





## ORIGINAL ARTICLE

# The proportion of computed tomography kidneys, ureters and bladder (CTKUB) scans that comply with scan extent protocol in an emergency department: a clinical audit and dose ramification study

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## Keywords

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## Abstract

**Introduction:** To assess computed tomography kidneys, ureters and bladder (CTKUB) scan extent protocol compliance and associated doses in the Emergency Department (ED) of an Australian tertiary hospital. **Methods:** A retrospective clinical audit of 150 consecutive ED CTKUB cases was completed. For each patient, scan extent compliance at the superior (kidneys) and inferior (pubic symphysis) borders, in reference to the protocol was recorded. Compliance and non-compliance (over-/under-scanning) was identified, described (superior/inferior), quantified (via IMPAX measurements) and recorded via a purpose-built audit tool. In addition, a PBU40 phantom was scanned to assess the percentage of dose (DLP) increase per centimetre of over-scanning to contextualise results. **Results:** A notable non-compliance with department protocol was noted. Eight cases (5.3%) demonstrated overall CT scan extent compliance. The remaining 142 cases (94.7%) demonstrated some form of non-compliance; superiorly, inferiorly or both. Analysing the 150 superior and 150 inferior data points independently, the most common non-compliance was over-scanning at the kidneys by 4 cm to 5 cm (19 cases, ~10% extra DLP) beyond tolerance and over-scanning inferiorly at the pubic symphysis by 1 cm to 2 cm (29 cases, ~6.4% extra DLP). Estimated dose increases of up to 35% to 45% were found when clinical audit results were simulated using a PBU40. **Conclusions:** Over-scanning is a predominant occurrence in CTKUB scans in this department. Reasons for over-scanning weren't investigated. It's anticipated this audit will lead to greater awareness of scan extent compliance and dose ramifications of non-compliance. The usage of more easily identified anatomical landmarks and a follow-up audit is suggested.

## Introduction

Unenhanced computed tomography kidneys, ureters and bladder (CTKUB) scans are the current gold standard for imaging patients presenting with acute renal colic symptoms to the emergency department (ED),<sup>1–4</sup> with a higher sensitivity and specificity (95–100%, respectively) in detecting small renal calculi than plain

radiography.<sup>1,2,3,5</sup> This examination results in a relatively high ionising radiation dose to the patient, with a mean CTKUB dose from 3 mSv to more than 10 mSv.<sup>1,2,4</sup> However, 'low dose' CTKUBs can impact image quality, calculi detection and the potential assessment of alternative diagnoses in an ED environment.<sup>1,2,4,6,7</sup>

CTKUBs are common and due to the high reported risks of urolithiasis recurrence (50% in 5–10 years, 75%

in 20 years);<sup>2,6</sup> regular, repeated re-imaging is often necessary, contributing to the patient's cumulative radiation dose.<sup>2,5,7</sup> Due to the radiation-sensitive organs (lungs, breasts and gonads) present at the most superior and inferior aspects of a CTKUB scan, scan extent reduction is extremely important.<sup>8,9</sup>

A clinical audit of ED CTKUB scans was undertaken at a large tertiary adult hospital to assess for protocol scan extent compliance, as any extension beyond the urinary tract is unnecessary radiation exposure for answering the clinical question.<sup>4</sup> Maintaining patient and population radiation safety, including reducing cumulative dose, is imperative, especially given the recent rise in CT usage and risks of ionising radiation.<sup>8,10,11</sup>

Consistent utilisation of vendor-specific dose-reduction strategies is essential in maintaining service standards and practice improvement.<sup>11,12</sup> CT topograms in conjunction with scan extent, helical pitch, tube potential, automatic exposure control, manual versus automatic scan cessation and more planning options, allow a patient-specific tailored CT scan, incorporating patient body habitus, education with breath holds, protocol justification and exhausting non-radiation medical imaging options if the scan is contra-indicated.<sup>11,12</sup> CT scan extent limitation is one of the most effective CT dose-reduction strategies, enabling radiographers to keep the dose 'as low as reasonably achievable' (ALARA),<sup>4,8,9,13</sup> in a similar fashion to plain radiography x-ray collimation.

Scan extent is operator dependent and directly proportional to the overall dose received.<sup>9,11</sup> Scan extent is planned from a frontal (and at times a lateral) topogram image, in order to plan superior and inferior scan borders of the anatomical region requested.<sup>8,9,14</sup> However, due to the difficulties in consistently identifying renal contours on topogram images and often unpredictable breathing rates of ED patients, scanning with manual cessation is this department's CTKUB protocol; starting at the inferior border of the pubic symphysis to the most superior aspect of the kidneys, with a 2 cm over-scanning tolerance allowed at both borders, for operator accuracy (Table 1). The topograms also assist in dose planning by the scanner. This department's manual cessation protocol is utilised only on contemporary scanners which provide almost instantaneous image display, other sites may have differing protocols.

