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FULL PAPER

# Application of 80-kVp scan and raw data-based iterative reconstruction for reduced iodine load abdominal–pelvic CT in patients at risk of contrast-induced nephropathy referred for oncological assessment: effects on radiation dose, image quality and renal function

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**Objective:** To evaluate the image quality, radiation dose, and renal safety of contrast medium (CM)-reduced abdominal–pelvic CT combining 80-kVp and sinogram-affirmed iterative reconstruction (SAFIRE) in patients with renal dysfunction for oncological assessment.

**Methods:** We included 45 patients with renal dysfunction (estimated glomerular filtration rate <45 ml per min per 1.73 m$^2$) who underwent reduced-CM abdominal–pelvic CT (360 mgI kg$^{-1}$, 80-kVp, SAFIRE) for oncological assessment. Another 45 patients without renal dysfunction (estimated glomerular filtration rate >60 ml per lmin per 1.73 m$^2$) who underwent standard oncological abdominal–pelvic CT (600 mgI kg$^{-1}$, 120-kVp, filtered-back projection) were included as controls. CT attenuation, image noise, and contrast-to-noise ratio (CNR) were compared. Two observers performed subjective image analysis on a 4-point scale. Size-specific dose estimate and renal function 1–3 months after CT were measured.

**Results:** The size-specific dose estimate and iodine load of 80-kVp protocol were 32 and 41%,, respectively, lower than of 120-kVp protocol ($p < 0.01$). CT attenuation and contrast-to-noise ratio of parenchymal organs and vessels in 80-kVp images were significantly better than those of 120-kVp images ($p < 0.05$). There were no significant differences in quantitative or qualitative image noise or subjective overall quality ($p > 0.05$). No significant kidney injury associated with CM administration was observed.

**Conclusion:** 80-kVp abdominal–pelvic CT with SAFIRE yields diagnostic image quality in oncology patients with renal dysfunction under substantially reduced iodine and radiation dose without renal safety concerns.

**Advances in knowledge:** Using 80-kVp and SAFIRE allows for 40% iodine load and 32% radiation dose reduction for abdominal–pelvic CT without compromising image quality and renal function in oncology patients at risk of contrast-induced nephropathy.

## INTRODUCTION

Contrast-enhanced abdominal–pelvic CT plays an essential role in screening, diagnosis, and follow up of primary or metastatic neoplasm. However, it requires a relatively large amount of iodinated contrast medium (CM) and a high radiation dose for sufficient depiction of subtle tumours in solid organs.[1–3] As they usually need to undergo repeated CT studies, reduction of radiation dose is crucial to minimise the potential adverse effects of ionizing radiation exposure.[4] Despite recent controversy regarding the causal association between intravenous CM administration and contrast-induced nephropathy (CIN),[5,6] minimizing the iodine dose may also be desirable for oncology patients, because they tend to have multiple risk factors for kidney injury (*e.g.* high prevalence of renal insufficiency and glucose intolerance, receiving nephrotoxic chemotherapy, old age, and dehydration due to anorexia).[7–9]

Low-tube-voltage (kVp) scans with an iterative reconstruction (IR) algorithm constitute an efficient approach for reduction of iodine and radiation doses. The radiation dose is proportional to the square of the tube voltage, and iodine attenuation increases at low-kVp as the mean photon energy approaches the k-edge (33 keV), while the increased quantum mottles that cause problems with filtered back-projection (FBP) could be counterbalanced by using IR. Their utility for radiation and CM doses reduction has been demonstrated primarily in CT angiography (CTA);[10,11] on the other hand, only a few studies have reported on parenchymal organ evaluation such as liver CT, using the different IR algorithms provided by each vendor.[12–15]

Among various IR techniques, sinogram-affirmed iterative reconstruction (SAFIRE, Siemens Healthcare, Forchheim, Germany) utilises both raw data and image data iterations with up to five strength levels available for adaptation of the regularization term to control for image texture and noise reduction. It has been reported to be capable of reducing radiation and iodine doses in CTA by combination with low-kVp (70- or 80-kVp) scans.[10,11] However, whether these techniques can be applied to abdominal–pelvic CT for oncology assessments, which require both high-contrast resolution (*e.g.* to detect the vascular invasions) and sufficient detectability of low-contrast abnormalities (*e.g.* liver or pancreatic tumours), remains to be assessed in *in vivo* clinical research.[16] Additionally, while most investigations on CTA protocols with low-kVp and SAFIRE for iodine and radiation dose reduction were performed using dual-source CT (DSCT) with high-pitch spiral mode,[10,11] there is scant evidence that dose reduction protocols can be applied successfully with the more widely available single-source CT (SSCT) systems.

