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The Role of the Integrated Digital Radiology System in Assessing the Impact of Patient Load on Emergency Computed Tomography (CT) Efficiency

Suzanne O'Hagan[1] · Carl J. Lombard[2] · Richard D. Pitcher[1]

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Abstract
Time-critical management is of particular significance in the trauma and emergency setting, where intervals from patient arrival to diagnostic imaging and from imaging to radiology report are key determinants of outcome. This study, based in the Trauma and Emergency Unit of a large, tertiary-level African hospital with a fully digital radiology department, assessed the impact of increased workload on computerised tomography (CT) efficiency. Sequential, customised searches of the institutional radiology information system (RIS) were conducted to define two weekends in 2016 with the lowest and highest emergency CT workloads, respectively. The electronic RIS timestamps defining the intervals between key steps in the CT workflow were extracted and analysed for each weekend. With the exception of radiologist reporting time, workflow steps were significantly prolonged by increased workload. This study highlights the potential role of the integrated digital radiology system in enabling a detailed analysis of imaging workflow, thereby facilitating the identification and appropriate management of bottlenecks.

Keywords Radiology information system · Picture archiving and communication system · Radiologist report turnaround time · Imaging workflow · Emergency CT · Trauma CT

Introduction

Clinical medicine has become increasingly reliant on diagnostic imaging for both accurate diagnosis and assessment of treatment response [1]. Growth in the use of computed tomography (CT) has been particularly rapid as a result of the modality's major technological improvements, increasing availability, and undisputed clinical value. In the emergency setting, CT has the capacity to change diagnoses in up to half the cases, increase diagnostic confidence, modify clinical management, and reduce length of stay [1, 2]. In the USA alone, between 1996 and 2010, CT usage tripled in the acute care setting [3].

✉ Suzanne O'Hagan
suzanneohagan@gmail.com

[1] Division of Radiodiagnosis, Department of Medical Imaging and Clinical Oncology, Faculty of Medicine and Health Sciences, Stellenbosch University and Tygerberg Hospital, Francie van Zijl Drive, Tygerberg, Cape Town 7505, South Africa

[2] Biostatistics Unit, South African Medical Research Council, Cape Town, South Africa

Time-critical management is particularly important in acute care, where the intervals from patient arrival to diagnostic imaging and from imaging to radiology report are key determinants of outcome [4]. Norms for the completion of emergency imaging have not been defined. However, the "golden hour" after injury is commonly construed as the optimal window for definitive intervention [5].

Several studies have assessed factors responsible for delayed emergency care, and most have implicated imaging. All reports underscore the importance of imaging efficiency and the impact of imaging delays, which increase length of stay and aggravate emergency unit overcrowding, thereby further restricting access to care and ultimately compromising outcomes [2, 4, 6, 7].

Three digital systems enhance workflow in the modern imaging environment: the radiology information system (RIS), the picture archiving and communication system (PACS), and voice recognition (VR) technology. The three systems are usually seamlessly integrated, with the RIS commonly, but not exclusively, serving as the platform for overall system cohesion. The inherent business intelligence functionality of the modern RIS facilitates efficiency evaluations, by generating electronic timestamps at key steps of the digital workflow [8].

Notwithstanding the capacity of the modern integrated digital radiology system to facilitate such analyses, there has been limited work on enhancing efficiency in the emergency CT environment. Studies to date have largely been conducted in well-resourced settings and have either assessed overall emergency unit efficiency, with imaging being a step in the broader analysis [6, 7, 9–11], or evaluated specific components of the imaging workflow, rather than the radiology workflow in totality [6, 7, 12]. Preceding studies have also tended to employ small sample sizes and varying methodology, with contrasting outcomes.

To our knowledge, there has been no study of the overall imaging workflow in a high-volume, low-resource environment. In addition, the impact of variations in CT workload on imaging efficiency has not been assessed in any setting. Such studies could foster a better understanding of the imaging domain and facilitate appropriate interventions to enhance workflow and improve outcomes. The sequential digital timestamps provided by the RIS afford ideal data for such analyses.

In common with other resource-limited settings, public sector hospitals in South Africa have recently experienced mounting pressure in providing trauma and emergency department services, with overcrowding and prolonged waiting times a feature of peak periods [13].

Aim

To analyse the impact of patient load on emergency CT efficiency in a large Trauma and Emergency Unit.

Methods

This retrospective cohort study was based at a large, 1386-bed, public sector, tertiary-level teaching hospital affiliated to the university, which has an active postgraduate radiology teaching program and a fully digital radiology department, with electronic imaging requests, an integrated PACS/RIS, and VR software. The hospital has a high-volume Trauma and Emergency Unit, with a dedicated six-slice CT scanner and a senior radiology resident on-site at all times [14]. The duty resident assumes first-line responsibility for after-hour CT reporting, with telephonic and/or teleradiology support from an on-call consultant. Resident reporting workflow formed the basis of this study. The overall accuracy of such reporting has previously been shown to be 92% [15]. Of note, weekend staffing resources within the Trauma Unit remain constant throughout the year.