The recent literature recommends the use of consistent anatomical landmarks that confidently include the kidneys; mid or inferior margin of 10th thoracic vertebra,<sup>4,9,14</sup> mid or superior margin of the 11th thoracic vertebra,<sup>4,9,14,15</sup> or the intersection of the left or right diaphragmatic dome and the anterior margin of the vertebral bodies, on the topogram images.<sup>4,9</sup> However,

**Table 1.** Tertiary hospital computed tomography kidneys, ureters and bladder (CTKUB) scan department protocol.

Computed tomography kidneys, ureters and bladder (CTKUB)/renal colic			
Protocol Title	Computed tomography kidneys, ureters and bladder (CTKUB)/renal colic		
Radiologist Protocol	CTKUB		
Pre-requisites	Patient identification checked		
Indications	?renal stones haematuria flank pain		
Reconstructions	KUB Dual energy stone analysis (SyngoVia) plus 3D with colour map		
Scanning	<b>Series</b>	<b>Start</b>	<b>Finish</b>
	1 – lateral scout	above diaphragm	below pubic symphysis
	2 – anteroposterior (AP) scout	below pubic symphysis	above diaphragm
	3 – KUB (containing tolerance)	2 cm below pubic symphysis	2 cm above kidneys
Tolerance	2 cm from pubic symphysis (below) and kidneys (above) is allowed		

<sup>†</sup>All amounts in centimetres (cm)

this is not possible in patients presenting with vertebral anomalies, where a customised scan is required.<sup>4</sup>

The aim of this study was two-fold: to determine the proportion of CTKUB scans that comply with department scan extent protocol in an ED using manual cessation, and to estimate the dose impact of over-scanning.

## Materials and Methods

This audit was undertaken at a large, Australian Metropolitan tertiary hospital in collaboration with a local University. Ethics approval was received from the Queensland University of Technology and Metro South Health Human Research Ethics Committee. No identifying data or patient demographics were collected. One hundred and fifty consecutive ED CTKUB scans performed between January and September 2018 were identified using the department's picture archive and communications system (IMPAX, Agfa Healthcare). Four scans were excluded; intravenous contrast ( $n = 2$ ), patient re-imaging ( $n = 1$ ) and changed protocol ( $n = 1$ ).

All 150 CTKUBs were performed on a Siemens Somatom Definition Flash, (manufactured in Forchheim, Germany), in the ED, using the endorsed department CTKUB protocol, justified clinical indications and 'CTKUB' protocolling (Table 1). All CTKUB scans were

individually analysed by the principal investigator, using a specifically designed Excel audit tool, modified from the Royal Australian and New Zealand College of Radiologists (RANZCR) CT Image Review Self-audit worksheet,<sup>16</sup> a nationally validated tool for CT image quality review. Data analysis was completed on Microsoft Excel, using standard descriptive statistics.

Over- and under-scanning was measured on IMPAX, using the ruler tool on a coronal image of the patient's abdomen and recorded in centimetres (cm), including the location of error and mode. Over-scanning was measured from the superior aspect of the kidneys (including protruding pathology) to the superior end point of the scan and the most inferior aspect of the pubic symphysis to the most inferior end point of the scan. The 2 cm tolerance was then deducted to obtain a result for over-scanning beyond the protocol tolerance allowance (Fig. 1; Table 1). Scans were categorised as displayed in Table 2.