The maximum dose reduction potential without loss of diagnostic performance depends on diagnostic task[17–19] and IR algorithm used.[20,21] The radiation dose for low-contrast diagnostic tasks, such as for the detection of brain or liver lesions, cannot be decreased as much as for high-contrast tasks, such as CTA or CT colonography. This is because even if the objective image noise can be maintained by the IR, the detectability of low-contrast lesions deteriorates at reduced doses,[20–25] and a blurry appearance associated with IR (known as IR-specific artefacts) may also be more problematic in low-contrast diagnostic tasks.[18,19,26] In addition, there are intervendor and interscanner differences in the maximum tube current, the number of X-ray tubes, and the iodine attenuation even at the same kVp settings.[15,27,28] Thus, the clinical efficacy of low-kVp and IR techniques should be carefully evaluated according to these factors. Furthermore, the influence of these techniques on renal safety has been scantly evaluated in patients at risk of CIN, who underwent abdominal–pelvic CT for oncology assessment.[29–31]

The purpose or this study was to evaluate the image quality, radiation dose, and renal safety of reduced iodine dose abdominal–pelvic CT combining 80-kVp and SAFIRE in patients with renal insufficiency for oncology assessment by comparison with those of a conventional 120-kVp protocol performed in patients without renal dysfunction.

## METHODS AND MATERIALS

This retrospective study was approved by institutional review board at Kumamoto City Hospital, and the requirement for written informed consent was waived. All patients had consented to the use of their medical records for research purposes.

### Patients

Our radiology database included 1053 adults who underwent contrast-enhanced abdominal–pelvic CT for malignant tumour screening, diagnosis, or follow up between January 2015 and March 2016. Serum creatinine (SCr) levels and estimated glomerular filtration rate (eGFR) within 3 months before CT were measured in all patients. The eGFR was calculated using the following equation[32]: eGFR (ml per min per 1.73 m$^2$) = 194 × age$^{-0.287}$ × (SCr)$^{-1.094}$ (×0.739 in females)

Among them, we identified 45 patients with decreased baseline renal function (eGFR <45 ml per min per 1.73 m$^2$) and whose SCr and eGFR within 3 months after CT were available. All of them had undergone the 80-kVp protocol as standard care for patients with renal dysfunction at our institution (Kumamoto City Hospital). The control group consisted of the first consecutive 45 patients with eGFR >60 ml per min per /1.73 m$^2$ who underwent our standard oncological 120-kVp protocol during the same period and whose SCr and eGFR within 3 months after CT were available. At the visit to the radiological department, all patients received 100 ml of intravenously administered saline as 30 min infusion during examinations. Patients considered to have elevated risk of kidney injury received additional 200–500 ml infusion of saline before or after the examinations at the discretion of physicians (80-kVp group, $n$ = 43; 120-kVp group, $n$ = 18). Each group's detailed patient demographics are shown in Table 1.

### Scanning parameters and CM infusion protocols

All scans were performed on a 128-slice SSCT system (Definition AS+; Siemens, Forchheim, Germany). The tube current was modulated using automated exposure control (AEC) for each protocol. For the 120- and 80-kVp protocols, scans were performed at 250 and 642 quality reference mAs, respectively. When the automated exposure control system recommended a tube current of more than 642 mA (the scanner's maximum current at 80-kVp), the pitch factor was semiautomatically reduced by the system to counterbalance the insufficient tube current.[33]

In the 120- and 80-kVp protocols, an iodine dose of 600 and 360 mgI kg$^{-1}$, respectively, was delivered over 30 s,[2] followed by a 30 ml saline flush at the same injection rate. We chose a 40% reduction in iodine dose on the basis of phantom studies and previous reports[15] suggesting that increasing the tube voltage from 80 to 120 kVp decreased iodine attenuation by about 40% in our scanner. For all examinations, we used a power injector (Dual shot GX 7; Nemoto-Kyorindo, Tokyo, Japan) to deliver iohexol (Omnipaque-300, Daiichi-Sankyo, Tokyo, Japan), iopamidol (Iopamiron-370; Nihon-Schering, Osaka, Japan), or iomeprol

Table 1. Patient demographics for each protocol

| | 120-kVp protocol | 80-kVp protocol | *p*-value |
|---|---|---|---|
| Age (years) | 62.8 ± 15.4 (30–84) | 78.5 ± 8.6 (53–94) | <0.01[a] |
| Male:female | 19:26 | 23:22 | 0.53[b] |
| Weight (kg) | 55.4 ± 9.2 (35–80) | 55.3 ± 10.6 (34–79) | 1.0[c] |
| Body mass index (kg $m^{-2}$) | 22.2 ± 2.5 (17.0–29.1) | 22.5 ± 3.2 (16.9–32.5) | 0.62[c] |
| Distribution | | | 0.83[b] |
| <18.5 | 5 (11.1) | 6 (13.3) | |
| 18.5–24.9 | 35 (77.8) | 32 (71.1) | |
| 25.0–29.9 | 5 (11.1) | 6 (13.3) | |
| ≥30.0 | 0 (0) | 1 (2.2) | |
| Effective diameter (cm) | 22.5 ± 1.1 (19.2–24.2) | 22.6 ± 1.1 (19.7–24.7) | 0.74[a] |
| Risk factors for kidney injury | | | |
| CT after chemotherapy ≤ 45 days | 6 (13.3) | 14 (31.1) | <0.01[b] |
| Diabetes | 13 (28.9) | 13 (28.9) | 1.0[b] |
| Hypertension | 10 (22.2) | 12 (26.7) | 0.81[b] |
| Indicated disease for abdominal CT | | | 0.07[b] |
| Primary or metastatic liver cancer | 23 (51.1) | 16 (35.6) | |
| Colorectal cancer | 12 (26.7) | 12 (26.7) | |
| Pancreatic cancer | 3 (6.7) | 2 (4.4) | |
| Urinary tract cancer | 2 (4.4) | 6 (13.3) | |
| Uterine cancer | 2 (4.4) | 2 (4.4) | |
| Gastric cancer | 0 (0) | 5 (11.1) | |
| Ovarian cancer | 1 (2.2) | 0 (0) | |
| Gastrointestinal stromal tumour | 0 (0) | 2 (4.4) | |
| Malignant lymphoma | 2 (4.4) | 0 (0) | |

Note. Data are presented as numbers (percentages) or mean ± standard deviation (ranges).
[a]Mann–Whitney *U* test.
[b]Fisher's exact test.
[c]Student's *t*-test.

