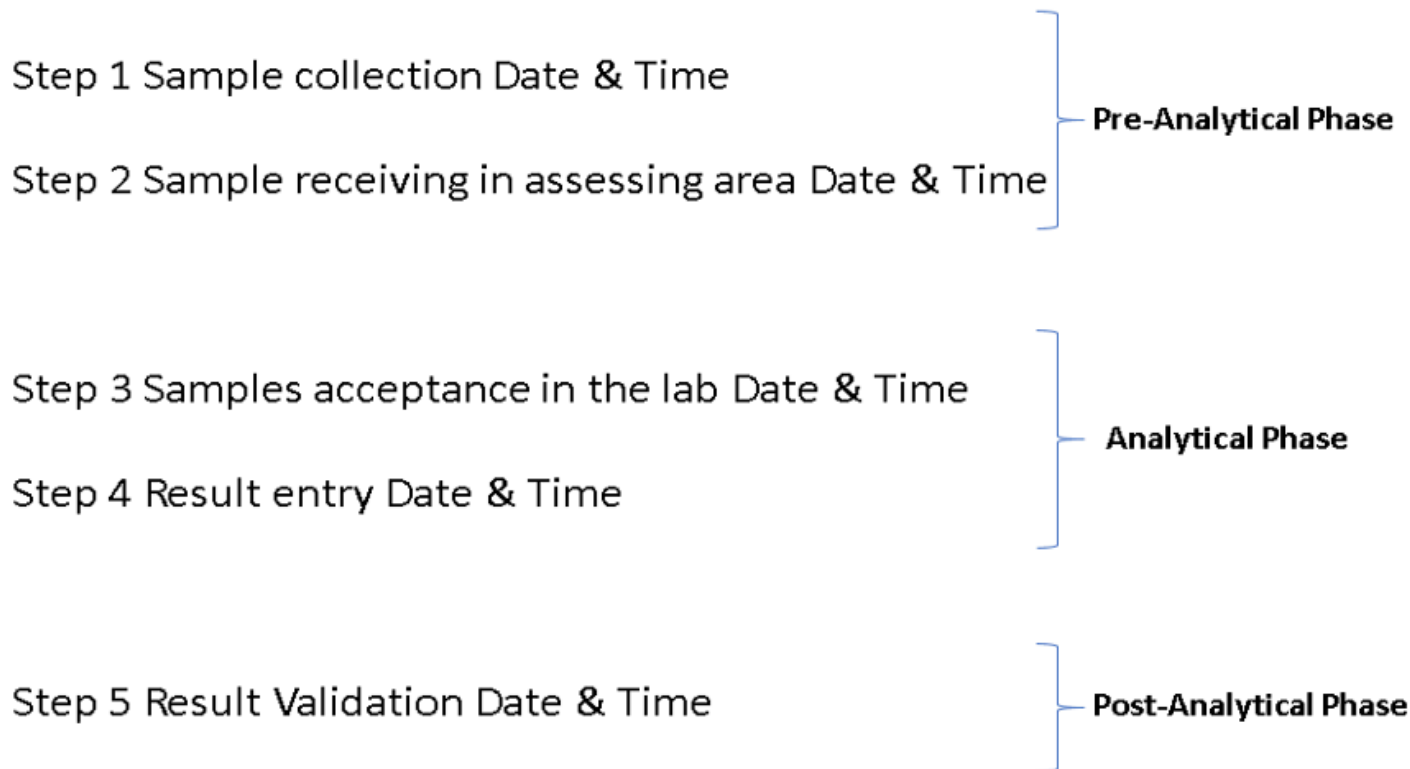


Figure 1

Time stamps recorded in the HIS in relation to each stage of laboratory testing.

