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Workflow Mapping: A Q-Probes Study of Preanalytic Testing Processes

A College of American Pathologists Q-Probes Study of 35 Clinical Laboratories

Peter Perrotta, MD; David A. Novis, MD; Suzanne Nelson, MS; Barbara Blond, MT(ASCP), MBA; Anna Stankovic, MD, PhD, MSPH; Michael Talbert, MD

• ***Context.***—**Workflow mapping is a tool used to characterize operational processes throughout most industries and to identify non–value-added activities.**

Objective.—**To develop a set of workflow mapping tools to compare the sequence and timing of activities, including waiting steps, used by clinical laboratories to process specimens during the preanalytic testing phase.**

Design.—**Laboratories enrolled in this College of American Pathologists Q-Probes study created workflow maps detailing the steps they used to process specimens from the time of sample arrival in the laboratory to the time of sample delivery to chemistry analyzers. Enrollees recorded the sequence and types of steps involved in specimen processing and the time needed to complete each step.**

Results.—**Institution average total specimen processing times (SPTs) and the number of steps required to prepare samples varied widely among institutions. Waiting steps, that is, steps requiring specimens to wait before advancing to the next process step, and specimen centrifugation consumed the greatest amount of processing times for both routine and STAT testing. Routine and STAT testing SPTs were shorter at institutions that used rapid centrifuges to prepare samples. Specimen processes requiring more sample waiting steps and computer entry steps had longer aggregate total process times than those with fewer such steps.**

Conclusions.—**Aggregate specimen processing times may be shortened by reducing the number of steps involving sample waiting and computer entry activities. Rapid centrifugation is likely to reduce overall average institutional SPTs.**

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Workflow mapping, also referred to as process mapping, is a technique used commonly throughout manufacturing and service industries, aimed at increasing production capacities by improving operational efficiencies. By diagraming tasks performed by all workflow team members, or performed in different areas of the clinical laboratory from beginning to end (Figure 1), workflow maps identify nonvalue activities that waste resources, undermine efficiency, and decrease testing capacitiy.[1–3]

Since 1989, the College of American Pathologists (CAP) Q-Probes studies have determined normative ranges of performance in anatomic pathology and laboratory medicine.[4,5] Participants in these studies, representing the entire spectrum of practice settings worldwide, have compared their performances to those of their peers and have shared laboratory practices shown to be associated with superior performance. In this Q-Probes study, we provided participating laboratories with tools to help them map current state workflows used in their specimen processing areas. This Q-Probes study is the first detailed examination designed to evaluate laboratory specimen processing workflows.

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From Novis Consulting, LLC, Portsmouth, New Hampshire (Dr Novis); the Department of Pathology, West Virginia University, West Virginia University Hospitals Inc, Morgantown (Dr Perrotta); Quality Practice Committee, College of American Pathologists, Northfield, Illinois (Ms Nelson and Ms Blond); Koliada Consulting LLC, Flemington, New Jersey (Dr Stankovic); and the Department of Pathology, University of Oklahoma College of Medicine, Oklahoma City (Dr Talbert).

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Corresponding author: David A. Novis, MD, Novis Consulting, LLC, 213 South Street, Portsmouth, NH 03801 (email: dnovis@comcast.net).

METHODS

Participants in this CAP Q-Probes study constructed current-state workflow process maps for general chemistry testing commencing with the arrival of specimens in their laboratories, and concluding with the presentation of those specimens to chemical analyzers. Participants included samples that their laboratory protocols designated as both routine and STAT during day and evening/night shifts. We required participants to include specimens collected from inpatients, and from outpatients and outreach (reference) facilities only if their processing procedures were the same as those used for inpatients. We excluded from this study, samples that were accessioned outside the laboratory (ie, preaccessioned) and samples that required clerical resolution (eg, mislabeled, unlabeled.).

