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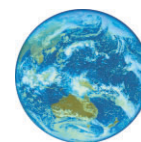
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Low-dose computed tomography versus plain abdominal radiography in the investigation of an acute abdomen

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Key words

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Introduction

Plain abdominal radiography (AR) has long been considered the primary imaging investigation in patients presenting with acute abdominal pain. However, it is now accepted that AR has significant limitations, including poor diagnostic yield and accuracy.¹⁻⁴ Recently, abdominal computed tomography (CT) has gained interest as a possible substitute for AR with studies demonstrating superior sensitivity and specificity^{5,6} and improved diagnostic certainty.⁷ However, the major disadvantage of CT compared to AR is the increased radiation dose and its associated risk of cancer.⁸ In view of this, low-dose CT (LDCT) has been suggested as a replacement, and based on a limited number of observational⁹ and non-randomized

Abstract

Background: To compare low-dose abdominal computed tomography (LDCT) with plain abdominal radiography (AR) in the primary investigation of acute abdominal pain to determine if there is a difference in diagnostic yield, the number of additional investigations required and hospital length of stay (LOS).

Methods: This randomized controlled trial was approved by the institutional review board, and informed consent was obtained. Patients presenting to the emergency department with an acute abdomen and who would normally be investigated with AR were randomized to either AR or LDCT. The estimated radiation dose of the LDCT protocol was 2–3 mSv compared to 1.1 mSv for AR. Pearson's chi-square and the independent samples *t*-test were used for the statistical analysis.

Results: A total of 142 patients were eligible, and after exclusions and omitting those with incomplete data, 55 patients remained for analysis in the AR arm and 53 in the LDCT arm. A diagnosis could be obtained in 12 (21.8%) patients investigated with AR compared to 34 (64.2%) for LDCT ($P < 0.001$). Twenty-eight (50.9%) patients in the AR group required further imaging during their admission compared to 14 (26.4%) in the LDCT group ($P = 0.009$). There was no difference in the median hospital LOS (3.84 days for AR versus 4.24 days for LDCT, $P = 0.83$).

Conclusion: LDCT demonstrates a superior diagnostic yield over AR and reduces the number of subsequent imaging tests for a minimal cost in radiation exposure. However, there is no difference in the overall hospital LOS between the two imaging strategies.

studies,¹⁰ some only reported in abstract form;¹¹ the benefits over AR appear to be maintained. We aimed to compare LDCT and AR in patients presenting to the emergency department with an 'acute abdomen' to determine if there are differences in diagnostic yield and accuracy as well as in the required number of additional investigations and length of hospital stay.

Method

This was a randomized controlled trial conducted at a tertiary level, university teaching hospital with close to 700 beds in Perth, Western Australia. The trial was approved by the institutional ethics committee. All patients with an acute abdomen deemed to require plain AR

and attending the emergency department between May and December 2008 during the hours of 8 am and 5 pm were eligible. An acute abdomen was defined as a severe and rapidly developing abdominal pain requiring urgent medical or surgical treatment. This study considered conditions such as suspected bowel obstruction or ileus, suspected perforated abdominal viscus, ingested foreign body and severe generalized abdominal pain requiring opioid analgesia where AR is usually indicated. The daytime recruitment period was chosen to allow rapid access to CT services to assist with the smooth running of the trial. Patients with clinically suspected appendicitis, acute cholecystitis, pancreatitis, renal colic, gynaecological pathology and uncomplicated constipation, which are not conventional indications for AR, were excluded. Patients with a history of abdominal surgery in the previous 6 weeks, those younger than 18 years of age and pregnant women were also not eligible.

A block randomization schedule with a block size of 6 was used. The randomization sequence was determined using a random numbers table and allocation was concealed through the use of sequentially numbered, opaque sealed envelopes. Emergency department staff, who were unaware of the randomization sequence, invited all eligible patients to participate and, after obtaining informed consent, assigned recruited patients according to the allocation number contained in the next consecutive envelope. Patients were randomized to either unenhanced low-dose abdominal CT (LDCT) or the standard hospital plain AR protocol.

