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Title: Early repeat computed tomographic imaging in transferred trauma and neurosurgical patients: incidence, indications and impact.

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ABSTRACT

Introduction: Computed tomographic (CT) imaging is widely available in Australian rural and remote hospitals, and is often performed prior to patient transfer to definitive tertiary hospital care. We hypothesised that critically ill trauma and neurosurgical patients might have CT scans repeated after interhospital transfer, and that the utility of this practice might be low in relation to the additional financial cost and radiation exposure.

Methods: We conducted a retrospective review of clinical records to determine the proportion of trauma and neurosurgical patients transferred to our tertiary ICU from other hospitals between 1 June 2013 and 30 June 2014 who underwent a repeat CT scan. The additional effective radiation dose was estimated using the dose length product method, and the Australian Medicare Benefits Schedule was used to estimate the associated cost.

Results: Of the 247 patients transferred for trauma and neurosurgical indications, many (144; 58%) had undergone CT imaging at the referring hospital. Repeat scans were performed in 60 (42%) of already imaged patients (24% of all transferred patients), most frequently for changed clinical indications. While in 11 (18%) of those 60 already imaged patients the repeat scan led to an identifiable change in management, for another 13 (22%) patients the repeat scans appeared to be potentially avoidable. The median

cost of a repeat scan was AU$250 and the median additional effective radiation dose was 2.74mSv per patient.

Conclusion: Repeat CT scans for patients already imaged prior to transfer were relatively common, occurring mostly for apparently valid clinical reasons. However, the additional radiation risk and financial cost of these repeat scans appeared on retrospective audit to be potentially avoidable in approximately one in five cases.

Keywords: Computed tomography; intensive care; neurosurgery; repeat imaging; trauma transfer

INTRODUCTION

Computed tomography (CT) is an integral component of modern healthcare, particularly for trauma and neurosurgical patients. Access to this imaging modality has increased in rural and remote areas of Australia.[1-3] Consequently, patients often undergo CT scanning prior to being transferred to larger institutions for definitive management. This introduces greater potential for low-diagnostic-yield duplication of CT scans at the receiving hospital, which has been described by a number of groups internationally.[4-10] This problem is incompletely characterized in the Australian setting, where long distances can delay transport to definitive care by up to 24 hours. Needlessly repeating CT studies increases radiation exposure to patients and cost incurred by the receiving hospital and broader health system. We hypothesised that these detrimental effects might not always be outweighed by the benefits of obtaining repeat imaging.

This study was designed to investigate repeat CT scanning in Australia by evaluating practice at a large tertiary hospital in the state of Queensland. We sought to determine the proportion of repeat CT scans in patients referred to our tertiary institution for trauma and neurosurgical indications, to evaluate the rationale for obtaining any repeat imaging and to estimate how often these scans contributed meaningfully to a change in each patient's management. In addition, we estimated the increased radiation burden and financial costs associated with acquiring repeat CT scans.

METHODS

This study was approved by the Human Research Ethics Committee at the Royal Brisbane and Women's Hospital (RBWH) as a quality improvement activity. Access to patient data was approved under the Queensland Public Health Act.

Study population:

Using information contained within existing clinical databases, we conducted a retrospective observational cohort study at the RBWH, a 900-bed tertiary and quaternary adult level one trauma facility serving a population of approximately 900 000. The data collection period ranged from 1 June 2013 to 30 June 2014. Included subjects were those who were transferred to the Intensive Care Unit (ICU) at our institution from other acute hospitals. Only those patients referred for trauma and neurosurgical indications as defined by the Acute Physiology and Chronic Health Evaluation (APACHE) criteria were included. Patient demographics, length of stay, disease severity and outcome were obtained. Patients who did not have imaging performed prior to transfer were excluded from further analysis.