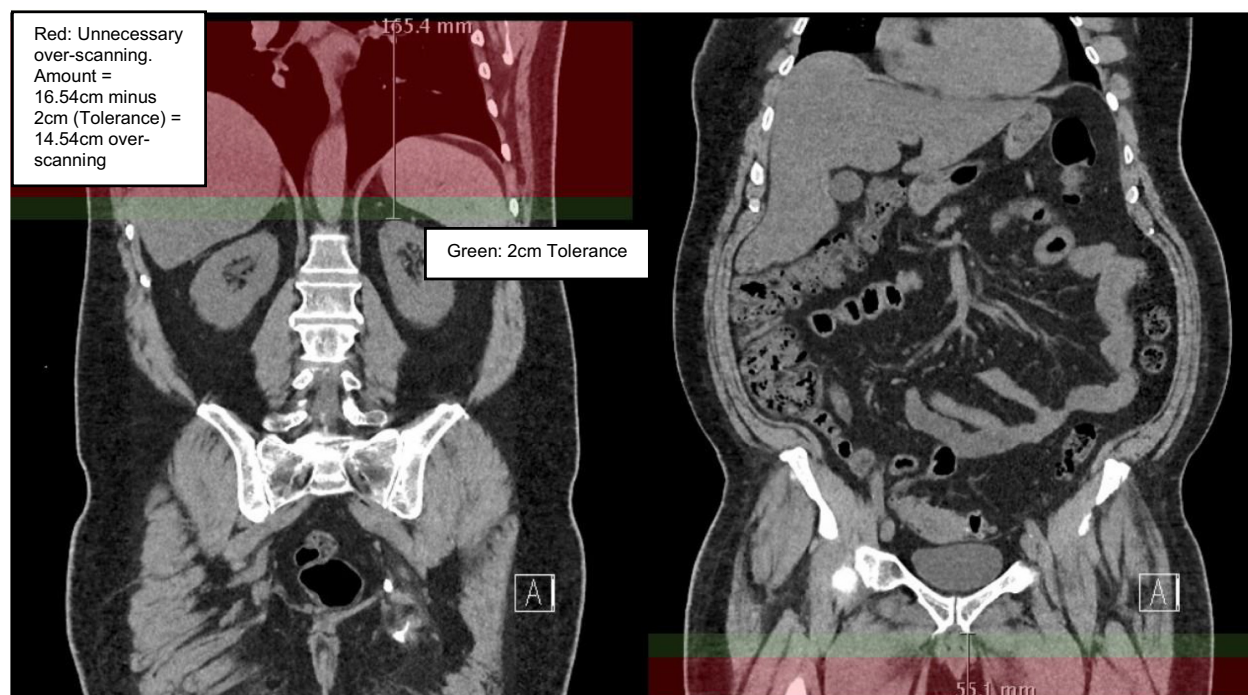
Dose length product (DLP) was not collected for each CTKUB scan. Instead, a PBU40 phantom was scanned using the same CT scanner and protocol to measure the percentage of DLP increase for each centimetre of over-scanning at either border, compared to the DLP for the CTKUB tolerance protocol scan (i.e. including 2 cm at both borders as the baseline). The calculation involved: DLP (for each centimetre of over-scanning as per the results) minus the DLP (from the tolerance scan). This

figure was divided by the tolerance scan DLP and expressed as a percentage. These phantom results were used to compliment the clinical audit and offer contextualisation for the rate of dose increases with over-scanning.

## Results

150 CTKUB scans were included in analysis with four additional exclusions. Results indicate the amount (each centimetre) of over-scanning beyond the 2 cm over-scanning protocol tolerance. Eight (8) cases (5.3%) demonstrated compliance to department scan extent protocol (at both borders) and 142 cases (94.7%) demonstrated non-compliance (increase or decrease) in scan extent to department protocol, either inferiorly, superiorly or both (Table 3).

As identified in Table 3, measuring non-compliance in one, both or no regions; the rate of scans with non-compliance in both regions was 70%, almost triple the rate of non-compliance than in one region of error (24.7%). As CT scan extent is operator adjustable, over-, under- and protocol-compliant scanning were analysed independently rather than on an overall case basis, to identify the greatest region of error. Therefore, within 150 CTKUB cases, a total of 300 data points were extracted and analysed (150 superior data points and 150 inferior).



**Figure 1.** Diagram of superior and inferior scan extent border measurements (different slices required). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

**Table 2.** Definitions of terms and abbreviations related to computed tomography (CT) scan extent auditing.

<b>CT scan extent</b>	The amount/extent in centimetres (cm) of CT scanning and therefore radiation to a given patient. The term scan 'extent' was chosen instead of scan 'length' because the length may differ for each patient according to anatomical landmarks. Scan 'extent' therefore terms the accuracy the operator can scan to at each scanning border, as per the protocol, rather than the total 'length'.
<b>Over-scanning (Non-compliant)</b>	Any CT scan extent beyond the department scan extent protocol. For CTKUBs, any scan extent beyond the 2 cm tolerance from the superior border of the kidneys and the inferior border of the pubic symphysis was deemed as over-scanning. Signifying unnecessary extra dose.
<b>Under-scanning (Non-compliant)</b>	Any scan extent less than the complete imaging of the urinary tract, as per the protocol for this department. This may be left as under-scanned or consequentially require a repeat or section repeat, with potential extra dose.
<b>Accurate scanning (Compliant)</b>	Scan extent completely imaging the urinary tract, within or equal to the 2 cm tolerance. No extra dose to unnecessary tissues outside the region of interest.
<b>CT protocol tolerance</b>	2 cm of scan extent is tolerated in this department beyond the stated scan extent in the protocol. This allowance is for operator discrepancy and accuracy. This was not included in the results. Scan extent audit results in this study begin incrementally after this tolerance.
<b>mSv</b>	Millisievert

**Table 3.** Computed tomography kidneys, ureters and bladder (CTKUB) scan extent border compliance at both (pubic symphysis and kidneys) or one scan extent border.