Preparing the Process Map

Participants began this study by creating high-level flowcharts of their current-state processes. Participants were directed to identify

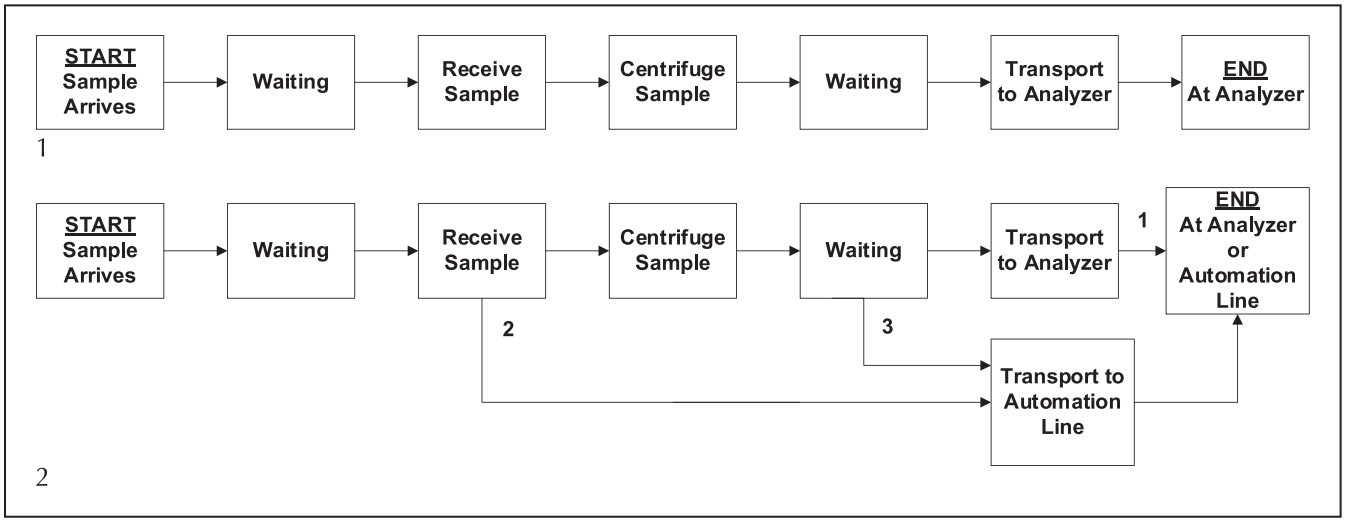

Figure 1. *Simple workflow map showing steps a sample may follow upon arrival in the laboratory until it arrives at an analyzer for testing.*

Figure 2. *Sample workflows for processing a laboratory specimen.*

steps and decision points commencing from the time they received samples into their laboratories to the moments that those samples were readied for analysis. We instructed participants to include waiting times as process steps. We provided participants with sample flowcharts (Figure 2) that demonstrated several possible workflows that laboratories might use. These included steps during which samples are received, centrifuged, and transported to analyzers (Workflow 1); samples are received and brought to automation lines that include centrifugation (Workflow 2); and samples are received, spun, and brought to automation lines (Workflow 3). We did not attempt to determine or evaluate whether the number of steps or the time to complete those steps was necessary or appropriate in each laboratory's testing operations.

Timing Studies for Overall Sample Processing and for Individual Process Steps

We encouraged participants to study their laboratory testing processes during periods of relatively high specimen volume demands because we believed that weaknesses in processes might be more easily identified during busy periods. For timing overall specimen processing, we instructed participants to use a stopwatch or other timer to record the total processing times for 10 chemistry specimens (eg, basic metabolic panel, electrolytes) ordered on routine priority and 10 chemistry specimens ordered on STAT priority; 20 specimens in all. We instructed participants to commence process timing when specimens arrived in their laboratories and cease timing when specimen arrived at their analyzers or automation lines. We provided participants with worksheets to record the start and stop times for the entire testing process (Figure 3). For timing each step of routine and STAT processing workflows, we provided participants with separate worksheets upon which to record those durations (Figure 4). Each step in the workflow process was defined for participants; these descriptions follow.