LDCT was performed extending from the diaphragm to the symphysis pubis without oral or intravenous contrast using a Philips Brilliance 64 multidetector scanner (Philips Medical Systems, Cleveland, MA, USA) with the following settings: collimation 64×0.625 mm, 1.1 cm/s table movement per gantry rotation, 120 kV and 64 mAs for patients with a body mass index (BMI) of 30 or less (estimated radiation dose of 2 mSv) and 96 mAs for a BMI of greater than 30 (estimated radiation dose of 3 mSv). CT exams were reconstructed using axial images at 4-mm intervals. Plain radiographs were obtained with a Philips Bucky Diagnost TH (Philips Medical Systems). The radiography protocol consisted of four radiographs: an erect and two supine anterior–posterior projections to cover the abdomen from the diaphragm to the symphysis pubis (35×43 cm cassette, 16 mAs, 81 kV) and an erect anterior–posterior projection of the chest (35×43 cm cassette, 20 mAs, 125 kV) with a total estimated radiation dose of 1.1 mSv for the average 70-kg patient. Patients randomized to either group were not denied subsequent access to standard dose CT with or without contrast enhancement if this was clinically indicated. All exams were reported by consultant radiologists or registrars as soon as possible following their completion.

The primary outcome measure for this trial was the difference in diagnostic yield between the two imaging strategies. Secondary end points included differences in diagnostic accuracy, the proportion requiring further imaging and the median hospital length of stay (LOS). We estimated that a diagnosis would be obtained in 50% of those in the LDCT group compared to 20% for those in the AR group based on previous studies.⁵ With a power of 0.9 to detect this difference and a type I error rate of 0.05, a required sample size of 50 was calculated for each arm. This was increased to 60 to account for participants with incomplete data. Patient demographics, subsequent

imaging investigations during the admission and LOS were obtained from the medical records. For the analysis of sensitivity and specificity, the final discharge diagnosis as stated in the medical records was accepted as the reference standard. Data were analysed on an intention-to-treat basis.

Pearson's chi-square and Fisher's exact test were used to assess for differences in proportions and the independent samples *t*-test and Mann–Whitney *U*-test were used for differences in means and medians. Two-sided significance was determined at the 5% level. The analysis was performed using the Statistical Package for the Social Sciences (SPSS, version 17.0, Chicago, IL, USA).

Results

A total of 142 patients were eligible for the study, of which 18 were excluded for not meeting the entry criteria or other reasons such as previous enrolment in the trial (Fig. 1). Of the remaining 124 patients, 60 were randomized to AR and 64 to LDCT. Two patients allocated to LDCT were inadvertently investigated with AR but were analysed as part the LDCT group. There were five patients with incomplete data in the AR arm and 11 in the LDCT arm, leaving a total of 55 and 53 patients, respectively, for each arm. The baseline characteristics of the two groups were similar and are summarized in Table 1.

The most common clinical diagnoses suspected in the emergency department in both arms were bowel obstruction (46/55 (83.6%) for AR, 43/53 (81.1%) for LDCT) and pneumoperitoneum or perforated viscus (6/55 (10.9%) for AR, 6/53 (11.3%) for LDCT). The median time from the first medical consultation to the allocated imaging investigation was 1.52 h (interquartile range

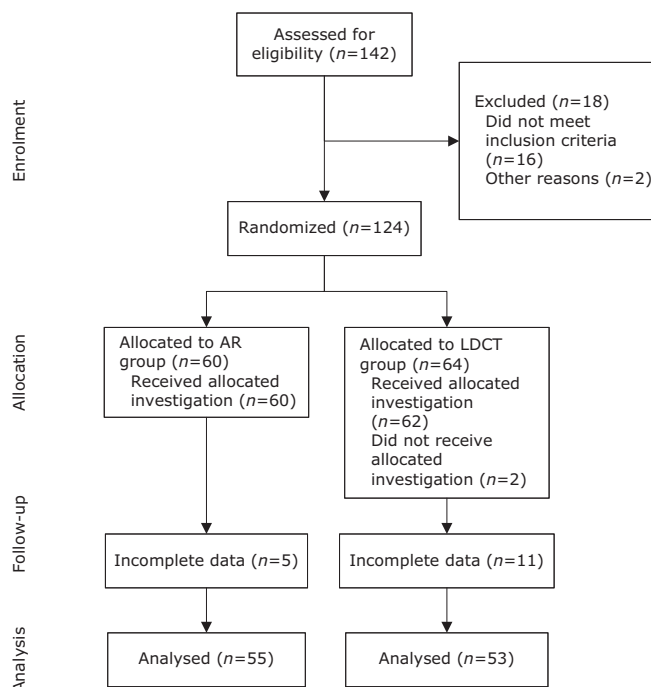


Fig. 1. Flow of participants through each stage of clinical trial. AR, abdominal radiography; LDCT, low-dose computed tomography.