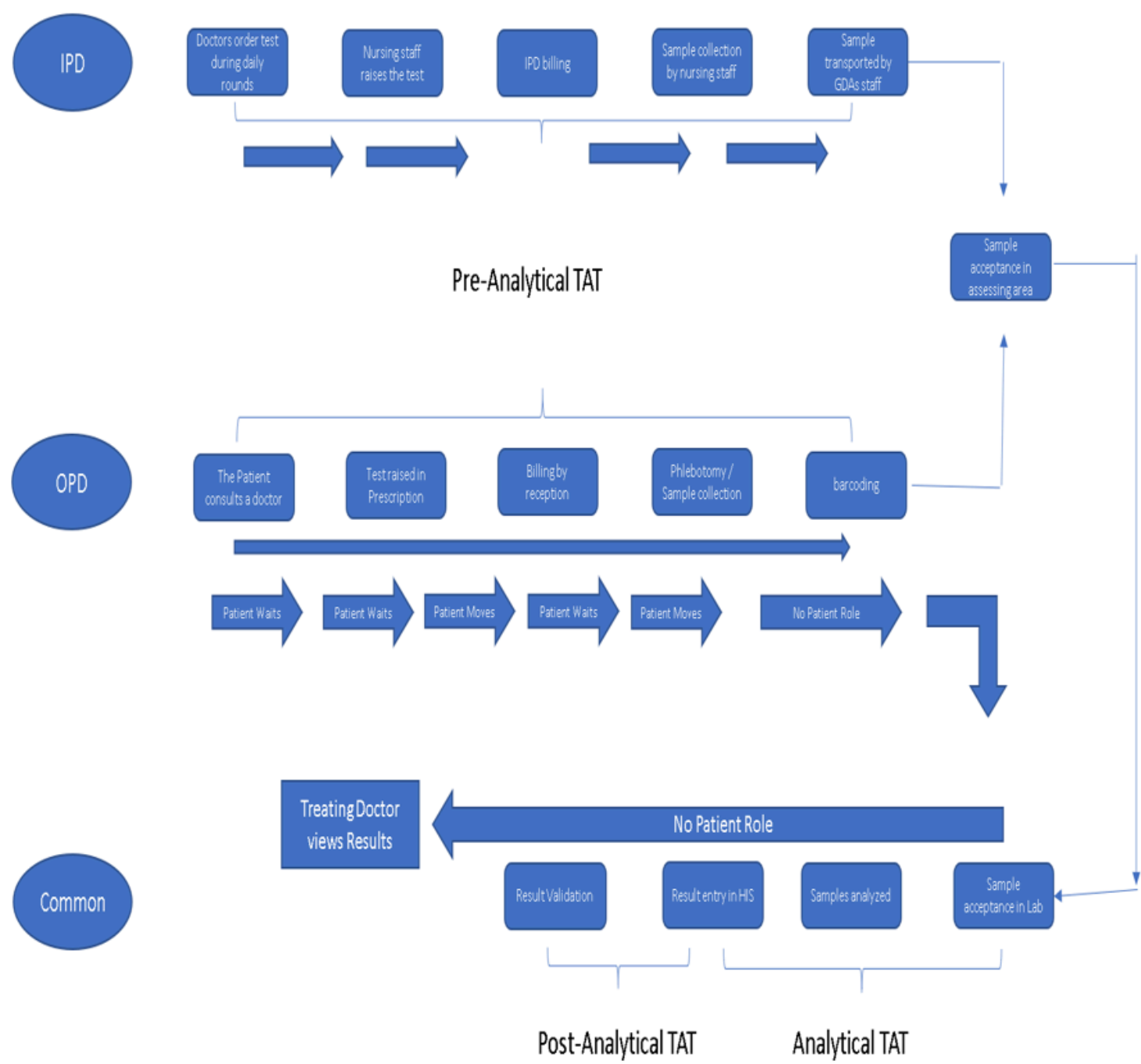


Figure 2

Overall sample testing process flow of OPD and IPD.

