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Audit of CT scans done at Chris Hani Baragwanath Academic Hospital in 2014

Arbee, Suraya Osman

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AUDIT OF CT SCANS DONE AT CHRIS HANI BARAGWANATH ACADEMIC HOSPITAL IN 2014

Dr Suraya Osman Arbee

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Medicine in Diagnostic Radiology

Johannesburg, 2018

Declaration

I, Suraya Arbee, declare that this research report is my own work. It is being submitted for the degree of Master of Medicine (Diagnostic Radiology) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

DR SURAYA ARBEE

On this 22th day of January 2018.

To my family

I express my deepest appreciation to my family, for their continued support and encouragement, especially Bibi Fatima and Firoz for their contributions.

Publications and presentations

This work has never been published.

It has never been presented at a congress.

Abstract

INTRODUCTION:

In resource limited environments careful consideration should be made to ensure adequate patient referral and limitation of unnecessary radiation exposure to patients. By evaluation of the current practices and processes, insight can be gleaned so as to specifically target quality improvement initiatives.

AIM:

This study aimed to evaluate the computed tomography (CT) scans performed at Chris Hani Baragwanath Academic Hospital (CHBAH) in 2014 by means of an audit. The audit assessed referral patterns and workflow in the CT Department in order to identify possible areas that could be targeted to improve service delivery.

METHOD:

A retrospective descriptive study was performed using data from hand written logbooks of CT scans performed in the CT Department at CHBAH over a 6 month period. The referral patterns and the workflow (i.e. patient through put) was also observed.

RESULTS:

A total of 11181 CT scans were performed of which 54.2 % were CT brain scans. The 20-29 year age group constituted the greatest proportion (20%) of patients referred to the CT department. The majority (40.6%) of the CT scans performed were for patients from the wards, followed by urgent requests from the emergency departments (34%). It was

noted that two-thirds of CT scans performed in the CT department were done after hours and there was a trough of productivity between 06h00-09h00 in the morning. Interestingly, the use of two operational CT scanners instead of one resulted in a smaller, than expected, increase in the total number of CT scans performed.

CONCLUSIONS:

The CT Department at CHBAH was not functioning optimally during the period of the study. There was suboptimal use of both equipment and human resources. Further in depth and detailed review of each step in the operational chain of the CT department at CHBAH is recommended to identify bottlenecks in the system in order to specifically target and monitor quality improvement efforts.

Acknowledgements

None of this would be possible without my Creator.

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List of abbreviations

CHBAH	Chris Hani Baragwanath Academic Hospital
CT	Computed Tomography
CTs	Computed Tomography scans
C-spine	Cervical spine
CTPA	Computed Tomography Pulmonary Angiogram
PACS	Picture archiving and communications system
UPS	Uninterruptible power supply
V/Q	Ventilation/Perfusion

1. Introduction

There is greater reliance on computed tomography (CT) scans in the diagnosis and management of both medical and surgical patients. Although there are many benefits of such a modality, in resource limited environments, careful consideration should be made to ensure relevant referral and limitation of unnecessary radiation exposure to patients. This study aimed to evaluate the work flow and referral patterns to the CT Department at Chris Hani Baragwanath Academic Hospital (CHBAH) in 2014 by means of an audit. Evaluation of the current practices and processes would highlight bottlenecks in the system so as to strategically and specifically target quality improvement initiatives in the future.

2. Literature Review

2.1. Purpose of an audit

An audit is an analysis of records to assess and improve the effectiveness of a concern. "You can't manage what you can't measure" emphasizes the requirement for measurable evaluation in initiatives to better patient care (1). It is imperative to appreciate and evaluate the various contributing components within an operation in order to recognise and direct attention strategically to the links that are the weakest and areas where improvement would yield better outcomes. These components of a CT system comprise of the patient, the clinicians, the support staff, the radiologists as well as the CT scanners (2). The extensive usage of medical imaging and effect on quality of care has directed the focus of improvement projects on to radiology departments in order to improve operations and service delivery (1).

2.2. Role of CT

Radiological investigations have a pivotal contribution in the assessment and treatment of patients (3). With advances in technology CT scans have become a highly favourable modality for imaging (4). CT scans in particular are fast where an entire body can be scanned in just a few minutes, non-invasive and effective in diagnosing disease as well as in the trauma setting (3).

CT scans are being used for the diagnosis of an increasing number of indications (2). For example, when a guideline is passed, recommending a CT scan of that body region before

treatment for that particular condition, it results in an increase in CT requests for that body region (5). Larson *et al* reported that CT scans are not only requested for the same clinical conditions, but are also requested for additional clinical conditions where CT scans have superseded other modalities (6). This burdens the CT system further especially if resources have remained unchanged (5) and/or are limited such as at CHBAH.

2.3. Referral patterns

Determining referral patterns can potentially identify departments that would benefit from imaging referral guidelines (7). This would streamline referrals, ensure more appropriate requests for investigations and avoid unnecessary imaging (7).

2.4. Proposed reasons for popularity of CT scans

The CT scanners themselves are considerably much faster and more technologically advanced (8). The simplicity and ease at which CT scans can be obtained and reported on timeously by means of tele-radiology or onsite radiologists has contributed immensely to the popularity of CT scans (9). Picture archiving and communications systems have aided in distributing reports swiftly (6). Countries where CT scans had become more easily accessible showed a more rapid inflation in the use of CT scans (2).

CT scan utilization may be partly accounted for by the evolution of the disease spectrum (10). CT scans are particularly appealing, given their accuracy in diagnosing an array of conditions, especially those with detrimental effects on morbidity and mortality (10). A

rise in the proportion of sicker patients warrants a rise in the number of CT scans requested and performed (8).

Other propositions for the growing appeal of CT scans include: the use of CT scans as a screening modality (as part of the first assessment of the patient, sometimes prior to completion of history taking and physical evaluation) versus traditionally for diagnosis (as a result of the first assessment), thereby speedily arriving at a decision regarding patient discharge as opposed to previously admitting to the wards for observation (8-11). This is further pressured by time limitations in patient evaluation, where clinicians are pressured to get through more patients in shorter time periods (12).

CT scans are also used as a form of triage to determine appropriate referral to a speciality or department (8). The consulting specialist often insists on a CT scan before a consultation with the patient (10). Given these factors, it is expected that the admissions would proportionately decline with a more rapid arrival at diagnosis. However, studies noted that admissions were not continuing on a downward trend, proposing the possibility that there may be excessive use of CT scans, above what is generally regarded as appropriate (11, 12).

On the other hand, earlier identification of pathology will lead to more expeditious treatment potentially shortening the stay in hospital and achieving more positive outcomes (6, 12).

CT scans have replaced other imaging modalities as the investigation of choice for an array of pathology (10). It is noted in the study by Broder *et al*, that a significantly larger number of CT scans were done for those specific pathologies compared to the studies it had superseded, indicating that a higher proportion of patients were investigated for those specific pathologies (10).

It has been suggested that clinicians exercise extra caution to prevent any probability of a lawsuit by thoroughly and perhaps over investigating patients, adopting a more guarded type of medicine (9, 11, 12). Clinicians may be coerced by patients into ordering CT scans to promptly provide answers and certainty (10).

Zhou *et al*, demonstrated that less experienced clinicians, even though having patients that were less ill or with less severe injuries, tended to request more CT scans compared to their more experienced colleagues (13).

2.5. Important effects of CT for consideration

2.5.1. Radiation

A major concern regarding the use of a CT scan as a primary investigation is the risk of developing cancer from radiation exposure. It is an important factor that has to be weighed against the benefits when justifying the indication and determining the appropriateness of the CT request (4, 5). The incidence of cancer from radiation exposure has been largely summated from studies of the atomic bomb survivors and their

subsequent generations (3). The International Commission on Radiological Protection notes that there is the possibility of cancer related to approximately the amount of radiation associated with one body CT scan (4, 14). The United States National Council's Biological Effects of Ionizing Radiation (BEIR) VII Committee indicated a similar risk assessment (4, 15).

It is suggested that younger patients are more susceptible to radiation and its consequences, including cancer (8, 15). The cancer risk associated with radiation is of an upward slanted trend to about 40 years and only tapers thereafter (8, 15).

Larson *et al*, suggested that radiation dose escalated out of proportion to the number of CT scans performed due to the institution of more advanced CT scanners, requests for multiple CT scans per patient and requests for CT scans that require larger amounts of radiation (6). Multi-detector CT scanners have the ability to deliver more radiation to the patient than Single-detector CT scanners (4).

2.5.2. Hypersensitivity reactions to contrast

Many CT scans require the use of iodinated contrast media, especially when the request is non-trauma related and not to exclude a haemorrhage. The effects and reactions to contrast media administered for CT scans is therefore of particular importance. Some underlying conditions such as Asthma, as well as patients who had a hypersensitivity reaction when contrast was given for a CT scan on a previous encounter, have been proven to have an elevated incidence of untoward reactions to contrast media (16-18).

The most effective way to treat an adverse reaction is to not allow a reaction to occur (18). Corticosteroids given in preparation before a CT scan, have been reported to reduce the event of a contrast reaction (18).

There are a range of reactions possible in response to contrast that has been delivered, including: “nausea, flushing, urticaria, bronchospasm, vasovagal reaction, diffuse erythema, cardiovascular collapse, laryngeal oedema, loss of consciousness and seizure” (18).

Studies have proven that non-ionic low-osmolal contrast media resulted in a significantly lower percentage of unfavourable reactions as compared to ionic high-osmolal contrast media, and therefore are preferred for use (18, 19).

2.5.3. Contrast-induced nephropathy

Contrast-induced nephropathy refers to an elevated serum creatinine above the normal level within 2-3 days after having had a CT scan with contrast (20). Previous literature on contrast-induced nephropathy was predominantly derived from angiographic procedures utilizing profoundly larger volumes of contrast (21). Recent studies have indicated that after taking into account underlying co-morbidities, kidney injury in the time period following contrast administration could not clearly be attributed to contrast media as an individualistic cause (20).