Table 1 Comparison of baseline characteristics of the plain radiography and low-dose CT groups of randomized controlled trial

	Plain radiography (AR) (n = 55)	Low-dose CT (LDCT) (n = 53)	Statistical significance
Males	28 (50.9%)	27 (50.9%)	<i>P</i> = 0.99
Age (years, mean ± SD)	59.9 ± 20.7	63.6 ± 17.8	<i>P</i> = 0.33
Clinical diagnosis			<i>P</i> = 0.90
Bowel obstruction	46 (83.6%)	43 (81.1%)	
Perforated viscus	6 (10.9%)	6 (11.3%)	
Other	3 (5.5%)	4 (7.6%)	
Time to exam† (hours, median, IQR)	0.92 (0.70–1.47)	1.52 (1.21–2.69)	<i>P</i> < 0.001
Number requiring further imaging	28 (50.9%)	14 (26.4%)	<i>P</i> = 0.009
Number admitted	42‡ (76.4%)	41‡ (77.4%)	<i>P</i> = 0.90
Length of stay (days, median, IQR)	3.84 (0.54–9.90)	4.24 (1.28–8.02)	<i>P</i> = 0.83

†From first medical consultation in emergency department.

‡Includes two patients in AR arm and one in LDCT arm who self-discharged against medical advice. IQR, interquartile range; SD, standard deviation.

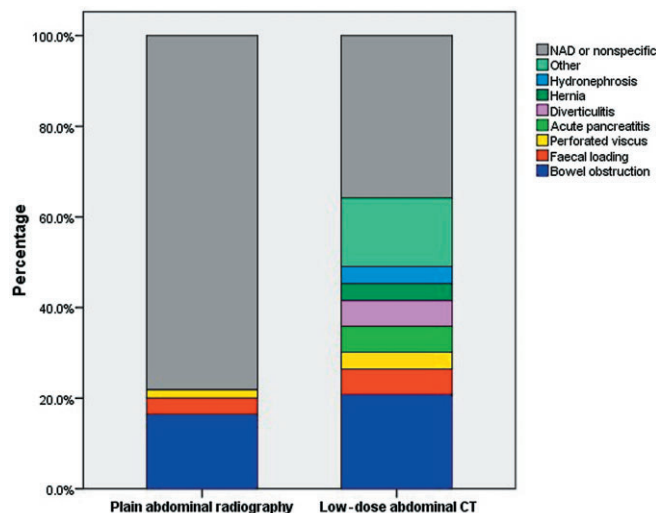


Fig. 2. Reported diagnoses in the two arms of randomized controlled trial. NAD, no abnormality discovered.

(IQR 1.21–2.69) for LDCT and 0.92 h (IQR 0.70–1.47) for AR (*P* < 0.001). All scans were performed within 5 h of the patient being seen by a physician.

Of those investigated with AR, a diagnosis was obtained in 12 (21.8%) patients, which included nine (16.4%) cases of bowel obstruction, two (3.6%) of faecal loading and one (1.8%) of pneumoperitoneum. Of the nine patients with bowel obstruction, seven involved the small bowel (all with no identifiable cause on AR) and two involved the large bowel (one due to a sigmoid volvulus and the other with no definite cause). The remainder in the AR arm were reported as normal or as non-specific findings such as non-specific bowel gas patterns or non-specific abdominal calcifications. In comparison, there was a significantly higher diagnostic yield (*P* < 0.001) in the LDCT group where a diagnosis could be determined in 34 (64.2%) patients including 11 (20.8%) cases of bowel obstruction, three (5.7%) of diverticulitis and three (5.7%) of acute pancreatitis (Fig. 2). Of the 11 patients with bowel obstruction, nine involved the small bowel (two due to strictures and seven with no cause identified but likely due to post-surgical adhesions) and two involved the large bowel (one due to a caecal volvulus and the other due to an obstructing sigmoid mass). Of the remaining 19 (35.8%) cases in the LDCT

arm which were reported as either normal or non-specific findings, only six had a diagnosis at discharge including one patient who was randomized to LDCT but was erroneously investigated with AR (Fig. 3). Considering only the subgroup where bowel obstruction was clinically suspected, the proportion of diagnostic studies with LDCT (27/43, 62.8%) compared to AR (11/46, 23.9%) was also significantly higher (*P* < 0.001).