Sequential, customised searches of the institutional RIS were conducted to define two weekends (WE1 and WE2) during 2016 with the lowest and highest Trauma and Emergency Unit CT workloads, respectively. A weekend was defined as the 60 h from 16h00 Friday–08h00 Monday. Emergency CT scans for which all workflow steps were completed during WE1 and WE2 were included and subject to comparative analyses. Scans with a portion of the workflow conducted outside the defined WE1 and WE2 periods were excluded from the analysis.

The RIS workflow data pertaining to each CT were interrogated. For each study, five electronic timestamps were extracted, defining four key workflow intervals:

Approval time: Clinical request to radiologist approval
Waiting time: Radiologist approval to start of scan
Scan time: Duration of scan
Reporting time: Scan completion to resident report distribution

For comparison of weekend workloads, CTs were stratified anatomically as vascular, brain, abdominal, musculoskeletal, and two-region or more than two-region scans.

The Trauma and Emergency Unit CT scanner was fully functional during WE1 and WE2.

The study was approved by the Health Research Ethics Committee of the Stellenbosch University Faculty of Medicine and Health Sciences.

Statistical Analysis

Descriptive statistics were generated by utilising the extracted RIS timestamps to calculate the median time and interquartile range for each workflow step, by weekend. Quartile regression was used to compare the median times for workflow steps between weekends. For each workflow step, the median time difference between weekends was estimated with a 95% confidence interval.

A chi-squared test was used to compare the weekend workloads by anatomical distribution of scans.

Results

Two hundred and seventeen scans ($n = 217$) were included. Ninety-two ($n = 92$) were performed on WE1 (Friday 11th–Monday 14th November 2016) and 125 ($n = 125$) on WE2 (Friday 16th–Monday 19th December 2016), representing a 36% increase in CT workload on WE2. Notwithstanding the numerical increase in vascular investigations in WE2, there was no statistically significant difference in the proportion of scans by anatomical region across the two periods ($p = 0.194$) (Table 1).

There were significant differences in the median times of all workflow steps across the two weekends. The 36% increase in WE2 workload extended the median "approval",

Table 1 Clinical workload distribution by weekend

Clinical category	WE1 *n*, %	WE2 *n*, %
Vascular	12 (13.0)	33 (26.4)
Head	45 (48.9)	44 (35.2)
Abdomen	11 (12.0)	13 (10.4)
Musculoskeletal	7 (7.6)	9 (7.2)
Two regions	12 (13.0)	17 (13.6)
> two regions	5 (5.4)	9 (7.2)
Total	92 (100.00)	125 (100.0)

"waiting", "scan", and "total" times by 188%, 155%, 375%, and 95% respectively, while decreasing the "reporting time" by 32% (Table 2). The median WE1 "waiting time" (83 min) accounted for approximately 60% of the total workflow, while that of WE2 (212 min) was almost three-quarters.

Discussion

To our knowledge, this is the first comprehensive analysis of the emergency CT workflow in a high-volume, limited-resource setting, and the first to assess the direct impact of clinical workload on service delivery. The study highlights the potential role of the RIS in facilitating a detailed workflow analysis and enhancing understanding of the dynamics of the modern diagnostic imaging environment. The analysis is broadly applicable to digital radiology systems globally. The results provide a clinical benchmark for similarly resourced settings, while allowing comparison with better-resourced environments.

Analyses such as this are particularly important, since norms for the completion of emergency imaging have not been defined [16]. In the absence of a gold standard, it is perhaps prudent to strive for emergency imaging times that are "as low as reasonably achievable", in line with the principles governing radiation exposure [17].

In this context, the WE1 "total time" of 140 min may be construed as institutional "best performance" for the review period (2016), since it documents parameters attained with the lowest patient load, while the WE2 "total time" of 286 min arguably represents institutional "worst performance" for the same period.

Of note, our finding of a 9-min median "approval time" for WE1 compares favourably with the 12 min which Rogg et al. recently documented for this step at the Massachusetts General Hospital [7]. Similarly, the 83-min "waiting time" for WE1 scans is comparable to the 93 min recorded by Wang et al. in a 2015 Toronto study [6]. The 4-min WE1 "scan time" is the fastest documented to date for this phase of the CT workflow, surpassing times reported by Fung Kon Jin in Seattle, Easton in New South Wales, and Wang [6, 9, 10]. Additionally, the median WE2 "scan time" of 19 min was acceptable in the light of the 14–20 min recorded in other studies [6, 9, 10]. The median WE1 "reporting time" of 44 min also compares favourably with other centres, where times from 52 to 86 min have been recorded, while the 30-min WE2 "reporting time" highlights exceptional local reporting efficiency in the face of high scan loads [6, 7, 11]. A "total time" of 147 min on WE1 approximates the total workflow times found by Rogg (112 min) and Wang (160 min) [6, 7].