2.5.4. Workload

The added workload affects CT scan interpretation with a greater error rate after hours, as demonstrated in the study by Terreblanche *et al* (2). There is generally minimal staff working in the after hours' shift. This is an important concept to consider as a workflow design comprising of a single radiographer was regarded insufficient and a design with at least 3 radiographers was deemed necessary for optimal workflow and productivity, in the study done by Boland *et al* (22).

2.5.5. Waiting times, length of stay and cost

The more CT scans requested, the longer each patient has to wait before their CT scan is performed (23). CT scan usage was associated with a longer stay in hospital, in China according to Zhou *et al* (13). In the same study, there was a resultant higher cost as well as greater likelihood that the patient would be operated upon, however, they did not note a substantial difference in the proportion or rate at which patients were admitted to stay in the wards (13).

Hu *et al*, also revealed remarkably longer stay in hospital, greater cost but a decrease in the number of patients admitted to the ward, in Taiwan (11). Kocher *et al*, in the initial years of their study done in the United States showed a decrease in admissions as an effect of CT scans, however the more recent years of their study revealed no difference in the rate at which patients were admitted to the wards (12).

2.5.6. Outcomes

In the case where CT scans have replaced or are favoured over another investigation, for example CT pulmonary angiograms to exclude pulmonary emboli, studies have shown that more CT pulmonary angiograms have been requested, however lower rates of positive results were obtained, thereby not necessarily achieving more successful outcomes (24-26).

2.6. Statistics from around the world

2.6.1. Trend of overall CT scans

There are several studies, done in different countries around the globe, which have demonstrated an exponential escalation in the use of CT scans (2).

In the study by Street *et al*, at the Emergency Department of the Alfred Hospital in Australia, "CT scans performed have increased by 47%" from 2004-2007 (4).

In a study by Toms *et al*, at Addenbrooke's National Health Service Trust in the United Kingdom, there was an increase in the body CT workload by an annual growth rate with an average of more than ten percent in a few years (5).

The study by Larson *et al* revealed a greater than expected rise in CT scan usage per annum in a number of Emergency departments located in the United States (6). Broder *et al*, also in the United States, depicted an incredibly large overall increase in CT scans

performed, out of proportion to the number of patients attended to at the hospital (10). The number of CT scans had increased over all age groups, however more so for elderly patients (10). Lee *et al*, in their study in New York showed a similar pattern of results (23). Kocher *et al*, in their study of multiple centres in the United States, showed an increase of over 300 percent, with a 10 times less of an increase of patients presenting to the hospital (12).

Boone *et al*, representing statistics from the University of California, reported elevated CT scan utilization in patients who were admitted to the wards more so than outpatients, with an increase of more than 100 percent for patients presenting to the emergency department (8). These figures coincided with and were partly attributed to the addition of two new CT scanners (8).

Zhou *et al* demonstrated increased utilization of CT over the four years in their study in China (13). They reported that these trends were similar to those of developed countries (13).

Bigger centres with larger numbers of patients presenting to the emergency department were associated with significantly higher use of CT scans compared to centres with smaller numbers of patients presenting to the emergency department, according to Kirsch *et al* (9).

2.6.2. Trend in terms of anatomic region scanned

The rate of increase varies regarding the type of scan in terms of part of the body scanned but all types of scans have increased significantly more compared to the rise in the number of patients arriving at the Emergency Department (10). In a study by Broder *et al*, done in the United States of America, "the total number of patients undergoing head CT increased by 51%, cervical spine CT by 463%, chest CT by 226%, abdominal CT by 72%, and miscellaneous CT by 132%" (10). Therefore, the category with the greatest escalation was CT scans of the cervical spine followed by CT scans of the chest (10). They suggested that these results could be accounted for by the change in protocols where CT scans were recommended for cervical spines taking the place of plain films; in the chest for pulmonary emboli instead of a ventilation/perfusion (V/Q) scan as well as other chest pathology; in the abdomen for renal colic superseding intravenous urography as well as a host of other abdominal pathology (10).

Zhou *et al*, showed increases of more than 200 percent in chest and abdominal CT scans with lesser increases in the other types of CT scans (13). CT scans of the brain accounted for most of the CT scans done in the study in China by Zhou *et al* (13).

CT scans of the brain and abdomen represented the greatest proportion of CT scans done in Taiwan (11).

More than half of the total number of CT scans done, were CT scans of the brain, in the study in New York by Lee *et al* (23). CT scans of the chest represented a very small

fraction of the total number of CT scans performed, however showed the most magnificent increase over the years, according to Lee *et al* (23). All the other types of CT scans had also increased but to a lesser degree (23).

2.6.3. Trends in terms of patient age

Kirsch *et al*, revealed a markedly lower use of CT scans in children with lowest numbers of CT scans for children with ages of less than ten years, compared to adults presenting at emergency departments in their analysis of several states in the United States (9). Boone *et al*, in their study in California, United States, had reported similar findings of decreased utilization of CT scans in children (8). Larson *et al* had also noted that CT scans performed in the paediatric population may have begun to decrease (6).

In a study done in China, the above 30 age-group represented the greatest proportion of patients for whom CT scans were performed (13).

Hu *et al*, in contradistinction, showed the dominant age group to be above the age of 60 years in their study based in Taiwan (11). In several studies that were undertaken in the United States, significantly more CT scans were done for the older age population as demonstrated by Kocher *et al* (12) and progressively increased with age, with most CT scans done for patients over the age of 65 years, as demonstrated by Kirsch *et al* (9). The study done in New York by Lee *et al*, also reported the highest proportion of CT scans were for the older aged patients, with the average age marginally increasing over the years evaluated, to the age of approximately 54 years (23).

Boone *et al*, in a study done at the University of California, in the United States, demonstrated a significant, sharp rise in the number of patient presentations to the hospital, admissions and CT scans done for adult patients below the age of 25 years (8). Most of these patients were male patients (8). They suggested that this was indicative of the prevalence of trauma and motor vehicle accidents associated with that particular age group and gender as well as the type of service provided by the hospital, in this case being a trauma centre (8). Broder *et al*, and Lee *et al*, supported the premise that these variables were influenced by the types of service provided by a hospital and the location of a hospital (10, 23).

2.6.4. Trends in terms of department requesting scans

The department requesting the majority of the number of CT scans performed at a hospital is thought to be influenced by the type of the hospital as well as the location of the hospital (11, 24). Hu *et al* reported that approximately 70 percent of the total number of CT scans performed were requested by the internal medicine department, in their study done in Taiwan (11).

2.6.5. Trends in the after hours' shift

A study done in the United States demonstrated that 40 percent of CT scans were performed in the after hours' shift (also referred to as night shift, graveyard shift or outside of office hours) (27). A mean of approximately 18 CT scans were done in the after

hours' shifts with a heavy workload categorized as having reported more than 24 CT scans in the shift, as demonstrated in the study done in South Africa by Terreblanche *et al* (3).

2.7. Statistics at Chris Hani Baragwanath Academic Hospital

There is limited literature with regards to the status and functioning of the CT system at Chris Hani Baragwanath Academic Hospital. This study will dissect and evaluate the components and processes involved in the CT system at Chris Hani Baragwanath Academic Hospital. This study will assist in identifying areas of weakness within the CT system. The information derived from this study will serve as a guide to improve the efficiency and quality of care. At the end of it all, it is essential to attain the highest level of benefit to the patient while completely eliminating harmful effects of the associated risks or at the least to reduce these risks to the bare minimum (2).

2. Study objectives

The primary objective of the study was to analyse several descriptors of the CT scans done at Chris Hani Baragwanath Academic Hospital in 2014.

An audit was performed on the CT scans in terms of the following parameters:

- To quantify the number of CT scans performed at Chris Hani Baragwanath Hospital in 2014.
- To evaluate the types of CT scans done (i.e. region of body scanned for example: brain, body, staging, PAN scan, peripheral angiogram, and cervical spine).
- To determine the referral patterns for CT scans (i.e. casualty/emergency, ward, outpatient, referral hospital/clinic).
- To determine the 'peaks and troughs' of productivity in relation to time and utilization of human resources and machinery.

3. Materials and Methods

Chris Hani Baragwanath Academic Hospital is a central academic hospital located in Johannesburg, South Africa. Chris Hani Baragwanath Academic Hospital has two Toshiba (Aquilon) multidetector computed tomography scanners (128 and 64 slice). CT is available 24 hours a day, 7 days a week.

A retrospective descriptive study was performed to assess the quantity and type of CT scans requested in view of resources and referral patterns at Chris Hani Baragwanath Academic Hospital in 2014. An audit of the radiographers' hand written logbooks, in which all the CT scans done at Chris Hani Baragwanath Academic Hospital were recorded, was performed for the period starting from 01 February 2014 to 31 July 2014.

All the CT scans were recorded in a logbook by the radiographer who performed the CT scan at the time that the CT scan was performed. The radiographer logbooks contained the following information: The patient name, hospital number, patient age, referring ward or department, type of CT scan done, the date the CT scan was done and the time the scan was done, the start and end time of each scan was also recorded. These logbooks were stored in the department archives.

The information from the above logbooks were collected and entered onto Microsoft Excel. The required categories of variables were extracted. Simple mathematical calculations were used to quantify and compare the data. The descriptive and statistical analysis was performed with the aid of a statistician.

Ethics clearance was obtained from the Human Research Ethics Committee of the University of the Witwatersrand. Ethics clearance number: M150448 (see Appendix A).

