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ORIGINAL ARTICLE

Lean-driven interventions, including a dedicated radiologist, improve diagnostic imaging turnaround time and radiology report time at the emergency department

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Abstract

Purpose Emergency departments (EDs) worldwide face crowding, which negatively affects patient care. Diagnostic imaging plays a major role in management of ED patients and contributes to patients' length of stay at the ED. In this study, the impact of Lean-driven interventions on the imaging process at the ED was assessed.

Methods During a 6-month multimodal intervention period, Lean-driven interventions and a dedicated radiologist present at the ED were implemented during peak hours (12 a.m.–8 p.m.). Data concerning patient population, radiology department turnaround time (RDTT), radiology report time (RRT), and examination time (ET) for ED patients were compared with a control period of 6 months 1 year earlier.

Results RDTT, RRT, and ET were significantly shorter in the intervention period compared with those in the control period. Median RDTT was respectively 36 min (interquartile range (IQR) 24–56) and 70 min (IQR 39–127), RRT 11 min (IQR 6–21) and 37 min (IQR 15–88), and ET 22 min (IQR 14–35) and 23 min (14–38).

Conclusion Lean-driven interventions on the imaging process at the ED significantly reduced RDTT, RRT, and ET.

Keywords Emergency department · Staffing · Crowding · Imaging · Radiology turnaround time · Quality improvement

Introduction

Emergency departments (EDs) worldwide face crowding. Crowding leads to a lower quality of care and more complications [1, 2]. In the United States of America (USA), crowding is reported in 92% of surveyed EDs [3]. In The Netherlands, there seems to be less of a problem compared with the USA, though in 68% of surveyed hospitals, crowding is experienced more than twice a week [4].

Diagnostic imaging plays a major role in the management of ED patients. Providing emergency physicians (EPs) with imaging findings as rapidly as possible contributes to a timely and accurate diagnosis, facilitates effective management, and thus optimizes patient care. Implementation of picture archiving and communication systems (PACS), voice recognition (VR), and a dedicated computed tomography (CT) scanner on the ED decreased the radiology department turnaround time (RDTT) over the last years [5–7]. Nevertheless, several studies show that diagnostic tests, including both laboratory and radiology examinations, contribute to an increased length of stay (LOS) and thereby to crowding [4, 8].

A 5-day Lean project focusing on the diagnostic imaging process of ED patients was organized in our hospital in 2017 to improve patient flow and quality of care. The project team included a representation of key stakeholders such as radiographers, radiologists, EPs, and ED nurses [9]. Two key principles of Lean methodology are eliminating unnecessary waste while maximizing value to the customer and ensuring continuous flow of work with minimal delays [10, 11]. Hitti et al. described how Lean methodology was effective in reducing transportation time of patients for conventional radiography (CR) in the ED with consequently a reduction in RDTT and LOS [11].

Rogg et al. described that the final step in an ED-CT cycle, the time from a completed head CT to a preliminary report,

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was most often the bottleneck in diagnostic imaging processes, namely in 42% of patients [12]. In our study, this final step was defined as the radiology report time (RRT). Other bottlenecks in their study were time between patient arrival at the ED and CT order (30%) and time between CT scheduled to CT completion (27%) [12]. In our study, this last step is an element of the examination time (ET). The authors hypothesize that implementation of Lean strategies and adding a dedicated radiologist to the ED staff during peak hours will reduce RDTT, RRT, and ET.

Material and methods

Study design and setting

A prospective pre-post analysis was conducted at an inner-city teaching hospital with 380 beds. The 26-bed ED serves as a level 1 trauma and neurovascular center and has approximately 54,000 adult and pediatric patient visits annually, with a 24% admission rate. All patients are registered in the hospital database and subsequently triaged. After triage, patients eligible for treatment by a general practitioner (GP) are redirected to the GP cooperative (GPC). Remaining patients are assessed at the ED. Patients who are redirected to the GPC are excluded from this study.

