Review Article

Laboratory Turnaround Time

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Abstract
Turnaround time (TAT) is one of the most noticeable signs of laboratory service and is often used as a key performance indicator of laboratory performance. This review summarises the literature regarding laboratory TAT, focusing on the different definitions, measures, expectations, published data, associations with clinical outcomes and approaches to improve TAT. It aims to provide a consolidated source of benchmarking data useful to the laboratory in setting TAT goals and to encourage introduction of TAT monitoring for continuous quality improvement. A 90% completion time (sample registration to result reporting) of <60 minutes for common laboratory tests is suggested as an initial goal for acceptable TAT.

Introduction
Quality can be defined as the ability of a product or service to satisfy the needs and expectations of the customer.[1] Laboratories have traditionally restricted discussion of quality to technical or analytical quality, focusing on imprecision and inaccuracy goals. Clinicians however are interested in service quality, which encompasses total test error (imprecision and inaccuracy), availability, cost, relevance and timeliness.[2] Clinicians desire a rapid, reliable and efficient service delivered at low cost.[3] Of these characteristics, timeliness is perhaps the most important to the clinician, who may be prepared to sacrifice analytical quality for faster turnaround time (TAT).[2] This preference drives much of the proliferation of point-of-care testing (POCT) seen today.[4]

Laboratorians may disagree with such a priority, arguing that unless analytical quality can be achieved, none of the other characteristics matter.[5] Nevertheless TAT is one of the most noticeable signs of a laboratory service and is used by many clinicians to judge the quality of the laboratory.[6] Delays in TAT elicit immediate complaints from users while adequate TAT goes unremarked.[7] Unsatisfactory TAT is a major source of complaints to the laboratory regarding poor service and consumes much time and effort from laboratory staff in complaint resolution and service improvement. Despite advances in analytical technology, transport systems and computerisation, many laboratories have had difficulties improving their TATs. Emergency department (ED) TATs have not improved over several decades. In 1965 a mean ED TAT of 55 minutes was reported, in 1978 a mean of 55 minutes was reported while in 1983 mean collection to report TAT was 86 minutes for a chemistry panel including potassium.[8] A College of American Pathologists (CAP) Q-Probes survey of ED TAT in 1998 showed low satisfaction rates concerning the laboratory's sensitivity to urgent testing needs (39%) and meeting physician need (48%).[8] Laboratory TAT was felt to cause delayed ED treatment more than 50% of the time (43%) and also increased ED length of stay (LOS) over half the time (61%). With the increasing interest in the extra-laboratory phases of the testing process, more laboratories are including TAT as a key performance indicator of their service but often have problems meeting their internal goals.[9,10]

This review summarises the literature regarding laboratory TAT, focusing on the different definitions, measures, expectations, published data, associations with clinical outcomes and approaches to improve TAT. It aims to provide a consolidated source of benchmarking data useful to the laboratory in setting TAT goals and to encourage introduction of TAT monitoring as a performance indicator.

Definition and Measures of Turnaround Time
Inspection of the literature reveals a variety of different approaches to definition of TAT. TAT can be classified by test (e.g. potassium), priority (e.g. urgent or routine), population served (e.g. inpatient, outpatient, ED) and the activities included. This last area is the greatest source of variation in reporting of TAT. The steps in performing a laboratory test were outlined by Lundberg, who described the brain to brain TAT or "total testing cycle" as a series of nine steps: ordering, collection, identification, transportation, preparation, analysis, reporting, interpretation and action.[11,12] The term "therapeutic

TAT" is sometimes used to describe the interval between when a test is requested to the time a treatment decision is made.[13-15] Although the laboratory can and perhaps should be involved in all these steps, many laboratories restrict their definition of TAT to intra-laboratory activities, arguing that other factors are outside their direct control and that timing data for extra-laboratory activities are not readily available.[16] Such an approach will necessarily underestimate TAT since non-analytical delays may be responsible for up to 96% of total TAT.[17,18] In the ED, delay in review of results by clinicians is the greatest component of perceived TAT.[16]

Intra-laboratory TAT can also vary in its definition with possible start points of sample receipt time, registration time, or analytical sampling time and end points of analytical completion time, result verification time, result transfer to electronic medical record time and report printing time.

Another classification of time periods separates the steps into the pre-analytical (order to preparation), analytical (analysis) and post-analytical (reporting to action) phases.[19,20] These divisions have often been used when classifying errors and delays and are sometimes used for description of TAT.

There are differences between clinicians and laboratories in their definitions of TAT. In the 1998 CAP Q-Probes program, 41% of laboratories defined ED TAT as time of receipt in the laboratory until time of report, 27% as ordering of test to result reporting and 18% as specimen collection to reporting.[8] However over 40% of physicians defined ED TAT as starting at physician request and only 9% at laboratory receipt (Table 1). There was better agreement between laboratories and physicians in the choice of endpoint with over 40% of physicians choosing when the physician gets the results as the end point and 50% when the ED gets the results. Similar results were seen earlier in the 1990 CAP Q-Probes survey with test ordering or phlebotomy the preferred start point and laboratory reporting or physician receipt the preferred endpoint for the majority of physicians.[21]

Use of different measures to describe TAT also complicates comparisons. It is important to examine a frequency histogram of data before deciding on appropriate descriptive measures. In the case of TAT, the overall process is composed of multiple sequential steps, each with a minimum or fastest time possible. For example, if a centrifuge is set to 10 minutes spinning time, centrifugation can take no less than 10 minutes and may take longer if there are delays (e.g. balance problems). This means that Gaussian distributions for each of the individual steps or for the total TAT are not expected. It is thus inappropriate to use means and standard deviations as descriptors of TAT distributions.

A non-Gaussian distribution with a positive skew (or tail to the right) is seen for TAT distributions, meaning that median and tail size are the preferred measures.[22] Tail size can be quantified as the percentage exceeding a defined time (outlier rate) or as the time corresponding to a defined percentile of the distribution (e.g. 90th). This last measure is increasingly common in the literature and is referred to as the 90% completion time. Valenstein and Emancipator studied the performance of four measures of laboratory TAT: the mean, median, 90th percentile, and outlier rate.[22] For tests with long TATs, the most important quality of a TAT measure is high reproducibility, so that improvement in reporting speed can be distinguished from random variation resulting from sampling.