Repeat CT scans:

Repeat CT scans were deemed to have occurred if the external CT was obtained in the 24 hours prior to transfer and a CT of the same anatomic region using the same technique (e.g. contrast enhancement) was obtained at our institution within 24 hours of admission. Request forms, radiology reports and inpatient medical records were evaluated to determine the indication for repeat imaging and whether the scan findings resulted in an identifiable change in patient management. Indications for repeating CT scans were classified as “change in clinical status”, “image/technical reasons”, “assessment of progress” and “unknown” (despite thorough review of the clinical records). Patients who had repeat non-contrast studies performed routinely prior to obtaining an additional contrast-enhanced or angiographic series were treated as a separate group. In cases of patient deterioration and post-operative assessment, clinical indications were deemed to have been present and the repeat scan was considered necessary. Scans performed to assess progress were not included in the “change in clinical status” group if there was no supporting clinical information available that clearly established the need for repeating the study. Therefore these studies were considered potentially avoidable. Similarly, scans repeated because of image problems or technical reasons were also considered potentially unnecessary. This included cases in which there was

inadequate or incomplete external imaging, and when external imaging was not available for review at the accepting hospital.

Radiation exposure:

The dose length product (DLP) for each repeat study was obtained. For those studies considered to be potentially avoidable, the effective dose (in milliSieverts, mSv) was calculated using the following formula:

$E = k \times DLP$[11]

Published values for the coefficient k were used.[12]

Additional cost:

The medical imaging department at our institution provided information to estimate the additional costs associated with repeat CT scans. These figures were based on the Australian Medicare Benefits Schedule fees for the item numbers relevant to each study.

Statistical analysis:

The Mann-Whitney U test was utilised to determine the equivalence of medians between the repeat and non-repeat group, whilst chi-squared tests assessed equality of proportions. Analysis was conducted on the entire group, and following stratification according to diagnosis (trauma or neurosurgical). We used univariate logistic regression to assess the patient factors associated with repeat CT scanning coded as a binary variable. Logistic models were derived using a backwards stepwise approach, incorporating as putative predictors only information that could have been known at the time of admission to ICU and using $p<0.2$ for retention in the model. A preferred model was identified by considering both included covariates and the overall goodness-of-fit (Hosmer-Lemeshow deciles of risk) test results. Statistical significance in the final model was defined as $p<0.05$. All analyses were conducted using Stata statistical software version 12.1 (StataCorp LP, Texas, USA).

RESULTS:

During the study period there were 571 patients transferred from other acute hospitals to the intensive care department of our hospital, with 247 (43%) referred for trauma and neurosurgical indications. External CT imaging had been performed in 197 (80%) of these trauma and neurosurgical cases, and in 144 (73%) of this externally imaged trauma and neurosurgical patient subgroup, the CT scans were obtained in the 24 hours prior to transfer. Sixty of these patients (42%) had at least one repeat CT study performed within 24 hours of arrival at our facility and were included in this study for further analysis. Eight of these 60 patients (13%) underwent more than one repeat study of the same body region in the first 24 hours following arrival at our institution, however, for this study only the initial repeat scan was included for analysis.

When each anatomic region was considered as a separate scan, the 60 patients who underwent repeat imaging accounted for a total of 72 repeat CT scans. The most commonly repeated study was non-contrast CT head, accounting for 72% (Table 1). In the repeat imaging group, 25 of the 60 (42%) patients also had an additional investigation, which involved either imaging of another body region or being scanned using a different technique.

Indications for repeating CT studies:

Most patients (42 of 60 (70%)) had imaging repeated for clinical reasons (Table 2). These studies were deemed to have been unavoidable, and were considered necessary repeat scans. Six (10%) underwent a repeat non-contrast study alongside a contrast-enhanced series and these were also considered unavoidable scans. All six were diagnoses of subarachnoid haemorrhage and involved repeating a non-contrast CT head prior to a CT angiogram of the same region. The remaining 13 of the 60 (21.7%) patients had unclear indications for repeat imaging, and in these cases the repeat CT scans were considered to have been potentially avoidable. One patient underwent repeat imaging of multiple body regions for different indications and has therefore been included in two categories.

For four of the 60 patients (7%) the repeat imaging was requested to assess progress, without a detailed record of clinical justification. In a further four (7%) patients, image problems or technical reasons accounted for the need to repeat CT studies, with lack of access to external images being cited in one case. In five of the 60 (8%) patients justification for obtaining a repeat CT study could not be determined retrospectively from the available clinical records.