	Number of CTKUB cases	Percentage (%)
Overall compliance: both borders	8	5.3%
Overall non-compliance		
Non-compliance: both borders	105	70%
Non-compliance: one border	37	24.7%
- Superior extent		30
- Inferior extent		7
<b>TOTAL</b>	<b>150</b>	<b>100%</b>

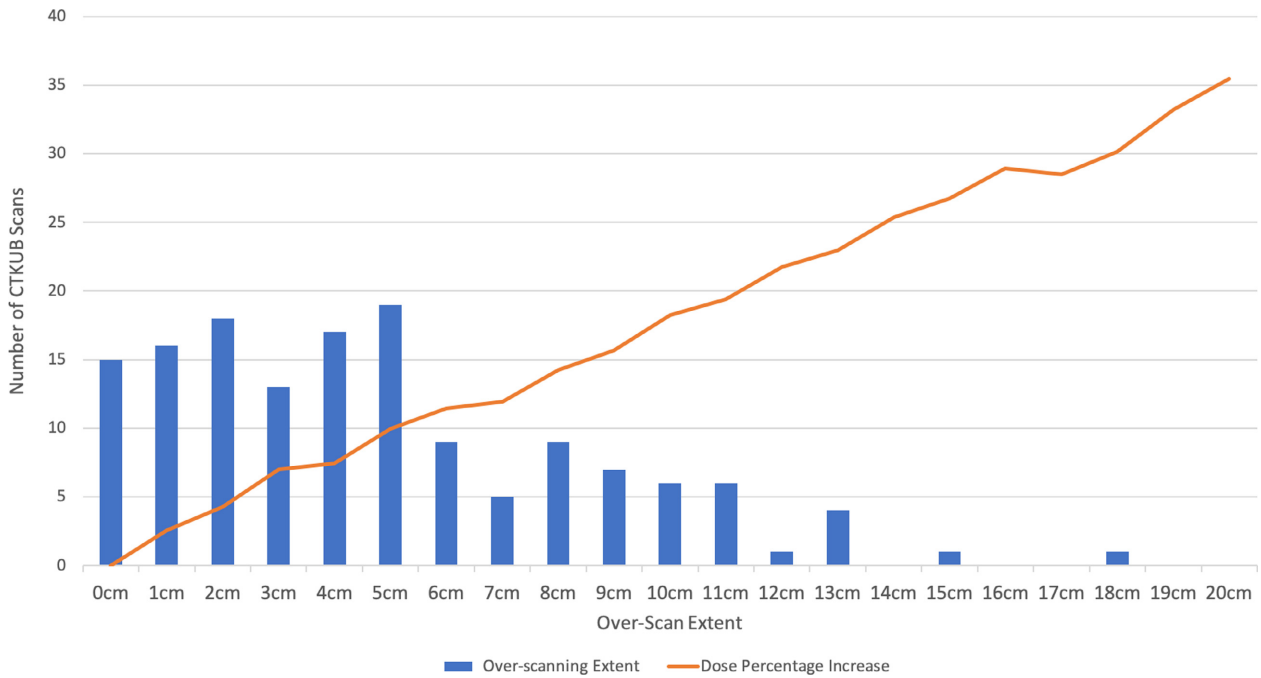
This was coupled with the dose results from the PBU40 phantom study (with the opposite border kept at tolerance). Therefore, results only signify the over-scanning amount (cm) and DLP for one region, not cumulative for patient-specific cumulative scores, which is a limitation of the study.

At the superior extent (kidneys), 15 cases demonstrated CTKUB scan extent compliance as seen in Figure 2 at 0 cm. The largest amount of over-scanning at the kidneys was ~ 17.5 cm (*n* = 1) beyond tolerance, which resulted in a dose increase of ~ 30.1% DLP greater than if the patient was scanned to protocol scan extent (with tolerance). The most common amount of over-scanning at the kidneys was 4 cm to 5 cm (*n* = 19, ~10% DLP extra), followed by 1 cm to 2 cm (*n* = 18, ~4.2% DLP extra) and 3 cm to 4 cm (*n* = 17, ~7.4% DLP extra). Non-compliant CT scanning included under-scanning (*n* = 3) and excessive over-scanning up to 18 cm (over tolerance).