Table 1. Physician definitions of ED TAT start and end times (% responses).[8]

	All	ED	Paediatrics	Surgery	Int. Med.	Other
Start Time						
Lab Receipt	9	13	8	4	5	7
When Drawn	15	13	22	14	14	18
On ED Order	28	40	16	18	19	16
Physician Request	45	33	51	63	58	57
Physician Realisation	2	1	4	1	3	2
End Time						
Physician acts on results	0	0	0	1	1	3
When charted	5	3	3	7	6	7
ED gets results	50	67	26	33	32	29
Physician gets results	44	26	72	22	62	57

The mean was found to be the most reproducible of the four measures, followed by the median. The mean achieved acceptable precision with sample sizes of 100-500 tests. For tests with normally rapid TATs, the most important quality of a measure is high sensitivity and specificity for detecting whether TAT has dropped below standards. The outlier rate was found to be the best measure of TAT in this setting but required sample sizes of at least 500 tests to achieve acceptable accuracy.

Use of outlier rates has been recently promoted but use of dual measures is useful in providing information on the norm (the median) as well as the exception (the tail size).[23,24] This allows a more balanced appreciation of TAT and avoids excessive attention to a single parameter. An alternative single measure is the use of the mean as this will be sensitive to outliers as well as the bulk of the population.[7]

Another approach is the use of failure time analysis to study TAT such as Kaplan-Meier survival curve plotting, log-rank tests and Cox proportional hazards model.[25] The Kaplan-Meier approach treats active samples like living patients. At sample registration, the sample TAT clock is set to 0. Upon sample completion, its status is analogous to a patient who has died (TAT clock is set to 1) and the time lapse from registration is its "survival" time. This methodology allows different distributions (e.g. urgent vs. routine samples) to be compared using the log-rank test and can help identify variables that affect TAT using the Cox model, but is of limited use in routine TAT monitoring.

Unfortunately the variety of different approaches in the literature creates difficulties when searching for benchmarking or state-of-art data. Inspection of journal abstracts is sometimes insufficient to allow clear identification of how TAT was measured and study of the original text does not always clarify the details. The descriptions in external quality assurance programs of TAT (e.g. CAP Q-Probes, Q-Tracks) often provide the clearest and most easily understood procedures. Howanitz, who has published widely on the CAP survey results, has suggested that TAT be defined from the time the test is ordered to the time that results are available to the caregiver and that TAT goals be expressed as a percentage of all results completed within the time interval (e.g. 90% or 95% of results completed within the time interval).[26,27] However laboratories without electronic order entry systems may have difficulty collecting accurate ordering times and may find intra-laboratory TAT a more feasible option at present.

Expectations of Turnaround Time

Over 80% of laboratories receive complaints about TAT, yet there is little agreement among clinicians on what constitutes acceptable TAT.[19] Service to the ED is a particular source of dissatisfaction with 87% of institutions reporting complaints.[21] Expectations have increased despite technological innovations (e.g. analytical, pneumatic tubes, computers) in the laboratory.[28] This may reflect greater attention to reducing patient LOS in the ED and wards and greater clinician familiarity with the analytical speed of POCT devices such as blood gas analysers.

Unhappiness with TAT remains a problem today. A 2006 report of a CAP Q-Probes study of nursing satisfaction with hospital clinical laboratory services in 162 hospitals showed most satisfaction with result accuracy, phlebotomy courtesy toward patients and nursing staff, and notification of abnormal results.[29] Respondents were least satisfied with urgent test TAT, laboratory management responsiveness and accessibility, phlebotomy responsiveness to service requests, and routine test TAT. The most important aspect of laboratory service reported by nursing personnel was urgent test TAT.

Published data on TAT expectations are generally scanty. Clinician and laboratory staff expectations of ED TAT for haemoglobin, potassium, glucose and pO_2 measurements were surveyed as part of the 1990 CAP Q-Probes survey of 2763 clinicians and 722 institutions.[21] The distribution of expected TAT (phlebotomy to result reporting) is shown in Table 2. As can be seen, laboratory staff set less timely goals for all four analytes than the clinicians. Of the different physician groups surveyed, generally surgeons had the fastest TAT expectations. Based on past CAP Q-Probes data, Steindel and Novis have suggested that reasonable component TATs are 15 minutes for order to collection and collection to receipt times and 30 minutes for receipt to verification time for urgent samples from the ED or intensive care unit (ICU).[24]

The CAP Q-Probes study on biochemical markers of myocardial injury TAT from 2004 collected data from 159 hospitals regarding the expectations of order to report TATs.[30] The median (and inter-quartile range) physician expectation of 90% completion TAT was 37.5 (31-45) minutes. These times were shorter than those estimates from laboratory staff (median 60 minutes) and actual performance (median 91 [74-105] minutes). The laboratories' 60 minute expectations may have been shaped by the National Academy of Clinical Biochemistry's goal of a TAT (collection to reporting) of 1 hour or less.[31,32]

One author from a diagnostic product vendor stated that despite a standard TAT for acute care laboratory testing in tertiary care institutions of typically less than 15 minutes for blood gas or electrolyte values, from a clinical perspective the desirable TAT is closer to 5 minutes.[33] It was argued that

Table 2. ED TAT in minutes (phelebotomy to result reporting) expectations of clinicians and laboratory staff for ED.[21]

	<10	10-20	20-30	30-40	40-50	50-60	>60
Hb							
Clinicians (%)	15	34	32	2	6	12	1
Laboratorians (%)	2	8	18	4	9	54	8
K							
Clinicians (%)	6	28	38	4	12	12	2
Laboratorians (%)	0	6	16	5	8	58	10
Glucose							
Clinicians (%)	12	30	36	4	8	12	2
Laboratorians (%)	0	6	14	5	10	56	10
pO2							
Clinicians (%)	57	34	8	1	1	1	0
Laboratorians (%)	22	35	18	4	2	18	4

meeting this requirement necessitates the use of POCT and that this approach would become the future standard of care.