3.1. Inclusion and exclusion criteria

All CT scans done for patients of all ages, from birth onwards at Chris Hani Baragwanath Academic Hospital during the time span of 6 months from 01 February 2014 to 31 July 2014 were included.

Records that were illegible or incomplete, missing entries and scans redone/repeated on the same patient due to technical errors were excluded.

3.2. Data collection

The data for this study was collected using Microsoft Excel software (as seen in the data collection sheet in Appendix B). Data was collected for each CT scan performed (11181 CT scans) during the period from 01 February 2014 to 31 July 2014 (181 days). For each CT scan, the data collected included the type of CT scan done, the referral department, the hour and shift in which the CT scan was performed.

Data was also collected on the number of CT scans performed each day at Chris Hani Baragwanath Academic Hospital for the 181 days. For each day the number of operational scanners was recorded.

The variables of interest were captured as displayed in Appendix B.

3.3. Statistical analysis

Sample size estimations were based on the key research question to be answered. Using the 5% significance level and 80% power, the detection of small, medium and large effect sizes were calculated. Sample size calculations were carried out in G*Power (28). The sample size of 11 181 used in this study was deemed more than adequate by a statistician, for the purposes of the study. The relationship between number of CT scans per day and the number of operational CT scanners was assessed by the independent samples t-test. The strength of the associations was measured by Cohen's d. For the comparison of the mean number of scans at different hours of the day, a one-way ANOVA with 24 groups (the hours of the day) was used. Post-hoc tests were conducted using the Tukey-Kramer test.

Tabulating the frequencies and percentages of the specific variables and representing them on bar charts formed the descriptive analysis of the data. The continuous variables were evaluated by specific measures (mean, standard deviation, median and interquartile range) and the corresponding distributions were represented on histograms. The data analysis was performed with SAS (Windows version 9.4). The significance level of 5% was used. The p-values of <0.05 were regarded as significant results.

4. Results

Data was collected for a period of 181 days (from the 01 February 2014 to 31 July 2014).

A total of 11181 CT scans were performed during this period. Unfortunately the gender of the patients were not recorded in the radiographer logbooks and we are therefore, not able to comment on the gender demographics for the study.

The CT scans were evaluated in terms of the age of the patient. Patients in the age range from birth to 12 years were regarded as paediatric patients. Patients with ages above 12 were considered adults. From the total number of CT scans, 87.5% (n=9784/11181) of the CT scans were for adult patients and 10.6% (n=1183/11181) of the CT scans were for paediatric patients, as shown in Figure 4.1.

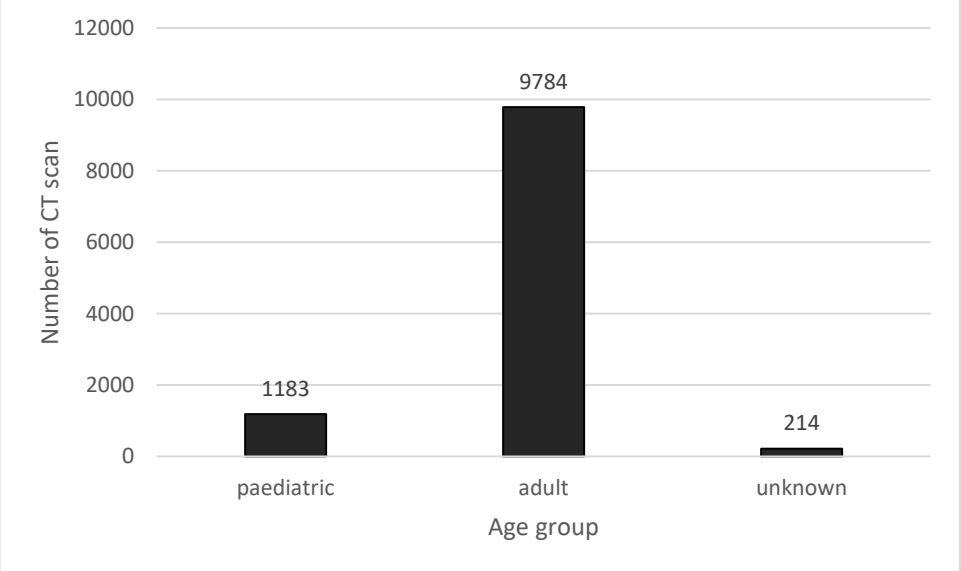


Figure 4.1. The number of CT scans according to age, categorized into paediatric and adult patients.

The CT scans were analysed in terms of the shift in which they were performed. There are two distinct types of shifts: working hours and after hours. Working hours was defined as a shift from 8am to 4pm from Monday through to Friday. The after hours' shift on a weekday (i.e. Monday to Friday) was from 4pm to 8am (16 hours). Weekends and public holidays consisted of after hours' shifts from 7am to 7pm and 7pm to 7am (i.e. two 12 hour shifts). The number of CT scans done during working hours represented 33.9% of the total number of CT scans done (n=3788/11181) and the number of CT scans done after hours represented 66.1% of the total CT scans done (n=7393/11181) as shown in Figure 4.2. An average of 40 CT scans per day were done afterhours.

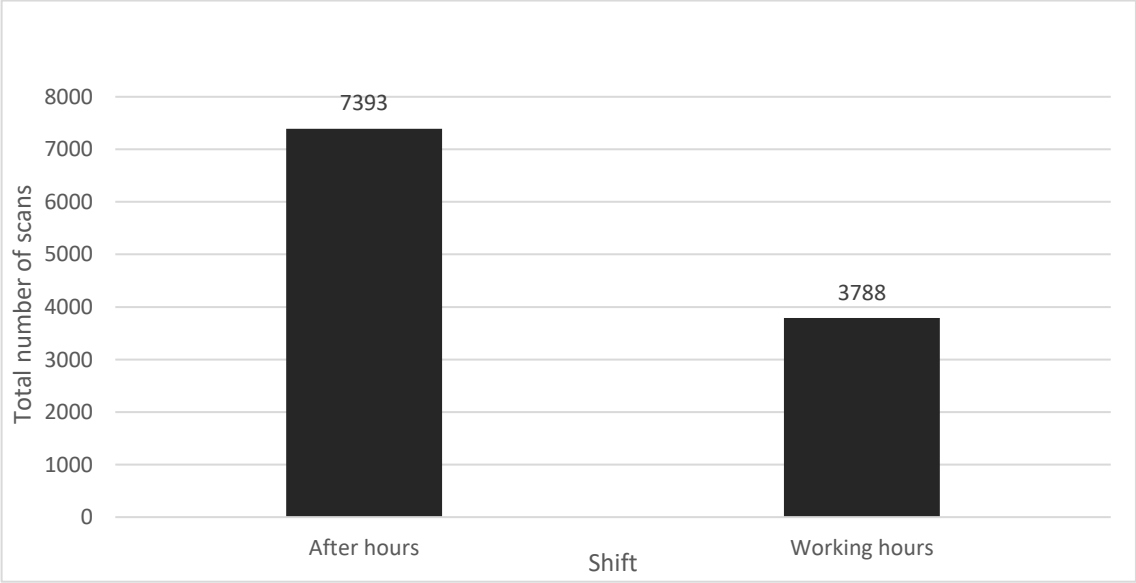


Figure 4.2. The total number of CT scans done during working hours and after hours.

The CT scans where divided into body region scanned. CT scans of only the brain represented 54.2% of the total number of CT scans performed (n=6060/11181). The term body included CT scans of the cervical spine (c-spine)/neck, chest/computed tomography pulmonary angiogram (CTPA), abdomen, temporal bones, sinuses, musculoskeletal, peripheral angiograms and intervention individually or as a combination thereof and represented 45.6% of the CT scans done (n=5102/11181). The type of CT scan was unknown in 0.2% of the total CT scans performed (n=19/11181). This distribution is shown in Figure 4.3.

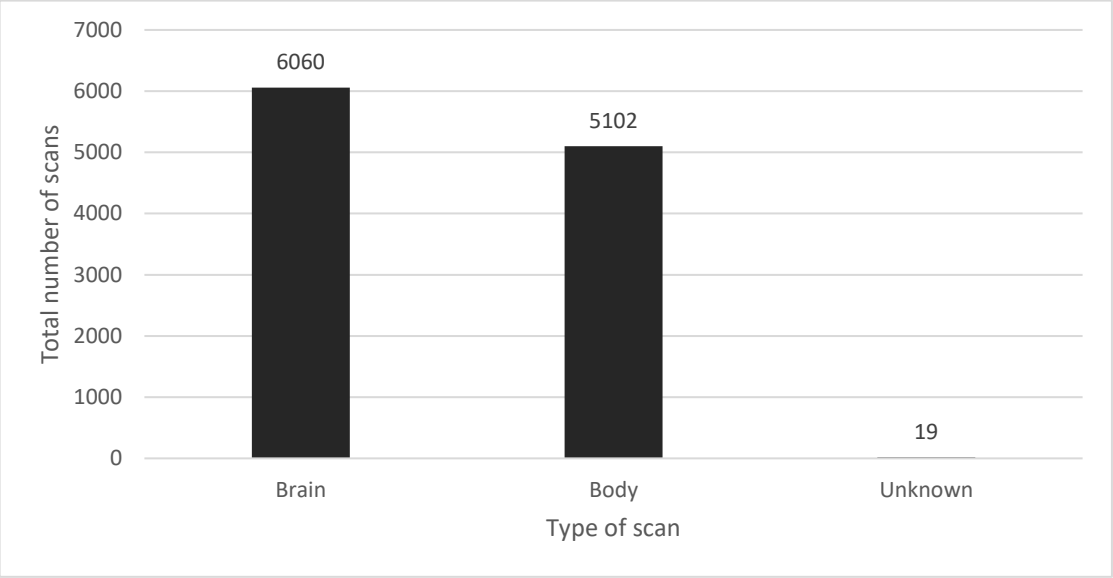


Figure 4.3. The number of the different types of CT scans categorized into two major groups: brain and body.