Using the final discharge diagnosis as the reference standard, the sensitivity of LDCT for the diagnosis of bowel obstruction was 81.8% (95% confidence interval (CI) 51.2–96.0%) compared to 62.5% (30.4–86.5%) for AR (*P* = 0.60). The specificity of LDCT was 92.9% (95% CI 80.3–98.2%) and that of AR was 91.5% (79.5–97.2%, *P* = 0.81). Other discharge diagnoses were not considered in the analysis due to the low numbers in the study sample.

Patients were more likely to require further imaging investigations with AR. Thirty-two subsequent investigations for 28 (50.9%) patients were required in this group including 22 (68.8%) standard-dose CT scans, six (18.8%) ultrasounds and four (12.5%) repeat abdominal radiographs. In comparison, only 14 additional tests for 14 (26.4%, *P* = 0.009) patients were required for those initially investigated with LDCT including seven (50.0%) standard-dose CT scans and seven (50.0%) ultrasounds. The mean number of additional tests per patient was 0.58 (95% CI 0.40–0.76) for the AR group compared to 0.26 (95% CI 0.14–0.39) for the LDCT group (*P* = 0.004) (Fig. 4). The mean estimated radiation dose for the AR group was 5.18 mSv (95% CI 3.86–6.50) compared to 3.53 mSv (95% CI 2.57–4.49) for the LDCT group (*P* = 0.046) assuming that the approximate radiation dose from a conventional CT of the abdomen in an adult is commonly quoted at 10 mSv.¹²

When considering hospital LOS, the median duration for patients investigated with AR (3.84 days, IQR 0.54–9.90) was slightly shorter than for LDCT (4.24 days, 95% CI 1.28–8.02). However, the difference was not statistically significant (*P* = 0.83).

Discussion

Acute abdominal pain is a common clinical presentation to emergency departments and medical imaging is an integral component of the diagnostic work-up of the patient. Plain AR, being simple to perform with relatively low cost, has traditionally been the preferred initial modality. However, current evidence indicates that AR is