Winkelman et al. measured the time interval from result entry by the clinical laboratory to inquiry for full blood count (FBC) reports by clinicians as a proxy for the actual TAT required to meet current patient care needs.[34] The median time to report inquiry was 90 minutes for routine inpatient tests, 35 minutes for urgent inpatient tests, and 30 minutes for urgent outpatient test, while only 31% of routine outpatient reports had been requested by 8 hours. Such delays between the availability of a result and its review by clinical staff should be remembered when discussing the need to improve intra-laboratory TAT.

Turnaround Time Benchmarks

Although there are many individual case studies reporting TAT in the literature, the consolidated data available via external quality programs such as the CAP Q-Track and Q-Probes studies and the Study Group for the Standardization and Promotion of Turnaround Time Control program are most useful in describing the state of the art. The CAP surveys are a particularly good source of data back to 1990 and can be freely accessed through their website.[35] However some data are only provided in graphical form, requiring some estimation by the reader of the true values from the graphs available. This approach has been used to obtain the data in Tables 1, 2 and 3.

Q-Probes are quality assurance programs run by CAP which ask laboratories to collect data over a specified period and submit it to the Q-Probe office at CAP.[36] Statistical analysis of the data is performed and the office prepares an individual report for the laboratory as well as a summary of the whole study. The laboratory's performance is compared to hospitals of equivalent size and workload. Q-Tracks is a similar program using data submitted on a monthly or quarterly basis to allow trend analysis and continuous performance monitoring. Q-Probes, on the other hand, are single audits of performance at a given point in time.

A typical example is a study of routine outpatient test TAT (collection to verification) in 118 hospital based laboratories

Table 3. Percentiles of 90th percentile completion times (minutes) for K and Hb TAT from CAP Q-Probes studies.[8]

	10th	25th	50th	75th	90th
K TAT (min)					
Order to draw	43	29	21	13	4
Draw to receipt	45	31	18	11	7
Receipt to reporting	66	54	45	37	29
Draw to reporting	95	75	57	45	40
Order to reporting	0101	85	69	57	47
Hb TAT (min)					
Order to draw	41	29	21	14	4
Draw to receipt	45	30	19	12	6
Receipt to reporting	50	38	28	21	16
Draw to reporting	75	59	44	33	25
Order to reporting	87	62	55	44	35

in 2002 for FBCs, thyroid tests and basic metabolic panels.[37] A test was considered to have completed within one day if the result were available to clinicians by 0700h on the first non-holiday weekday after the date of specimen collection. This criterion was met by 98.8% of institutions for basic metabolic panel measurement, 99.5% for FBC and 88.8% for thyroid tests. For the 65 institutions who had previously participated in a similar study in 1997, the percentages meeting the criterion rose from 91.3% to 98.2% (metabolic panel), 95.9% to 99.6% (FBC) and 63.7% to 90.0% (thyroid tests).

The 1998 CAP Q-Probes study of ED TAT definitions previously described also examined potassium and haemoglobin TAT performance.[8] The distribution of 90% completion times of the 693 responding laboratories is shown in Table 3. Half of the laboratories responded that 90% of potassium tests were ordered and reported in 69 minutes or less, whereas the TAT for 90% of haemoglobin results was 55 minutes or less.

In a 1996 CAP Q-Probes study, Steindel and Novis examined order to verification times for urgent samples from the ED or ICU.[24] Using a 70 minute TAT to define outliers, the % of outliers was 10.0% for ED and 14.7% for ICU. Major areas in which delays occurred were test ordering, 29.9%; analytical phase, 28.2%; collection of the specimen, 27.4%; post-analytic phase, 1.9%; and undetermined, 12.5%. Personnel problems (primarily staff shortages) were a major cause of delays and occurred in the test ordering (37.8%), collection (51.4%) and analytical (33.7%) phases. Problems relating to test performance accounted for only 10.9% of the delays. The low percentage of errors involving test performance is well documented elsewhere in the literature.[38,39]

The 2004 CAP Q-Probes study on biochemical markers of myocardial injury TAT examined order to report TATs for CKMB and/or troponin measurement for patients presenting to the ED with symptoms of acute myocardial infarction.[30] The distribution of institutional 90% completion TAT (order to report) is shown in Table 4. Shorter troponin TATs were associated with performing cardiac marker studies in EDs or other peripheral laboratories and having cardiac marker specimens collected by laboratory rather than by non-laboratory personnel.

A 1989 Q-Probes study of cerebrospinal fluid cell count, protein, glucose and Gram stain testing TAT of more than 400 laboratories found median intra-laboratory (accessioning to reporting) goals of 60 minutes with 30 and 45 minutes being the next most common goals.[7] Actual median actual TATs were: cell count 32 minutes, glucose 34 minutes, protein 37 minutes and Gram stain 45 minutes.

Table 4. Percentiles of institutional median and 90th percentile completion times (minutes) for troponin and CKMB order to report TATs from CAP Q-Probes.[30] Reprinted with permission from the Archives of Pathology & Laboratory Medicine. Copyright 2004. College of American Pathologists.

	n	10th	25th	50th	75th	90th
Troponin						
Median	158	74.5	67	57.8	50	45
90th Percentile	158	129	108	93	76	66.5
CKMB						
Median	112	82	69.5	58.0	48.3	40
90th Percentile	112	131	112	91.5	73.0	61

The TAT for routine early morning blood collections was monitored in a CAP Q-Probes study of 657 institutions.[40] Delivery time was from sample collection to laboratory receipt and analytical time from sample receipt to test completion or verification. The median (and inter-quartile ranges) distributions for institutional median TATs were: delivery time 25 (17-35) minutes; analytical time 42 (32-55) minutes; total TAT 73 (58-92) minutes. ICUs had a faster TAT (medians: delivery 22; analytical 38; total 67 minutes) than non-ICUs (medians: delivery 30 minutes, analytical 43 minutes; total 80 minutes). For all collections, the median TATs for haemoglobin were delivery time 25, analytical time 34 and total TAT 67 minutes while for potassium the medians were delivery time 28, analytical time 47 and total TAT 82 minutes. Factors shown to correlate with shorter total TATs were rural locations, a lower sample collection to staff ratio, intensive care unit specimens, plasma for potassium measurements, the practice of delivering each specimen as it is collected, pneumatic tube delivery system, direct delivery route, and continuous versus batch testing.