(Iomeron-350; Eisai, Tokyo, Japan) via an antecubital vein. The contrast agent was selected according to the total iodine mass required for each CT examination (<30 gI: iohexol, $n$ = 49; 30–37 gI: iopamidol, $n$ = 13; >37 gI: iomeprol, $n$ = 28). To minimise the effects of iodine concentration, we used a fixed fractional dose for each protocol (20 and 12 mgI $kg^{-1}$ $s^{-1}$ for the 120- and 80-kVp protocols, respectively). Scan initiation was determined using a bolus tracking technique. A region of interest (ROI) cursor (0.8–2.0 $cm^2$) was placed on the aorta at the L1 vertebral level. Monitoring scans (at 15 and 30 mAs for the 120- and 80-kVp protocols, respectively) began 10 s after the start of CM injection, and the scan was started 55 s after a threshold of 150 Hounsfield unit (HU) was reached. Detailed scanning parameters for each protocol are shown in Table 2.

## Image reconstruction

The 120-kVp images were reconstructed with FBP (B31f), whereas the 80-kVp ones were done with SAFIRE at strength level 3 (I31f, S3) as the standard reconstruction for each protocol during the observation period. We selected the S3 level on the basis of our clinical experiences and studies, which indicated that higher IR strength results in a pixelated, blotchy, plastic image appearance (*i.e.* IR-specific artefacts) and S3 is the preferable setting to obtain well-balanced image quality between appearance and diagnostic performance for reduced dose abdominal CT.[34–36] The slice thickness and interval were both 5 mm for all images.

## Radiation dose measurements

The volume CT dose index ($CTDI_{vol}$) was recorded from the CT-generated patient dose record for each examination, and the size-specific dose estimate (SSDE) was calculated according to patient effective diameter, as measured on the axial images at the midliver level.[37]

## Quantitative image analysis

A board-certified radiologist with 7 years of experience in abdominal CT performed quantitative image analyses. To

Table 2. Scanning parameters and image reconstruction for each protocol

| | 120-kVp protocol | 80-kVp protocol |
|---|---|---|
| Tube voltage (kVp) | 120 | 80 |
| Tube current (QRM) | 250 | 642 |
| Pitch factor | 0.9 | 0.5–0.9 |
| Rotation time (s) | 0.5 | 0.5 |
| Iodine dose (mgI $kg^{-1}$) | 600 | 360 |
| Injection duration (s) | 30 | 30 |
| Bolus tracking trigger (HU) | 150 | 150 |
| Scan delay (s) | 55 | 55 |
| Slice thickness (mm) | 5 | 5 |
| Image reconstruction | FBP (B31f) | SAFIRE (I31f, S3) |

FBP, filtered back-projection; HU, Hounsfield unit; QRM, quality reference mAs; SAFIRE, sinogram-affirmed iterative reconstruction.

measure the attenuation of each object ($ROI_{object}$), circular ROIs were placed on the abdominal aorta, portal vein, liver, spleen, kidney, and erector spinae muscle. Attempts were made to select ROIs of approximately 100 and 25 $mm^2$, respectively, in the aorta and PV. An attempt was also made to maintain a constant ROI area of approximately 80 $mm^2$ in the liver, spleen, kidney and erector spinae muscle (the actual ROI area ranged from 60 to 100 $mm^2$). Visible blood vessels, bile ducts, focal lesions, calcifications, and artefacts were carefully excluded from the ROI measurements. To familiarise the operator with ROI placement, a dedicated training session was provided using five patients not included in this study. To minimise bias from single measurements, an average of two consecutive measurements was used to ensure data reliability. Image noise was defined as the standard deviation (SD) of the value for $ROI_{liver}$. The contrast-to-noise ratio (CNR) was calculated using the following formula:

$$CNR_{object} = (ROI_{object} - ROI_{muscle})/\text{image noise}.$$

### Qualitative image analysis

Two board-certified radiologists with 7 and 9 years of experience in abdominal–pelvic CT independently performed qualitative image analyses using a 4-point scale at the soft-tissue window setting (window level, 50 HU; window width, 280 HU). The CT data sets were randomised, and the radiologists were blind to the acquisition parameters and patient demographics. Image contrast was graded as 1 = undiagnostic, 2 = suboptimal, 3 = average, 4 = excellent. Image noise and IR-specific artefacts were graded as 1 = undiagnostic, 2 = noise or artefacts may influence depiction of adjacent structures or lesions, but still diagnostic, 3 = noise or artefacts are present without interfering with depiction of adjacent structures or lesions, 4 = no noise or artefacts. Finally, overall image quality was graded as 1 = undiagnostic, 2 = suboptimal, 3 = average, 4 = excellent. To familiarise the raters with the scoring system, a training session was provided before evaluation using 10 patients not included in this study. Interobserver disagreements were resolved by consensus to attain the final score.