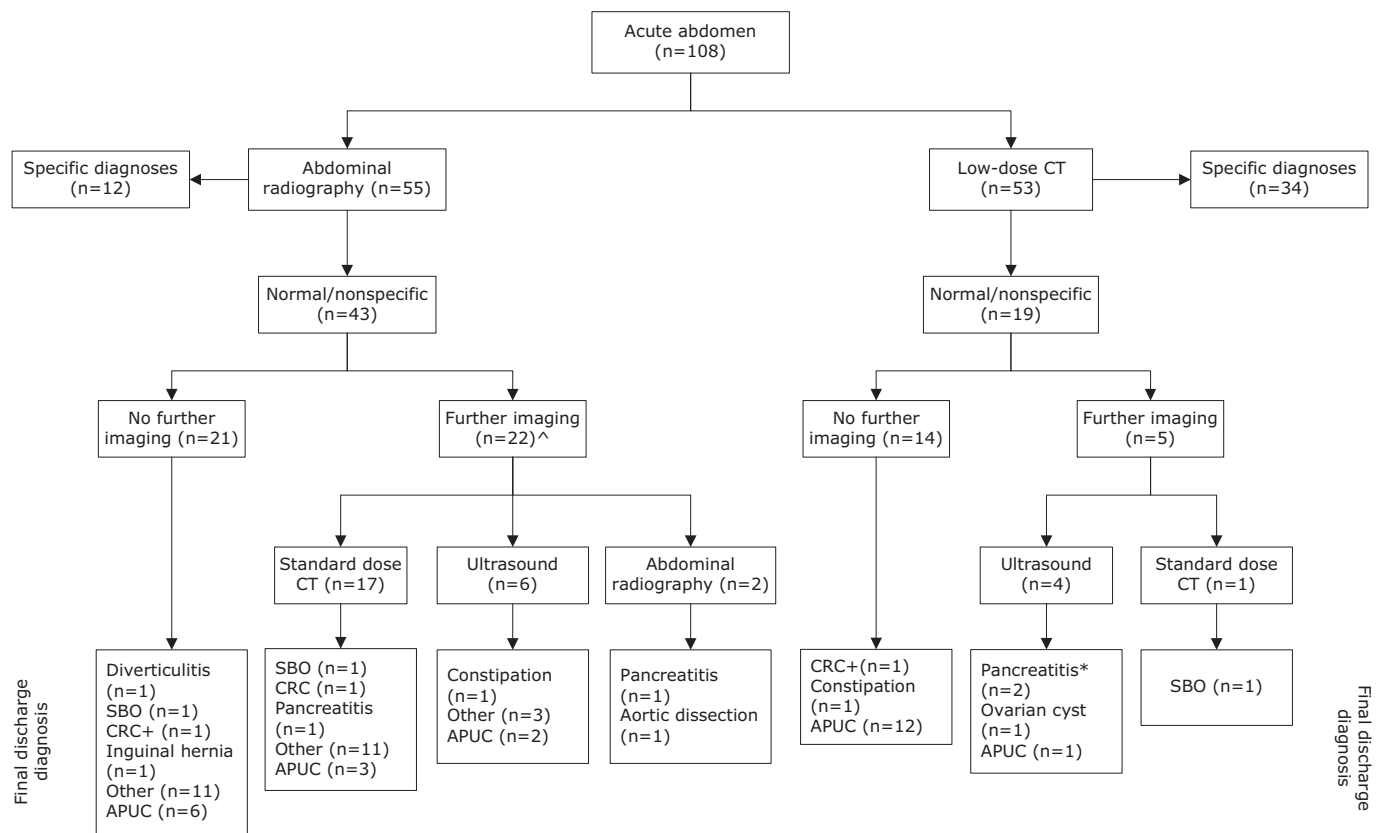


Fig. 3. Summary of further investigations and final diagnoses of patients with normal or non-specific findings on low-dose CT or plain abdominal radiography. ^Includes patients with multiple further imaging tests. *Diagnosed at surgery. *Randomized to LDCT but investigated with plain radiography (intention-to-treat analysis). SBO, small bowel obstruction; CRC, colorectal carcinoma; APUC, abdominal pain of uncertain cause.

significantly limited by poor diagnostic yield (as little as 10% in some series),²⁻⁴ low accuracy for common clinical conditions^{2,4,13} and poor interobserver agreement.¹⁴ In the past decade, several studies have investigated the use of abdominal CT as a replacement for AR and results have been promising, with some showing a higher diagnostic accuracy and certainty,^{5-7,9} improved efficiency in clinical management,^{7,15} reduced hospital admissions,¹⁵ improved cost-effectiveness⁹ and even reduced mortality.¹⁶

The principal disadvantage of abdominal CT, however, is the higher ionizing radiation dose which is estimated at approximately 15 mSv (15 times the dose of AR or the equivalent of 5 years of natural background radiation).⁸ In Australia, the number of CT services in the last decade has increased by more than 140%¹⁷ and it is suspected that up to 430 new cases of cancer annually nationwide can be attributed to medical imaging.¹⁸ Therefore, replacing plain radiography with CT for a clinical condition as common as acute abdominal pain must necessarily consider the potential adverse effects of the increased radiation burden.

In response to this, several groups of authors have recently investigated the use of LDCT as a means of restricting emitted radiation. The prospective study by Udayasankar *et al.* demonstrated preserved diagnostic accuracy for common conditions associated with acute abdominal pain while achieving up to 78% reduction in mean radiation dose.¹⁰ The retrospective study by Haller *et al.* showed similar findings.⁹ However, both were non-randomized in design

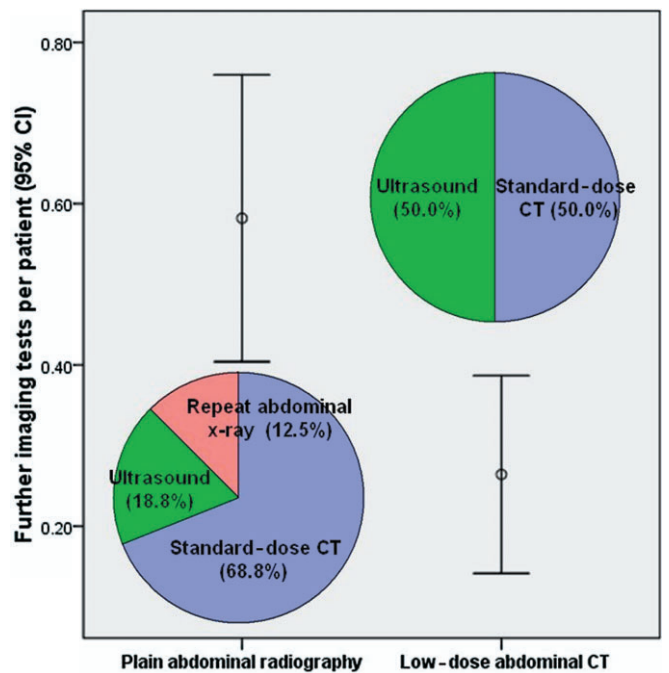


Fig. 4. Comparison of mean number of further imaging investigations required per patient during their hospital admission and pie charts of specific tests performed.