From the total number of CT brain scans, 83.6% were adult patients (n=5069/6060) and 14.5% were paediatric patients (n=878/6060). From the total number of body CT scans,

92% were adult patients (n=4698/5102) and 6% were paediatric patients (n=303/5102), as shown in figure 4.4.

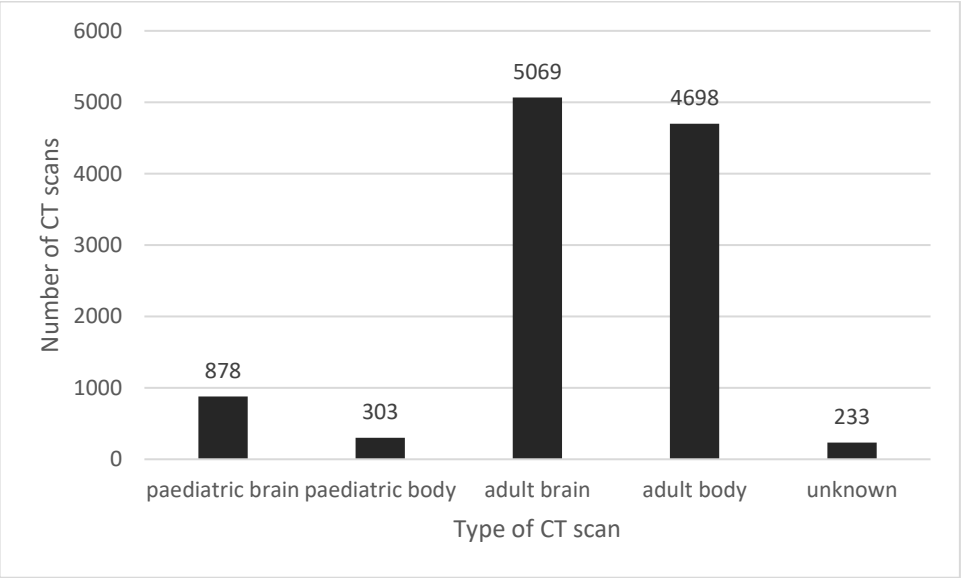


Figure 4.4. The number of brain and body CT scans for paediatric and adult patients.

CT scans of the brain ordered in combination with a CT scan of the c-spine represented 12.7% of the total scans done (n=1422/11181). A further 5% (n=607/11181) of the CT scans of the body included a CT scan of the brain. The spectrum of CT brain scans are shown in Figure 4.5.

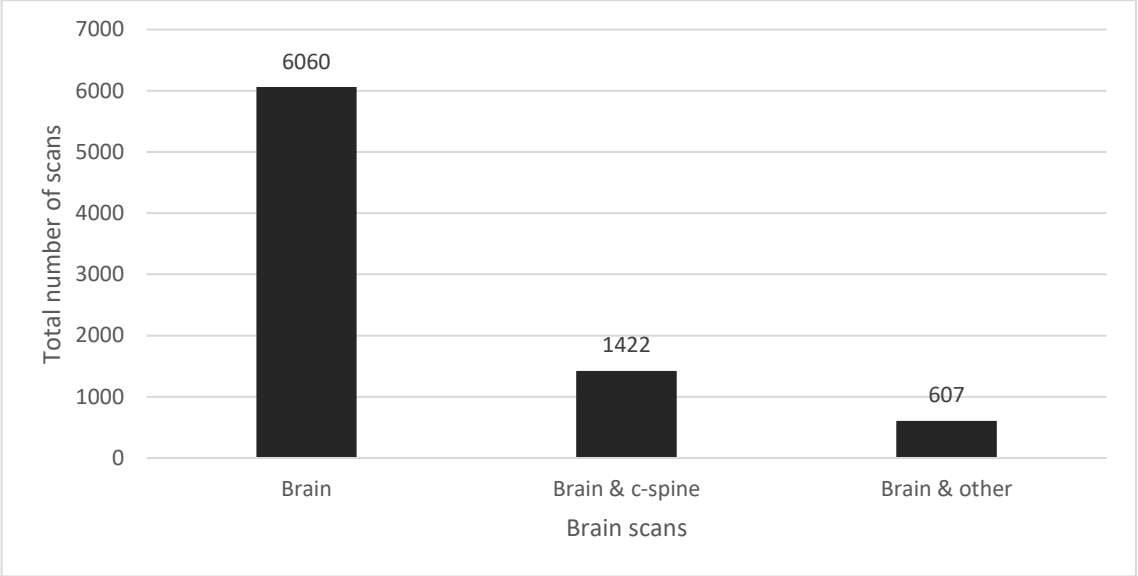


Figure 4.5. The total number of CT brain scans alone and in combination with a CT scan of another body region.

A staging CT scan is a scan of the whole body that included the neck, chest, abdomen and pelvis for the purpose of staging a malignancy. Staging CT scans represented 1% of the total number of CT scans (n=110/11181) and 2% of the total number of body scans (n=110/5102). A PAN scan is a scan of the whole body which consisted of a CT scan of the brain, c-spine, chest and abdomen in a trauma patient. PAN scans represented 2% of the total number of CT scans done (n= 205/11181) and 4% of the total number of body CT scans (n=205/5102). Peripheral angiograms represented 2% of the total CT scans done (n=243/11181) and 5% of the body scans (n=243/5102). The spectrum of these select type of body CT scans is shown in Figure 4.6.

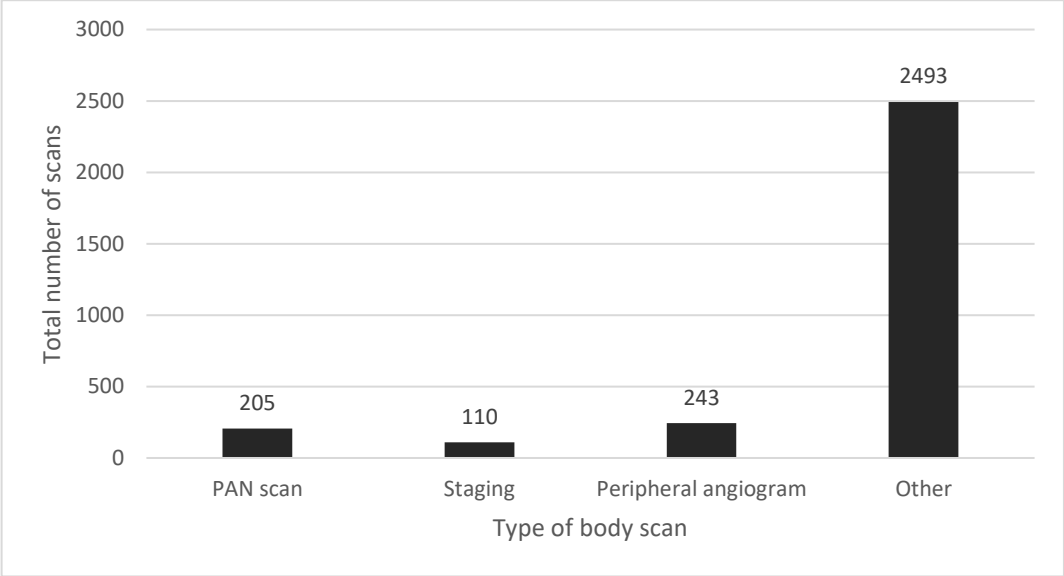


Figure 4.6. Total number of PAN CT scans, Staging CT scans and peripheral CT angiograms.

The CT scans were evaluated in terms of the referral pattern, that is, the department from which they came. The CT scans were divided into emergency, ward, outpatient and outlying clinic/hospital. The total number of CT scans that were requested from the emergency department represented 34% of the total number of CT scans done (n=3806/11181). The number of CT scans that were requested for patients in the ward represented 40.6% of the total number of CT scans done (n=4539/11181). The number of CT scans that were requested for outpatients represented 18% of the total number of CT scans done (n=2033/11181). The number of CT scans that were requested from referral clinics/hospitals represented 3% of the total number of CT scans done (n=348/11181). The referral pattern was not known in 4% of the total CT scans done (n=455/11181). This is shown in Figure 4.7.

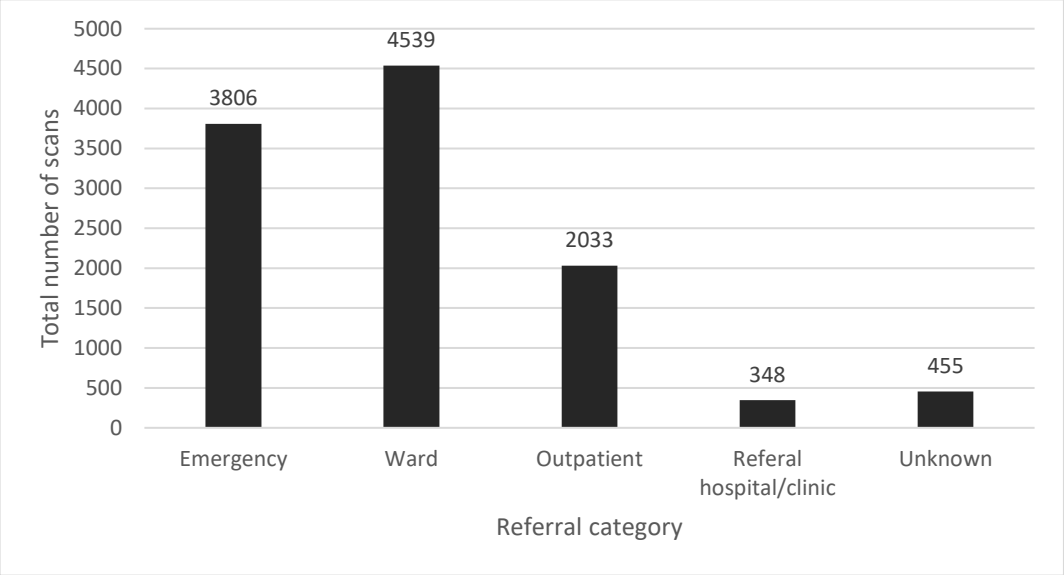


Figure 4.7. Total number of CT scans from each department.