Critical or notifiable values have faster communication requirements than other results. Ricos et al. have published a useful summary of extra-laboratory quality indicators that can be used as specifications for benchmarking.[41] They suggested a mean of 6 minutes to communicate critical results on inpatients and 14 minutes on outpatients. They also suggested 11% as an acceptable fraction of laboratory reports delivered outside of the time goal specified by the clinician.

A CAP Q-Probes survey in 1997 examined the timeliness of critical value reporting.[42] The details of the median institutional TATs from this survey of 671 institutions are shown in Table 5. Verification time was defined as time between test completion to result ready for reporting. Notification time was defined as

Table 5. Critical values: percentiles of median TATs (minutes) for individual institutions.[42]

TAT Interval	n	10th	50th	90th
Prothrombin Time				
Verification	630	17	3	<1
Notification	602	13	3	<1
Total	631	28	10	1
K				
Verification	640	14	4	<1
Notification	607	8	2	<1
Total	643	22	8	1
Blood Cultures				
Verification	584	193	40	2
Notification	561	24	5	<1
Total	592	234	55	15

the time from result being ready for reporting until notification of health care provider. Total TAT was time from test completion to notification of provider. Factors associated with longer TATs included larger institutions and teaching hospitals, outpatients, institutions that require verification of results before reporting, reporting to physicians (vs other health care providers) and use of continuous monitoring systems for blood cultures.

Between 1998 and 2002, the Study Group for the Standardization and Promotion of Turnaround Time Control under the auspices of Comitato Italiano per la Standardizzazione dei Metodi Ematologici e di Laboratorio, Società Italiana di Biochimica Clinica and Società Italiana Medicina di Laboratorio ran an external quality program assessing urgent test intra-laboratory TAT for potassium, haemoglobin, troponin or CKMB and prothrombin time measurements.[43,44] Participants recorded the time when the specimen reached the laboratory and the time when the result is reported. Laboratories collected data for urgent determinations for seven consecutive days. The results are shown in Table 6 (troponin data were only available for 2002). There is little evidence of improvement over the five years of the program, either in TAT means or outlier rates.

A 2005 study examined mean TAT (received to verified) and percentage outliers (>30 minutes: FBC, >40 minutes: chemistry measurements, >60 minutes: troponin I, >30 minutes: urinalysis) in 11 community hospitals.[23] The best/average/worst values for mean TAT (minutes) were: FBC 6, 10, 12; urinalysis: 8, 10, 13; metabolic panels: 13, 25, 29 and troponin 28, 37, 41. The best/average/worst values for TAT outliers (%) were: FBC 0.9, 2.5, 4.8; urinalysis: 1.1, 3.6, 8.2; metabolic panels: 2.4, 8.3, 17.3 and troponin 0.8, 5, 8.1.

Table 6. Mean (and standard deviations) of urgent K, Hb, Prothrombin Time and Troponin intra-laboratory TAT from the Study Group for the Standardization and Promotion of Turnaround Time Control.[44]

Cycle	Analyte	n	Mean TAT in min (SD)	Time (min) to complete 90% of tests (SD)	% Tests completed within 60 mins (SD)
1998	K	24	47.0 (14.0)	79 (30.0)	78.1 (15.2)
I	Hb	23	35.5 (14.0)	67.4 (29.6)	85.1 (12.4)
	PT	22	49.5 (16.8)	85.7 (33.4)	75.2 (18.2)
1998	K	30	45.3 (14.0)	77.3 (31.2)	80.6 (14.6)
II	Hb	28	34.3 (16.9)	64.4 (34.7)	85.8 (12.9)
	PT	26	44.3 (11.6)	74.4 (26.7)	80.9 (15.1)
1999	K	32	44.5 (13.9)	73.7 (25.7)	81.7 (20.1)
I	Hb	30	30.6 (11.7)	55.6 (25.3)	90.3 (10.3)
	PT	27	42.9 (9.8)	72.7 (29.3)	85.0 (12.9)
1999	K	28	40.7 (12.8)	66.1 (21.2)	85.9 (14.6)
II	Hb	28	30.5 (16.7)	54.3 (30.4)	89.3 (13.2)
	PT	24	41.3 (14.0)	63.9 (24.5)	85.9 (16.9)
2000	K	33	44.1 (15.1)	72.4 (31.3)	83.1 (16.3)
	Hb	32	33.6 (16.7)	61.5 (30.3)	86.6 (15.3)
	PT	29	41.4 (14.0)	63.9 (24.5)	85.9 (16.9)
2001	K	32	46.1 (14.2)	73.0 (25.7)	80.2 (18.7)
	Hb	32	34.4 (13.5)	59.2 (22.2)	87.5 (13.0)
	PT	32	45.5 (12.4)	72.6 (25.3)	80.8 (17.3)

A recent summary of ED TATs posted on the Association of Clinical Biochemists general chemistry e-mail list summarised 12 replies from laboratories regarding their TATs.[45] Ten of the responses were from the UK, one from Canada and one from Australia. In terms of goals, five labs aimed for TAT within 60 minutes (for 90-95% of samples), one laboratory 45 minutes (90%) and one laboratory 55 minutes (% not stated). One regional audit of six labs was reported with an average TAT of 31–70 minutes and a 95th percentile TAT of 76-109 minutes. The poster's laboratory had an average TAT for urea and electrolytes of 30 minutes and a 95th percentile of 72 minutes. Many of the respondents mentioned delays in receiving samples and it was felt that a within-laboratory TAT of 40 minutes was achievable as an average but not as a 95% percentile without compromising quality because of sample dilutions, quality assurance failures, "problem

samples" and clashes with peak workloads such as when samples from general practices arrive. Solutions suggested by the respondents to improve TAT included use of profiles to reduce sample registration time, not delaying reporting of results until sample dilutions are completed and the use of heparinised plasma samples.

Phlebotomy time was measured by Leung et al. in a private hospital setting.[46] 1867 phlebotomy requests were included in the study. Average time (and standard deviation) for the procedure was 10.4 (2.4) minutes. The success rate at first phlebotomy attempt was 97%.