Factors associated with repeat scanning:

Univariate analysis of patient factors associated with repeat CT imaging revealed associations with a lower Glasgow Coma Score (GCS), a higher APACHE II score, a higher APACHE II risk of death and longer stay in the ICU (Table 4). Following stratification of the patients into trauma and neurosurgical groups the strength of these univariate associations remained similar for all but the ICU length of stay in the trauma group.

A multivariable logistic model including the whole cohort found male sex and two categorical bands of GCS (13-14 and 3-12), remained independently predictive of the occurrence of a repeated scan, adjusted for the APACHE II prediction model risk of death (assessed at time of the tertiary referral hospital admission). For neurosurgical patients alone, the independent predictors of repeat scanning were male sex and a GCS less than 13 whilst for trauma patients the strongest independent predictor was APACHE II risk of death.

Impact of repeat CT scans on patient management:

For less than half of the 60 (45%) patients who underwent repeat imaging, the repeat scans demonstrated a change in imaging appearance when compared to the external study. Some showed progression of known findings and others detected new pathology (Table 3). In a small proportion of these patients (2/60, 3%) there were contradictory findings. For 11/60 (18%) patients in the repeat imaging group, the findings of the repeat study led to a documented change in management, with identifiable clinical indications for repeat imaging being present in eight of these cases. For all but one patient the change involved

performing a procedure. For 33/60 (55%) patients who underwent a repeat CT, the imaging appearances were stable and there were no apparent changes made to patient management. Fourteen of these patients with stable imaging findings (14/33, 42%) had a repeat study performed for post-operative evaluation. For the majority of those patients (9/13, 69%) deemed to have undergone a potentially avoidable repeat study, the repeat scan did not result in an apparent change in management identified in the medical record.

Additional costs associated with repeat scanning:

The estimated additional cost associated with repeat CT imaging was calculated in the 13 cases where repeat scanning was performed apparently for non-clinical indications and was therefore potentially avoidable. These 13 patients accounted for a total of 23 repeat scan regions. The cost of repeat scanning per patient ranged from AU$240 to AU$1050, with a median of AU$250.

Additional radiation exposure associated with repeat CT scanning:

DLP values were available for 12 of the 13 patients deemed to have had potentially avoidable repeat CT studies. The estimated effective dose (mSv) for each repeat scan ranged from 1.44mSv to 130.4mSv per patient, with a median of 2.74 mSv. The patient who received the highest effective dose in this study (130.4mSv) had multiple body regions imaged in the setting of marked obesity.

DISCUSSION

During the study period, over three-quarters of critically ill trauma and neurosurgical patients transferred to the RBWH ICU underwent CT imaging at their referral site, often in the 24 hours prior to transfer. More than one-third of these patients underwent duplication of this imaging during the first 24 hours of their admission at the receiving hospital. In some cases the same study was repeated more than once in this time. In approximately one in five cases of repeat CT scanning, the clinical justification was not apparent from retrospective assessment of the available medical records.

Rates of repeat imaging found by international groups investigating this issue in their respective trauma settings have been varied. Hill et al[6] found that 48% of patients transferred to their facility underwent repeat imaging, although it is unclear what proportion of this was accounted for by CT as they also included plain radiographic studies. Jones et al[7] determined that 39% of patients underwent preventable repeat imaging but did not describe how many other repeat scans were performed for clinical, or unavoidable, reasons. In a study comparing repetition rates between integrated (electronically linked radiology and medical records) and non-integrated systems, Liepert et al[13] found that the rate of repeat imaging was far lower (16% compared with 48%) when electronic connectivity was available. The characteristics of the present study site align with the integrated model, with widespread image transfer capability. This was reflected in our results as image availability problems were a cause for repeat imaging in only one case. Moore et al[8], Flanagan et al[5] and Cook et al[4] found lower rates of repeat imaging than the present study, although only Moore et al[8] defined a repeat scan as a study which was obtained in the 24 hours following transfer to the referral centre and Cook et al[4] evaluated repeat scanning in a paediatric population. Young et al[9] demonstrated a rate of repeat imaging comparable to that found in the present study, with 41% of patients included in their retrospective analysis found to have undergone a repeat scan following arrival at their trauma centre.