A more detailed evaluation of the CT scans requested by the emergency department was done, in terms of the discipline ordering the CT scan. CT scans from the Trauma department contributed 40.8% of the total (n=1554/3806), followed by the surgical department with 39.9% (n=1517/3806), the medical department with 12.7% (n=485/3806) and for the remaining 6.6%, the specific emergency unit was not specified (n=250/3806). These figures are demonstrated in Figure 4.8.

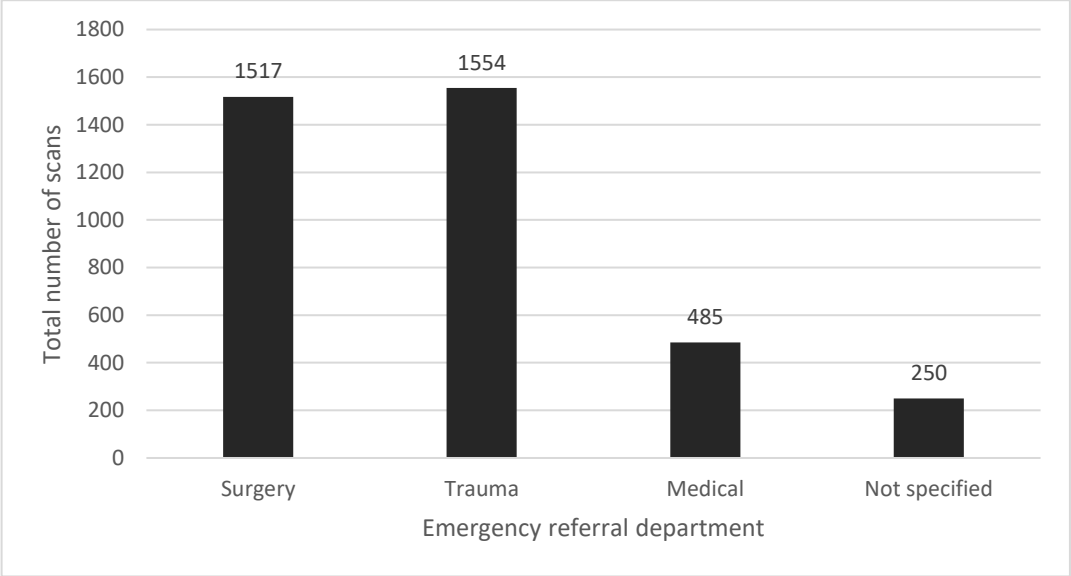


Figure 4.8. The total number of CT scans from each discipline.

A comparison of the number of CT scans in relation to the number of operational CT scanners was done. There were no days on which no machines were operational. On 89 days (49.2%), both machines were operational, while only one machine was operational on the other days. Machine A was operational on 92.3% of the days (n=167/181). Machine B was operational on only 56.9% of the days (n=103/181).

Using only the data for days when they were operational, the mean daily number of scans for Machine A was 48 (SD=17; range 1-87), and the mean daily number of scans for Machine B was 31 (SD=18; range 1-89). The distributions of the data are shown in Figure 4.9. for Machine A and Figure 4.10. for Machine B. The mean daily number of scans in total was 62 (SD=15; range 3-104). The distribution of the data is shown in Figure 4.11. The distribution of the total number of scans per day, categorised by the number of operational scanners, is shown in Figure 4.12.

The mean number scans per day when two scanners were operational (65; SD=15) was statistically significantly higher than the mean number of scans per day when only one scanner was operational (58; SD=14) (p=0.0017). The effect size was small (Cohen's d=0.49). We can say, equivalently, that having two scanners operational, instead of one, resulted in a mean increase in the number of scans per day of 7 (95% confidence interval: 3 to 11) which is far less than one scanner working alone is capable of.

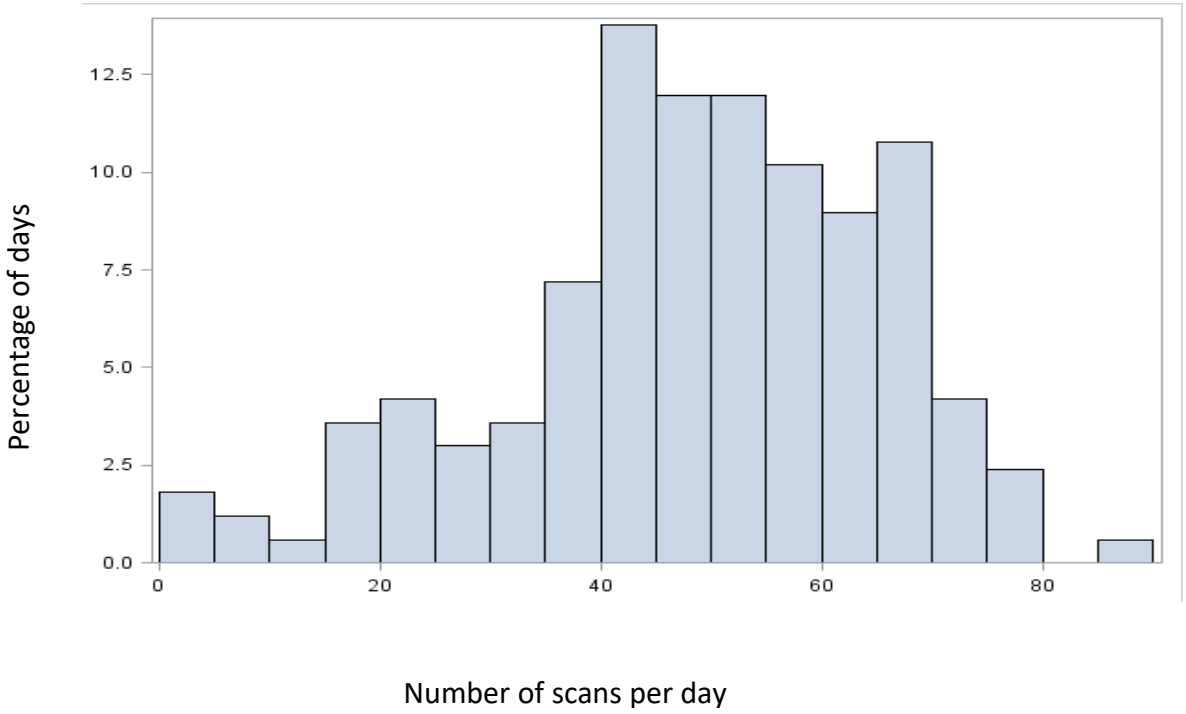


Figure 4.9. The distribution of the daily number of CT scans for Machine A.

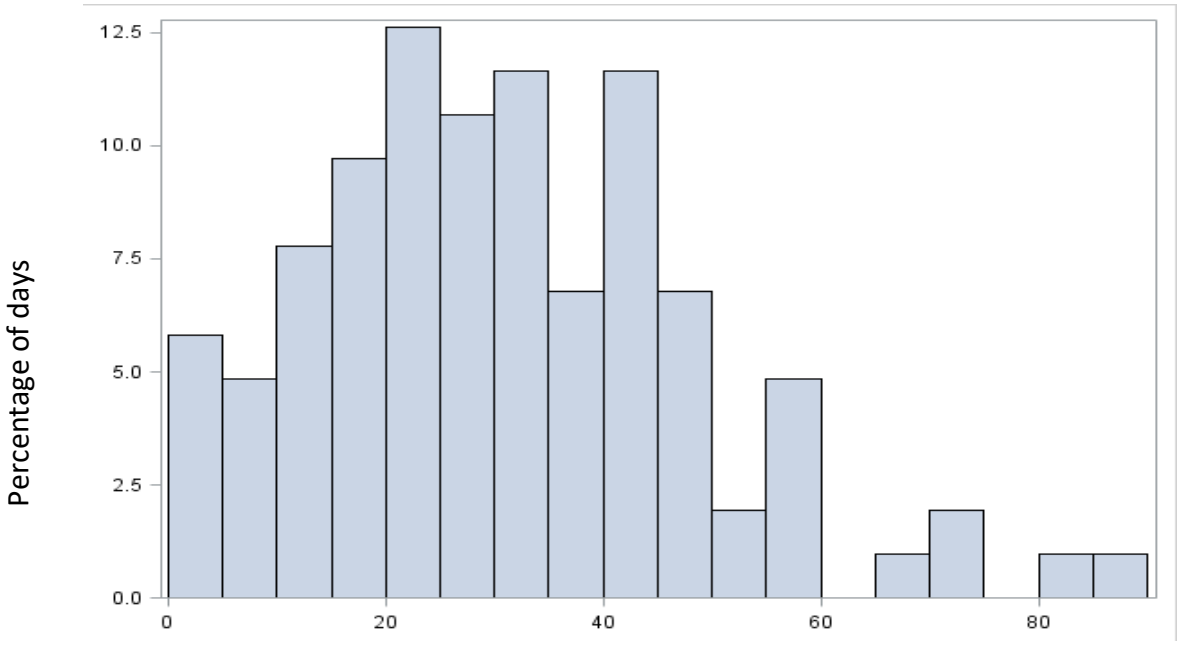


Figure 4.10. The distribution of the daily number of CT scans for Machine B.