1. *Aliquoting*, time spent transferring samples to other tubes including decapping and recapping tasks.
2. *Centrifuging/Spinning*, time spent processing specimens in a centrifuge (time spent centrifuging on an automated line was not included in this step).
3. *Computer Entry*, time spent on a computer including accessioning specimens, barcode scanning, verifying orders in computer, ordering tests in the laboratory information system.
4. *Distraction*, time that laboratory workers processing specimens were diverted from moving samples through specimen receiving areas by unrelated tasks (eg, phone calls, questions, other distractions).
5. *Identify*, time spent verifying sample/patient identities, checking sample labeling.
6. *Label/Relabel*, time spent applying laboratory-specific labels (eg, instrument-ready barcoding) to specimens.
7. *Moving/Transporting*, time spent physically moving specimens to other areas, including transporting specimens within the specimen processing areas or moving them to where testing was performed (eg, instrument, front-end automation).
8. *Paper*, time performing any activity that involved writing on paper or organizing paper, such as writing in log books or filing paper (printing paper orders or requisitions from a computer were listed as a *Computer Entry* step).
9. *Sorting*, time spent organizing specimens into batches, for example, before delivery to another part of the laboratory.
10. *Specimen Integrity*, time spent checking or inspecting samples before transporting them to laboratories where they were processed or before they were placed on instruments (eg, hemolysis, clotting, volume).
11. *Waiting*, times samples wait before continuing to the next step in processing, including waiting for a centrifuge, waiting to aliquot, and waiting for transport.

To investigate what conditions might influence the efficiency of the testing processes, participants completed questionnaires surveying their hospital and laboratory demographics and testing practices. This list of inquiries concerning practice characteristics included testing volumes (overall and chemistry test volumes), types of patient testing included in the study (inpatient versus outpatient), use of laboratory automation, and other questions specific to laboratory workflow. Finally, we invited participants to offer their own unscripted comments concerning their tribulations and insights with regard to this study and process mapping.

Statistical Analysis

Institution-level statistical analyses were performed to determine which practice characteristic and institution demographic variables were significantly associated with routine and STAT test overall average specimen processing times (SPTs). These 2 measures were normally distributed after excluding outliers, satisfying a statistical assumption needed to use *t* tests to test for differences in means for 2-level discrete independent variables. Outliers for routine and

Routine Sample #	Time Start – Specimen Received in Laboratory	Time Stop – Specimen at Testing Platform	Total Time (seconds, eg '65')
1 - Day			
2 - Day			
3 - Day			
4 - Day			
5 - Day			
6 - Evening-Night			
7 - Evening-Night			
8 - Evening-Night			
9 - Evening-Night			
10 - Evening-Night			

Figure 3. *Sample overall processing time worksheet.*

STAT test overall average SPTs were excluded if the value was greater than the 75th quartile + [1.5 × Interquartile Range]. Forward stepwise multiple regression was used to determine the models with optimal fit, using demographic and practice characteristic variables univariately associated with routine and STAT test overall average SPT at a significance level of .10.

Statistical analyses were performed to determine whether aggregate specimen process step counts were correlated with the total process time for 320 routine and 305 STAT individual specimen processes. Aggregate total process time was not normally distributed for both routine and STAT processes; therefore nonparametric, rank-based Spearman correlation tests were used. Specific step types were only considered for analysis if no more than 25% of processes reported a count of 0 for the step type. All statistical analyses were performed with SAS 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Institution Demographics

Of the 35 institutions that submitted data for at least 1 aspect of the study, 31 (88.6%) were located in the United States, 2 (5.7%) in Saudi Arabia, and 2 (5.7%) in the United

Process Codes			
11 Wait Time	15 Moving/Transporting	18 Identify	21 Paper
12 Centrifuge/Spin	16 Specimen Integrity	19 Label/Relabel	22 Distraction
14 Sort	17 Computer Entry	20 Aliquot	01 Other