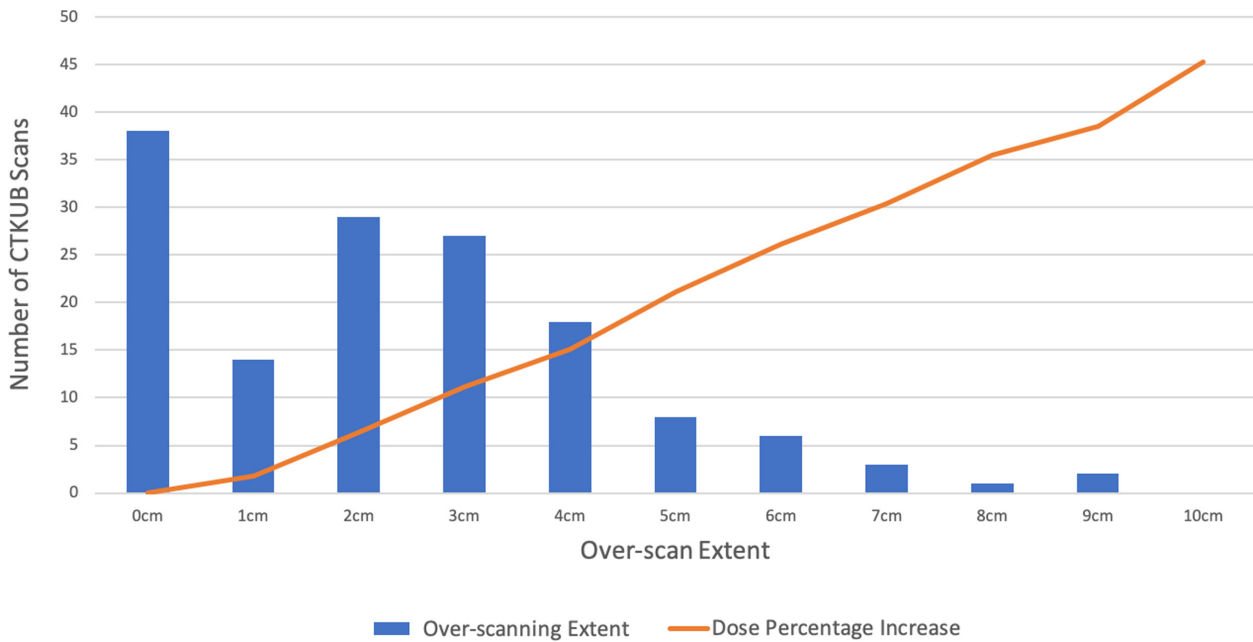
Results for the inferior extent (pubic symphysis) establishes only 38 cases that demonstrated accurate CT scan extent; however, this was the most common result (Fig. 3). In assessment of over-scanning, the most common inferior result was 1 cm to 2 cm (*n* = 29, ~6.4% DLP extra), 2 cm to 3 cm (*n* = 27, ~11.2% DLP extra) and 3 cm to 4 cm (*n* = 18, ~15.1% DLP extra). The largest amount of over-scanning was 8 cm to 9 cm, resulting in a ~ 38.6% extra dose (DLP) to the patient. Four (4) cases demonstrated under-scanning by less than 1 cm (by extrapolation) and no repeats or significant loss of anatomical visualisation.

### Discussion

This study found that the overall operator compliance to department CTKUB scan extent protocol was 5.3% (*n* = 8) of cases. This result is congruent with the high rate of CT over-scanning demonstrated in previous studies of current literature; however, this is an area of CT imaging which has not been extensively reported. Uldin et al.<sup>4</sup> researching the standardising of the 11th thoracic vertebra as the superior extent of CTKUB planning reduced over-scanning from 94.4% of scans (similar to our study) to 35.2%, with a mean over-scan extent percentage decrease from 28.2% to 10.6%. A study assessing 167 chest and/or abdominal CT examinations identified that 133 (80%) contained extra CT scanning (mean 4.6 cm, range 1 cm to 19.5 cm).<sup>17</sup> Schwartz et al. completed a research study between six (6) hospitals, assessing the scout images of chest CTs compared to the actual scan range acquired and identified an over-scanning incidence between 7% and 60%, including an increased total and organ effective dose.<sup>10</sup> Another recent



**Figure 2.** Data point level distribution – Kidney scan extent compliance and associated phantom dose (DLP). [Colour figure can be viewed at wileyonlinelibrary.com]



**Figure 3.** Data point level distribution – Pubic Symphysis scan extent compliance and associated phantom dose (DLP). [Colour figure can be viewed at wileyonlinelibrary.com]

study highlighted that for most examinations, CT scan extents were significantly larger, the greatest were CT skull scans (120% of prescribed length), and cervical spine and lumbar spine whereby 4 cm to 6 cm (specific protocol to image disc space disorders) were being

extended to a mean of 11 cm to 15 cm.<sup>18</sup> These are concerning results considering the few scan types being audited in all these studies. Schwartz et al.<sup>10</sup> also utilised a 2 cm tolerance of over-scanning, and identified that this tolerance impacts the patient’s overall dose, due to a

potential 4 cm extra scan extent dose; hence, accurate scanning is opted for.