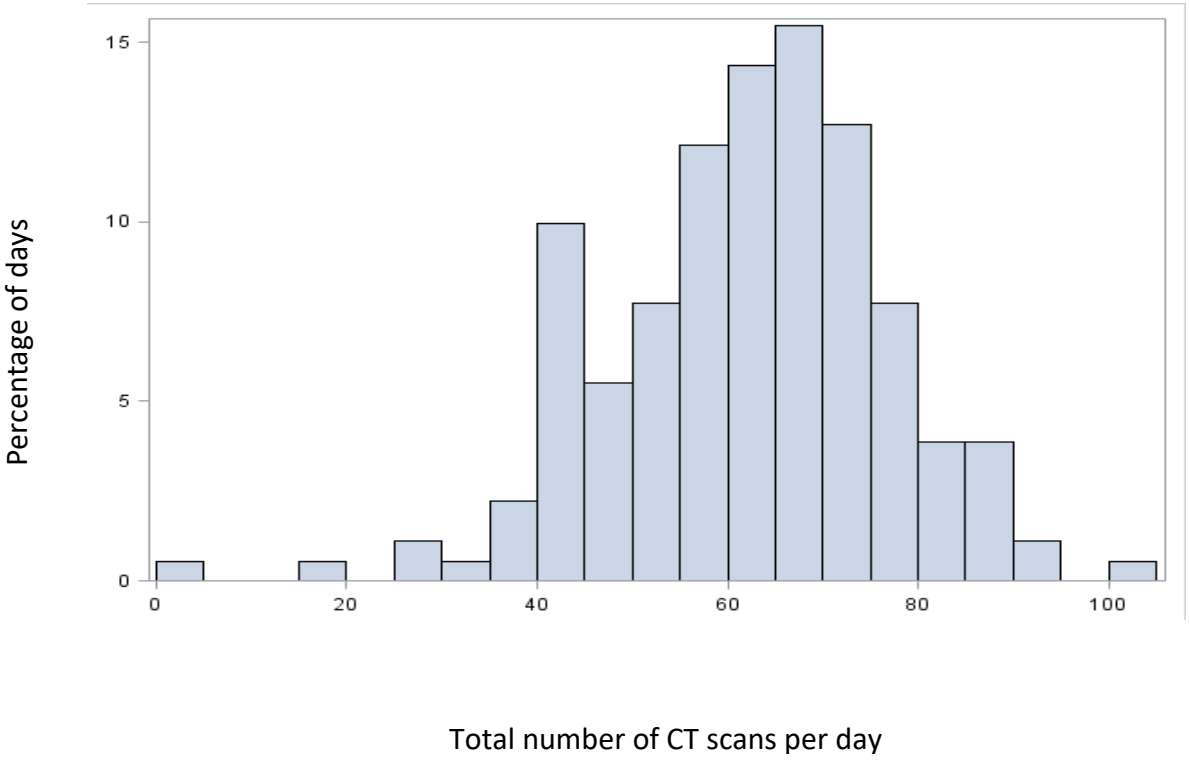


Figure 4.11. The distribution of the total number of CT scans per day.

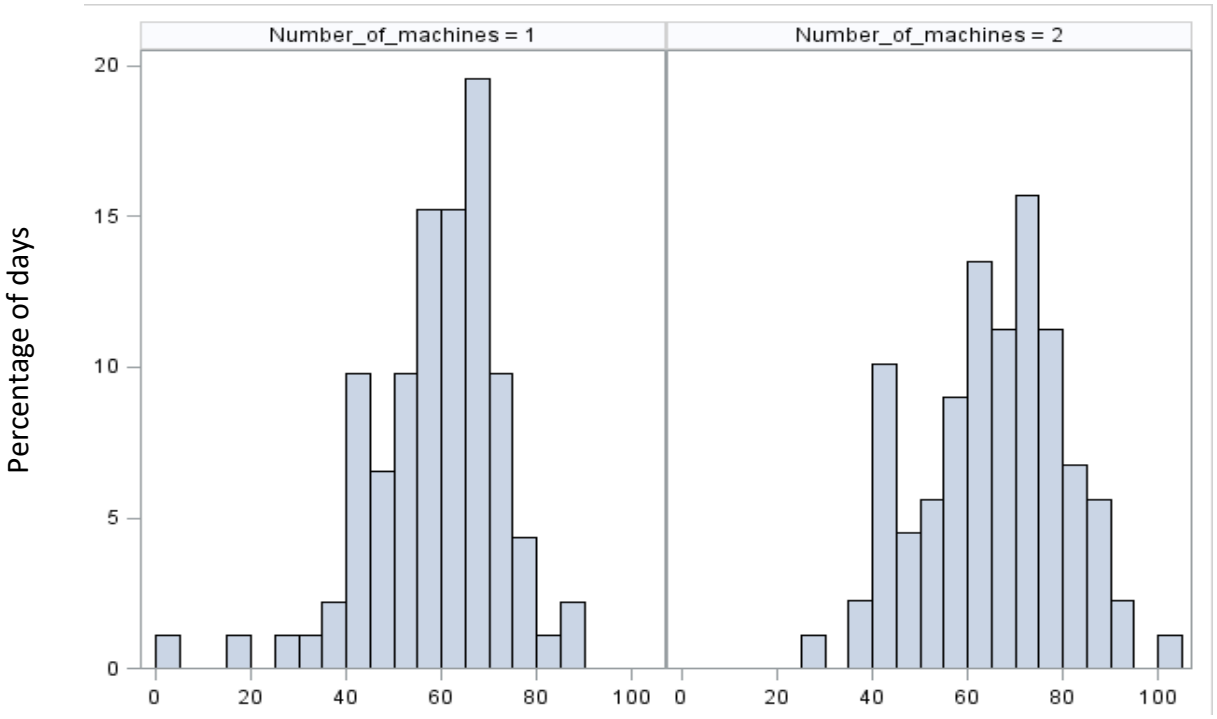


Figure 4.12. The distribution of the number of CT scans per day for when one and two machines were operational.

The number of CT scans were also assessed for each hour of the day. Data for the hour of the day was missing for 54 scans, reducing the sample size to 11,127. The median number of scans per hour was 2 (IQR 1-4; range 0-10). The distribution of the median number of CT scans is shown in Figure 4.13.

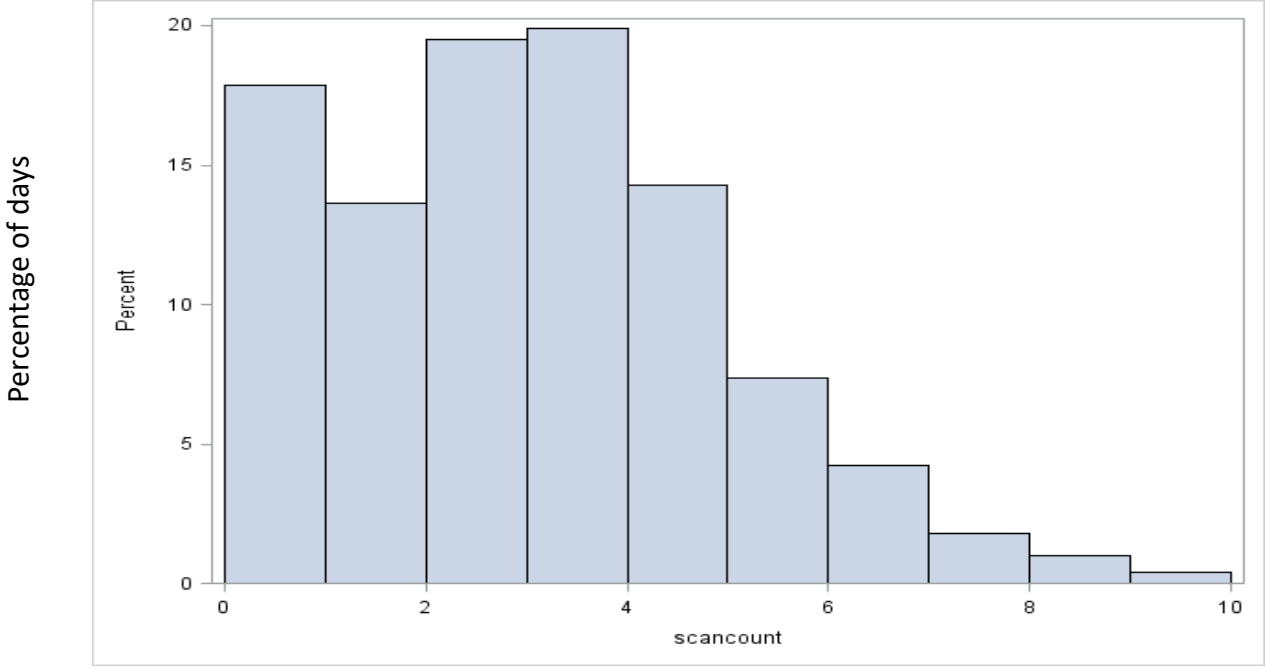


Figure 4.13. The distribution of the median number of CT scans per hour.

The distribution is positively skewed; i.e. relatively few scans per hour are performed at most times, with more scans per hour being performed infrequently. There were 776 study hours where no scans took place (17.9% of the 4344 study hours). The mean number of scans per hour (across all 181 study days) is shown in Figure 4.14. The error bars denote the 95% confidence intervals for the mean. The one-way ANOVA showed that the mean number of scans differed significantly between hours of the day ($p<0.0001$).

The peak hours were from 10h00-15h59, with a slight but significant decrease in the rate of scans from 16h00-01h59, followed by a steep decrease each hour from 02h00 to 08h59, with the lowest scan rates occurring from 06h00-08h59.