Audit of blood collecting practices in a paediatric hospital showed that the time spent collecting blood was 11.0 minutes per single request.[47] The analytical time for urgent blood gases was approximately six minutes with a total TAT of 16 minutes.

Turnaround Time and Clinical Outcomes

Faster TAT is universally seen as desirable. Statements such as "the more timely and rapidly testing is performed the more efficient and effective will be the treatment" and "it is almost axiomatic that providing a more rapid result saves time and therefore money" are common in the literature.[47-49] However faster TAT does not necessarily improve patient outcome. Steindel et al. examined the timeliness of early morning routine clinical laboratory tests for inpatients in 653 institutions and found little evidence that longer routine test turnaround times affect patient length of stay.[27] Shortening the TAT of microbiological procedures was associated with an improved clinical outcome in two studies performed in the USA but not in Europe.[50-52] The hope of prompt medical decision making guided by quick convenient testing has led many hospitals to consider decentralised testing (by POCT or satellite laboratories) despite little evidence of decreased LOS or cost savings.[53,54] POCT has been suggested for analytes that have a required reporting TAT of <30 minutes.[15] Proponents argue that total cost should theoretically decrease if TAT is faster through use of decentralised testing as episodes of care will be shorter and transport costs reduced. However, on a direct charging basis, decentralised testing is more expensive.[12,55,56] POCT glucose measurement, for example, is 3-4 times the cost of central laboratory measurement.[12,55-58] These increased costs reflect duplication of staff and equipment.[17,59]

The relationship between laboratory TAT and patient LOS in the ED is unclear, but it is now generally accepted that POCT is not a panacea for LOS problems in the ED.[13] Use of laboratory tests is associated with longer LOS. Heckerling described a higher percentage of patients discharged from the ED within two hours if no laboratory or radiology investigations were requested (80% no investigations vs. 42% with laboratory tests and 57% with radiology tests).[8] However the importance of laboratory test delays in contributing to prolonged LOS is less certain. Saunders et al. described a computerised model of ED operations, showing that the time taken to see the initial care giver is the key factor in LOS and that testing (laboratory or radiology) only has a potential impact when the stay exceeds 1 hour.[60] Delays in ED TAT are most commonly pre-analytical and post-analytical. Steindel and Howanitz describe a study of ED TAT in hospitals in Washington DC which found that the most common reasons for test delays were linked to sample collecting and transport, the practice of interrupting routine testing for urgent analyses, and communicating results to clinicians.[8] These same reasons were also seen in later studies in 1990-1993 and 1999.[10,24]

The value of POCT in ED has been examined both in theory and in practice. A hypothetical approach was taken in a study examining central laboratory testing against (blinded) POCT in the ED.[55] Mean TAT was reduced from 59 minutes with central laboratory testing (sample collection to result entry into mainframe computer) to eight minutes with POCT (sample collection to results shown on the POC device display). Mean therapeutic TAT (using the central laboratory) was 85 minutes (sample collection to physician review of results). Physicians estimated that POCT would have resulted in earlier therapeutic action for 19% of patients and based on this estimate, the authors said "the ability to minimise TAT with use of a POCT device … can result in quicker decisions regarding patient admission and discharge, earlier and more appropriate diagnosis, fewer tests and shortened length of stay". Decision analysis modelling has suggested that blood gas analysis by POCT in postoperative coronary artery bypass graft patients has an expected positive economic outcome and may be associated with decreased incidence of adverse clinical events or earlier detection of such events.[61]

However real life studies have not necessarily borne out such predictions. The maxim "faster is better" is not always true and non-laboratory limiting factors need to be considered.[62] Parvin et al. examined the use of POCT during a five week experimental period in which ED personnel used a POCT device to perform Na, K, Cl, glucose and urea testing.[63] No decrease in ED LOS was observed in the tested patients during the experimental period. Median LOS during the experimental period was 209 minutes vs. 201 minutes in the control periods. Stratifying patients by presenting condition (chest pain, trauma, etc.), discharge/admit status, or presence/absence of other central laboratory tests did not reveal a decrease in patient LOS for any patient subgroup during the experimental period. The reason POCT did not improve LOS was that laboratory TAT was not the rate-limiting factor for discharge.

Kendall et al. used a randomised controlled design in which samples were randomly allocated to POCT or testing by the hospital's central laboratory.[64] Changes in management in which timing was considered to be critical occurred in 7% of patients in the POCT arm of the trial. Decisions were made 74 minutes earlier when POCT was used for haematological tests as compared to central laboratory testing, 86 minutes earlier for biochemical tests, and 21 minutes earlier for blood gas analysis. However there were no differences between the groups in the amount of time spent in the department, LOS in hospital, admission rates, or mortality.

van Heyningen et al. described their experience in placing a whole blood electrolyte analyser in the ED for a trial period. TAT (sample collection to result availability) using POCT (median five minutes) was faster than a porter system to carry samples to the central laboratory, with results returned electronically (median 58 minutes) or a pneumatic tube rapid transport system (median 49 minutes).[65] However total patient waiting time (medians: 219 minutes with POCT; 212 minutes with the porter system; 258 minutes with the rapid transport system) did not change. Other factors, such as reduced bed availability on the wards and delays associated with other investigations (such as radiology, enzymes, drug assays, and blood cell counts) had a greater impact on patient disposition. The importance of factors other than test TAT in influencing outcomes was further demonstrated by Nichols et al., who studied the ability of POCT to decrease inpatient and outpatient waiting times for cardiovascular procedures.[66] They found that moving testing from a central laboratory to the medical unit did not improve waiting time until significant changes in workflow were made.

Other studies have demonstrated advantages of POCT in the ED but generally suffer methodological shortcomings. For example, Singer et al. examined the effect of cardiac troponin I POCT on ED LOS in chest pain patients. This was a before and after design with two weeks of central laboratory testing of troponin followed by two weeks in which nurses performed POCT for troponin I. ED LOS reduced from 7.1 to 5.2 hours with POCT availability.[67] However this was not a randomised trial and was limited to admitted patients. Caragher et al. examined the effect of cardiac biomarker POCT in the ED on sample collection to result reporting TAT and saw a reduction in mean TAT from 87 to 39 minutes.[68] Unfortunately no clear data on LOS were reported.