### Assessment of renal function

The most recent values of SCr and eGFR during the 3 months before CT were considered as the baseline level of renal function. Post-CT renal function was defined as the SCr and eGFR values 1–3 months after CT, and the earliest values were used when multiple data sets were available for a patient. We adapted the standard definition of CIN (a relative ≥25% or an absolute ≥0.5 mg $dl^{-1}$ increase in SCr)[8] to a wider time interval (1–3 months) to assess long-term renal safety.

### Statistical analysis

All numerical values are reported as mean ± SD, and normality of distribution was determined by Kolmogorov–Smirnov tests. Differences in mean values between the protocols with normal and non-normal distributions were determined with the two-tailed independent *t*-test and Mann–Whitney *U* test, respectively. Differences in renal function between before and after CT were compared by paired *t*-tests. Fisher's exact test was used to measure differences between categorical variables. The scale for the Kappa coefficients assessing interrater reliability was: ≤0.20 = poor, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–1.00 = near perfect. Differences of $p < 0.05$ were considered statistically significant. Statistical analyses were performed with the R statistical software package (v. 2.6.1; www.r-project.org/).

## RESULTS

### Iodine load and radiation dose for each protocol

The iodine dose, $CTDI_{vol}$ and SSDE were significantly lower in the 80-kVp than the 120-kVp protocol (iodine load: 19.6 ± 3.5 *vs* 33.2 ± 6.4 gI, $p < 0.01$; $CTDI_{vol}$: 7.3 ± 1.3 mGy *vs* 10.6 ± 1.4 mGy, $p < 0.01$; SSDE: 10.7 ± 1.2 mGy *vs* 15.8 ± 1.6 mGy, $p < 0.01$; Figure 1).

### Quantitative image analysis

The CT attenuation and CNR of the vessels and organs in the 80-kVp images were significantly higher than those in the 120-kVp images ($p < 0.05$), whereas no significant differences in image noise ($p = 0.702$) were observed (Table 3).

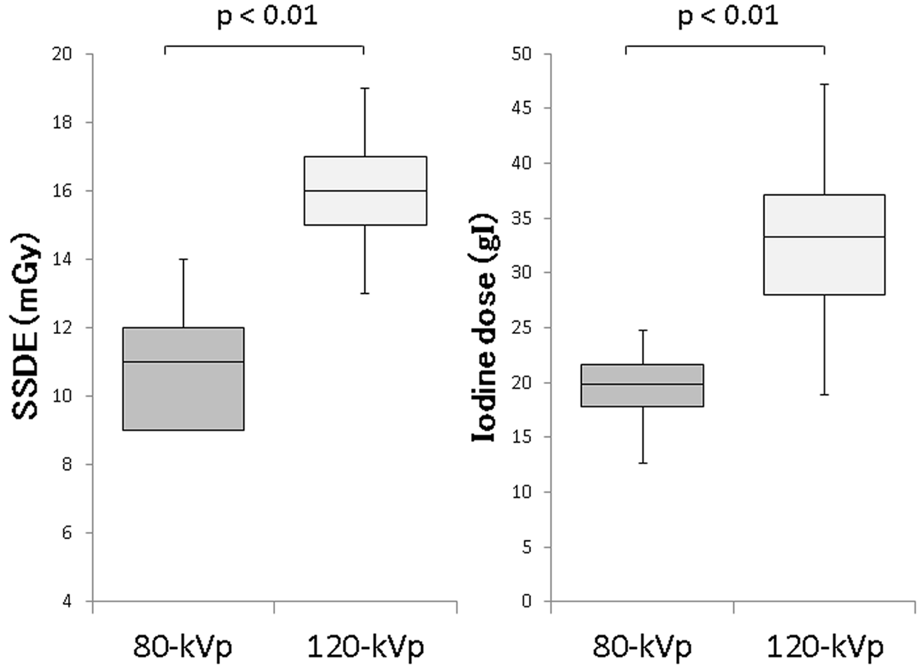
### Qualitative image analysis

The visual contrast of the 80-kVp images was rated as significantly better than that of the 120-kVp images ($p = 0.03$). Although IR-specific artefacts were noted in the 80-kVp images ($p < 0.01$), no cases were rated as suboptimal (score <3). There were no statistically significant differences in image noise or overall image quality between the two protocols ($p = 0.12$ and 0.83, respectively). There was moderate-to-high interobserver agreement for each criterion (0.54–0.71) (Table 4). Representative cases are shown in Figures 2–4.

### Assessment of renal function

There was no significant difference in mean interval from CT scan to post-CT renal function measurements between groups (52.1 ± 18.7 and 49.9 ± 23.0 days for 120 and 80 kVp respectively,

Figure 1. Box-and-whisker plots of SSDE and iodine dose for each protocol. The SSDE and iodine dose were both significantly lower under the 80-kVp than the 120-kVp protocol (SSDE: 10.7 ± 1.2 *vs* 15.8 ± 1.6 mGy, respectively, $p < 0.01$; iodine dose: 19.6 ± 3.5 *vs* 33.2 ± 6.4 gI, respectively, $p < 0.01$). SSDE, size-specific dose estimate.