Notwithstanding these favourable comparisons, our study clearly identifies "waiting time" as a local imaging bottleneck. "Waiting time" comprises three distinct periods: an initial "holding time" in the Trauma and Emergency Unit resuscitation area or ward, followed by "transfer time" to the CT scanner, and a further "holding time" in the CT waiting area. Nursing surveillance is required through all phases of the "waiting time", while "transfer time" can be regarded as part of the porter workflow. "Waiting time" therefore reflects the availability of a number of key resources, including nurses, porters, radiographers, and time on the CT scanner. The finding that a 36% increase in workload more than doubled the WE2 "waiting time" suggests that some or all of the resources required in this workflow step are operating close to capacity, even in the quietest periods. Such knowledge facilitates targeted further interrogation and intervention.

Table 2 Workflow duration by weekend

Workflow step	Period	Median time [IQR]	Median time difference [95% CI]	*p* value
Approval time (minutes)	WE1 WE2	9 [2–46] 26 [4–88]	17 [2.4–31.2]	0.023
Waiting time (minutes)	WE1 WE2	83 [25–200] 212 [73–511]	129 [37.2–216.6]	0.006
Scan time (minutes)	WE1 WE2	4 [2–13] 19 [13–35]	15 [10.2–19.8]	< 0.001
Reporting time (minutes)	WE1 WE2	44 [24–87] 30 [19–57]	− 13.8 [− 26.4–3.6]	0.011
Total time (minutes)	WE1 WE2	147 [65–298] 286 [143–630]	138 [42–234]	0.004

Certain RIS configurations incorporate dedicated porter workflow timestamps, such as the time of the radiographer's request for patient transfer, the time of patient collection, and the time of arrival at the CT waiting area. Typically, there is also a provision for digital porter feedback notes, documenting constraints to service provision, such as "patient clinically unstable and not suitable for transfer", "no nursing support available", and "patient undergoing another investigation". At the time of our study, our RIS did not include porter workflow timestamps. However, these could be configured as part of the next PACS-RIS upgrade. Our findings certainly highlight the need for such a workflow. We would recommend that all environments considering commissioning a digital radiology platform include porter workflow as a standard specification.

Digital imaging systems typically also support the inclusion of digital radiographer notes, detailing delays in the CT waiting area. Such notes could include "awaiting laboratory results", "no intravenous access", "bowel preparation required", and "patient became clinically unstable—physician called". Radiographer notes can also be included on factors impacting the "scanning time" such as "intravenous line occluded", "patient unco-operative, required sedation", and "radiologist called for immediate review of initial scan findings, for additional study/change in protocol". Although the institutional RIS supports such radiographer notes, a prospective study would be required to ensure recording in a standard manner for all patients, thereby allowing for a meaningful analysis and incorporation into future workflow studies.

The current study did not correlate workflow efficiency with patient load *within* weekends, assuming steady patient throughput. This is a recognised limitation, since interpersonal violence and motor-vehicle accidents are typically more prevalent on Friday and Saturdays evenings. This shortcoming could be addressed in future studies, with a view to identifying the patient threshold above which delays can be anticipated. In future, RIS data could be further analysed to assess the extent to which available CT scan time is optimally utilised. Such knowledge would inform the need for an additional CT resource during peak periods as opposed to greater support services, by way of porters and nurses. Furthermore, iterative RIS timestamp analyses can be used to assess the impact of any intervention.

Not all interventions have resource implications. Mere awareness on the part of referring clinicians and radiologists of the significant impact of an increase in CT workload on "approval time" could impact behaviour. For example, clinicians may be more inclined to substantiate electronic requests for emergency imaging through a phone call to the duty radiologist, and radiologists may adopt more stringent routines for the approval of electronic requests. The delays incurred by validation during WE2 raise questions around the need for validation of all requests in this setting. However, a recent study of the impact of comprehensive real-time validation of special radiological examinations on our hospital imaging equipment utilisation showed substantial resource savings and enhanced patient safety through the limitation of unnecessary investigations and unwarranted radiation exposure [18].

Despite being retrospective, workflow studies such as this are strengthened by the inherent integrity of the RIS data, which is intrinsically robust, comprehensive, and accurate. There is thus boundless scope for future workflow interrogations in the digital imaging environment. It is hoped that this work will stimulate such initiatives, especially in the light of the burgeoning digital conversion of radiology departments, globally, and the increasing sophistication of the modern RIS data. In making the transition from an analogue to a digital department, and when upgrading digital departments, administrators, clinicians, radiologists, and information technologists alike need to be active participants in ensuring that appropriate RIS-based workflow metrics are incorporated into all acquisitions.

Conclusion

The study highlights the pivotal role of the modern RIS in enabling a detailed analysis of the digital imaging workflow. By facilitating the identification of bottlenecks, it informs intervention strategies. Careful attention should be given to the inclusion of RIS-based workflow metrics when acquiring digital imaging systems.

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Compliance with Ethical Standards

The study was approved by the Health Research Ethics Committee of the Stellenbosch University Faculty of Medicine and Health Sciences.

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