Acute Abdomen in the Emergency Department: Is CT a Time-Limiting Factor?

David Chenhan Wang[1]
Craig R. Parry[2]
Michael Feldman[3]
George Tomlinson[4]
Josée Sarrazin[5]
Phyllis Glanc[5]

OBJECTIVE. The purpose of this study was to quantify and integrate key emergency department (ED) and radiology department workflow time intervals within the ED length of stay (LOS) for patients presenting with acute abdomen who require CT.

MATERIALS AND METHODS. An 11-month retrospective review was performed of all patients presenting to the ED with an acute abdomen who required abdominal CT. Nine key time points associated with ED LOS and CT workflow were collected: triage, physician assessment, CT request, porter schedule, CT start, CT complete, provision of first CT report, ED disposition decision, and physical discharge. The median and 90th percentile times for each interval were reported.

RESULTS. Ninety-six percent (2194/2292) of ED encounters during the study period met the inclusion criteria. The median ED LOS was 9.22 hours (90th percentile, 15.7 hours). Intervals associated with CT workflow accounted for 29% of the total LOS. Radiology turnaround time accounted for 32% of the entire CT workflow interval. Timeline analysis found three unique patterns of ED disposition: disposition after initial imaging report, disposition before report, and disposition before CT.

CONCLUSION. To our knowledge, this study is the first to quantify the contribution of CT-related workflow time intervals within the context of ED LOS. We have shown that patients do not have identical ED transit pathways, and this may under- or overestimate time interval calculations. These results show the importance of site-specific ED LOS timeline analysis to identify potential targets for quality improvement and serve as baseline targets for measuring future quality improvement initiatives.

Keywords: acute abdomen, CT abdomen and pelvis, emergency department, length of stay, medical imaging, turnaround time, wait times

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[1]Faculty of Medicine, University of Toronto, Toronto, ON, Canada.

[2]Department of Medical Imaging, University Hospital of Wales, Cardiff, United Kingdom.

[3]Department of Emergency Medicine, University of Toronto, Toronto, ON, Canada.

[4]Institute of Health Policy, Management & Evaluation, University of Toronto, Toronto, ON Canada.

[5]Department of Medical Imaging, Sunnybrook Health Sciences Centre, 2075 Bayview Ave, Toronto, ON M4N 3M5, Canada. Address correspondence to P. Glanc (phyllis.glanc@sunnybrook.ca).

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Emergency department (ED) overcrowding is a well-recognized issue in both the United States and Canada and is associated with restricted access to health services, decreased quality of care, poorer clinical outcomes, and overall decreased patient satisfaction [1–4]. The causes of ED overcrowding are multifactorial, consisting of complex interactions of input, throughput, and output variables [5–9]. ED length of stay (LOS) is a well-recognized indicator of ED throughput, and prolonged LOS is considered a major contributor to ED overcrowding [10–13]. Abdominal pain is one of the most frequent reasons for visiting an ED, accounting for 5–10% of all visits [14–16]. Furthermore, CT of the abdomen and pelvis, a common imaging investigation for abdominal pain, accounts for approximately 10–20% of ED CT examinations [15]. Thus, evaluation of the LOS pathway of a patient presenting with an acute abdomen who requires CT of the abdomen and pelvis affects a significant proportion of ED visits.

Previous studies have highlighted the association of imaging procedures as a major contributor to increased ED LOS [17–20]. Specifically, a number of studies have attempted to quantify radiology workflow in the ED [21–23]. However, these trials have had small sample sizes [21, 23] or reported endpoints that included nonradiology time intervals (e.g., triage to CT report) [22]. Other trials have evaluated strategies aimed at shortening radiology turnaround time (TAT) [24–27]. However, this may not accurately reflect the numerous factors that can influence CT workflow independently of radiology TAT. The primary objective of this study was to quantify key ED and radiology workflow intervals within an ED LOS for encounters that required abdominal CT. A timeline analysis was performed using time points derived from both ED and radiology information systems for patients who pre-