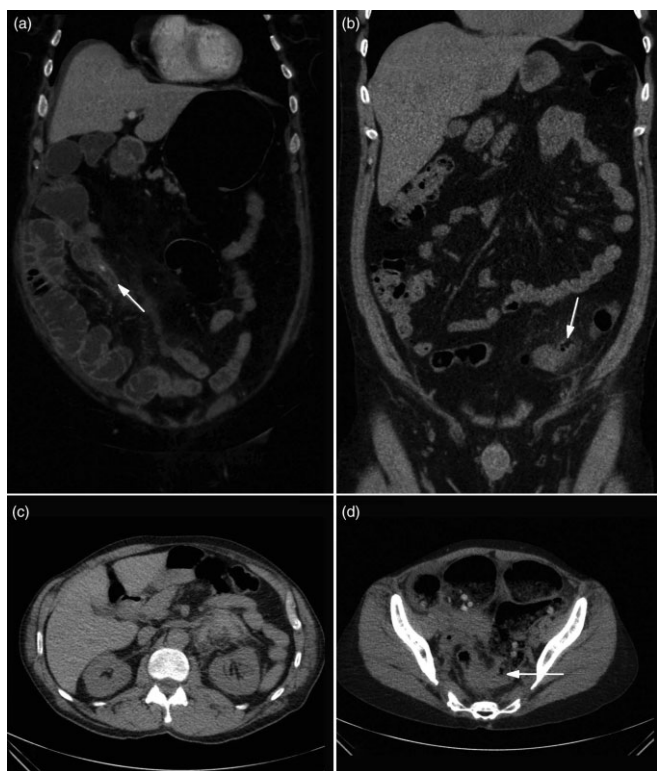


Fig. 5. Examples of images obtained from low-dose CT protocol showing (a) acute appendicitis with appendicolith (arrow); (b) sigmoid diverticulitis with localized perforation (arrow); (c) left adrenal haemorrhage with probably underlying mass; and (d) sigmoid mass lesion (arrow).

with no concurrent comparator group. Ours represents the first randomized controlled trial directly comparing the use of LDCT with AR for the assessment of an acute abdomen. We restricted the population to those who would normally be investigated with AR for conditions such as suspected bowel obstruction and perforated viscus to reflect current clinical practice. The calculated radiation dose from our LDCT protocol was estimated to be between 2 to 3 mSv which is two to three times greater than the 1.1 mSv associated with our three film AR series. Compared with the radiation dose of a standard abdominal CT which is generally regarded as 10 mSv,¹² our LDCT protocol gives three to five times less radiation.

Our results indicate that despite the expected deterioration in acquired images from the reduced radiation dose, LDCT exams remain of sufficient diagnostic quality, producing a superior yield compared to AR (64.2% versus 21.8%, $P < 0.001$), with only a slight increase in radiation dose (Figs 2,5). Even when exclusively considering the subset of patients with clinically suspected bowel obstruction where AR has been shown to be of particular benefit,¹⁴ the proportion of informative studies was again significantly higher for LDCT (62.8% versus 23.9%, $P < 0.001$). Of the remaining patients with normal or non-specific findings on LDCT, six (31.6%) were discharged with a specific diagnosis which included one case of constipation which is predominantly a clinical diagnosis and another who was allocated to LDCT but erroneously investigated with AR (Fig. 3). Therefore, only four cases (sigmoid carcinoma, small bowel obstruction, pancreatitis and ovarian cyst confirmed on further tests

or at surgery) can be fairly considered to be false-negatives on primary LDCT.

These findings support those of the retrospective study of Ahn *et al.* where 80% of patients investigated with conventional CT obtained a diagnosis for their acute abdominal pain compared to only 10% for AR.⁵ Although a greater yield was observed for the standard-dose CT protocol used in this study, it is difficult to draw definitive conclusions as their population differed from ours by considering all patients who presented with abdominal pain, not only those requiring AR. Renal stones and hepatobiliary disease represented their most common findings on CT, and both these conditions, if clinically suspected, were not considered in our trial (as they would ordinarily be investigated at our institution with CT kidneys, ureters and bladder (CT-KUB) and ultrasound, respectively). To our knowledge, there are presently no direct comparisons of diagnostic yield between standard-dose CT and LDCT reported in the setting of acute abdominal pain.