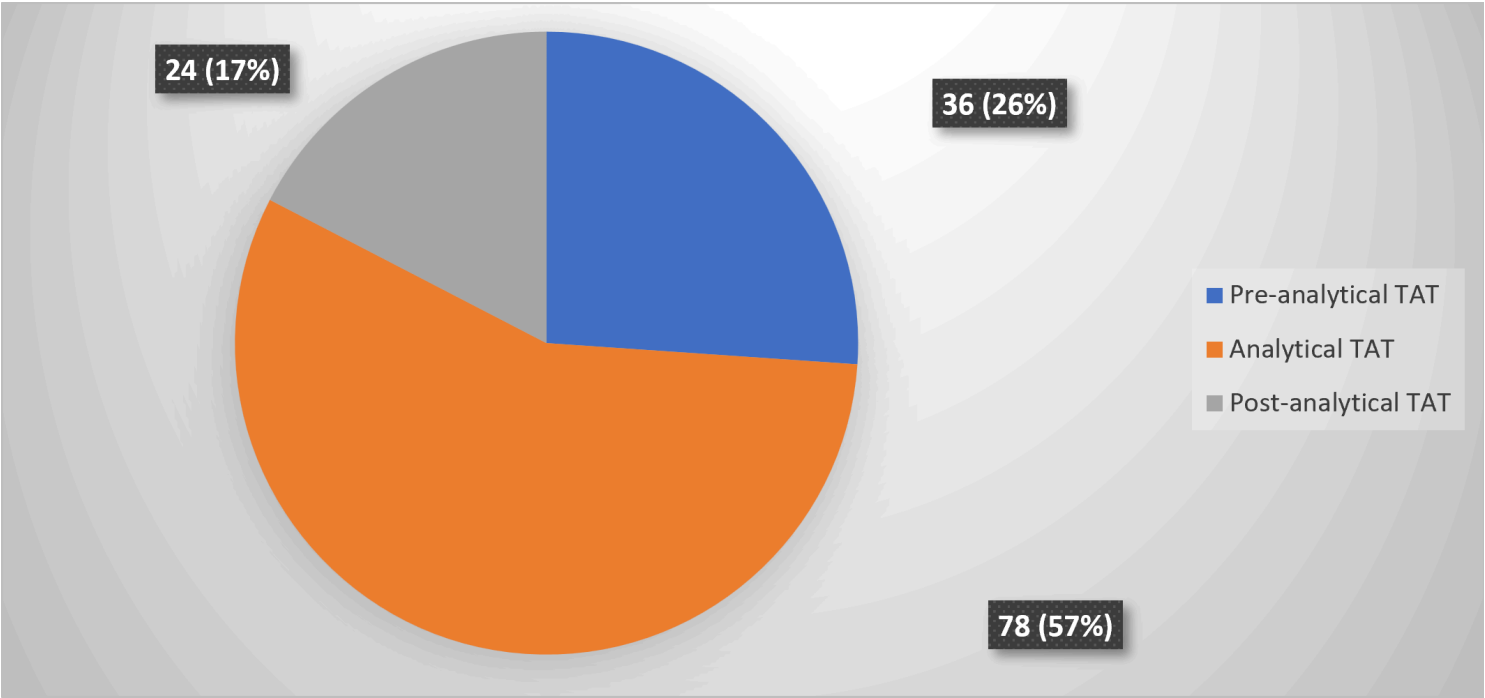


Figure 3

Proportional Distribution of Turnaround Time Stages Based on Overall Turnaround Time (138 Minutes).