The usual staffing on the ED, corresponding with the staffing level in the control period, includes residents and EPs 24/7. Residents of cardiology, neurology, surgery, and internal medicine are 24/7 in-house available for ED patient care. Medical specialists are available in the hospital (office hours) and on-call (out-of-office hours). The same situation accounts for the radiologist; during office hours, there is no dedicated radiologist for the ED as all subspecialized radiologists report the ED examinations with priority, alongside their daily work. ED patients who need an ultrasound examination are seen in between outpatient clinic patients at the radiology department, three floors apart from the ED. Outside office hours, a radiology resident is on call for ED and inpatient studies, with supervision from a senior on-call radiologist if necessary.

The ED is equipped with a CT scanner and a bucky unit. Prior to the intervention period, a remodeling of the ED took place which created a room for ultrasound examinations and 2 radiology report workstations. The CT scanner was replaced by a faster and dual-gantry scanner.

The 5-day Lean project focusing on the diagnostic imaging process of ED patients was organized in our hospital in September 2017. The project team included a representation of key stakeholders: radiographers, radiologists, EPs, ED nurses, and managers from both the radiology department and the ED. The first step in instituting Lean was to educate the team about Lean principles and techniques. In the next step, the stakeholders drew a process map of the total diagnostic imaging process at the ED, including every step from ordering examinations, preparation and transport of patients, to performing and reporting examinations. Thereafter, the team had a meeting twice a day, at 8 a.m. and 3.30 p.m., in order to evaluate the steps in the process for identification of bottlenecks and to gain insight in each other's workflow. All the stakeholders working at the ED could address problems or observations to the Lean team.

After 5 days of observation and data collection, the Lean team identified both small and big bottlenecks throughout the imaging process and suggested improvements and accompanying conditions. For example, patient preparation often (subjectively) caused a delay in the process. A complete radiology order, including information on mobility and location of the patient, and undressing the patient and removing relevant jewelry prior to an examination were defined as improvements in patient preparation. Also, if applicable, the ED nurse instead of the radiographer supplied intravenous access for CT. An accompanying condition for these improvements was availability of ED staff or runners for instruction and transport of patients. Other Lean interventions included a diagnostic fast-track for CT, clinical algorithms for decision-making in diagnostic imaging, and agreements on communication by telephone to prevent unnecessary, interfering calls. The complete list of the implemented Lean strategies is summarized in Box 1.

Box 1 Implemented Lean strategies

A dedicated radiologist is present at the ED during peak hours
All radiologic examinations are immediately performed after an order; change of mindset
Diagnostic fast-track for CT
The ED nurse supplies intravenous access for CT if applicable
Complete application of the radiology examination order, including information concerning mobility and location of the patient
The installation of runners for transport of immobile patients between the ED and radiology examination room
Mobile patients are instructed to walk to a central point at the radiology department and ED, respectively, prior to and after an examination
Patients are instructed by the ED nurse and/or runner to undress as appropriate and take off relevant jewelry prior to the radiology examination
Agreements on communication by telephone to prevent unnecessary, interfering calls
Implementation of clinical algorithms for decision-making in diagnostic imaging
Implementation of rapid C-reactive protein testing (appendicitis fast-track)

An observation from the Lean project team was that the number of orders for imaging procedures was 4 or more per hour between 12 a.m. and 8 p.m., and less than 4 per hour outside these hours. Based on these numbers, on data from earlier studies in our hospital and on literature, these hours were defined as peak hours, regarding a peak in both the number of patients and diagnostic imaging examinations [9, 13]. During the 6-month intervention period (1 November 2017–1 May 2018), the Lean strategies were implemented. Also, a radiologist was stationed at the ED in a room with ultrasound facilities and 2 workstations, between 12 a.m. and 8 p.m., 7 days a week.