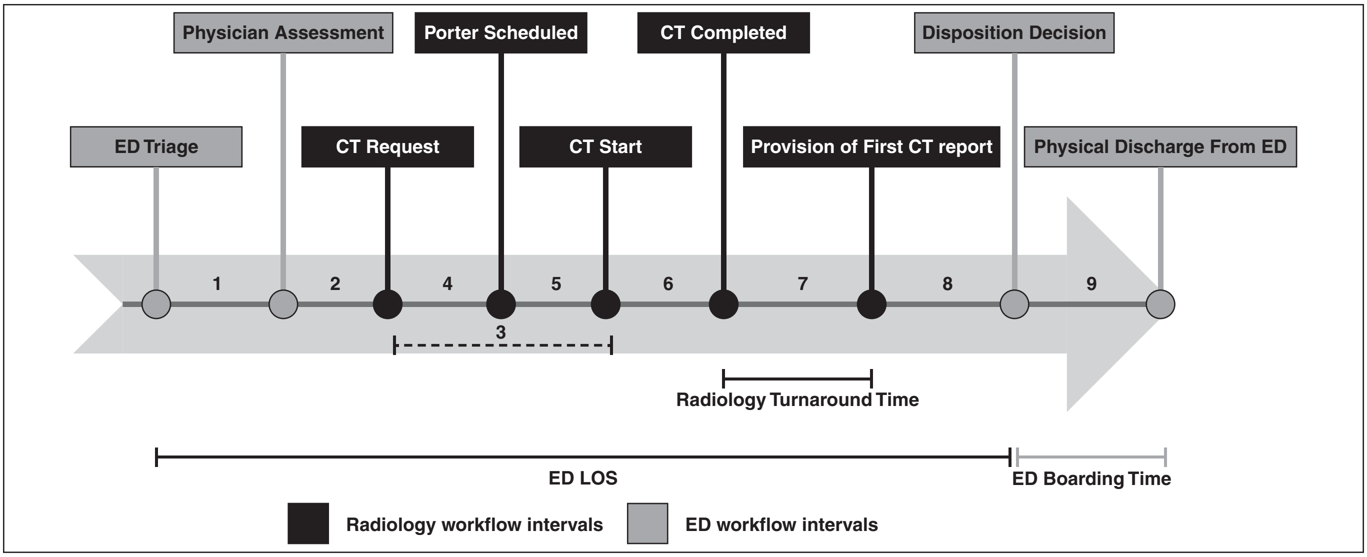

Fig. 1—Schematic shows emergency department (ED) length of stay (LOS) workflow time intervals recorded. Time intervals were derived from variables from ED information system (*black*) and from PACS (*gray*). Major workflow labeled in schematic are as follows: (1) triage to physician assessment; (2) physician assessment to CT request; (3) CT request to CT start, which includes (4) CT request to porter schedule and (5) porter schedule to CT start; (6) CT start to CT complete; (7) CT complete to provision of first CT report (radiology turnaround time); (8) provision of first CT report to ED disposition decision; and (9) disposition to physical discharge (boarding time). ED LOS is defined as time from triage to disposition decision. Boarding time represents time when patient physically leaves ED. Schematic shows disposition pattern 1. Patient's disposition decision occurs after provision of first report, so disposition decision is likely based on findings of CT.

sented to the ED with acute abdomen who required urgent CT of the abdomen and pelvis. We describe key CT imaging workflow time intervals within the ED LOS workflow to establish a baseline for future timeline comparisons, as well as to identify potential areas of improvement. To our knowledge, there have been no studies that describe radiology time intervals within a patient's ED LOS in the setting of acute abdomen requiring CT of the abdomen and pelvis.

Materials and Methods

Setting

Research ethics board approval was obtained. A retrospective review of all ED visits was conducted for the 11-month period from December 2009 to November 2010 at Sunnybrook Health Sciences Centre in Toronto, ON, Canada. Sunnybrook Health Sciences Centre is a large academic and regional level I trauma center with more than 46,000 adult ED visits annually. The ED is supported by an acute care emergency surgery service and by 24-hour subspecialty acute radiology services performed by residents, subspecialty clinical fellows, and staff radiologists. CT examinations are performed in the scanner located within the ED, and acute abdominal CT reporting is provided by a combination of residents, fellows, and staff.

Study Population

All adult patients presenting to the ED with a complaint of an acute abdomen who required urgent abdominal CT were included in the analysis. Exclusion criteria included patients who had experienced trauma (because they undergo a separate dedicated fast-track protocol), direct ward admissions, patients transferred from another hospital, patients with a repeat CT study within the individual visit, or nonacute cases (e.g., oncologic staging). Records were excluded if they contained a timeline documentation error (e.g., physician assessment before triage time). Cases with an incomplete data point were excluded from specific subanalyses only, thus maintaining a good sample size for the majority of analyses.

Outcome Measures

ED workflow time intervals were recorded from the ED information system, which electronically documents patient demographics and key points within a patient's ED LOS. The time points derived from the ED information system include the following: triage, initial physician assessment, ED disposition decision, and physical discharge from ED. All time intervals involved with CT workflow were collected from the Impax PACS (version 4.5, Agfa Health Care). The following radiology-specific time points were recorded: CT request, porter scheduled, CT start, CT complete, and provision of first CT report (Fig. 1). The median and 90th percentile times for each interval were reported. Both the ED information system and the PACS used the same clock synchronization from an external Internet-based source.