$p = 0.61$). No significant differences in SCr and eGFR between before and after CT were observed [SCr: 0.68 ± 0.14 *vs* 0.69 ± 0.17 mg $dl^{-1}$ (120 kVp, $p = 0.56$) and 1.27 ± 0.23 *vs* 1.26 ± 0.26 mg $dl^{-1}$ (80 kVp, $p = 0.35$); eGFR: 81.0 ± 13.8 *vs* 81.1 ± 15.9 ml per min per 1.73 $m^2$ (120 kVp, $p = 0.91$) and 38.3 ± 4.1 *vs* 39.1 ± 5.7 ml per min per 1.73 $m^2$ (80 kVp, $p = 0.15$)] in either group (Figure 5). No cases meeting the CIN criteria, need for dialysis, or kidney-related death were observed during follow up.

Table 3. Quantitative image analysis

| | 120-kVp protocol | 80-kVp protocol | *p* value[a] |
|---|---|---|---|
| CT attenuation (HU) | | | |
| Liver | 109.6 ± 11.6 | 118.7 ± 11.3 | <0.01 |
| Portal vein | 157.2 ± 14.6 | 177.5 ± 24.5 | <0.01 |
| Abdominal aorta | 150.5 ± 14.9 | 170.2 ± 20.0 | <0.01 |
| Spleen | 111.4 ± 10.3 | 124.0 ± 13.7 | <0.01 |
| Kidney | 166.5 ± 22.4 | 182.8 ± 34.0 | <0.01 |
| Image noise (HU) | 9.5 ± 1.5 | 9.4 ± 2.0 | 0.70 |
| Contrast-to-noise ratio | | | |
| Liver | 5.7 ± 1.7 | 6.8 ± 2.5 | 0.02 |
| Portal vein | 10.9 ± 2.7 | 13.4 ± 4.7 | <0.01 |
| Abdominal aorta | 10.1 ± 2.2 | 12.5 ± 3.6 | <0.01 |
| Spleen | 6.0 ± 1.8 | 7.3 ± 2.3 | <0.01 |
| Kidney | 11.8 ± 3.1 | 13.9 ± 5.1 | 0.02 |

HU, Hounsfield unit.
Note. Data are shown as mean ± standard deviation (range).
[a]Student's *t*-test.

## DISCUSSION

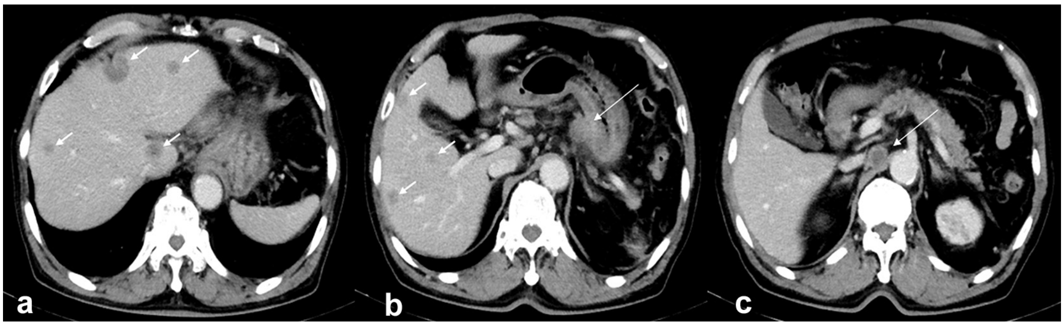
The results demonstrate that compared with conventional 120-kVp abdominal–pelvic CT, 80-kVp scans with SAFIRE allowed 40 and 32% reduction in doses of iodine and radiation, respectively, without impairing image quality for oncological assessment in patients at risk of CIN. The resulting radiation dose of 80-kVp protocol ($CTDI_{vol}$: 7.3 mGy) was much lower than the diagnostic reference levels for abdominalpelvic CT in European countries ($CTDI_{vol}$: range 12–14 mGy).[38,39] In addition, the iodine load reduction for patients with renal insufficiency might be clinically relevant, because no significant persistent kidney injury associated with CM exposure was observed during the follow-up period.

Table 4. Qualitative image analysis

| | 120-kVp protocol | 80-kVp protocol | Kappa | *p*-value[a] |
|---|---|---|---|---|
| Image contrast | 3.7 ± 0.5 | 3.9 ± 0.3 | 0.71 | 0.03 |
| Image noise | 3.2 ± 0.4 | 3.4 ± 0.5 | 0.64 | 0.12 |
| IR-specific artefacts | 3.9 ± 0.3 | 3.3 ± 0.5 | 0.54 | <0.01 |
| Overall image quality | 3.5 ± 0.5 | 3.5 ± 0.5 | 0.68 | 0.83 |

IR, iterative reconstruction.
Note. Data are shown as mean ± standard deviation.
[a]Mann–Whitney *U* test.