During the intervention period, the ED radiologist was at all times available for consultation and had no other obligations beside the ED examinations. The aim for radiographers and radiologists was to have a RDTT of 30 min or less for each examination, with either a digitally available preliminary or definitive report. When a radiology examination was completed and processed by the radiographer, it became available in PACS and at the top of the radiologists worklist in the radiology information system (RIS) for review and report. A voice recognition system was used for transcription (Dragon NaturallySpeaking, Nuance Communications, Inc.). At the moment of authorization of the (preliminary) radiology report, it became directly visible in the hospital information system (HIS) for EPs. The same RIS, HIS, and VR were used during the intervention and control periods. During both periods, ultrasound examinations were performed by radiologists, supported by a doctor's assistant for patient preparation. No sonographers are employed at the radiology department in our hospital. Outside of peak hours, there were no changes in staffing levels or workflow compared with the control period. The control period was defined as a 6-month period 1 year earlier (1 November 2016–1 May 2017).

This study is a subanalysis of an ED-wide study, deemed exempt by the regional medical research committee (Southwest Holland, nr. 17-122).

Data measurements and analysis

The outcomes of interest of our study were radiology department transition time, examination time, and radiology report time, with the following definitions:

- RDTT: time between the clinical order for an examination and authorization of the radiology report,
- ET: time between the clinical order and finishing the examination,
- RRT: time between finishing an examination and authorization of the radiology report.

Regarding CR and CT examinations, ET and RRT add up as the RDTT and correspond respectively with radiology technician's and radiologists' efforts. For ultrasound examinations (US), the ET encompasses both the time for patient transport and preparation and the time to perform the examination by the radiologist.

Data including number of ED visits, patient and visit characteristics (age, triage level, method of referral to ED, discharge disposition, length of stay), and radiology characteristics (number of examinations, modality, transition times, requesting medical specialist) were obtained from two separate databases (HIS and RIS). Triage levels were assigned according to the Manchester triage system: immediate (level 1), highly urgent (level 2), urgent (level 3), standard (level 4), and non-urgent (level 5). For analysis, triage categories 1–3 were combined as urgent and categories 4 and 5 as non-urgent.

Included in the analysis were the modalities US, CR, and CT. RDTT outliers of 24 h or more were deemed unlikely to be accurate and were excluded.

Data were analyzed using descriptive statistics, Chi-square tests, and Mann-Whitney U tests where appropriate. Significance thresholds were set at $p \leq 0.05$. Odds ratios (OR) and their 95% confidence intervals (CI) were reported when applicable. The statistical package for the social sciences (IBM Corp., IBM SPSS Statistics for Windows, Version 26.0 Armonk, NY, USA) was used for analysis.

Results

A total of 20,186 patients visited the ED during peak hours in the study period. Of these patients, 0.4% were excluded from the analysis for a RDTT outlier of more than 24 h (87/20,186 patients). During the control period, a total of 9772 patients were included, compared with 10,327 during the intervention period. Patient characteristics are described in Table 1.

In the intervention period, significantly more patients were triaged in the urgent category (76.4% vs 74.0%; OR 1.140; 95% CI 1.068–1.216). The medical specialties to which patients were appointed did not differ significantly between the control and intervention period (Table 1). There was no significant difference in the number of patients admitted to a regular ward after their ED visit, 2651 (27.1%) and 2771 (26.8%) in the control and intervention periods, respectively. Slightly more patients were admitted to an intensive care unit and cardiology care unit or went straight to the operating room during the intervention period (141 (1.4%) vs 103 (1.1%), $p = 0.044$). Mortality was 8 (0.1%) in the control period versus 18 (0.2%) in the intervention period and did not differ significantly ($p = 0.068$).

There was no difference in the number of patients with one or more imaging procedures during their ED visit. Respectively, 5148 (53%) and 5408 (52%) patients had at least one examination during the control and intervention periods ($p = 0.656$) (Table 2). Significantly more patients had one or more ultrasound examinations in the intervention period (891 (8.6%) compared with 765 (7.8%); $p = 0.039$).