ED timeline intervals used are based on definitions established by a previous expert group consensus published by Welch et al. [10]. ED LOS is defined as the time interval between ED triage to disposition decision, and boarding time is defined as the interval between disposition decision and physical discharge from the ED. Imaging reports are generated in one of two ways: the "i-banner" within the Impax 4.5 PACS permits an immediate electronic access to an initial report in the electronic patient record on which the referring ED physician can base their immediate clinical decisions, or a final dictated report is immediately available electronically. Radiology TAT is defined as the time interval between completion of CT to the initial electronic generation of a CT report; this may be either a provisional or a final report (Fig. 1). Subgroup analyses were performed according to the type of contrast agent used, the use of abdominal ultrasound, and the pattern of ED disposition (i.e., order of ED LOS time points). Figure 1 provides a schematic of the time intervals that are measured in this study.

Statistical Analysis

Timeline data were recorded in an Excel spreadsheet (version 2013, Microsoft). Descriptive statistics were used for patient demographics and ED timeline intervals. No imputation methods were used for missing timeline data. The Kruskal-Wallis test was used to compare median ED LOS between predefined groups according to the use of contrast agent and between the most common dis-

TABLE 1: Emergency Department (ED) Length of Stay (LOS) Time Intervals

Time Interval	No. of Patients	Median Time (h)	Percentage of Median ED LOS	90th Percentile (h)	Minimum (h)	Maximum (h)
Triage to physician assessment	2194	2.15	23.3	5.34	0	16.2
Physician assessment to CT request	2133	1.37	14.9	4.57	0	11.9
CT request to CT start	2180	1.55	16.8	3.57	0	13.3
CT request to porter schedule	2189	0.38	4.1	1.92	0	13.1
Porter schedule to CT start	1444	0.5	5.4	2.45	0	7.1
CT start to CT complete	1439	0.25	2.7	0.52	0.02	4.85
CT complete to first report	2193	0.87	9.4	2.43	0	27.8
First report to disposition decision	1903	2.05	22.2	6.41	0	44.3
Triage to disposition decision (ED LOS)	2194	9.22	NA	15.7	0.58	51.4
Triage to physical discharge	2194	10.9	NA	24.9	1.85	85.7

Note—NA = not applicable.

position patterns based on the recorded order of the key LOS time points (triage to physical disposition). Statistical significance was set at $p < 0.05$. All analyses were done in R software (version 3.0.3, R Core Team).

Results

Study Population Characteristics

Overall, 2292 patient encounters during the study period met the inclusion criteria. Of these, 98 (4.3%) patients were subsequently excluded from analysis because of timeline documentation errors, thus leaving 2194 (95.7%) CT studies of the abdomen and pelvis available for review. The mean age of patients was 60.1 years (SD, 18.9 years) and 47% (n = 1031) were male. At the end of the ED visit, 49.4% (n = 1082) were admitted as inpatients, and 50.6% (n = 1110) were discharged.

Emergency Department Length of Stay

The median ED LOS for patients with an acute abdomen complaint requiring a CT of the abdomen and pelvis was 9.22 hours (90th percentile, 15.7 hours; range, 0.58–51.4 hours). Using ED information system data, the total ED LOS can be subdivided into the following consecutive time intervals: triage to physician assessment (median, 2.15 hours; 90th percentile, 5.3 hours; range, 0–16.2 hours), physician assessment to CT request (median, 1.37 hours; 90th percentile, 4.57 hours; range, 0–11.9 hours), and provision of first report to ED disposition (median, 2.05 hours; 90th percentile, 6.41 hours; range, 0–44.3 hours). The median time between triage and physical ED discharge was 10.9 hours (90th percentile, 24.9 hours; range, 1.85–85.7 hours). Summaries of the ED LOS interval times are presented in Table 1.

Radiology Time Intervals

Radiology-specific time intervals, derived from the PACS, are presented in Table 1. The median time interval between CT request and CT start was 1.55 hours (90th percentile, 3.57 hours; range, 0–13.3 hours). Included in this time interval are porter scheduling times (median, 0.38 hour; 90th percentile, 1.92 hours; range, 0–13.1 hours) and patient-to–CT scanner transport time (median, 0.5 hour; 90th percentile, 2.45 hours; range, 0–7.1 hours). After CT, the median time to first report of the image (radiology TAT) was 0.87 hour (90th percentile, 2.43 hours; range, 0–27.8 hours). Overall, the time intervals associated with CT workflow contribute approximately 29% (2.67 hours) of the entire ED LOS. Furthermore, radiology TAT make up approximately 32% (0.87 hour) of the CT workflow time.