Test results affect the decision to admit or discharge patients in the ED in a minority of cases. Sands et al. examined the use of bedside Na, K, Cl, urea, glucose, and/or haematocrit measurement in the ED against routine testing in the central laboratory.[69] The results from bedside testing were available 43 minutes faster for Na, K, and Cl, and 44 minutes faster for urea and glucose than from the central laboratory but physicians reported that had the bedside results been available, a different or an earlier therapeutic approach would have resulted in only 9.5% of the cases. The decision to release or admit the patient was based on one or more of the laboratory values for 10.7% of patients sampled. In no case in this series did a physician report that final ED clinical outcome would have been affected.

The literature on turnaround time and patient outcome is inconclusive at best. With few exceptions, there is little evidence of the benefit of faster TAT on LOS or patient care despite the intuition that faster results must be better. Certainly more studies are needed but there will always be difficulty generalising findings given the unique work processes in each healthcare setting. However the existing literature already reliably demonstrates the importance of factors other than laboratory TAT in determining patient outcomes and the need to consider work processes together with TAT to achieve improvements.

Methods to Improve Turnaround Time

Between 1993 and 1998, the mean 90% completion time (collection to reporting) for potassium and haemoglobin in the CAP Q-Probes program improved minimally from 60 and 45 minutes to 57 and 44 minutes respectively, demonstrating the difficulty in improving TAT service.[26,27] The CAP programs help identify factors associated with faster performance and provide suggestions for service improvement.

An example is the CAP Q-Tracks monitor of outlier rates for ED urgent potassium and routine inpatient morning blood results over two years from 291 hospitals.[70] Outliers were defined as those tests whose TAT exceeded the institution's agreed TAT from sample receipt by the laboratory until result release to the physician (for ED potassium) and collection to reporting (for inpatient morning blood results).[71] The median ED urgent potassium outlier rate dropped from 11.2% to 7.1% over 8 quarters and the median morning rounds test reporting outlier rate similarly dropped from 9.9% to 7.8% over the same time period. Factors suggested by superior (top 25%) participants in the urgent ED potassium survey that may have contributed to their performance were: electronic test order entry, automatic printing of specimen labels and assignment of accession number at time of sample acquisition, use of different coloured labels for urgent specimens, use of three minute urgent centrifuge, use of plasma rather than serum specimen, use of whole blood rather than plasma or serum specimens, specimens transported to the laboratory by pneumatic tube systems, training of laboratory staff to expedite handling of urgent samples, utilisation of urgent laboratory located in the ED. Factors suggested by superior (top 25%) participants in

the morning round result survey that may have contributed to their performance were: initiation of phlebotomy rounds earlier in morning, revision of work schedules to co-ordinate available manpower with workload needs, addition of personnel to process specimens and expedite transport of specimens to the laboratory, transportation of specimens to the laboratory in batches such that testing can begin on the first batch of specimens while phlebotomists return to the wards to collect a second batch, a new category of specimens (e.g. "Urgent 2") to expedite processing of morning samples, regular review of pending logs, use of plasma or whole blood for chemistry testing, printing of results in patient care area immediately following result verification, transportation of specimens to the laboratory by pneumatic tube.

In 1995, Steindel reviewed the results of previous CAP Q-Probes on timeliness of laboratory results and noted some common elements to their findings.[72] Some observations, such as that computer systems yielded slower TATs, refer to 1990-1993 data and may now be outdated. Others however may still be relevant. TATs distributions were the same for laboratories that monitored TAT and those that did not, suggesting laboratories were not using the data collected for quality improvement activities. Urgent laboratories, located either in the ED or elsewhere, did not yield clinically significant decreases in TAT, with differences in the order of minutes. Urgent laboratories had the slowest 10% of samples, suggesting inadequate staffing or equipment for peak workloads.[73] Transportation time was a major factor in TAT and could be reduced by moving analysis closer to the point of collection or providing faster transport (e.g. pneumatic tube systems).[74] Sample collection done by laboratory staff resulted in faster TAT than when collected by others. Sample preparation delayed TAT- whole blood or plasma analysis was faster than serum testing.[8,10]

In 1999, Steindel and Novis examined TAT outliers (defined as urgent tests with order to verification TAT >70 minutes).[24] They felt that a system to monitor outlier TATs was easy to establish. Each laboratory should determine the distribution of outlier TATs in its own institution and set an outlier criterion at the TAT seen when a sufficient volume of outlier specimens (recommendation 10%) is observed. When investigating outliers, the cause for all specimens exceeding the outlier criterion should be established. If delays are in the pre-analytical phase, one should study the collection and transport processes used. They felt that the laboratory should manage these activities as lack of laboratory control of the pre-analytical phase was a common cause of delay. Such suggestions, although laudable, may not be feasible for many laboratories in terms of data availability, resources and time needed to routinely investigate the TAT of 10% of all urgent samples.

Pneumatic tube systems can speed up TAT without reducing sample quality. Fernandes et al. examined the effect of a pneumatic tube system on ED test TAT (order to report) and sample haemolysis rates.[75] Use of the pneumatic tube system reduced mean haemoglobin TAT from 43 to 33 minutes and mean potassium TAT from 72 to 64 minutes with no significant difference in haemolysis rate (6% with a pneumatic tube system and 10% with a human courier). Individual studies have demonstrated improved TAT with savings in transport staff costs. However such systems can under-perform due to poor design (which is often based on mail transport) or insufficient canisters.[16,76] The 1990 CAP Q-Probes study on ED TAT showed the few laboratories using pneumatic tube transport systems had slower TATs and later studies showed a higher uptake rate but below average TAT independent of their tube system design classification.[8,10,77] It was conjectured that such delays reflected problems with staff not sending or retrieving specimens promptly and underlined the need to consider all aspects of workflow rather than just physical installation in planning a transport system.