Table 1 Patient and patient visit characteristics

	Control period, Nov 1, 2016–May 1, 2017	Intervention period, Nov 1, 2017–May 1, 2018	Odds ratio (95% CI), *p* value
Number of patients, *n*	9772	10,327	
Age (years), median (IQR)	48 (26–67)	49 (27–68)	< 0.001
Triage category[a], *n* (%)			
Urgent	7080 (72.5)	7554 (73.1)	1.140 (1.068–1.216), < 0.001
Non-urgent	2491 (25.5)	2332 (22.6)	
Medical specialism, *n* (%)			
Surgery	3235 (33.1)	3378 (32.7)	0.982 (0.926–1.042), 0.552
Internal medicine	1472 (15.1)	1538 (14.9)	0.987 (0.913–1.066), 0.735
Cardiology	1381 (14.1)	1481 (14.3)	1.017 (0.940–1.101), 0.672
Neurology	1284 (13.1)	1363 (13.2)	1.005 (0.926–1.091), 0.902
Other	2400 (24.6)	2567 (24.9)	1.016 (0.953–1.083), 0.625
LOS (min), median (IQR)	165 (113–233)	155 (102–221)	< 0.001
Destination, *n* (%)			
Mortality	8 (0.1)	18 (0.2)	2.131 (0.926–4.903), 0.068
Admission regular	2651 (27.1)	2771 (26.8)	0.985 (0.926–1.048), 0.637
Admission ICU, CCU, OR	103 (1.1)	141 (1.4)	1.299 (1.006–1.678), 0.044
Other[b]	7010 (71.7)	7397 (71.6)	0.995 (0.935–1.058), 0.865

CI confidence interval, *IQR* interquartile range, *LOS* length of stay, *ICU* intensive care unit, *CCU* cardiology care unit, *OR* operating room

[a] Based on 19,475 cases, since 642 cases had no triage score; 201 and 441 cases in respectively the control and intervention periods

[b] Other destinations include mostly being dismissed or referral to policlinic or nursing home

Median RDTT for all modalities combined was significantly shorter during the intervention period compared with that during the control period, with respectively 36 min (IQR 24–56) and 70 min (IQR 39–127) ($p < 0.001$). Median RRT was

Table 2 Radiology characteristics

	Control period	Intervention period	*p* value
Number of patients, *n*	9772	10,327	
Number of patients with at least one examination, *n* (%)	5148 (52.7)	5408 (52.4)	0.656
CR, *n* (%)	3483 (35.6)	3560 (34.5)	0.082
US, *n* (%)	765 (7.8)	891 (8.6)	0.039
CT, *n* (%)	1860 (19.0)	1897 (18.4)	0.227
RDTT (min), median (IQR)*	70 (39–127)	36 (24–56)	< 0.001
CR (min), median (IQR)	55 (32–97)	29 (20–43)	< 0.001
US (min), median (IQR)	109 (70–173)	32 (23–51)	< 0.001
CT (min), median (IQR)	86 (51–162)	53 (36–80)	< 0.001
RRT (min), median (IQR)	37 (15–88)	11 (6–21)	< 0.001
CR (min), median (IQR)	30 (12–71)	8 (5–15)	< 0.001
US (min), median (IQR)	45 (18–99)	8 (4–16)	< 0.001
CT (min), median (IQR)	50 (21–116)	18 (10–34)	< 0.001
ET (min), median (IQR)	23 (14–38)	22 (14–35)	< 0.001
CR (min), median (IQR)	19 (12–29)	18 (12–28)	0.034
US (min), median (IQR)	49 (29–79)	23 (14–35)	< 0.001
CT (min), median (IQR)	28 (18–43)	29 (19–46)	0.002

CR conventional radiography, *US* ultrasound, *CT* computed tomography, *LOS* length of stay, *IQR* interquartile range, *RDTT* radiology department turnaround time, *RRT* radiology report time, *ET* examination time. *Data are presented as medians and therefore, the sum of the RRT and ET does not add up to the RDTT

37 min (IQR 15–88) during the control period and 11 min (IQR 6–21) during the intervention period ($p < 0.001$). Subanalysis of the different modalities showed significant reduction in both RDTT and RRT for all 3 modalities (Table 2).