Subgroup Analysis

Patterns of length of stay—In addition to the time interval measurements, analysis of individual patients' overall time in the ED revealed three distinct patterns of disposition. For all three patterns, the sequence to disposition is identical until the time point of CT request. After the CT request, pattern 1 represents a traditional ED visit where CT is performed and interpreted before the disposition decision (Fig. 1). Pattern 2 represents the sequence of events where a disposition decision has been made before the availability of the first radiology report but after the scan has been performed (Fig. 2). Finally, pattern 3 represents an ED visit where the disposition decision was made before the start of the CT (Fig. 3). The most common sequence (pattern 1) accounts for 83% (1818/2189) of patients, with patterns 2 and 3 accounting for 7% (154/2189) and 6% (124/2189) of patients, respectively. The ED LOS stratified by disposition pattern is presented in Table 2. The ED LOS for pattern 1 (10.4 hours) is statistically significantly longer than those for pattern 2 (8.1 hours) and pattern 3 (6.9 hours) (Kruskal-Wallis test, $p < 0.0001$).

TABLE 2: Mean Emergency Department (ED) Length of Stay (LOS) for Selected Patterns of ED Disposition

Pattern	Mean LOS (h)	No. of Patients
Pattern 1	10.4	1818
Pattern 2	8.1	154
Pattern 3	6.9	124

Note—All $p < 0.001$ (Kruskal-Wallis test).

TABLE 3: Median Time Interval Stratified by Contrast Agent Use

Interval (h)	Oral Contrast Agent (n = 1145)	IV Contrast Agent (n = 229)	No Contrast Agent (n = 615)
CT request to CT start[a]	2.03	1.35	0.90
Triage to disposition decision[b]	10.2	9.35	7.45

Note—All $p < 0.001$ (Kruskal-Wallis test).
[a]All statistically significantly different from each other at $p < 0.001$.
[b]All statistically significant different from each other at $p < 0.001$ other than between IV and oral contrast agent, which was statistically significantly different at a $p < 0.05$.

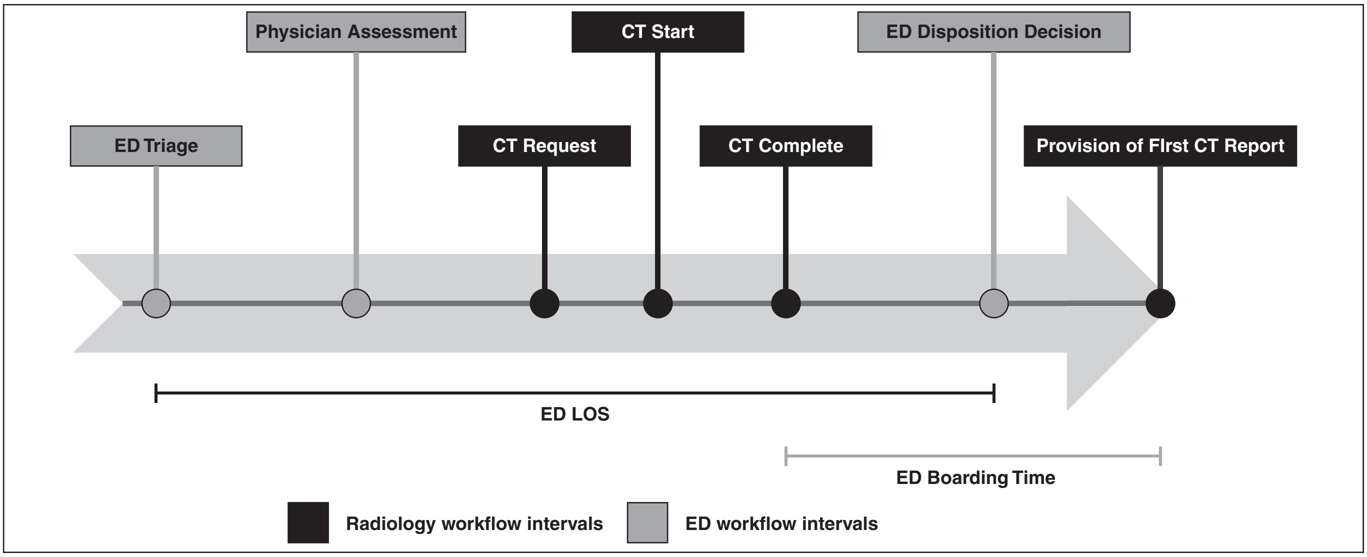

Fig. 2—Schematic shows emergency department (ED) length of stay (LOS) disposition pattern 2. Time intervals were derived from variables from ED information system (*black*) and from PACS (*gray*). In pattern 2, patient's disposition decision occurs before provision of first CT report. Measured radiology turnaround time is not entirely included in ED LOS.