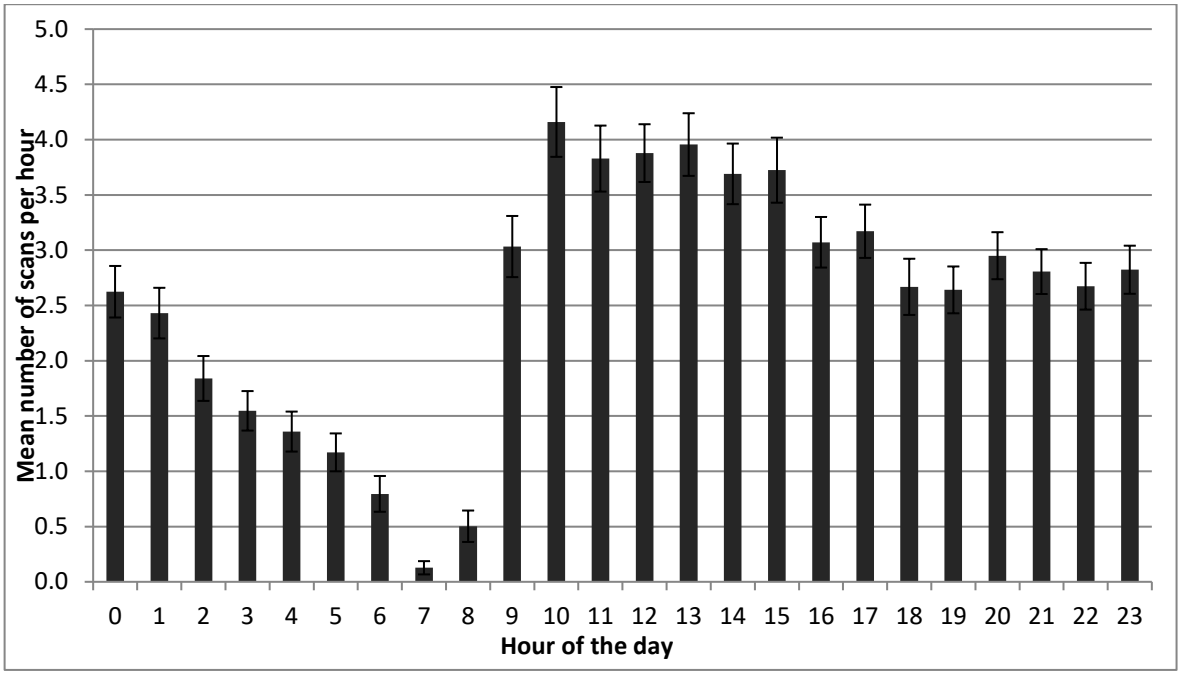


Figure 4.14. The mean number of CT scans per hour.

5. Discussion

The total number of CT scans performed represents a slight underestimation of the true number as missing and illegible entries were not included in the data set. This figure differed for each variable, ranging from 19 (region of body scanned) to 455 (referral pattern) and was indicated as 'unknown' on the respective set of results. Nonetheless, the total number of CT scans is a large number indicating the heavy workload experienced at Chris Hani Baragwanath Academic Hospital.

A broad division of the type of CT scan into brain versus body indicated that just over half of the CT scans performed were CT scans of the brain only. A distinction as to whether contrast was given or not, was not taken into account in this study. If a scan was repeated with contrast or for technical reasons, it was not recorded as a separate scan. The significance of body CT scans which represented almost half of the CT scans performed (45.6%) is that the radiation of one body CT scan is associated to the possibility of cancer according to the International Commission on Radiological Protection (4, 14).

Body CT scans represent various types and combinations of CT scans. Of particular interest is the staging and PAN scans that are essentially whole body scans for oncological staging and trauma evaluation respectively. There is a trend towards more requests for this type of scan. However, in this study staging scans represented 1% of the total number of CT scans and PAN scans represented 2% of the total number of CT scans. This may be largely underestimated as for example, a CT chest or CT chest and abdomen done for staging of a malignancy would have been recorded as a CT chest or CT chest and

abdomen respectively and not as a staging CT scan. Also if a patient had a recent CT chest for another reason (for example to exclude a pulmonary embolus), then the patient would only require a CT abdomen to complete the staging and as such the CT scan would be recorded as a CT abdomen and not as a staging scan. Therefore, to better evaluate and appropriately categorize these types of CT scans, correlation with the history and indication for the scan would be required.

These CT scans consisting of more than one body region were counted as one CT scan and not as separate CT scans for each body region.

In terms of the referral pattern, most of the CT scans were done for patients admitted in the hospital wards (40.6%) followed closely by patients from the emergency department (34%). The general impression was that most of the emergency CT scans were for trauma patients, however, this study revealed that surgical emergency CT scans (39.9%) were almost as many as trauma emergency CT scans (40.8%). It would be interesting to follow up the requests for these surgical emergency CT scans to reveal the spectrum of pathologies and indications for the scans.

During the week, the after hours' shift is 16 hours long with one CT scanner being used for the duration of the entire shift. During working hours, two CT scanners are used (if both were in working order) for the 8 working hours, which equates to 16 hours of work time. Thus, it would be expected that as many scans done after hours' can be done during

working hours, if not more. This study revealed that two thirds of the total number of CT scans were done after hours despite limited resources and staff after hours.
Days when the number of scans for a scanner was 0, is when that CT scanner was either not working or was being serviced. Considering the number of CT scans that can be done with one CT scanner, results demonstrated that there was a mean increase of 7 CT scans when two CT scanners were used. Therefore, this reflects underutilization of the second CT scanner and human resources when it is available and increased overflow of CT scans from the working hours shift into the after hours' shift. It was not noted when a scanner stopped working or broke down during a shift so if a scanner scanned only a few scans and then broke down, it was regarded as operational on that day and this underestimates the total number done by the second scanner.

The current scheduling system is a key factor contributing to the overflow of patients into the after hours' shift. A set number of CT scans are booked, that does not make provision for the time that specific CT scan would take. A CT brain scan is given one slot. A staging CT scan is also given one slot even though is consists of a CT scan of the brain, neck, chest and abdomen, which technically is equivalent to four stand-alone CT scans. These factors need to be taken into account in the future scheduling of patients. This would allow for better planning of workflow, reduce the overflow in to the after hours' shift, improve operations in the CT scan department and reduce patient waiting times.

The period with the lowest scan rates is between 06h00 and 08h59 which correlates with the time around changeover of staff (07h00) as well as the start of the new working day.

This indicates that there is a slow start to the working hours' shift of the day. Possible areas that may contribute to the delay include:

- Time taken for porters to bring patients from the wards to the radiology department. Some of the wards are located rather far from the radiology department.
- The administrative processing and registering of patients by clerks that is required before patients can be scanned. There is shortage of clerical staff with a single clerk allocated to the radiology department, who registers patients for all the units, including: CT, screening, high intensity focused ultrasound (HIFU), intervention and magnetic resonance imaging (MRI).
- The preparation of the patient for the scan, including inserting intravenous (IV) lines for contrast injection, consent, oral contrast administration and sedation for paediatric and confused patients.
- The cleaning and preparation of the CT scanner room
- The calibration of the CT scanners

5.1. Results in context

The highest number of CT scans per decade was for the 20-29 age group in this study and in two studies done in the United States. Whereas, the age group was older in the studies done in China and Taiwan. (9, 11-13) These figures are shown in Table 5.1. Chris Hani Baragwanath Academic Hospital is the largest trauma hospital in South Africa and Africa. There is a high trauma burden (29) with most cases referred from the trauma unit. The age group with the highest number of CT scans correlates with the age when most trauma occurs (30).

Table 5.1. Percentage of CT scans according to age group.

Country	0-9 years	10-19 years	20-29 years	30-39 years	40-49 years	50-59 years	60-69 years	70-79 years	>80 years
South Africa	9%	8%	**20%**	**17%**	14%	12.6%	8%	6.5%	
Multi-state, US (9)	14.1%	10.6%	17.1%	14.1%	13.8%	10.4%	6.8%	6.2%	6.9%
China (13)		14-29 :8.5%		30-49 :12.3%		50-69 :16.3%		>70: 21.1%	
Taiwan (11)			18-40: 29.1%		40-65: 35.6%		>65: 35.4%		
US (12)		<18: 10.38%	18-34: 22.22%	35-49: 20.95%	50-64: 16.41%		65-79: 15.05%		>79: 12.09%

In a study by Terreblanche, *et al*, done in South Africa, published in 2011: a call or after hours' shift was regarded as a high workload if 24 or more CT scans were done (2). This

study evaluating statistics for 3 years later, revealed the average number of CT scans done after hours (40) to be almost double what was previously regarded as a high workload, demonstrating the exponential increase in the number of CT scans performed. Increased CT scan usage was also noted in other countries such as Australia, United Kingdom and the United States (3, 5, 6). The impression in our setting indicates that several factors contribute to this increase: increased reliance on CT scans by clinicians for decision making in terms of diagnosis and treatment; this imaging modality being easily accessible, fast and accurate; as well as the general increase in patient volume at emergency departments.

Carroll, *et al* showed that 40% of CT scans were done on call in their study in Vermont, United States for the year 01/10/2001-30/09/2002 (27). In contrast, this study demonstrated a much higher percentage of CT scans done after hours (66.1%).

A comparison with studies done evaluating similar parameters is depicted below in Table 5.2. Chris Hani Baragwanath Academic Hospital (CHBAH) is a large hospital with approximately 3200 beds (31), double compared to the highest in the comparative studies. A limiting factor is that the data was of a more recent year than the comparative studies. The average age of the patients at CHBAH was similar to those seen in China and younger than in the studies in United States, Taiwan and New York (United States, Taiwan and New York included only adult patients or patients above a certain age).The total number of CT scans done in 6 months at CHBAH is comparable to the total number of CT scans done in 1 year in the study in the United States and significantly more than what

was done at the other hospitals in one year. CT Brain scans were of higher proportion of the total number of CT scans at CHBAH as opposed to the studies in the United States and Taiwan where body CT's were of a higher contribution (10, 11, 13, 23).