Median ET for all modalities was 23 min in the control period and 22 min in the intervention period ($p < 0.001$). Median ET for CR decreased from 19 to 18 min, for CT increased from 28 to 29, and for US by 26 min (49 compared with 23 min), all significant changes (Table 2).

LOS significantly decreased to a median of 155 min (IQR 102–221) in the intervention period, compared with a median of 165 min (IQR 113–233) in the control period ($p < 0.05$).

Discussion

This study illustrates the value of implementation of Lean strategies in the diagnostic imaging process at the ED and the presence of a dedicated radiologist during peak hours. Median RDTT, RRT, and ET significantly decreased with respectively 34, 26, and 1 min. Although a statistically significant reduction of 34 min does not necessarily mean a clinically significant reduction, we hypothesize that a reduction of RDTT contributes to a clinically valuable decrease in LOS. We found a reduction in patients' LOS at the ED in the intervention period of 10 min (median 155 min compared with 165 min, $p < 0.001$), which theoretically leads to 138 days of non-occupied beds on the ED during peak hours and could substantially minimize crowding. An interesting note, this 10-min decrease in LOS, compared with the 34-min decrease in RDTT, implies that delays in imaging processes do not correspond with an increased LOS on a 1:1 basis and that they might be less contributory to crowding than previously thought.

Significant reduction in RDTT was found in all 3 most common modalities (CR, US, and CT; 26, 77, and 33 min, respectively). To what extent the implemented Lean strategies and the dedicated radiologist were responsible for the reduction in RDTT can be deduced from respectively the examination time and the radiology report time. Overall, especially for CR and CT, the relatively small difference in ET implies that the effect of the presence of the dedicated ED radiologist was larger on the RDTT than the effect of the implemented Lean strategies. Of the Lean strategies, we feel that most contributory were the agreements on patient transport. Although the process improvements were not particularly novel, we think that they were accepted and fully deployed because the Lean project team had a great support base among stakeholders. Most of all, we feel that the gained insight by stakeholders in each other's (disturbances in) workflow created a better collaboration. DeFlorio et al. stated that a willingness to improve service, and staff education on expectations of ED radiology, resulted in a decrease in RRT [5].

The ET encases transport of patients to the radiological modality and performs and processes the examination in order to be ready to be reported. There was only a reduction of 1 min in ET for CR examinations, but a reduction of 26 min for US. The definition of ET for US is more complex than for CR and CT, since it encompasses both the logistic factors on patient preparation and the time to perform the examination by the radiologist. The large reduction on ET for US was probably due to the fact that ultrasound examinations during the intervention period were being performed at the ED by the dedicated radiologist, instead of at the radiology department in between outpatient clinic patients, reducing both transportation and waiting time. Data on the duration of the actual ultrasound examinations are not available, but are assumed not to differ significantly between the intervention and control periods, since the same group of radiologists performed the examinations. We have no indication that the examinations would have been more focused rather than extensive during the intervention period. Despite the new, faster CT scanner at the ED, the ET for CT examinations increased with 1 min, from 28 min in the control period to 29 min in the intervention period. We hypothesize that implementation of the new scanner requires a training period for radiography technicians to get familiarized with the new scanner and its software.

Our radiologists hypothesized that less examinations would be requested when a dedicated radiologist was available for low-threshold consultation. However, the number of patients who received at least one radiology examination remained similar during the intervention and control periods. Whether emergency physicians or residents actually consulted the radiologist more often was not recorded.

A potential risk of having a dedicated radiologist at the ED is that radiology residents will have less exposure to ED examinations. Towbin et al. implemented multiple interventions to improve RDTT in the ED, including increased staffing, and concluded that there was no major change in percentage of ED radiographs read by residents and fellows (respectively 59.9% and 62.0% in the intervention and control periods) [14]. Resident training and exposure should be an issue of concern in teaching hospitals, but must be balanced against service demands and optimizing patient care. Residents and radiologists in our hospital have not experienced a decrease in exposure during the intervention period and even noticed educational benefits from the presence of the ED radiologist by closer collaboration.