Patient factors associated with repeat imaging were evaluated in a study by Emick et al[14] and, similarly to the present study, it was reported that patients who underwent a repeat scan were likely to be more severely injured than those who did not. Emick et al[14] excluded repeat CT head from their analysis, whilst the present study observed that the most commonly repeated scans were non-contrast CT examinations of the head. This is in accord with the findings of many international studies that the head and cervical spine were the most frequently re-imaged body regions.[4,7,13,15-18]

The present study noted that CT scans were repeated for predominantly clinical reasons. These scans, including the non-contrast studies repeated as part of a

pre- and post-contrast enhanced series of the same region, could be regarded reasonably as unavoidable. In contrast, avoidable or potentially unnecessary repeat CT studies for which no clinical indications were identified occurred in over one in five patients who underwent repeat imaging. However, the magnitude of this proportion of potentially avoidable scans was dependent on the inclusion of cases where our retrospective research methodology was unable to identify from the available medical records documentation to explain or justify the acquisition of the duplicate series.

Many authors have acknowledged the difficulty of ascertaining reasons for performing repeat CT scans, particularly when the analysis is retrospective, and a number of groups do not comment on this aspect of the repeat imaging issue.[7-9,14,17] Of those studies which assessed indications for repeat imaging, Gupta et al[18] and Sung et al[19] reported similar findings to the present study, namely that clinical need was the most commonly cited reason for a repeat CT scan. This is in contrast to a number of other studies which reported that inadequate or poor quality external imaging was the predominant reason for needing to perform a repeat scan.[5,13,16] Notably, image availability issues were identified as the primary reason for repeat CT scans in reports by three international groups.[4,7,8]

Medical imaging is described as the largest contributor to per capita radiation dose in the United States, with exposure increasing over recent decades.[20] This is considered largely to be due to the utilisation of CT imaging.[20] Additional radiation exposure associated with repeat CT scans has been evaluated by a number of international groups. In contrast to the present study, previous works have commonly utilised published data[5,15] or standardised in-house values[8] to estimate effective dose. Hill et al[6] obtained data from dose reports associated with each scan when available, using these values to develop averages for their study population, whilst Jones et al[7] chose an approach similar to that used in the present study and utilised DLP values and conversion coefficients to estimate effective dose.

Consideration of the effective dose associated with medical imaging is important because of associated stochastic effects leading to potential carcinogenesis. There are difficulties in extrapolating data from high-exposure situations, such as the Hiroshima and Nagasaki atomic bombings, to the low-exposures associated with imaging such as CT.[20,21] However, as there is no known threshold dose for carcinogenesis, any dose to a patient is potentially important.[20] Kritsaneepaiboon et al[21] studied the life-time attributable risk of radiation-induced cancer associated with CT and found that the highest risk existed for those patients under the age of 30 years and for those who underwent multiple CT scans. They reported that the risk was minimal at effective doses of less than 20mSv. The median effective dose associated with repeat scanning in our setting was 2.74mSv, which is lower than the median reported by Moore et al,[8] who estimated radiation exposure for the first 21 of the 38 patients found to have undergone repeat imaging at their facility. Unlike the present study, the estimates reported by Moore et al[8] were based on standardised dose charts rather than actual patient data. Other groups reported only the mean additional radiation dose, with values ranging between 5mSv-11.8mSv.[4-7,15]

Published studies often emphasise the long-term risks of additional radiation associated with unnecessary repeat CT scanning. In contrast, the impact of repeat imaging on short-term clinical management has been less frequently documented. Moore et al[8] found that for 42% of patients undergoing repeat imaging a change in management subsequently occurred, despite the most common indication for repeat scanning being lack of image availability. This proportion is higher than that found in the present study, however, Moore et al[8] did not further explore which group of indications for repeat scanning had the greatest association with a change in management. Similarly, Cook et al[4] determined that additional injuries were detected in 39% of patients undergoing a repeat scan, which is again a much higher proportion than in the current study. These additional injuries were far more likely to be detected in the repeat scans that were performed because external images were not available than in the scans performed to evaluate a clinical deterioration. Those circumstances

are in contrast to the findings of the present study, where changes in management were more likely to be identifiable in the clinical records if the repeat scan had been obtained for clinical reasons.