Contrast agent use for CT of the abdomen and pelvis—We stratified the time intervals of ED LOS as well as CT request to CT start between the groups that received no contrast agent, IV contrast agent only, or both IV and oral contrast agent (Table 3). There was a statistically significant increase in ED LOS of 2.75 hours ($p < 0.001$) for oral contrast agent use compared with no contrast agent use. Furthermore, there was a 1.90 hours ($p < 0.001$) difference between IV contrast agent use compared with no contrast agent use. There was also a statistically significant increase in the ED LOS of 0.85 hour for oral contrast agent use compared with IV contrast agent use ($p < 0.001$). There was a statistically significant increase of 0.68 hour in the CT request to CT start interval between oral contrast agent use compared with IV contrast agent use ($p < 0.0001$) (Table 3).

Abdominal Ultrasound Use

We identified 127 (5.8%) cases in which abdominal ultrasound was performed in addition to CT. All 127 patients had their ultrasound performed before the CT request. Of these, 27 ultrasound studies were done before physician assessment and 100 were done after physician assessment. The median time interval for physician assessment to CT request was 3.97 hours (range, 0–11.7 hours) for patients who underwent pre-CT ultrasound and 1.30 hours (range, 0–12 hours) for those who did not undergo pre-CT ultrasound. The use of abdominal ultrasound was associated with a 2.67-hour increase in the interval of physician assessment to CT request (Wilcoxon rank sum test, $p < 0.0001$).

Discussion

The purpose of this study was to describe and quantify the key radiology workflow time intervals that contribute to overall ED LOS for patients presenting with acute abdomen requiring urgent CT. To our knowledge, this is the first study to analyze the multistep process of ED LOS with the integration of radiology workflow variables in the setting of an acute abdomen requiring CT of the abdomen and pelvis.

Overall, the median ED LOS (triage to disposition decision) was 9.22 hours (90th percentile, 15.7 hours). Within the ED LOS, triage to physician assessment (2.15 hours; 90th percentile, 5.3 hours) is the longest individual time interval and accounts for 23.3% of the total ED LOS. This interval represents wait times in the ED, periods where no active care is taking place [10]. Triage to physician assessment time represents the wait time for initial physician assessment and is a commonly used indicator of crowding [10]. Previous reported median wait times for similar patient populations ranged from 70 to 290 minutes [21, 22, 28, 29]. Although the triage to physician assessment time in our cohort does fit within the previously reported range, it still falls short of the recommended target for initial physician assessment of 60 minutes by the Canadian Association of Emergency Physicians [30] or the 15–60 minutes target for urgent ED presentations recommended by the U.S. Government Accountability Office [31]. Furthermore, the overall ED LOS in our cohort is considerably longer than the LOS target set out by the Canadian provincial governments or the reported national U.S. median ED LOS [13, 32, 33]. Although our data appear to state that the ED performance has not met governmental and professional society benchmarks, it is important to recognize that our hospital is a level I trauma center that receives patients with significantly more complex conditions compared with regional hospitals, which may account for the increase in overall LOS and wait times [34]. It is also important to note that the reported population does not reflect the range of severity of patients seen in the ED, many of whom do not require cross-sectional imaging. For example, previous trials in level I trauma centers in Massachusetts and a level II trauma center in Texas found an average ED LOS of all-comers of 232 and 363 minutes, respectively [35, 36]. Although we do not have the data for all-comers in our institution, we hypothesize that the ED LOS would be reduced if we had chosen that population for analysis.