Process Steps and Times - ROUTINE Evening/Night Shift					
Step Number	Process Code	Time (seconds)	Step Number	Process Code	Time (seconds)
Sample arrives in laboratory			Step 9	170	180 .
Step 1	010	020 .	Step 10	190	200 .
Step 2	030	040 .	Step 11	210	220 .
Step 3	050	060 .	Step 12	230	240 .
Step 4	070	080 .	Step 13	250	260 .
Step 5	090	100 .	Step 14	270	280 .
Step 6	110	120 .	Step 15	290	300 .
Step 7	130	140 .	Step 16	310	320 .
Step 8	150	160 .	Sample arrives at platform		

Figure 4. *Sample processing steps and timing worksheet.*

Table 1. Annual Test Volumes and Full-Time Equivalents (FTEs) Among Participants							
				All Institutions Percentiles			
	No. Labs	Mean	Min	25th	50th (Median)	75th	Max
Laboratory total							
Annual test volume	27	1 816 574	3635	412 556	1 202 534	3 068 859	5 895 722
FTEs	29	76.54	1.00	27.00	63.00	109.00	266.00
Chemistry laboratory							
Annual test volume	26	1 428 589	1800	168 000	681 243	1 789 501	9 357 134
FTEs	30	13.73	0.00	4.00	11.70	17.00	55.00
Specimen processing							
FTEs	29	9.00	0.00	2.00	4.87	15.40	30.00

Abbreviations: Max, maximum; Min, minimum.

Arab Emirates. Within the last 2 years before data collection, 87.5% (28 of 32) of laboratories underwent licensing accreditation inspections by the CAP. Facility sizes included 63.3% (19 of 30) of institutions with 300 occupied beds or fewer and 36.7% (11 of 30) with more than 300 occupied beds. A total of 15 of 32 facilities (46.9%) had teaching programs and 11 of 32 (34.4%) support pathology resident training programs. Overall, 46.9% (15 of 32) of institutions were located in cities and 90.3% (28 of 31) were nongovernmental.

Practice Characteristics

Seventeen of 31 participants (54.8%) provided data on both inpatient and outpatient samples; 12 of 31 participants (38.7%) provided data on inpatient samples only; and 2 of 31 participants (6.5%) provided data on outpatient samples only. The laboratory total test volumes ranged from 3635 to 5 895 722 and laboratory staff full-time equivalents ranged from 1.0 to 266.0 among participants (Table 1). Approximately two-thirds (64.5%) of 31 laboratories reported no use of automation, whereas the remaining 11 laboratories reported using either complete or partial laboratory automation in their testing processes (Table 2). Approximately three-fourths of laboratories (74.2%) processed small batches (eg, 2–5 specimens) or single "one-at-a-time" samples. Nine of 31 participants (29.0%) used rapid centrifuges to process most specimens.

Table 2. Specimen Processing Practices of Participating Institutions	
Laboratory Practice Characteristic	No. (%)
Type of automation used for testing processes (N = 31)	
No automation used	20 (64.5)
Automation line with centrifuges in-line	7 (22.6)
Automation line without in-line centrifuges	3 (9.7)
Front-end automation not attached to the analyzer	1 (3.2)
Batching of specimens in specimen processing area (N = 31)	
In small batches (eg, 2–5 specimens)	13 (41.9)
One-by-one	10 (32.3)
In larger batches	6 (19.4)
Other	2 (6.5)
Use of rapid centrifuges to prepare samples (N = 31)	
Yes, for most samples	9 (29.0)
Yes, for some samples	12 (38.7)
No for all	10 (32.3)

Abbreviation: N, total number of responses.

Specimen Processing Times, Step Counts, and Step Types.—We calculated percentile distributions of institutional overall average SPTs (minutes) and overall median process step counts (Table 3). The median of the overall average SPTs (calculated from the maximum of 10 specimens) was 14.9 minutes for routine tests (n = 34) and 9.8 minutes for STAT tests (n = 31).