This study has a number of limitations, largely due to its retrospective nature relying on clinical records to obtain accurate information. Establishment of the indications for repeat scanning and the impact of the repeat scan on patient management required judgement in the context of the included patient population. There is inherent difficulty in the clinical assessment of critically ill patients to establish a clear clinical indication for repeat scanning. The present study's evaluation of the additional cost associated with repeat imaging using the Australian Medicare Benefits Schedule is likely to substantially underestimate the full costs of obtaining these studies, particularly given the advanced level of care provided in this critically-ill patient cohort. The full health service costs of performing CT scans would be inflated by ancillary clinical costs required for critically ill patient support and supervision for the repeat radiological imaging. Although calculation of the effective dose using the DLP method is widely reported, it remains an estimate, not a measured value of actual radiation exposure.[11] This study did not explore other potential drawbacks of repeat scanning, including the impact on the time to definitive care in this patient cohort where care is particularly time sensitive, and the issue of nephrotoxicity due to intravenous contrast. Lastly, the small sample size and restriction to a single facility for this pilot study are limitations to the generalisability of our results, although they do represent the practice of a single tertiary-referral Australian hospital serving a large geographical catchment region.

Conclusion:

The present study adds new Australian data to the existing international literature on duplication of CT imaging. We found that repeat CT scans were obtained in over a third of trauma and neurosurgical patients that were transferred to our tertiary referral hospital, with the proportions of repeat imaging being comparable to that found by some international reports. The

additional radiation exposure associated with repeat scans was also generally similar in our cohort when compared to the existing literature, whilst the indications for performing the scans differed somewhat to those most commonly reported by other authors. In the present study, repeat scans were less likely to be required because of technical issues or image problems, and were more likely to be performed to assess a potential change in patient clinical status. Nevertheless, these repeat studies represent a source of additional radiation exposure for patients as well as a financial burden to the health system. Some of the repeat scans observed in the present retrospective study were identified as being probably avoidable or to have a potentially low diagnostic-yield. A future prospective study would be important to provide a more detailed exploration of the reasons for repeat imaging in Australia and simultaneously offer a useful quality assurance metric in Australian tertiary hospital radiology practice.

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FIGURE LEGENDS

Figure 1. Study population

TABLES

Table 1. Number of repeat scans by anatomic region

Anatomic region	Number of repeat scans
Head (non-contrast)	52 (72%)
Cervical spine	4 (6%)
Abdomen (contrast)	4 (6%)
Pelvis (contrast)	4 (6%)
CT Angiogram Head	3 (4%)
Chest (contrast)	2 (3%)
Thoracic spine	1 (1%)
Lumbar Spine	1 (1%)
CT Angiogram Neck	1 (1%)
TOTAL	**72**

Table 2. Indications for repeat CT scanning.

Indication for repeat scan	Number of patients
Clinical change/Post-operative	42 (70%)†
Non-contrast study in contrast enhanced series	6 (10%)
Assess progress	4 (7%)
Technical/Image problems	4 (7%)
Unknown	5 (8%)†
TOTAL	**60**

†One patient was included in two categories due to multiple scan regions being imaged for different reasons