Figure 2. An 82-year-old male (weight: 58 kg, BMI: 22.1 kg $m^{-2}$) with gastric cancer with lymph node (long arrows) and liver (short arrows) metastases underwent scanning with the 80-kVp protocol [$CTDI_{vol}$: 7.3 mGy; SSDE: 11.1 mGy; iodine dose: 20.7 gI (Omnipaque-300, 69 ml at 2.3 ml $s^{-1}$); pitch factor: 0.8]. Subtle hypoattenuating liver lesions were clearly depicted without being compromised by noise or artefacts, and there was no clinically significant decline in renal function between before and 1 month after CT (eGFR: 30–31 ml $min^{-1}$ $m^{-2}$). BMI, body mass index; $CTDI_{vol}$, volume CT dose index; eGFR, estimated glomerular filtration rate; SSDE, size-specific dose estimate.




Previous studies have shown that the combination of low-kVp scans (*e.g.* 70- or 80-kvp) and SAFIRE could dramatically reduce both the iodine and radiation doses in pulmonary and coronary CTA with promising results by using high-pitch spiral acquisitions with DSCT system.[10,11] The utility of low-kVp scans with SAFIRE for simultaneous reduction of iodine and radiation doses in abdominal CT was also demonstrated in a phantom study by Holmquist et al[16]. However, the technique has not yet been fully evaluated in *in vivo* clinical settings, probably because of concerns about increased noise associated with 80-kVp acquisitions and the inherent decrease in contrast due to the reduced iodine dose could degrade low-contrast detectability, which is essential for oncological assessment.[24,25] In addition, the impact of these techniques on kidney function has been scantly evaluated in oncology patients with renal insufficiency who underwent abdominal–pelvic CT.[29–31] In this context, we validated the efficacy and renal safety of the 80-kVp protocol with SAFIRE for abdominal–pelvic CT in patients at risk of CIN, using SSCT

Figure 3. CT images of two different patients with pancreatic adenocarcinoma (arrows) scanned at 120 kVp (a–c) and 80 kVp (d–e). The BMI of the patient scanned at 120 kVp was 21.2 kg $m^{-2}$ (weight: 65 kg; effective diameter: 22.1 cm), and that of the patient scanned at 80 kVp was 25.8 kg $m^{-2}$ (weight: 55 kg; effective diameter: 22.6 cm). The iodine dose at 120 and 80 kVp was 38.9 gI (Iomeron-350, 111 ml at 3.7 ml $s^{-1}$) and 19.8 gI (Omnipaque-300, 66 ml at 2.2 ml $s^{-1}$), respectively. For the 80-kVp scan, the pitch factor was decreased to 0.85 because of the scanner's limited maximum tube current. The SSDE was 14.6 and 10.1 mGy for the 120- and 80-kVp protocols, respectively. Enhancement of parenchymal organs and vessels was higher at 80 kVp than 120 kVp without a significant noise increase. No clinically significant kidney injury was observed 1 month after CT in either patient (eGFR: 120 kVp, 83–85 ml $min^{-1}$ $m^{-2}$; 80 kVp, 38–39 ml $min^{-1}$ $m^{-2}$). eGFR, estimated glomerular filtration rate; SSDE, size-specific dose estimate.

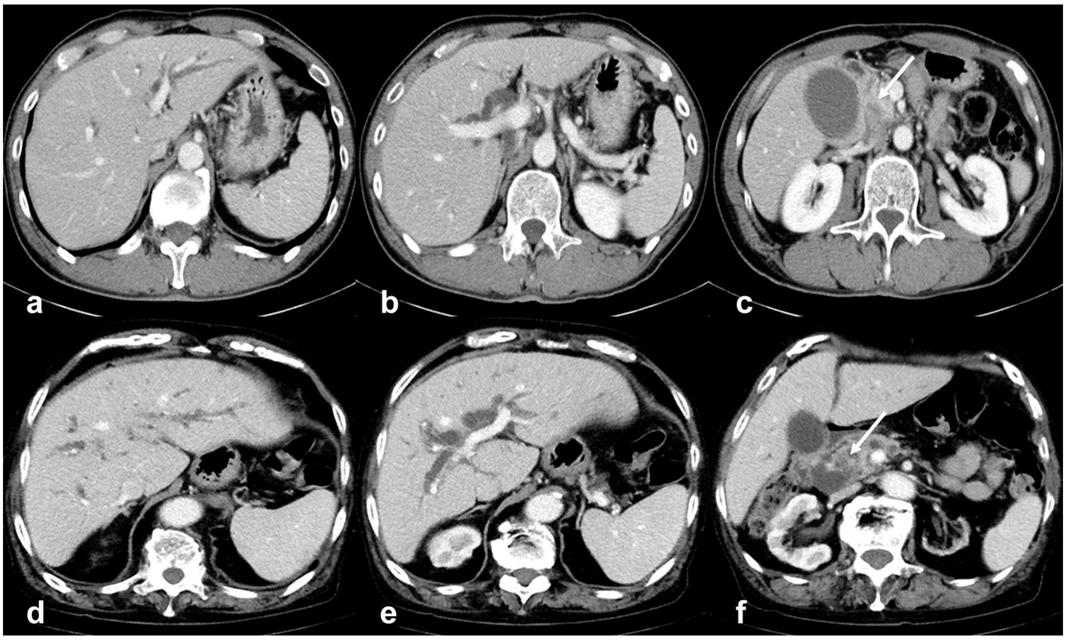
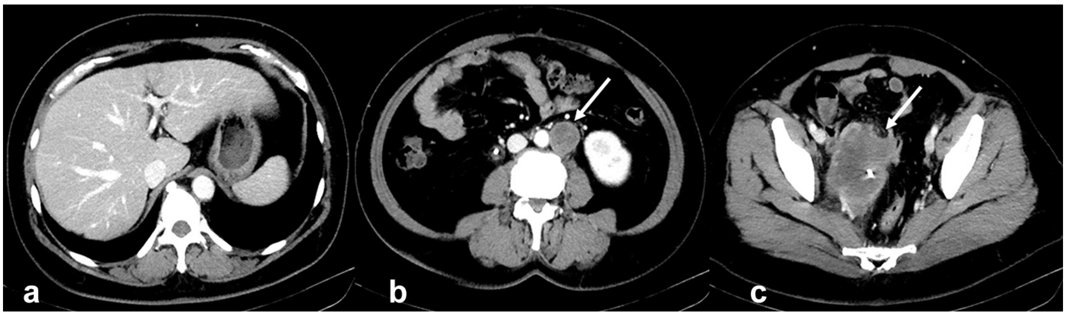