The time interval between initial physician assessment and provision of imaging report represents the time of active care [30]. The interval between physician assessment and CT request (median, 1.37 hours; 90th percentile, 4.57 hours) depicts the time for the initial phy-

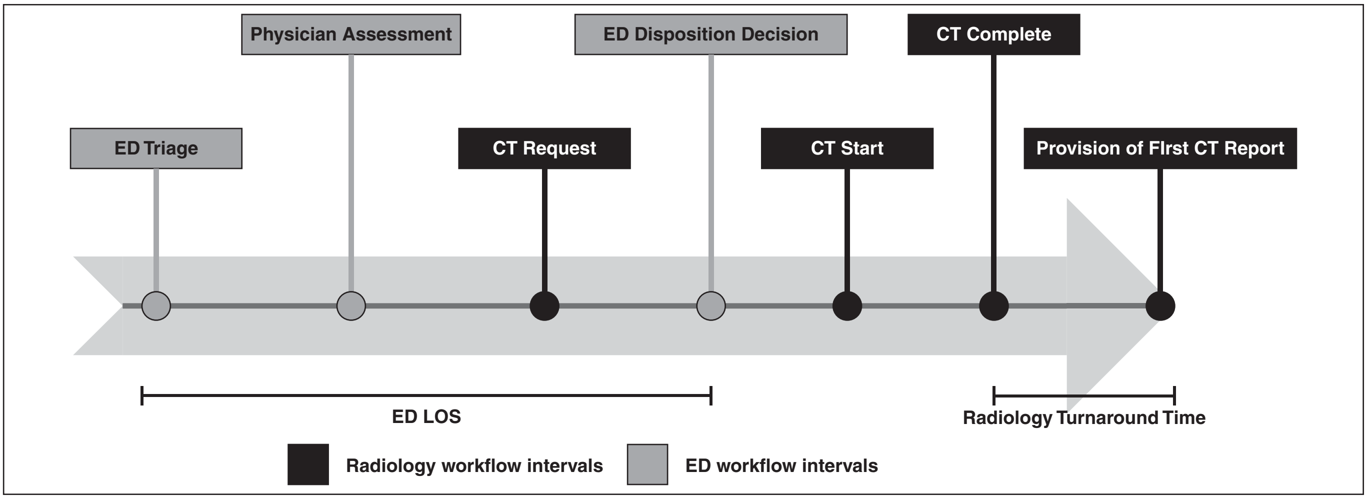

Fig. 3—Schematic shows emergency department (ED) length of stay (LOS) disposition pattern 3. Time intervals were derived from variables from ED information system (*gray*) and from PACS (*black*). In pattern 3, patient's disposition decision occurs before start of CT. Measured ED LOS does not encompass time intervals related to CT image interpretation.

sician assessment in the ED. Within this time interval are potential additional points of care or laboratory testing performed by the ED physician before ordering CT in the PACS. This time interval may also include the time for additional abdominal ultrasound imaging acquisition and interpretation. In our cohort, approximately 6% of patients underwent abdominal ultrasound before the CT of the abdomen and pelvis, which was associated with a 2-hour increase in the physician assessment to CT request interval compared with those who did not undergo abdominal ultrasound. The interval between first CT report to disposition (2.05 hours; 90th percentile, 6.41 hours) represents times when patients are waiting for additional test results or consultations from other services for admission to the hospital [30]. Our institution has already implemented a number of interventions targeting ED throughput, such as general surgery, acute care emergency surgery service teams, and fast-track zones for patients with lower-acuity complaints. The acute care emergency surgery service data showed a reduced time to surgery for patients presenting to the ED with appendicitis [22]. We have no other specific data to determine the effect of acute care emergency surgery service on ED LOS in an acute abdomen setting. These data may provide a baseline comparison for future quality improvement initiatives, such as increasing ED staffing and additional surgical acute care teams.

The interval associated with CT image acquisition (CT request to provision of first CT report) represents 29% (2.67 hours) of the entire ED LOS (Table 1). Within our cohort, the median radiology TAT (as defined by CT complete to provision of first CT report) is 0.87 hour (90th percentile, 2.43 hours). Although there are no definitive TAT guidelines published by the American College of Radiology, the majority of the diagnoses observed in our cohort fall within findings that must be reported within minutes to hours [37]. Comparatively, the current recommendations set out by the Canadian Association of Radiologists state a maximum time of 1 hour for urgent ED radiology TAT [38]. In our cohort, more than half of the cases fell within the recommended 1 hour radiology TAT. We speculate that the cases that did not fall within this timeline may be related, in part, to the case complexity associated with a tertiary referral center compared with a community hospital setting. Furthermore, the effect of a large level I trauma program may have affected the flow of CT studies by causing interruptions and further wait, because these patients have first priority on the clinical and imaging teams. In support of this supposition, previous reports of CT TAT in nontrauma sites ranged from only 36 to 81 minutes [25, 27]. Areas that may have contributed to optimizing radiology TAT, despite the complex tertiary case trauma setting, include an integrated radiology information system, voice recognition dictation, and a PACS [33].