The median number of overall total step counts was 7 for both routine (n = 35) and STAT (n = 33) testing. The counts of individual process steps (ie, mapping step types) are further summarized in Table 4. For both routine and STAT specimens, participants reported a range of 2 to 16 steps needed to complete overall processes, with a median of 7 steps reported for both 320 routine specimen processes and 305 STAT processes. The number of individual steps varied for each component of the testing processes. The number of moving/transporting steps within all aggregate processes ranged from 1 to 5 for both routine and STAT specimen processes containing at least 1 move/transport step.

The median total wait time spent per test was 240 seconds (4 minutes) for routine specimens and 120 seconds (2 minutes) for STAT specimens (Table 5). Wait time accounted for 49.7% of the overall processing time for routine priority tests and 32.4% for STAT tests across all aggregate specimen processes.

The aggregate number of computer entry steps was significantly and positively correlated with total processing times for both routine ($P < .001$) and STAT ($P < .001$) priority samples. The aggregate number of wait steps for routine samples was positively correlated with total pro-

Table 3. Percentile Distribution Summary of Institution Overall Specimen Processing Times and Median Overall Process Step Counts				
		All Institutions Percentiles		
	No. Labs	10th	50th (Median)	90th
Overall average specimen processing time, min				
Routine	34	3.4	14.9	30.3
STAT	31	2.0	9.8	20.9
Institution overall median process step count				
Routine	35	5	7	11
STAT	33	4	7	11

Abbreviation: STAT, *statim* (ie, without delay).

Table 4. Aggregate Processing Step Count for Routine and STAT Tests

	Test Priority							
			Process Step Count					
	No. Specimen		Minimum		Median		Maximum	
Mapping Step Type	Routine	STAT	Routine	STAT	Routine	STAT	Routine	STAT
Overall Process	320	305	2	2	7	7	16	16
Wait Time	263	251	1	1	2	2	5	4
Centrifuge/Spin	208	226	1	1	1	1	2	2
Computer Entry	261	246	1	1	1	1	3	3
Sort	200	175	1	1	1	1	4	4
Distraction	80	56	1	1	1	1	3	3
Moving/Transporting	273	268	1	1	1	1	5	5
Label/Relabel	112	126	1	1	1	1	2	2
Identify	171	177	1	1	1	1	3	3
Specimen Integrity	107	116	1	1	1	1	2	2
Paper	40	24	1	1	1	1	2	1
Aliquot	43	35	1	1	1	1	2	1
Other	62	54	1	1	1	1	1	1

Abbreviation: STAT, *statim* (ie, without delay).

cessing time ($P = .002$). A similar correlation was identified between STAT priority total processing time and the aggregate number of wait steps ($P = .01$); however, the median total process times were not observed to linearly increase as the wait step count increased (Table 6).

Associations Between Institutional Practice Characteristics and Average Specimen Processing Time.—We found several significant associations between institution demographic and practice characteristics with routine (Table 7) and STAT (Table 8) test overall average SPTs. Routine testing overall average SPTs were estimated to be 8.3 minutes shorter for institutions that prepare samples by using rapid centrifuges for some or most samples than for those that do not (median of 9.4 minutes versus 19.9 minutes, respectively; $P = .01$), while STAT testing average SPTs were estimated to be 7.4 minutes shorter for institutions that use rapid centrifuges for some or most samples than for those that do not (median of 7.3 minutes versus 14.1 minutes, respectively; $P = .01$).

Routine priority overall average SPTs were estimated to be 6.3 minutes shorter for institutions that train pathology residents than for those that do not (median of 8.4 minutes versus 14.2 minutes, respectively; $P = .04$), while STAT priority average SPTs were estimated to be 4.9 minutes shorter for institutions that train pathology residents than for those that do not (median of 4.1 minutes versus 10.3 minutes, respectively; $P = .03$). All estimated decreases in specified overall average SPTs were determined from their respective multiple linear regression models.