Our study identified that, out of 150 scans, 70% of cases demonstrated CT scan extent error in both regions (clinically of greatest concern), 24.7% demonstrated inaccuracy in one region and 5.3% of CT examinations displayed accurate CT scan extent in both regions (Table 3). In comparison to Gervaise et al., who identified a higher rate of CT under-scanning occurring in CTKUBs scans,<sup>9</sup> our study observed only a small occurrence of under-scanning ( $n = 7$ ) with a higher incidence of over-scanning, similar to Uldin et al.<sup>4</sup>

In assessment of the 300 (150: kidneys, 150: pubic symphysis) data points independently, to assess for the region of greatest compliance and non-compliance or region-specific errors, the superior region demonstrated a greater amount of error than the inferior region. The largest amount of over-scanning was 17 cm to 18 cm ( $n = 1$ ) at the superior extent and 8 cm to 9 cm ( $n = 2$ ) at the inferior extent.

The most common CT scan extent extension superiorly was 4 cm to 5 cm (12.7%,  $n = 19$ ) which is more concerning than 1 cm to 2 cm inferiorly (19.3%,  $n = 29$ ); however, over-scanning beyond a clearly identifiable bony landmark (pubic symphysis) on the topogram<sup>9</sup> occurred in 108 inferior cases (72%), which is a possible area for protocol compliance improvement. The reasoning behind the over-scanning was unclear; no included request form indicated any reasons for extension or protocol change, signifying the importance of written communication. In addition, over-scanning is a larger occurring error than under-scanning. As scan extent is operator dependent, there is scope for improvement in these results.

## Potential Explanations for Variance in CT Scan Extent

On a management level, the first consideration is whether the protocol is achievable and reproducible. On an operator level, non-compliance may be occurring over-time with the absence of clinical audits. Operator anxiety to not miss 'other pathologies' in ED may influence over-scanning.<sup>10</sup> Operator experience was not audited but may be influential.<sup>19</sup> Protocol variation can occur in response to patient needs, such as breathing difficulties. Scan direction change may explain inferior error, or difficulty in identifying renal contours on topograms.<sup>9</sup> Manual cessation instead of automatic cessation with the use of anatomical landmarks may contribute to over-scanning, due to operators required to stop the scan manually once anatomy is scanned through. Whilst modern scanners offer almost instantaneous image display, the lag between acquisition and display may contribute to over-scanning.

On an environmental level, the pressures of ED may affect staff performance and clinical decision-making; high-demand case overflow, critical care, shift work, organisational systems, case complexity and interdisciplinary teamwork on a macro- and micro-level may impact operator accuracy.<sup>20,21</sup> The increased use of ED CT, as much as 80% over a 10-year period, highlights this as a modality in high-demand.<sup>21</sup>

## Over-scanning Dose Implications

CT scan extent is directly proportional to patient radiation dose.<sup>7</sup> Proportionally decreasing the DLP with the associated reduction of tissues irradiated in scan extent exemplifies the ALARA principle.<sup>9,11,22</sup> Achieving high-quality diagnostic imaging in conjunction with low dose is the main goal.<sup>11,13</sup> Using low DLPs, although reducing exposure to patients, may result in higher image noise and may be detrimental in ED, where alternative diagnoses are common and may result in repeat scans.<sup>5,12</sup>

A phantom study by Badawy et al. demonstrated a 15% increased effective dose with 10 cm of CT chest, abdomen and pelvis over-scanning, including a greater effective dose when scanning through radio-sensitive organs.<sup>8</sup> Hence, the consequences of over-scanning may differ according to region.<sup>8</sup> Female radiation-sensitive gonads are exposed in CTKUBs; however, minimising over-scanning superiorly can reduce the effective dose to breast and lung tissue.<sup>1,9</sup> Similarly for males, lung tissue exposure can be minimised, and inferiorly, direct gonad exposure can be avoided with accurate scanning.<sup>1,9</sup>

Multiple abdominal organs will also be unnecessarily irradiated if over-scanning occurs. This research highlights a dose increase of up to ~ 35% DLP more than the standard tolerance protocol DLP when over-scanning up to 20 cm superiorly, and a ~ 45% DLP dose increase for over-scanning up to 10 cm inferiorly, highlighting a greater dose increase for over-scanning inferiorly due to anatomical density differences (Figs. 2 and 3). This confirms the importance of scan extent reduction in dose minimalisation.