Introduction of instrumentation can also improve TAT. Berry examined the effect on TAT (order to result) of introduction of automated urinalysis.[78] Use of the automated system showed a 30% increase in availability of reports at 30 minutes, 9% improvement at 45 minutes, and 3.2% improvement at 60 minutes. The urinalysis staff also handled haematology duties. With use of the automated system, a 44% improvement in FBCs was noted in the 30 minute TAT, 22% improvement at 45 minutes, and 8% improvement at 60 minutes. Laboratory staff were able to complete urinalysis testing more quickly and therefore attend to FBCs sooner, resulting in improved TAT for both tests. Holland et al. saw no change in received to verified ED potassium TAT means with the introduction of total laboratory automation but noted a reduction in outlier (defined as >40 minutes) percentage from 18% to 5%.[79]

Use of satellite laboratories in the ED can improve TAT and reduce patient LOS. Lewandrowski et al. described an average reduction of 51.5 minutes in test TAT, an ED patient LOS reduction of 41 minutes and an increase in physician satisfaction.[80] Similar results were seen by Leman et al. who noted a TAT (dispatch of sample to result availability) reduction of 47.2 minutes for FBC, 66.1 minutes for d-dimer testing, and 41.3 minutes for chemistry testing.[81] Decisions to discharge patients were significantly faster but no change was seen with decisions to admit patients. There was a trend for earlier laboratory results modifying intravenous drug or fluids orders.

Winkelman and Wybenga examined TAT for blood gas analyses performed at a central laboratory and at a satellite laboratory and found a mean TAT of 6 minutes for the central

laboratory (pneumatic tube system, broadcasting results to computer terminals at the originating site) and 4.5 minutes in the satellite laboratory.[82] The difference was attributed to savings in transit time in the pneumatic tube and accessioning time in the central laboratory. The total cost per reportable result was substantially higher for the satellite laboratory than for the central laboratory.

Other studies have shown similar results but such improvements are not guaranteed.[8,10,83,84] A 1996 CAP Q-Probes study showed testing in a urgent laboratory to be a significant factor in contributing to TAT outliers in ED and ICU samples.[24] It was hypothesised that urgent laboratories are not well suited to cope with high volumes of samples, resulting in sample queuing.[10] Thorough review of the timeliness of laboratory results, the factors causing delays and possible solutions is suggested before considering setting up a urgent laboratory.[8]

There is some evidence that use of computerised clinician order entry (CCOE) systems can reduce both intra-laboratory and total TAT.[85] However problems with capturing accurate specimen requesting and collection times exist even with CCOE systems, complicating assessment of therapeutic TAT.[86] Mekhjian et al. examined the effect of CCOE in two ICUs, one with and one without the technology.[87] The average laboratory result reporting TAT (receipt to reporting) in the surgical ICU (with CCOE) of 23 minutes was faster than in the medical ICU (without CCOE) with a mean laboratory TAT of 31 minutes. This reduction presumably reflects time saved by elimination of specimen registration. How comparable these two units were is not clear – the workload from the surgical ICU of 1142 requests a month was almost double that from the medical unit (683 requests a month) and test mix was not described in the paper.

Thompson et al. examined the effect of CCOE on timeliness of urgent laboratory and imaging tests in an ICU in a tertiary teaching hospital.[88] Median time from ordering to obtaining laboratory specimens decreased from 77 to 22 minutes, median time from ordering to laboratory result being reported decreased from 148 to 74 minutes, and median time from ordering to imaging completed decreased from 97 to 30 minutes.

Westbrook et al. used a controlled before and after study of the effect of implementation of a CCOE system.[89] TAT (receipt to availability of result) reduced for both prioritised (average 4.5 minutes) and non-prioritised tests (15.6 minutes), both within (12.8 minutes) and outside (17.8 minutes) business hours. This reduction reflected the elimination of sample requisition by laboratory staff upon specimen receipt. However the authors felt that the extent to which improvements can translate into improved patient outcomes was uncertain and a potentially limiting factor was clinicians' capacity to make use of faster test results.

Ostbye et al. examined the introduction of a module for laboratory test order entry and reporting in a hospital setting and noted a reduction in order to result availability time from 270-350 minutes to 90-180 minutes (average reduction 3 hours).[90] The details of the time savings, whether pre-analytical or post-analytical, were unfortunately not described in the paper.

Persoon et al. used lean production principles to reduce the pre-analytical processing time (accessioning to delivery to analyser) from 29 to 19 minutes and allowed the laboratory to meet its goal of a TAT (start and end points not specified) of less than one hour for 80% of results for 11 consecutive months.[91]

Multifactorial analysis shows TAT to be affected by a variety of factors that can be placed in two categories.[8] The first are uncontrollable institutional factors, such as institution type, bed size, location, which are probably surrogate markers for staffing levels, governance, case mix and geography. The second are controllable process factors, which should be the focus of quality improvement activities. These include the nature of the phlebotomy staff, extent of computerisation and method of specimen transport.[10]

The different approaches that can be taken are best summarised by Howanitz in his paper on errors in laboratory medicine and practical lessons to improve patient safety.[26] He lists more than 20 published suggestions for improving TAT (see Table 7). In terms of therapeutic TAT, reducing pre-analytical delay through faster sample transport and delivery is probably the most important single improvement. Within the laboratory, initial steps could be to review sample centrifugation time and speed requirements, review choice of quality control rules to minimise false rejection rates, and implement automatic dilution and rerun functions on analysers.[4] Other key laboratory processes to consider are the use of plasma or whole blood samples, primary tube sampling, consolidation of analytical platforms, interfacing instruments and autoverification of results. Process mapping to identify rate-limiting steps within the laboratory is useful and simple improvements should be considered before more complex ones such as total laboratory automation and computerised clinician order entry are contemplated.

Summary

Despite technical, transport and information technology improvements in recent decades, TAT continues to be a

Table 7. Suggestions to improve TAT.[26] Reprinted with permission from the Archives of Pathology & Laboratory Medicine. Copyright 2005. College of American Pathologists.