Interestingly, median radiology TAT represents approximately 32% (0.87 hour) of the entire CT workflow interval but only 9.4% of the entire ED LOS (Table 1). The interval of CT request to CT start (median, 1.55 hours; 90th percentile, 3.57 hours) represents the largest component of the CT workflow. This interval represents the time for patients to be given contrast medium and to be physically transported by hospital porters. Within our institution, we have dedicated ED porters for patient transport for medical imaging. To our knowledge, there has been no previous report on porter times for patients to arrive at the CT scanner, although this is likely highly variable and institution dependent, on the basis of location of ED relative to the scanner [23]. However, this information may provide baseline data for quality improvement monitoring for individual institutions. Our institutional routine CT of the abdomen and pelvis uses both oral and IV contrast agents with the following exceptions: no oral or IV contrast agent in renal colic and IV contrast agent only in appendicitis, diverticulitis, bowel ischemia, and small-bowel obstruction. In our cohort, patients who did not receive oral contrast agent had a statistically significantly shorter ED LOS, thus highlighting the importance of "no oral contrast agent" policies for CT of the abdomen and pelvis in the ED setting in the appropriate clinical scenario [15, 39] (Table 3). Surprisingly, we noted that there was a statistically significant time difference (1.90 hours) between the use of IV contrast agent only and no contrast agent use. We speculate that this may be related to two confounding factors: first, cases that require IV contrast agent only are more complex and require additional workup than do cases that require neither oral nor IV contrast agent (e.g., ischemic bowel vs renal colic); and second, given that unenhanced scans require less time than those using either IV or oral contrast agent, we have anecdotally noted an increased flexibility in the scheduling of unenhanced CT studies, in particular those for renal colic, which we speculate may result in a decreased wait time between CT request and CT start.

In addition to the individual time interval measurements, timeline analysis of the LOS of all patients in the cohort revealed three distinct patterns in which patients move through the ED (Figs. 1–3). Although most patients (83%) received imaging interpretation before the disposition decision (pattern 1), 13% of patients in our cohort had an alternative sequence of events. We hypothesize that these alternative patterns represent scenarios different from the traditional sequence of clinical evaluation in the ED. Patients within pattern 2 (7% of patients) had an ED disposition decision before the availability of the first CT report (Fig. 2). We speculate that this most likely represents the scenario where interpretation of CT images was performed but not officially recorded in the PACS. This is commonly referred to as a "wet read," where the radiologist verbally communicates urgent findings to the ED physician to allow rapid clinical decision making, with completion of the formal report at a later time. Wet reads previously have been shown to improve radiology workflow and process [40, 41]. In a busy ED setting, the radiologist may put these cases aside after the verbal report to prioritize clinical cases with higher acuity or for which the diagnosis remained unclear. This is a limitation of this study because we have no record of verbal or wet reads. However, although the wet reads will change the recorded time of the first report, the time would undoubtedly result in a smaller radiology TAT interval, and, thus, pattern 2 represents an overestimation of the impact of radiology acquisition workflow intervals.

Another scenario that may account for this pattern is where the provisional diagnosis is provided by the ED physician before the first CT report by the radiologist. In our institution, a common clinical scenario in which this may occur is when a renal colic CT protocol is performed to rule out an obstructing renal calculus, and the ED physician may choose to interpret the study without the aid of the medical imaging team. Patients in pattern 3 (6% of patients) had an ED disposition decision before the start of the CT (Fig. 3). This may represent situations where the disposition diagnosis can be made clinically or with other imaging modalities but will ultimately require CT. Examples of this may include overt peritonitis on physical examination or the presence of free air or severe bowel obstruction on radiographs. In pattern 2, CT images were interpreted but not officially recorded; in pattern 3, CT was no longer required to be urgently reported, allowing the radiologist to prioritize other studies. As a result, although the overall ED LOS is significantly reduced compared with pattern 1 (Table 2), the time interval of radiology TAT for both patterns 2 and 3 may be overestimated (Figs. 2 and 3).

Interestingly, our data differ from those of a previous publication on the ED LOS of patients with appendicitis at our institution [22]. In that study, Qureshi and colleagues attributed an interval from triage registration to CT preliminary report availability of 7 hours to delays in imaging interpretation. This interval included triage to physician assessment as well as physician assessment to CT request, two large time intervals in our analysis that are independent of the ED radiology workflow. This exaggerated the relative contribution of CT workflow intervals and minimized the effects of ED wait times. This discrepancy of reporting from the same institution highlights both the need to standardize definitions of various time intervals that may affect ED LOS and the value of stratifying ED LOS data into key time intervals. Nonetheless, compared with that study, we have achieved a reduction in the interval from triage to provision of first CT report of 1.6 hours (7.8 hours in Qureshi et al. [22]).