Table 5.2. Comparison of the age of the patients, number and type of CT scans from studies in different countries with similar parameters.

Country	**Year**	**Duration**	**Number of CT scanners**	**Number of beds**	**Mean age**	**Total number of CT scans**	**Number of CT Brain**	**Number of body CT**
South Africa (CHBAH)	2014	6 months	2	3200	39	**11181**	6060 (54.2%)	5102 (45.6%)
China(13)	2008	1 year	2	800	38.3	7855	NA*	NA*
United States (>14 years)(10)	2005	1 year	NA*	NA*	49.7	NA*	5289	7202
Taiwan (>18 years)(11)	2013	1 year	NA*	1520	55.6	9467	4053 (42.8%)	5414 (57.2%)
New York (>21 years)(23)	2007	1	NA*	NA*	54.4	7688	407 (53%)	NA*

(Note: For studies evaluating data for more than one year, the data for the latest year was used for comparison.)

**NA= values not specified in the respective referenced journal articles.*

5.2. Limitations of the current study

The data was collected from handwritten logbooks despite having a picture archiving and communication system (PACS), resulting in a laborious process of data collection. PACS is available, however the transfer and storage of information on to the PACS is hindered by frequent power outages, network interruptions and technical difficulties. As a result, the potential of such a great system cannot be maximized. Electronic bookings and clerking of patients are not possible at this stage. The shortage of clerical staff has led to incomplete or incorrect patient registration. The manual bookings and then electronic entering of patients when they arrive for the CT scan is a duplication of work and contributory to poor workflow.

The gender of the patient was not recorded in the radiographer logbooks and therefore, could not be analysed in this study. The radiographer logbooks were used as it was more reliable and complete compared to the PACS and other sources. Additional research to evaluate this variable is recommended as it may significantly impact factors such as intervention planning by the region or province.

This study does not compare the number of requests for CT scans to number of CT scans performed or the time patients wait before their scans are done, which may be better indications of the demand for this type of imaging.

The appropriateness and indications of requests were not dealt with in this study as this information was not recorded in the radiographer logbooks. Electronic bookings with scanning of the request forms aid in the evaluation of these factors.

Data for six consecutive months were collected, a full year's data would be required to assess seasonal variation which may have an impact on the number of CT requests.

The specific units within a discipline requesting the CT scans (for example, the hepatobiliary and gastrointestinal units within the surgical discipline) could not be analysed as this information was not recorded.

5.3. Future applications

Imaging referral guidelines for the departments with the most requests may assist in prioritizing and ensuring appropriateness of CT scan requests. Increasing the awareness of the possibility of cancer and other harmful effects associated with radiation dose may be required so that not only the benefits but also the risks are considered when requesting this particular imaging modality.

Maximizing on the time between 06h00-09h00 by identifying and addressing issues that may account for the lower scan rate can increase efficiency. To use the second scanner (when operational) to its full potential will increase the quantity of CT scans performed. Further research is required, to evaluate the reasons for the smaller than expected increase in the total number of CT scans performed when there were two operational CT scanners instead of one. The above may be due to staff allocation within the department. Ideally, most CT scans need to be done during working hours when more resources, staff and supervision are available to ensure that the quality of patient care is not compromised by an increasing afterhours workload and subsequent error rate (3).

Maintaining the CT scanners so that both are always functional will enable maximum usage of the CT scanners during working hours. A 24 hour service is of consideration, in which outpatients are scheduled and given specific time slot after hours. This may require a day ward or sleep over ward to accommodate these patients. Alternatively, outpatients can be scanned from 08h00 to 16h00 and inpatients from 16h00 to 07h00, with the urgent requests accommodated concurrently by a separate CT scanner. Future audits of

this period of down time correlating with the human resources available during this time are recommended to ascertain reasons for the down time and then to recommend and implement quality improvement mechanisms. This will enable the CT department to "work smart" and utilise its human and equipment resources more efficiently.

The median number of CT scans per hour is 2 in this study. It has the potential of being increased up to approximately 7 per hour as demonstrated in the study by Boland *et al*, however, this is dependent on the number of technologists (22) and support staff.

Maximizing productivity will assist in increasing the number of CT scans performed, but is not exponential in nature. With the continuous exponential increase in CT scan usage, an increase in resources (staff and machinery), which will have a greater increase in the number of CT scans performed, is required to keep up with the ever increasing and already massive workload with which Chris Hani Baragwanath Academic Hospital is burdened.

If staff and resources remain unchanged, while the workload increases, longer waiting times and booking lists are expected with more CT scans carrying over to the next shift. When the maximum number of CT scans possible is reached each day, a backlog ensues. Increasing the equipment, that is, the number of CT scanners is an option, however, is very costly. CT scans dedicated to and placed within the surgical and trauma departments (the departments with the most CT requests) may aid in getting the CT scans done quicker and more efficiently. Increasing the staff during peak hours as well as auxiliary staff such

as porters and nurses to streamline the work process is to be considered. Support staff to assist in transferring patients on and off the CT table to increase the turnover rate as scan times for a brain CT should not be the same as a body CT since body CT's cover larger areas and are typically of multiple phases. The most feasible option is to allocate or employ more support staff for the current equipment, especially during peak hours, also for more hours of the day and possibly more days of the week.

5.4. Recommendations:

Short term (1-3 months)

It is recommended that the hospital managers partner with the management in the radiology department to assist in providing the required human resources to ensure that the current resources are used to their full potential. This would require the employment of more staff in general and/or more staff during peak hours of the day. Additional staff required includes radiographers, porters, nursing staff and clerical staff. Currently the radiology registrars are injecting contrast, a role that could be adequately provided by a nursing sister, this would then free up the registrars who could then assist with the reporting of the CT scans. This arrangement would decrease patient waiting times as reports would be generated faster.

More clerical staff would enable the PACS system to be used properly resulting in electronic bookings which would result in improved booking allocation, decreased human error and verified studies on PACS. The verified studies would enable proper record

keeping and facilitate data mining for the identification of further quality improvement initiatives.

It would also be important for equipment to be serviced frequently and fixed when broken within 24-48 hours. Machine down time has long lasting impact on service delivery and clearing the backlog often takes weeks to months.

Meetings between the radiology department and the clinical head of departments to discuss and develop protocols to improve patient referral to the CT department, this will ensure that only relevant patients are referred to the CT department. This would also be an opportunity to arrange radiation awareness talks for the staff in the individual clinical departments.

Medium term (3-6 months)

A sleep over ward for CT patients would enable out patient to be scanned after hours on the second CT machine. This would benefit the patients, as they would not need to take time off work in order to have a CT scan, which is often the case.

It would improve service delivery if the hospital acquired a third CT scanner that could then be used to service the urgent and emergency cases from the wards and casualty departments.

Long term (6-18months)

The acquiring of a fourth CT scanner that would be situated in the emergency intake department, where the trauma and accident and emergency departments are located. This would result in the timeous scanning of emergency patients close to the emergency departments. This would facilitate quick scanning and diagnosis of patients that would in turn speed up treatment reaction times and ultimately improve patient outcomes.

The purchasing of generators and UPS specifically for the radiology department to ensure constant power supply to negate the negative impact of the recurrent power cuts and surges in the hospital.

6. Conclusion

Chris Hani Baragwanath Academic Hospital is a tremendously busy centre with an exponential increase in the number of CT scans performed and two-thirds being done after hours'. Most of the CT scans performed were for patients admitted in the wards of Chris Hani Baragwanath Hospital, followed by urgent requests from the emergency department. Trauma and surgery were almost equally the leading disciplines requesting urgent CT scans. The use of two operational CT scanners instead of one resulted in a smaller, than expected, increase in the total number of CT scans performed. This needs to be further researched and evaluated to improve workflow in the CT unit. The trough of productivity was between the hours of 06h00-09h00. The specific contributory factors need to be further investigated. Areas have been identified in which productivity can be maximized, however, limited resources is the factor with the largest impact and greatest limitation to productivity. There are many factors that contribute to workflow such as scheduling of patients, getting patients to the CT department timeously, registering patients, preparing patients for the CT scans, getting patients on and off the CT table, power supply and functioning of the PACS. Maximizing on the potential of the PACS which is already in place can improve workflow. Stabilizing the power supply and network to the PACS is relatively inexpensive in comparison to the financial investment made in acquiring the PACS. The benefits of a fully functional PACS to the radiology department, clinicians and hospital would certainly outweigh the cost of stabilizing the power supply and network. The data acquired manually for this study could then be retrieved by a push of a button. The data from the PACS could then be utilized to assess referral patterns, resources used, seasonal variation and allow for better planning of both inventory and

operations in the CT unit and the radiology department as a whole. For success in quantity, quality and efficiency, effort and participation is required from the entire team including the clinician, patient, radiographer, radiologist, administration, hospital management and the human resources department.

Appendix A: Ethics Clearance Certificate

R14/49 Dr Suraya Arbhee

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M150448

NAME: (Principal Investigator)	Dr Suraya Arbhee
DEPARTMENT:	Radiology Chris Hani Baragwanath Academic Hospital
PROJECT TITLE:	Audit of CT Scans done at Chris Hani Baragwanath Academic Hospital in 2014
DATE CONSIDERED:	24/04/2015
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr LT Hlabangana
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	29/05/2015

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix B: Data collection Sheet

Number	Study date	Patient code	Age	Time of scan	Type of scan	Referring ward	Number of scanners

Code for type of scan done:

1 - Brain
2 - C-spine
3 - Brain and C-spine
4 - Neck
5 - Chest
6 - Abdomen
7 - CTPA
8 - Chest and Abdomen
9 - Staging: neck, chest & abdomen
10 - PAN scan: brain, c-spine, chest & abdomen
11 - Peripheral angiogram

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