Step	Element	Action Reported to Improve TAT
Test selection and order entry	Test request	- Standardised nomenclature for easy look up - Customised screens for rapid ordering - Enable providers to order electronically
Specimen collection and delivery	Appropriate information and handling	- Ensure accuracy of admission, discharge and transfer data updates - Consider patient location tracking - Automate lookup of information on volume, container, and special precautions for handling specimens
	Phlebotomy	- Scrutinise phlebotomy practices
	Specimen labelling	- Use barcodes
	Specimen delivery	- Consider pneumatic tube, robots, dumbwaiter or conveyor belt-type system
	Specimen type	- Review use of plasma and serum separator tubes and whole blood
Accessioning	Specimen arrival	- Use barcode readers
	Specimen transport within laboratory	- Consider pneumatic tube, robots, dumbwaiter or conveyor belt-type system
	Specimen sorting	- Sample directly from specimen container (as appropriate)
Testing	Instrumentation	- Consider total laboratory automation - Evaluate throughput - Ensure minimal downtime and adequacy of backup - Use automatic repeats (for abnormal results) and dilutions for results exceeding linearity - Consider automatic verification of results within reference limits - Use incomplete test list frequently
	Quality control	- Adopt efficient quality control procedures
Reporting	Posting of reports	- Interface instrumentation to computer - Generate preliminary reports (e.g. microbiology, anatomical pathology) - Transmit results via computer, electronic broadcast, pager and/or - Blackberry - Consider automatic printing for locations such as intensive care - Provide assistance with results and interpretation (help desk, interpretative reporting, reflex testing)
For each step		- Monitor and improve TAT (mean, median, percentage meeting criteria and/or outliers) - Evaluate specimen flow to maximise efficiency - Track and eliminate errors

cause of customer dissatisfaction with the laboratory service. Laboratory staff can feel frustrated when the effects of improvements in intra-laboratory TAT are diluted by pre-analytical and post-analytical factors seemingly outside their control. Observations such that 45% of the results for urgent laboratory tests requested by the ED were never accessed or were accessed too late do little to encourage efforts by the laboratory to provide a faster service.[92] Clinician TAT

expectations that are unrealistic or infeasible are also a source of friction. In 1993, Howanitz reported that the fastest intra-laboratory TAT technically possible for serum glucose was 24 minutes, which was too slow for one third of physicians.[21]

This review of the literature illustrates the difficulty in recommending any universal evidence-based goals for laboratory TAT for two reasons. Firstly, the wide range of work practices (clinical and laboratory) and timing data availability hinders common agreement on TAT definitions. There has been progress in this area in recent years, with more explicit descriptions of TAT data in the literature and increasing availability of timing data through laboratory computerisation and electronic medical record development. Secondly, there is little indication that decreased TAT improves patient care or hospital LOS.[4] There is a need for well-designed studies of the effect of laboratory TAT on patient outcomes. However the outlook in this area is less optimistic. It is difficult to design and perform studies in stable operating environments that can separate the effect of the laboratory service from other confounding variables and that can produce generalisable results applicable to other sites.

Given this lack of evidence, should one dismiss TAT as an important quality measure? Howanitz and Howanitz argued that if laboratory results provide essential data for patient management, it follows that more timely results will improve patient care and that, despite the lack of evidence, it is reasonable to assume that timeliness of laboratory results affects physician efficiency and hospital LOS.[4] They felt that all common laboratory tests should ideally be reported as fast as possible by methods yielding high quality results, suggesting 60 minutes or less from sample registration to reporting under optimal conditions.

Evidence-based medicine proponents may be unconvinced by such reasoning. A pragmatic approach which recognises the importance of TAT to clinicians is to set TAT goals locally, informed by both the published literature and by local expectations. Providers and users should decide on standards that meet the clinical needs and can be accomplished by the providers.[30,93] This method offers the advantages of a local TAT definition that matches available timing data and an opportunity for dialogue with laboratory users to examine and moderate their expectations.

Several basic steps are required to assess TAT on an ongoing basis. An achievable and modest approach is preferable to one with unrealistic data collection plans and over-optimistic goals.

1. Choice of appropriate analytes for monitoring. These should be chosen to reflect different service needs of the areas served by the laboratory but should probably be restricted to no more than four. A variety of different tests, priorities and locations should be chosen to cover the range of work provided by the laboratory.
2. Clear definition of TAT in terms of start points and end points. Despite the attraction of assessing both intra-laboratory and extra-laboratory TAT, such data are often not available and the laboratory must use the data that can be gathered easily, reliably and on an on-going basis. With increasing availability of electronic timestamp data of clinician requesting and result reviewing times, a closer approximation to therapeutic TAT becomes possible. Intra-laboratory TAT may be the easiest to define, using start points of specimen receipt (or registration) and end points of result availability to requester (or hardcopy printing). However laboratories should ensure that the choice of timing points is relevant in their local context and that practices such as sample registration prior to sample collection (as is possible in an outpatient setting) or the addition of a test request to an existing sample requisition do not result in misleading time interval calculations. TAT histograms should be studied carefully to identify any unexpected patterns or the presence of anomalous data points.
3. Clear definition of measures to be measured. Medians, 90% (or 95%) completion times and outlier rates are preferred over Gaussian-based mean and standard deviation measures. Despite their attraction, 90% completion times are often not routinely calculated by laboratory information systems and may require offline analysis of extracted raw data. Outlier rates may be easy to obtain on an ongoing basis and can also be a source of cases for further investigation on a regular schedule (e.g. root cause analysis of delay for the slowest 20 troponin samples every month). Similarly median values are less commonly available than mean values – the laboratory should work with the available measures while appreciating any inherent shortcomings.
4. Clear definitions of acceptable and unacceptable performance based on clinical evidence, benchmarking data and local expectations. These goals should be negotiated with users. A sample registration to result reporting 90% completion time of <60 minutes for common laboratory tests is a good starting point for discussion.[4]
5. Establishment of a system for long term monitoring of performance using available data.
6. Regular review (e.g. monthly) of performance measures looking for unacceptable performance and trends.
7. Regular review of performance goals whenever systems, workflow or equipment change and on an annual basis.
8. Consider supplementation of internal TAT monitoring

with enrolment in external programs such as CAP Q-Track. Present programs available include urgent test turnaround time outliers, morning rounds inpatient test availability and TAT of troponin.

At a time when clinicians have increasing options for their diagnostic testing, laboratories cannot afford to have unhappy customers. To disregard TAT as a measure of laboratory service quality is dangerous given its importance to clinicians. The laboratory needs to manage clinician expectations and demonstrate that it is meeting those expectations. TAT monitoring is the ideal choice of activity to illustrate the laboratory's commitment to providing a high quality service. Improved TAT can be the key to greater user satisfaction with the laboratory.

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