Other Findings Regarding Practice Characteristics.—Approximately one-third (11 of 30) of participating laboratories reported that they identified opportunities for improvement in their specimen processing area by participating in this study. Participants observed bottlenecks,

Table 5. Aggregate Process Mapping Times for Routine and STAT Tests

					Time Spent on Step in Seconds					
	No. Specimen		Percentage of Total Time		5th Pctl		Median		95th Pctl	
Mapping Step Type	Routine	STAT	Routine	STAT	Routine	STAT	Routine	STAT	Routine	STAT
Overall Process	320	305	100	100	42 (0.7 min)	32 (0.5 min)	750 (12.5 min)	553 (9.2 min)	3678 (61.3 min)	1732 (28.9 min)
Wait Time	263	251	49.7	32.4	10	10	240	120	3180	945
Centrifuge/Spin	208	226	21.4	36.5	180	120	335	300	628	600
Computer Entry	261	246	5.9	6.3	2	3	40	30	300	215
Sort	200	175	5.5	5.0	2	1	30	15	562	470
Distraction	80	56	4.3	4.1	17	9	108	58	841	700
Moving/Transporting	273	268	3.7	5.6	3	3	23	20	180	180
Label/Relabel	112	126	2.8	2.1	2	2	27	17	169	101
Identify	171	177	1.4	1.8	3	2	15	11	120	80
Specimen Integrity	107	116	1.3	2.3	1	1	11	9	280	325
Paper	40	24	0.9	0.5	15	10	70	20	173	120
Aliquot	43	35	0.8	0.3	6	4	60	17	180	60
Other	62	54	2.3	3.1	7	5	60	40	500	420

Abbreviations: Pctl, percentile; STAT, *statim* (ie, without delay).

Table 6. Correlations Between Step Type Count and Total Process Time

	Test Priority									
			Total Process Time, min						Spearman Correlation Coefficient (*P* Value)	
	No. Specimens		10th Pctl		Median		90th Pctl			
Step Type	Routine	STAT	Routine	STAT	Routine	STAT	Routine	STAT	Routine	STAT
Computer Entry Step Count									0.35 (<.001)	0.37 (<.001)
0	59	59	0.6	0.4	6.9	6.8	22.4	16.0		
1	224	206	2.8	1.3	12.5	8.2	44.0	19.7		
2–3	37	40	11.5	8.5	28.0	16.3	61.5	34.1		
Wait Step Count									0.17 (.002)	0.15 (.01)
0	57	54	2.5	0.9	8.0	5.7	24.0	11.7		
1	121	115	1.2	1.1	12.5	11.4	40.0	25.3		
2	69	93	2.1	3.2	12.2	9.8	55.9	26.9		
3	56	34	0.6	0.5	14.2	8.7	101.1	19.3		
4–5	17	9	10.1	8.6	18.3	11.6	34.0	24.6		

Abbreviations: Pctl, percentile; STAT, *statim* (ie, without delay).

interruptions, and slowdowns in their operations, caused by backups at centrifugation steps, when receiving large batches of samples, and when processing staff needed to address other laboratory problems, obtain supplies, resolve duplicate patient orders, and clarify specimens delivered with multiple labels affixed to specimen tubes. Participants also reported that laboratory staff did not always follow laboratory-processing protocols and/or required additional training in maintaining standard workflow. Approximately one-third (10 of 31) of laboratories processed specimens one-by-one, also known as "single unit" or "just in time" processing. None of the other demographic and practice characteristics were associated with the number of process steps or the duration of process times.