## Clinical Suggestions for Greater Compliance to Scan Extent

Education addressing current CT scan range extension in one body region<sup>8</sup> and operator surveys,<sup>18</sup> combined with periodical clinical audits<sup>11</sup> (using a simplified audit tool), is known to create reductions in radiation dose and strengthening of clinician standards.<sup>23-28</sup> Another study by Badawy et al. noted a 15% reduction rate in the frequency of CT neck over-scanning, a 33% reduction in the average CT over-scanning extent and a 20% dose

reduction globally, following education on radiation awareness and dose optimisation targeting neck CT.<sup>19</sup> If results of a clinical re-audit are unsatisfactory, protocol review is suggested.

Trialling and implementing anatomical landmarks is a suitable approach to ensuring adequate and reproducible renal inclusion with minimal over-scanning. Existing literature currently suggests the use of the 10th or 11th thoracic vertebra as easily identifiable landmarks that guarantee renal inclusion and substantially reduce dose from over-scanning delivered to the patient.<sup>4,9,14,15</sup> Trialling, implementing and re-auditing would benefit this department.

Further research into the social, economic, environmental and personal factors that may influence radiographers to increase CT scan extent is warranted. CT scan extent minimisation is a costless, efficient and easy dose-reduction strategy, simply requiring education, trialling and auditing.<sup>2,12,15</sup> Miglioretti et al.<sup>26</sup> saw a 56% to 100% increase in the attitude of CT radiographers who 'always think about radiation dose when imaging a patient' post intervention.

Limitations of this study include a single assessor, assessment of a single area (CTKUB), site and the direction of scanning not being identified; however, this does allow for consistency in protocol and assessment through the use of a reproducible audit tool. Patient demographics and *P*-values were not collected, as this was independent to the aims of this study, however, may benefit future research.

Additionally, a moderately small sample size was assessed; however, the eight-month retrospective analysis allows for a cross-section of radiographers to be audited. Lastly, the compliance per region was measured at a data point level; hence, all 150 superior and 150 inferior measurements were independent and not representative of a total patient-specific CT scan extent error (cm) and total extra dose (DLP). The phantom study dose results do not offer patient-specific calculations or body habitus variations, but dose estimates do offer insight into trends of notable DLP increases with over-scanning, implying the importance of scan extent accuracy for patient radiation safety.

## Conclusion

In this retrospective clinical audit of 150 consecutive CTKUB scans in a large tertiary hospital, only 8 cases (5.3%) demonstrated accurate CT scan extent both superiorly (kidneys) and inferiorly (pubic symphysis), whilst 142 cases (94.7%) contained some form of non-compliance as per the department protocol. Additionally, the PBU40 phantom study discovered that over-scanning

1 to 20 centimetres beyond the kidneys (beyond protocol tolerance) equates to a ~ 2% to 35% extra dose (DLP) to the patient and inferiorly 1 to 10 centimetres beyond the pubic symphysis equates to a ~ 1% to 45% extra dose (DLP) than the standard tolerance protocol DLP. This research emphasises the need for periodical clinical audits of CT scan extent and result dissemination, to ensure patient radiation safety, dose optimisation and continual practice refinement.

## Conflict of Interest

The authors have no conflict to declare.

## References

1. Patatas K, Panditaratne N, Wah TM, Weston MJ, Irving HC. Emergency department imaging protocol for suspected acute renal colic: re-evaluating our service. *Br J Radiol.* 2012; **85**(1016): 1118–22.
2. Nadeem M, Ather MH, Jamshaid A, Zaigham S, Mirza R, Salam B. Rationale use of unenhanced multi-detector CT (CT KUB) in evaluation of suspected renal colic. *Int J Surg.* 2012; **10**(10): 634–7.
3. Lew H-BM, Seow JH-S, Hewavitharana CP, Burrows S. Alternatives to the baseline KUB for CTKUB-detected calculi: evaluation of CT scout and average and maximum intensity projection images. *Abdom Radiol.* 2017; **42**(5): 1459–63.
4. Uldin H, McGlynn E, Cleasby M. Using the T11 vertebra to minimise the CT-KUB scan field. *Br J Radiol.* 2020; **93**: 20190771.
5. Xiang H, Chan M, Brown V, Huo Y, Chan L, Ridley L. Systematic review and meta-analysis of the diagnostic accuracy of low-dose computed tomography of the kidneys, ureters and bladder for urolithiasis. *JMIRO.* 2017; **61**(5): 582–90.
6. Drake T, Jain N, Bryant T, Wilson I, Somani BK. Should low-dose computed tomography kidneys, ureter and bladder be the new investigation of choice in suspected renal colic?: A systematic review. *Indian J Urol.* 2014; **30**(2): 137–43.
7. Jo H, Buckley B. Assessment of referral patterns for CT KUB in a tertiary setting. *J Med Imaging Radiat Oncol* 2009; **53**(6): 516–21.
8. Badawy MK, Galea M, Mong KS, U P. Computed tomography overexposure as a consequence of extended scan length. *J Med Imaging Radiat Oncol* 2015; **59**(5): 1754–9485.
9. Gervaise A, Teixeira P, Hossu G, Blum A, Lapierre-Combes M. Optimizing z-axis coverage of abdominal CT scans of the urinary tract: A proposed alternative proximal landmark for acquisition planning. *Br J Radiol.* 2016; **89**(1067).