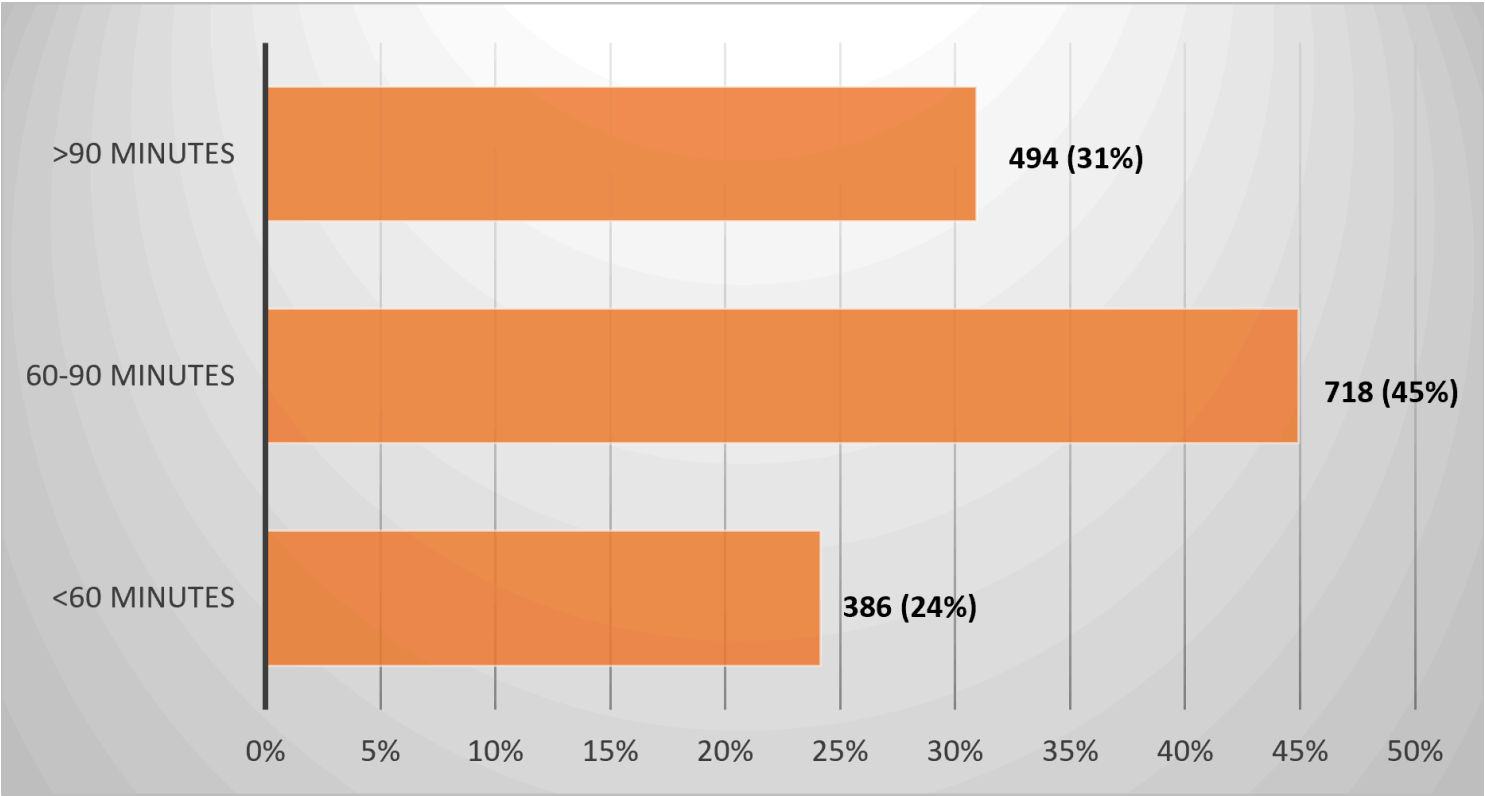


Figure 4

Frequency Distribution of Biochemical Test Specimens Across Analytical Turnaround Time Intervals (N = 1,598)