Table 3. Outcomes associated with repeat CT scans

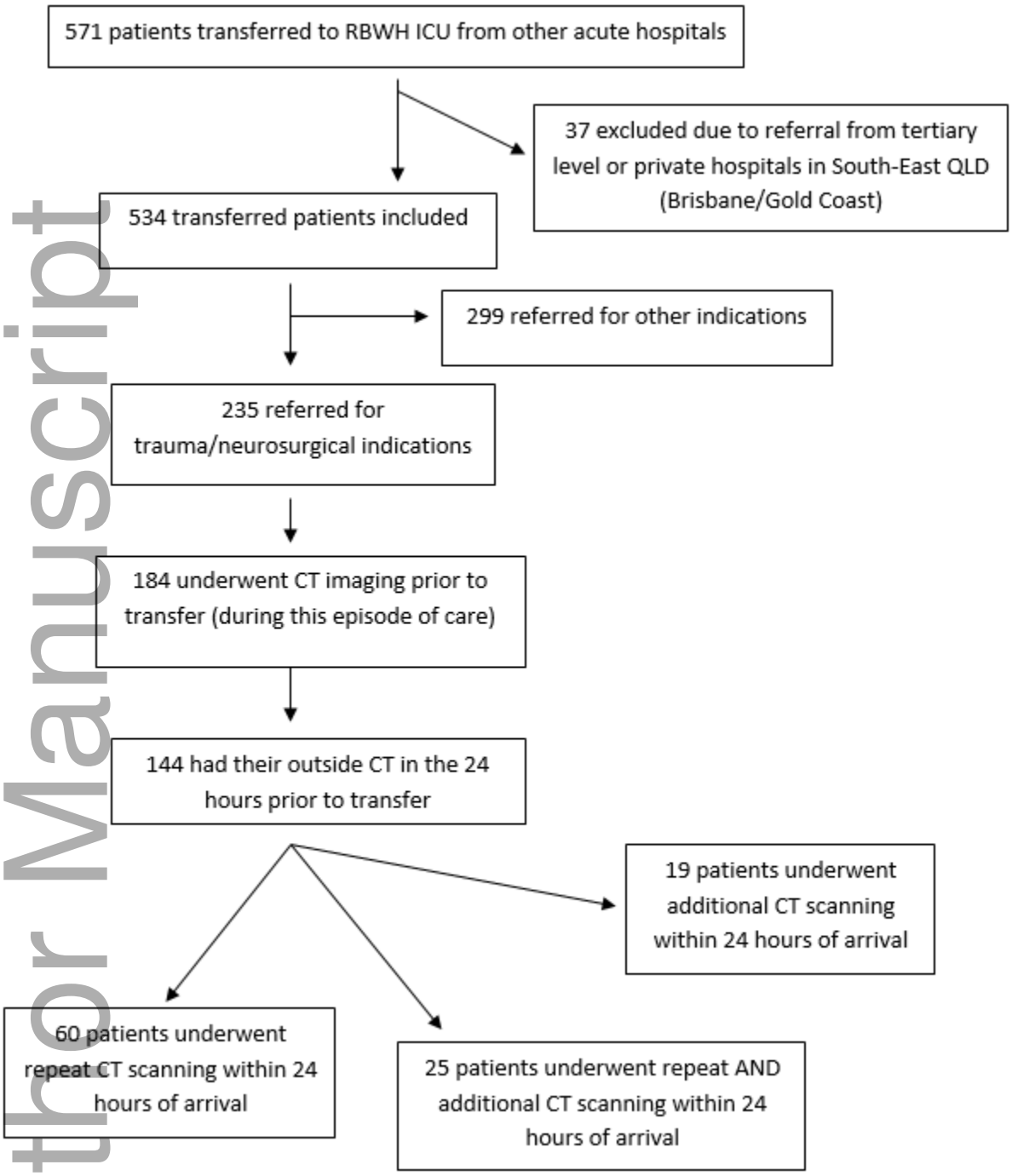
Outcome	Number of patients
Stable imaging appearance	33 (55%)
Different imaging appearance	27 (45%)
Progression of known pathology	14†
New finding	12†
Contradictory imaging appearance	2
Change in patient management	11 (18%)
Procedure required	10
Clinical change	1

† One patient is included in two categories

Table 4. Univariate analysis of patient factors associated with repeat CT imaging

Variable	Not Repeated n = 137	Repeated n = 60	p
Age, years, median (IQR)	54.6 (43-67.1)	55.6 (38.55-64.1)	0.72
Sex, % male	70%	55%	0.045
Diagnosis			0.07
Neurosurgical (n=136)	74%	26%	
Trauma (n=61)	61%	39%	
Glasgow Coma Score (GCS)			<0.0001
GCS15 (n=95), %	86%	15%	
GCS 13-14 (n=43), %	67%	33%	
GCS<13 (n=59), %	46%	54%	
APACHE II score, median (IQR)	11 (8-17)	18 (12-22)	0.0001

APACHE II risk of death, %, median (IQR)	18.85 (6.9-39.2)	39.2 (16.25-60.8)	0.0001
ICU length of stay (days)	2.88 (0.87-7.35)	5.025 (1.7-15.295)	0.005
Hospital length of stay (days)	13.97 (8.08 – 22.49)	12.95 (5.78 -25.42)	0.54
ICU outcome, % survived	96%	86%	0.011



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