Another potential risk is that a shorter RRT will come at the expense of interpretation accuracy. Changes in interpretation accuracy are difficult to discern, partly because there are few objective measures of quality. During the intervention period, there were significantly less unscheduled representations at the ED within 1 week after the initial ED visit (data not shown). It was not possible to retrieve data from HIS concerning readmission of individual patients, so we cannot find out whether representations were because of radiology-based misdiagnosis or interpretation errors.

An interesting finding in our study is that the RDTT and RRT outside of peak hours also significantly decreased (data not shown), even though the workflow and staffing level during these hours were unchanged. Towbin et al. showed a similar phenomenon; besides all ED radiographs, also all non-ED radiographs showed a significant improvement in RDTT [14]. Radiologists knew that RDTT and RRT were documented during the intervention period, which may have introduced the Hawthorne effect, a change in behavior induced by the study itself. Ideally, we would repeat our study without radiologists' awareness that data is being collected, to outrule the Hawthorne effect. Secondly, the remodeling of the ED might have contributed to the reduction of the RDTT both during and outside of peak hours, as the ED was equipped with an US examination room and a faster and on-site CT scanner during the intervention period. This contribution applies in particular for US examinations, since these yielded the largest reduction in ET, as stated earlier. Dang et al. described in 2015 how the presence of an ED CT scanner in their hospital was associated with decreases in RDTT, RRT, and LOS [7].

A possible confounder in our study is the unintentional change of workflow of reporting the radiology results to the EP. In the control period, the referring physician was usually contacted by telephone following a radiology examination, to communicate relevant findings. The written results, digitally available in HIS, would either follow directly to the call or sometimes minutes to hours later, based on the workload of the radiologist. During the intervention period, a preliminary or definitive report would be directly available in HIS, with or without an accompanying phone call. The moment of spoken communication could not be obtained from HIS in this study; the (preliminary) RDTT and RRT in the control period might have been less than stated. The authors think that this change of workflow may have influenced the accuracy of the RRT in the control period to some extent, given the relatively large IQR, but also think that the outlined way of communication by phone in the control period was in particular applicable outside of office hours, when only a radiology resident was (on-call) available. Since the defined peak hours mostly included office hours (with the exception of 6 p.m.–8 p.m. and weekend days), we believe that the RRT in both the control and intervention periods was quite accurate.

As there were more patients triaged in the urgent category and patients were slightly though significantly older in the intervention period, it is thought that the reduction in RDTT is not due to less urgent or complex problems and that it is unlikely that our results were (positively) influenced. Other baseline characteristics were not significantly different.

Cost-effectiveness was not evaluated in this study. The ED radiologist in this study equals one full-time equivalent (FTE); it is possible that the same effect on RDTT could be achieved in a less costly way. To evaluate value of the implementations using other metrics, for example, patient satisfaction, only indirect indications were available in this study. In the intervention period, there were significantly less patients leaving the ED without being seen and less unscheduled representations at the ED within 1 week after the initial ED visit, suggesting an increase in patient satisfaction (data not shown).

Finally, this is a single institution analysis. The analysis may have limited generalizability because of differences in patient population, level of crowding, or health care system. Some of the process changes may not be applicable to EDs with different organization structures; however, we think that evaluation and improving the diagnostic imaging process at the ED would be beneficial to many EDs.

In conclusion, this analysis illustrates the value of implementation of Lean strategies, including a dedicated ED radiologist during peak hours, with a significant reduction of RDTT, RRT, and ET.

Authors' contributions Each author had a substantial contribution and met the requirements for authorship. The manuscript has been read and approved by all the authors.

Data availability The data that support the findings of this study are available from the corresponding author, BK, upon reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This is an observational study. The Southwest Holland Ethics Committee has confirmed that no ethical approval is required (nr. 17-122).

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