DISCUSSION

Workflow mapping is a technique that uses pictorial symbols and diagrams to map from beginning to end, each step of a complete production process or sections of that process. Workflow mapping is particularly effective in allowing us to comprehend complex processes because we can assimilate pictures and symbols much faster than we can assimilate text. Production inefficiencies, wasted movements and supplies, and opportunities for improvement are easily recognized through visual depiction.[1,2]

This Q-Probes study examined preanalytic testing processes using workflow-mapping tools. We chose to have laboratories map workflows for routine and STAT priority chemistry testing because any operational inefficiencies in upfront specimen processing can cause testing delays and increased testing turnaround times. Our workflow map guide included 12 commonly used preanalytic testing step types or activities (eg, sorting, labeling). Participants used this guide to record the activity performed during each step in the process in the order they were performed, which included the number of seconds spent on each step. Aggregate total SPTs were then calculated by adding the times spent on each step participants recorded in their testing processes. From these data, we tested for correlations between the number of steps counted in each process (eg, computer entry, centrifugation, and waiting) and aggregate total SPTs.

The aggregate process mapping analyses included 320 routine specimens from 35 institutions and 305 STAT specimens from 33 institutions. In all, the number of steps

Table 7. Significant Demographic and Practice Characteristic Variables Associated With Routine Test Overall Average Specimen Processing Time (Minutes)

	All Institutions Percentiles: Routine Test Overall Average Specimen Processing Time, min				
	No. Labs	10th	50th (Median)	90th	*P* Value
Laboratory trains pathology residents					
Yes	11	1.0	8.4	18.9	.04
No	16	5.2	14.2	30.1	
Rapid centrifuge utilization (eg, StatSpin) for sample preparation status					
Yes, for some or most samples	19	1.3	9.4	21.8	.01
No	8	1.0	19.9	30.3	

Table 8. Significant Demographic and Practice Characteristic Variables Associated With STAT Test Overall Average Specimen Processing Time (Minutes)

	All Institutions Percentiles: STAT Test Overall Average Specimen Processing Time, min				
	No. Labs	10th	50th (Median)	90th	*P* Value
Laboratory trains pathology residents					
Yes	11	1.3	4.1	13.7	.03
No	14	5.0	10.3	22.5	
Rapid centrifuge utilization (eg, StatSpin) for sample preparation status					
Yes, for some or most samples	19	1.4	7.3	13.7	.01
No	6	1.3	14.1	23.6	

Abbreviation: STAT, *statim* (ie, without delay).

required to complete each routine or STAT preanalytic process ranged from 2 to 16. Both routine and STAT testing processes comprised median step counts of 7 and maximum step counts of 16, suggesting that laboratories used the same processes to prepare routine and STAT specimens, the only difference being that laboratories simply expedited the process of STAT samples. Greater numbers of steps involved in computer entry and waiting were associated with longer aggregate total SPTs for both routine and STAT testing (Table 6).

The durations that samples waited to enter subsequent phases of testing represented the highest percentage of total preanalytic times across all aggregate routine tests (49.7%) and the second greatest percentage for STAT (32.4%) testing. Aggregate specimen wait times varied widely across all processes reported: routine testing wait times ranged from 10 seconds to 53 minutes for the 5th and 95th percentiles, respectively; and STAT testing wait times ranged from 10 seconds to nearly 16 minutes for the 5th and 95th percentiles, respectively (Table 5).

Laboratories reported as few as 0 and as many as 5 waiting steps for their routine preanalytic processes and 4 waiting steps for their STAT preanalytic processes. The number of wait steps in both routine ($P = .002$) and STAT ($P = .01$) processes were significantly and positively correlated with total process time (Table 6). In other words, SPTs were longer for processes having more wait steps.

Centrifugation steps represented the second highest percentage of aggregate total preanalytic times reported for routine testing (21.4%) and the highest percentage for STAT testing (36.5%). Aggregate specimen centrifuge/spin times varied widely with routine tests, ranging from 3 minutes to 10.5 minutes for the 5th and 95th percentiles, respectively; and STAT tests, ranging from 2 minutes to 10 minutes for the 5th and 95th percentiles, respectively. Institutions that use rapid centrifuges (eg, StatSpin) to prepare some or most samples had significantly shorter routine and STAT institutional average SPTs than institutions that do not use rapid centrifuges (Tables 7 and 8).