In our analysis, we defined ED transit time from triage to disposition decision. However, this excludes a significant interval of 1.7 hours between disposition decision and physical ED discharge, also known as boarding time (Table 1). The reason for this exclusion involved our primary objective, which was to quantify the relative contributions of radiology workflow intervals on the ED encounter. This involved ED throughput factors, such as process improvement and bottlenecks within the ED. Comparatively, boarding time often is related to ED output and is influenced by systemic hospital factors, such as occupancy rate [1, 11]. Using our definition of ED LOS isolates the major throughput factors and allows greater appreciation of the contribution of CT workflow to ED performance. Nevertheless, our cohort indicates that boarding time remains an issue for patients with abdominal pain, although potential interventions are outside the scope of this article.

Strengths of our study include our large sample size; we have analyzed more than 2000 cases of acute abdomen over an 11-month period, which provides us with the confidence of providing an accurate description of a typical ED LOS within our institution. Second, with the exception of disposition decision, all timeline points used were passive markers previously embedded in the ED information system and PACS, so clinicians performed no active documentation specifically for this study, which increases the accuracy of the time interval information. To our knowledge, there have been only a small number of published reports related to the process of imaging acquisition of radiographs in the ED and no previous published reports on CT workflow variables other than radiology TAT. ED overcrowding is a common problem for both the United States and Canada, and the processes and challenges of ED imaging acquisition are likely similar between the two countries. Therefore, our report provides a unique analysis of the entire imaging acquisition process and helps to contextualize the effect of radiology TAT within the ED LOS that is likely applicable to either country. Although we recognize that many institutions have successful quality improvement programs within the ED and likely track CT acquisition time intervals [42, 43], we think that providing this information in a published format provides an important baseline for quality improvement reporting and we invite other institutions to publish their own timeline results.

Our study does have a number of limitations. The first major limitation to this study is that it is in one single institution, which may decrease generalizability because each hospital may have variable ED management structure, availability of resources, and differences in patient demographics. However, the benefit of analyzing one institution is the ability to control for ED policy changes. There were no major institutional pathway changes during the study period. In addition, given the retrospective study design, we were unable to isolate the specific cause of outliers within our database. For example, the minimum time calculated for most of the time intervals was less than 1 minute (Table 1). We infer that these outliers were likely due to specific clinical scenarios, such as when the ED physician assesses a patient before triage in suspected stroke, ST-segment myocardial infarction, or trauma, for which aspects of the ED LOS were bypassed or when care was expedited. We have used the median time interval measurement whenever available for comparison, to attempt to reduce the potential bias of these outliers in our analysis. In addition, given the retrospective study design, we were limited by our data collection, particularly in our ultrasound cohort. Finally, although it is well recognized that CT diagnosis is a crucial component of medical decision making [44–46], we were unable to capture whether the CT results significantly altered a physician's decision to discharge or admit a particular patient.

The data that we present are applicable to our institution, which is a regional level I trauma center in a large metropolitan city. We hypothesize that, although the specific time interval quantities may not apply to other institutions, the general trend of our data is applicable to similar institutions. In our institution, the median radiology TAT represents approximately 32% (0.87 hour) of the entire CT workflow interval, which is only 9.4% of the entire ED LOS. It is likely that, in other institutions, radiology TAT also only represents a relatively small percentage of the time involved in CT image acquisition. Overall, the time from CT request to provision of the first report represents approximately 29% of the ED LOS; thus, there may be an opportunity to improve the efficiency of time interval from CT request to CT acquisition. Individually, the two longest time intervals included triage to physician assessment and provision of first report to disposition decision; thus, interventions aimed at these two steps may improve efficiency and result in reduced ED LOS. Although both of these steps are dependent on available resources, potential strategies, such as incorporating nurse practitioners or physician assistants into the ED workflow, may alleviate the time constraints placed on the ED physician, and increasing the number of beds for admitted patients may help reduce ED boarding time [1, 11].

Conclusion

In conclusion, this study shows that multistep timeline analysis of the ED LOS provides important information on workflow time intervals that may be amenable to future improvement and serves as a baseline target for future quality improvement initiatives. Furthermore, we have shown that patients do not have identical ED transit pathways, which may under- or overestimate the relative contributions of image acquisition workflow timeline. Given the complexity of factors involved in ED LOS, we recommend the incorporation of specific timeline interval analysis to all LOS studies, thus permitting individual institutions to analyze their own timelines to define areas in which intervention may result in overall LOS reductions. This is particularly important for clinicians and administrators implementing quality improvement interventions at an individual hospital or at the regional level.

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