The trend in the current literature suggests that abdominal CT has a superior diagnostic accuracy over AR. However, studies do differ in their outcome measures and magnitude of their results. The sensitivity of standard-dose CT for the diagnosis of common conditions associated with acute abdominal pain including bowel obstruction has been shown to be similar¹⁶ or superior^{5,6} to AR. In the retrospective study by Haller *et al.*, the combined standard-dose CT and LDCT group was more sensitive than AR for a similar range of diseases, although there was no significant difference between the two CT protocols.⁹ In our trial, we considered the sensitivity of LDCT and AR for the diagnosis of bowel obstruction, but due to the small representation in our cohort, other conditions were not included. LDCT demonstrated a higher sensitivity for the diagnosis of bowel obstruction (81.8% versus 62.5%), although the difference did not reach statistical significance ($P = 0.60$). However, this may relate to insufficient statistical power to detect a difference of this magnitude, as calculation of our sample size did not consider secondary end points such as diagnostic accuracy.

Our trial also demonstrated that the use of LDCT significantly reduces the number of subsequent imaging investigations required during a patient's admission. The number of participants requiring further tests after their LDCT was approximately half that in the AR group (26.4% versus 50.9%, $P = 0.009$) and the mean number of tests per patient was significantly lower following LDCT (0.26 versus 0.58, $P = 0.004$) (Fig. 4). These results support those of previous observational studies which have shown similar reductions in the number of patients requiring additional investigations.⁹ Although a specific cost-benefit analysis was beyond the scope of our trial, the findings indicate potential significant improvements in the efficient use of imaging resources and reductions in cost and time with the primary use of LDCT for acute abdominal pain.

Interestingly, the median LOS for those investigated with LDCT was slightly longer than the AR group (4.24 versus 3.84 days). However, the difference was not of statistical significance. Other authors have similarly demonstrated no difference in LOS between standard-dose CT and AR in the setting of an acute abdomen.^{16,19} Therefore, although primary CT reduces the number of additional investigations required and possibly leads to an earlier definitive diagnosis, these benefits appear to be offset by other factors.

Clinicians may not be as confident in acting on their own interpretation of CT exams as with plain radiography, and therefore, decisions in clinical management may need to await the radiologist's report. Waiting times for CT services are unlikely to be responsible, as despite the statistically longer delays in the LDCT arm in our trial (1.52 h for LDCT versus 0.92 h for AR, $P < 0.001$), the difference in medians of 36 min is clinically unimportant. It may also be that early management in patients investigated with AR is guided more heavily by the clinical diagnosis which helps compensate for the shortcomings of plain radiography.

There were several limitations to this trial. Although the radiation dose associated with our LDCT protocol was assumed to be comparable to AR based on theoretical considerations, actual measurements of the emitted radiation were not performed to confirm these assumptions. This may need to be determined prior to widespread substitution of AR with LDCT for a common clinical presentation such as an acute abdomen. For the calculation of diagnostic accuracy, the reference standard used in the study was the discharge diagnosis from the medical record. Ideally, longer-term follow-up would be more reliable as some conditions may not manifest completely and therefore be correctly diagnosed several months following the initial presentation. This trial was also specifically powered to detect a difference in diagnostic yield between LDCT and AR which was the main outcome of interest. The sample size may not have been sufficient to assess secondary end points such as differences in sensitivity and specificity as well as hospital LOS. The restricted sample also meant that other clinical conditions such as pancreatitis and diverticulitis could not be meaningfully considered in the measurement of diagnostic accuracy. Finally, several other important outcomes were not included in this study which might need to be addressed in a trial setting prior to the widespread implementation of routine LDCT for acute abdominal pain. These include, but are not limited to, time to definitive diagnosis, changes to clinical management and cost-benefit analyses.

In summary, our randomized controlled trial confirms the superior diagnostic yield of primary LDCT compared to plain AR in the investigation of acute abdominal pain. LDCT also significantly reduces the number of additional imaging tests required during the patient's admission. However, despite these benefits, this does not appear to translate to a shorter hospital LOS.

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