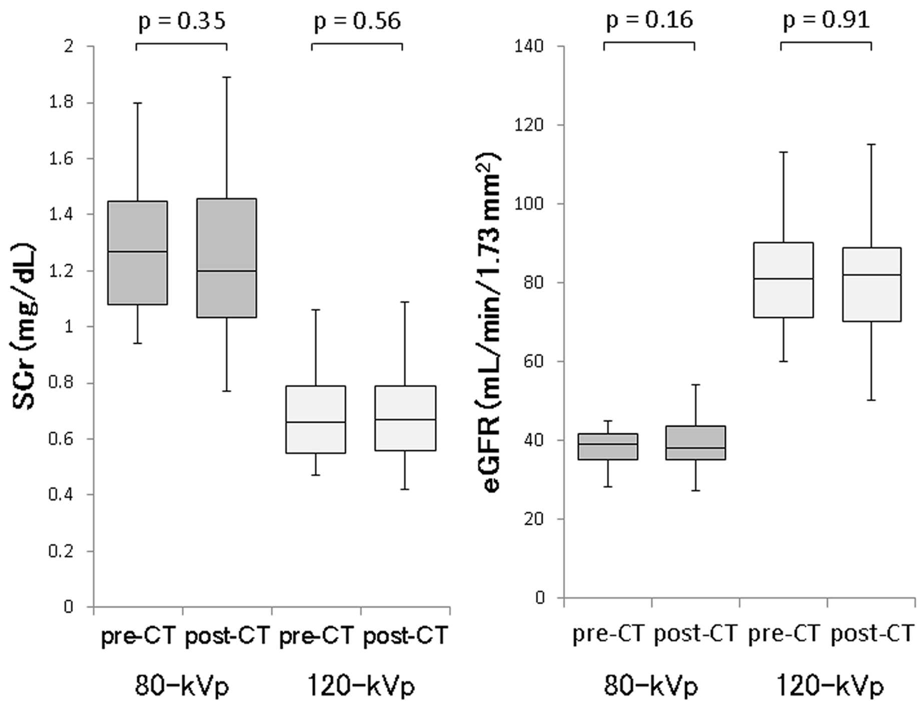
Figure 4. CT images of a 53-year-old female with endometrial cancer and lymph node metastases (arrows). She underwent scanning with the 80-kVp protocol [CTDIvol: 11.1 mGy; SSDE: 13.1 mGy; iodine load: 27.3 gI (Omnipaque-300, 91 ml at 3.0 ml $s^{-1}$)]. She had the largest BMI (32.5 kg $m^{-2}$) among any of our patients. The pitch factor was semiautomatically decreased to 0.5 by the AEC system because of the scanner's limited maximum tube current. There was no significant decline in renal function between before and 1 month after CT (eGFR both before and after CT: 43 ml/min/1.73 $m^2$). AEC, automated exposure control; BMI, body mass index; CTDI, CT dose index; eGFR, estimated glomerular filtration rate; SSDE, size-specific dose estimate.




system that is more widely available than DSCT systems. Given that 120-kVp acquisition with an SSCT system is still the standard for abdominal–pelvic CT at many institutions, our results may further prompt the widespread use of a low-kVp scans with IR, and contribute to overall reductions in patient radiation exposure and renal safety concern.