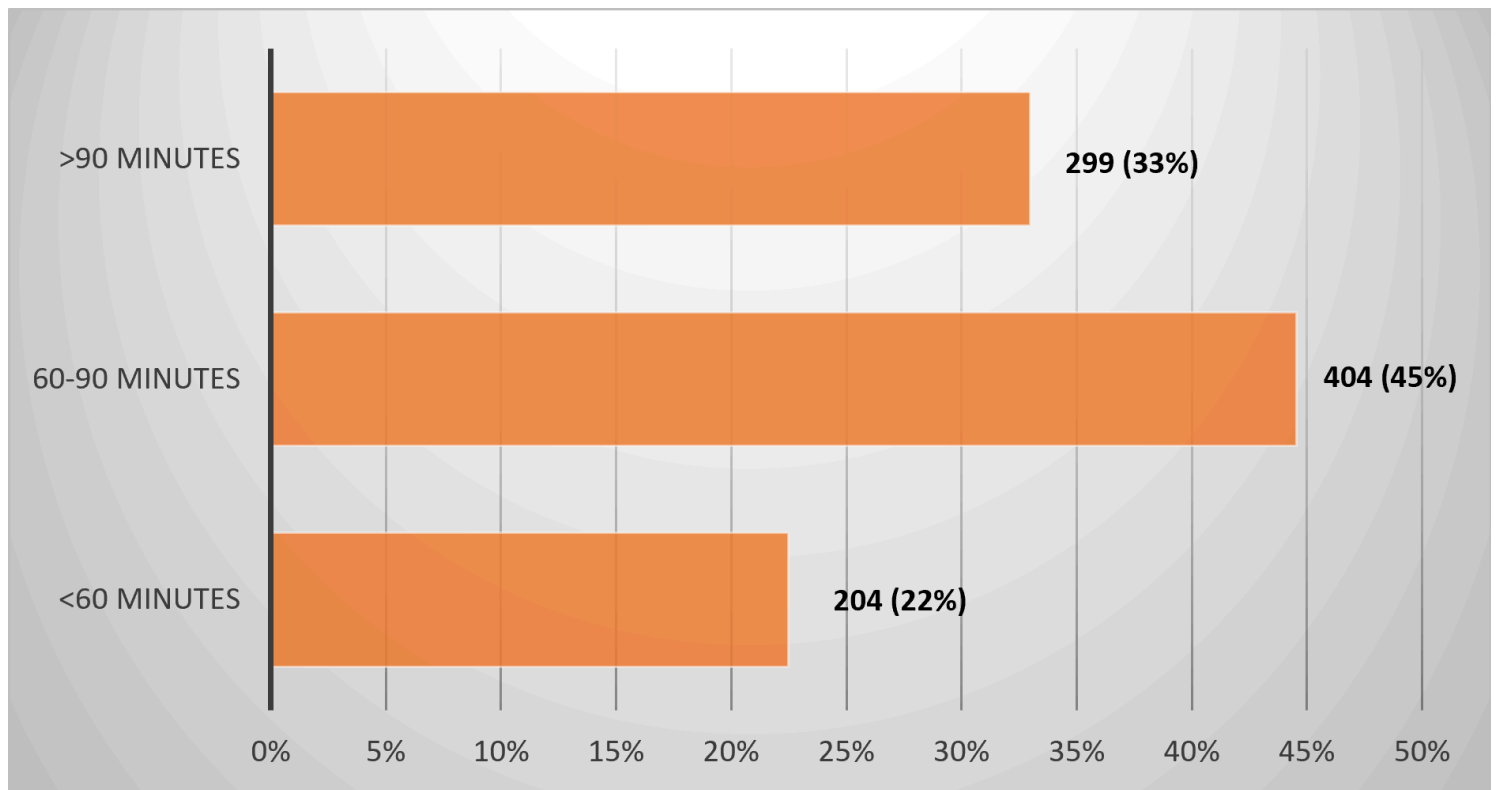


Figure 5

Frequency Distribution of Haematological Test Specimens Across Analytical Turnaround Time Intervals (N = 907)

Supplementary Files

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