Computer entry activities represented the third highest percentage of total preanalytic time for both routine (5.9%) and STAT (6.3%) testing. Computer entry steps ranged from 0 to 3 for all STAT and routine testing. The aggregate number of computer entry steps in both routine ($P < .001$) and STAT ($P < .001$) processes were significantly and positively correlated with total process times (Table 6). Stated otherwise, SPTs were longer for processes having more computer entry steps.

There are several ways to improve specimen processing workflows and remove operational bottlenecks that delay or stop production. These methods reflect practices that are consistent with lean manufacturing principles.[6] For example, breaks in workflows may occur when laboratories receive incorrect/incomplete test orders and improperly labeled blood tubes. Training phlebotomists and nurses who draw blood samples in proper specimen collection technique, and programming instruments to reject blood tubes that have multiple overlapping labels affixed to them, could minimize these breaks. Implementing standard work procedures that are designed to follow best practices—one of the most powerful lean manufacturing principles—may reduce errors that occur because of process variability. Implementing standard work procedures may also allow laboratory managers to quickly recognize opportunities for process improvement. Finally, processing samples one-by-one, that is, "just-in-time" can eliminate bottlenecks and errors caused by overloading the production system with too many simultaneous tasks to perform.

Several authors have identified additional practices, such as preanalytic automation in the processing area, such as "work cells" and stand-alone devices that may also reduce unnecessary waiting times and labor costs.[7,8] Work cells encompass many activities, such as presorting, centrifugation, volume check and clot detection, decapping, secondary tube labeling, aliquoting, and destination sorting into analyzer racks.[9] Stand-alone solutions focus on single activities, such as tube sorting and aliquoting. Minimizing the need for specimen relabeling by printing barcoded labels, assurance of proper label alignment, and use of specimen management systems may also improve efficiency.[10]

The distribution summary statistics of the number of process steps and time spent on each process step type published in this study are not benchmarks for preanalytic testing processes. There are many reasons why one laboratory will require more steps in its process. Additional steps may be needed to meet customer and institutional needs, to fulfill educational responsibilities, laboratory layout, or to address safety concerns; our study was not designed to account for such differences in laboratories. Furthermore, our study did not address the impact of other potentially confounding variables on sample processing, including local operational philosophies and economic circumstances. We caution readers in making definitive conclusions based upon the institution-level significant associations reported, owing to the relatively small institution sample sizes (routine: n = 27, Table 7; STAT: n = 25, Table 8), and instead encourage these findings to serve as groundwork for future larger confirmatory studies. Common forms of waste that are often necessary in a process were documented in our study. These included sample sorting, sample transport, and specimen relabeling. Regardless of an individual laboratory's overall average SPT, the number of process steps, and time spent on steps involving waiting, our hope is that study participants will use these results to create future-state process maps aimed at improving their preanalytic processes.

We focused our study on the preanalytic testing phase. However, other more complex processes might be improved by using the workflow mapping techniques described in our study. Laboratories can apply lean production techniques to all phases of their specimen processing in order to improve efficiency. For example, previous authors[11,12] have described reductions in emergency room cardiac troponin turnaround time by using value mapping to describe the entire testing process from the preanalytic through to the postanalytic phases.

SUMMARY

Results from this Q-Probes study highlight substantial differences in processes used by clinical laboratories to prepare specimens before analysis. To increase their efficiency, laboratories may consider concentrating their efforts on reducing the number of testing steps involving waiting, centrifugation, and computer entry activities. Rapid centrifugation is likely to reduce overall SPTs. Reducing the number of process wait steps and computer entry steps may reduce preanalytic SPTs. Finally, laboratories can also apply

lean production techniques to all other phases of their specimen analysis process in order to improve efficiency.

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