According to subjective and objective image analysis, the contrast of vessels and solid organs in the 80-kVp images was significantly higher than that in the 120-kVp images, despite the 40% iodine dose reduction. In the 80-kVp images, the noise was preserved to the same levels as in the 120-kVp ones by using SAFIRE, resulting in significantly higher CNR. However, these findings should be carefully interpreted considering each algorithm's noise and spatial resolution properties: even if quantitative noise and CNR are maintained by the IR techniques, the detectability of low-contrast lesions is compromised with reduced radiation dose.[20–23] Previous phantom studies have suggested that SAFIRE allows for 25–50% dose reduction while preserving low-contrast detectability.[20,21] Recent *in vivo* studies also demonstrated that by using SAFIRE, reduction of 16–62.5% in radiation exposure yielded similar detectability of hypoattenuating liver tumours compared with routine dose FBP.[34,40] Potential explanations for the reported dispersion of the maximum dose reduction potential with SAFIRE include differences in size and contrast of evaluated lesions. Solomon et al[40] demonstrated a smaller dose reduction potential of SAFIRE (approximately 16%) by evaluating the detectability of virtual liver lesions; they also

Figure 5. Box-and-whisker plots of SCr and eGFR in each group. There were no significant changes in SCr or eGFR values between before and after CT. eGFR, estimated glomerular filtration rate; SCr, serum creatinine.



mentioned the controversy over whether the radiation dose should be increased to maintain the detectability of very subtle lesions for the majority of patients, who may have more conspicuous lesions or no lesions at all, as in their study. Although we could not evaluate diagnostic accuracy in this study because of the lack of a reference standard, the results of above mentioned studies[20,21,34,40] imply that our 80-kVp protocol with 32% radiation dose reduction and improved image contrast might not lead to clinically significant loss of diagnostic performance.

Optimization of IR strength according to dose level and diagnostic task is desirable, especially in oncological assessment. Changes in image appearance in follow-up studies caused by IR-specific artefacts associated with higher IR strength can decrease diagnostic confidence or lead to interpretation errors.[18,19] Previous studies suggested that moderate SAFIRE strength levels (S3 or S2) are visually preferable[35,36] and preserve diagnostic accuracy in reduced dose abdominal CT.[34,41] Consistent with these results, in our 80-kVp protocol, IR-specific artefacts were rated as not compromising the delineation of organs and lesions, and subjective image noise and overall quality were rated as equivalent to those of 120-kVp images. Therefore, the S3 setting might be appropriate to obtain a good balance between image appearance and diagnostic acceptability. In addition, further reduction in IR-specific artefacts might be achieved with an advanced model-based IR technique without increasing image noise or decreasing low-contrast detectability.[26,42]

Regarding renal safety, we observed no significant kidney injury associated with CM exposure during follow-up. CIN is generally defined as an SCr increase of ≥25% or ≥0.5 mg $dl^{-1}$ from baseline within 72 h following CM administration; it is typically transient and reversible,[8] but in some cases, persistent kidney injury may occur and increase mortality.[43] Therefore, we evaluated renal function across a longer time span to avoid overestimating transient fluctuations and evaluate patient outcomes more precisely. Our results regarding renal safety after intravenous CM exposure are concordant with recent large propensity score-matched studies and investigations on CTA of the aorta and coronary artery.[5,6,29–31] Although the renal protective effect of iodine dose reduction should be rigorously confirmed in prospective randomised studies, our renal dysfunction group's significantly higher age and rate of receiving chemotherapy bodes well for the robustness of the renal safety of the 80-kVp protocol. Furthermore, this protocol would be beneficial not only in patients with renal dysfunction, but also in patients with normal kidney function for the patient safety.

This study has several limitations. First, our patients' body size is smaller than that of Western individuals. Although we could obtain adequate image quality even in overweight or obese patients using SAFIRE and decreased pitch factors ( Figures 3 and 4), the 80-kVp scans in large-bodied patients resulted in unacceptable increased noise due to insufficient photon flux. For these individuals, the third generation DSCT system has advantages for 80-kVp acquisition because of its substantially higher tube current output.[27] When using CT scanners with less powerful X-ray generators, as in this study, 100-kVp acquisition may be an effective alternative approach, as this intermediate tube voltage enables 20% CM dose reduction from 120-kVp acquisition, and the increased noise is not so problematic compared with that of 80-kVp scans.[44] Second, the number of patients included in our study was relatively small. Because the clinicians were likely to withhold CM administration to patients with decreased baseline renal function, we could identify only a limited number of cases undergoing the 80-kVp protocol. Further, we retrospectively included the same numbers of consecutive patients undergoing the 120-kVp protocol as controls to improve statistical accuracy, which might have introduced unavoidable selection biases. Additional large-scale prospective randomised studies will be needed. Third, we could not compare the diagnostic accuracy of each protocol, as already discussed above. To compare the diagnostic accuracy of two different protocols using validated statistical methods, it is necessary to image the same patient simultaneously with different scanning protocols; such a prospective study design exposing the patients to additional radiation dose and CM administration would not be ethically acceptable given that abdominal–pelvic CT requires relatively high radiation and iodine dose. Thus, we focused on comparing the protocols' subjective and objective image quality and renal safety. Finally, renal function within 72 h after CT could not be evaluated because of a lack of data from the majority of patients. However, we did not aim to detect acute, possibly transient increases in SCr levels, but rather persistent decline in renal function.[29–31]

In conclusion, the 80-kVp scans with SAFIRE allow for substantial reduction in iodine load and radiation dose while preserving subjective and objective image quality in abdominal–pelvic CT for oncological assessment. With this protocol, no kidney injury related to CM administration was observed in patients with renal dysfunction. Abdominal–pelvic CT using 80-kVp and SAFIRE may contribute to patient safety without compromising diagnostic image quality.

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