10. Schwartz F, Stieltjes B, Szucs-Farkas Z, Euler A. Over-scanning in chest CT: Comparison of practice among six hospitals and its impact on radiation dose. *Eur J Radiol.* 2018; **102**: 49–54.
11. Trattner S, Pearson GDN, Chin C, et al. Standardization and Optimization of CT Protocols to Achieve Low Dose. *J Am Coll Radiol.* 2014; **11**(3): 271–8.
12. Thaker A, Navadeh S, Gonzales H, Malekinejad M. Effectiveness of Policies on Reducing Exposure to Ionizing Radiation From Medical Imaging: A Systematic Review. *J Am Coll Radiol.* 2015; **12**(12): 1434–45.
13. ARPANSA. Fact Sheet – CT Imaging and Children: Australian Radiation and Nuclear Safety Agency. 2015. [Available from: <https://www.arpana.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/ct-imaging-and-children>]. Accessed on 16 November 2017.
14. Corwin MTCM, Fananapazir G, Seibert A, Lamba R. Accuracy and radiation dose reduction of a limited abdominopelvic CT in the diagnosis of acute appendicitis. *Abdom Imaging.* 2015; **40**(5): 1177–82.
15. De Leon AD, Xi Y, Champine J, Costa DN. Achieving Ideal Computed Tomographic Scan Length in Patient With Suspected Urolithiasis. *J Comput Assist Tomogr.* 2014; **38**(2): 264–7.
16. The Royal Australian and New Zealand College of Radiologists. CT Image Review Self-Audit Worksheet (n.d.). Retrieved from <https://www.ranzcr.com/college/document-library/ct-image-review-self-audit-worksheet>. Accessed on 15 February 2018.
17. Zanca F, Demeter M, Oyen R, Bosmans H. Excess radiation and organ dose in chest and abdominal CT due to CT acquisition beyond expected anatomical boundaries. *Eur Radiol.* 2012; **22**(4): 779–88.
18. Schegerer AA, Nagel H-D, Stamm G, Adam G, Brix G. Current CT practice in Germany: Results and implications of a nationwide survey. *Eur Radiol.* 2017; **90**: 114–28.
19. Badawy MK, Lane H, Galea M. Radiation Dose Associated with Over Scanning in Neck CT. *Curr Probl Diagn Radiol.* 2019; **48**(4): 359–362.
20. Zavala A, Day G, Plummer D, Bamford-Wade A. Decision-making under pressure: medical errors in uncertain and dynamic environments. *Aust Health Rev.* 2018; **42**(4): 395–402.
21. Bellolio MF, Heien HC, Sangaralingham LR, et al. Increased Computed Tomography Utilization in the Emergency Department and Its Association with Hospital Admission. *Western Journal of Emergency Medicine.* 2017; **18**(5): 835–45.
22. Wallace AB, Goergen SK, Schick D, Soblusky T, Jolley D. Multidetector CT dose: Clinical practice improvement strategies from a successful optimization program. *J Am Coll Radiol.* 2010; **7**(8): 614–24.
23. Oliveri A, Howarth N, Gevenois PA, Tack D. Short- and long-term effects of clinical audits on compliance with procedures in CT scanning. *European Society of Radiology.* 2015; **26**: 2663–8.
24. Rodrigues JCL, Negus IS, Manghat NE, Hamilton MCK. A completed audit cycle of the lateral scan projection radiograph in CT pulmonary angiography (CTPA); the impact on scan length and radiation dose. *Clin Radiol.* 2013; **68**(6): 574–9.
25. Patel DC, Huang Y-h, Meyer J, Sepahdari A. Abdominal-pelvic scanning parameters revisited: a case for Z-axis reduction in patients with clinical suspicion for acute appendicitis. *American Society of. Emerg Radiol.* 2017; 1–6.
26. Miglioretti DL, Zhang Y, Johnson E, et al. Personalized technologist dose audit feedback for reducing patient radiation exposure from CT. *J Am Coll Radiol.* 2014; **11**(3): 300–8.
27. Tack D, Jahnen A, Kohler S, et al. Multidetector CT radiation dose optimisation in adults: short- and long-term effects of a clinical audit. *European Society of Radiology.* 2013; **24**: 169–75.
28. Hojreh A, Weber M, Homolka P. Effect of staff training on radiation dose in pediatric CT. *Eur Radiol.* 2015; **84**(8): 1574–8.