Summary

Background: Imaging communities have already reached a consensus that the radiation dose of computed tomography (CT) should be reduced as much as reasonably achievable to lower population risks. Increasing attention is being paid to iodinated contrast media (CM) induced nephrotoxicity (CIN); a decrease in the intake of iodinated CM is required by increasingly more radiologists. Theoretically, the radiation dose varies with the tube current time and square of the tube voltage, with higher iodine contrast at low photon energies (Huda et al. [2000] Radiology, 217, 430–435). The use of low tube voltage is a promising strategy to reduce both the radiation dose and CM burden. The term ‘double low’ has been coined to describe scanning protocols that reduce radiation dose and iodine intake synchronously. These protocols are becoming increasingly popular in the clinical setting.

Purpose: The aim of this review was to describe all original studies using the ‘double low’ strategy in the last 5 years.

Methods: We searched an online electronic database (PubMed) from January 2011 to December 2015 for original studies published on the relationship of low tube voltage with low radiation dose and low iodine contrast media burden in patients undergoing CT scans. Studies that failed to reduce radiation dose or iodine CM burden were excluded in this study.

Results: Thirty-seven studies aimed at reducing radiation dose using low tube voltage combined with iodine CM reduced protocols were included in this study. Most studies evaluated conditions associated with arteries. Four were cerebral and neck computed tomography angiography (CTA) studies, 15 were pulmonary CTA (pCTA) and coronary CTA (cCTA) studies, one concerned myocardial perfusion, five studies focused on the thoracic and abdominal aorta, and one investigated renal arteries. Three studies consisted of CT venography (CTV) of the pelvis and lower extremities. Six publications examined the liver, and two focused on the kidney.

Conclusion: Overall, this review demonstrates that the low tube voltage CT protocol is a powerful tool to reduce the radiation dose in CTA, especially with pCTA and cCTA.
INTRODUCTION

Computed tomography (CT) has been a powerful tool for physicians since the 1970s. The application of CT, especially multi-detector row CT (MDCT), has quickly expanded from the head, chest, limbs and abdomen to the heart and all blood vessels with the help of iodine contrast media. Increased attention has been paid to the radiation risk from CT examinations. Contrast-induced nephrotoxicity (CIN) and acute kidney injury from iodinated contrast media (CM) are closely related to acute renal failure, especially in patients with chronic kidney disease. The intake of iodinated CM is a known risk factor for the development of acute renal failure. The term "double low" describes scanning protocols designed to reduce radiation dose and iodine intake, which are becoming more popular in clinical applications.

Several options are available to decrease radiation exposure in patients. In theory, the radiation dose varies with the tube current time and square of the tube voltage. One step to reduce radiation during CT was to use a low tube voltage protocol, which can be applied to all body regions. Another benefit of lowering tube voltage CT angiography (CTA) protocols is to increase the attenuation values of iodinated contrast media in the vessels. The effective energy of the X-ray beam approaches the absorption k-edge of iodine. Low iodine contrast media burden consists of either a reduction in the volume of CM or a decrease in the concentration at the same volume.

Further research was conducted to determine the optimal approach by which to combine low tube voltage and low iodine contrast media burden in different parts of the body.

The aim of this review was to assess the application of ‘double low protocols’ in humans over the last 5 years.

METHODS

2.1 Literature search

We performed a systematic search for studies that reported a contrast media reduction strategy combined with low tube voltage CT published from January 2011 to November 2015. Published and peer-reviewed articles in English language journals were identified in PubMed and on reference lists of articles available to the authors of this review.

Search terms for "low kilo-voltage CT" or "low tube voltage CT" and "contrast media" were combined for searches on PubMed; only human studies and those written in English in the past 5 years were included. The search resulted in a total of 67 articles in PubMed Central.

2.2 Inclusion criteria and selection process

Based on article titles and available abstracts, reports were initially evaluated for inclusion using the following criteria: original research of low tube voltage CT scans in humans written in English in which CM load reduction was conducted and both radiation dose and CM intake were reduced.

A total of 201 articles were excluded: studies evaluating low tube voltage protocol but not combined with CM reduction, studies with CM increasing or radiation dose increasing, or studies only comparing the image quality of low tube voltage protocols. Three authors independently evaluated potential studies based on the inclusion criteria. Thirty-seven relevant papers were selected (Figure 1).

2.3 Data extraction

The selected studies were divided into several groups according to anatomy; all studies were sorted according to author and year, number of participants in the study group, CT protocol, CM protocol and other relevant factors (Tables 1–6).

RESULTS

All original research articles were divided into different groups based on anatomy.

FIGURE 1 Flow chart of literature search
TABLE 1  Summary of cerebral and neck computed tomography angiography studies in humans (2011–2015)

| Author, year | Examination | No. (study) | Weight (kg)/Mean BMI (kg/m\(^2\)) | Mean age (years) | CT scanner, vendor | Iodine concentration (mg/mL) | CT protocols (study vs control) | Contrast media protocol (study vs control) | Radiation dose reduction | Iodine Load reduction |
|--------------|-------------|-------------|-----------------------------------|-----------------|-------------------|---------------------------|---------------------------------|-----------------------------------|---------------------|---------------------|
| Luo S, 2014  | Cerebral    | 40 (100 kVp)/40 (80 kVp) | –/–                                | 55/50           | 64-DSCT, Siemens   | 300                        | 100 kVp vs 80 kVp vs 120 kVp    | 30 mL vs 30 mL vs 70 mL/4 mL/s | 45% (100 kVp) 74% (80 kVp) | 30 mL vs 30 mL vs 70 mL |
| Xia W, 2014  | Neck        | 42          | 66.2/–                             | 59.5            | 64-MDCT, GE       | 350                        | 80 kV/600 mAs vs 120 kV/400 mAs | 175 mg I/kg (25–40 mL) vs 350 mg I/kg (50–80 mL) | 54% CTDI (mGy): 27.48 vs 59.11 | 50% 175 mg I/kg vs 350 mg I/kg |
| Zhang WL, 2013 | Cerebral and neck | 46 | 67.8/24.3 | 56.9 | 320-MDCT, Toshiba | 270 vs 320 | 80 kV/178–500 As vs 120 kV/100–500 mAs | 5 mL/s (<80 kg), 5.5 mL/s (80–100 kg), 6 mL/s (>100 kg)* | 50% CTDI (mGy): 3.9 vs 7.8 | – |
| Cho ES, 2012 | Cerebral    | 45          | 72.6/23.4                          | 24.6            | 64-MDCT, Philips   | 300 vs 370                 | 80 kVp/370 mAs vs 120 kVp/150 mAs | 70 mL, 5 mL/s | 22.2% ED (mSv): 0.7 vs 0.9 | 18.9% (300 vs 370) |

*The amount of contrast media=(10+scantime)×flow rate for individual.
3.1 | Head and neck CTA (Table 1)

Because magnetic resonance (MR) imaging provides excellent tissue contrast of head, neck and associated tissues without contrast media, a limited number of original research articles addressing ‘double low’ CTA in the head and neck was found. Likewise, radiosensitive organs, such as the thyroid gland, require protection from radiation exposure. For patients in whom MR is contraindicated, CTA can be used as an alternative to exclude conditions related to cerebral and carotid artery disease.

Compared to conventional tube voltage cerebral CTA (120 or 140 kVp), the use of low tube voltage (100 or 80 kVp) has been shown to be feasible in the literature. The body weight of patients had less impact on cerebral and neck CTA scans, and not all studies provided the reference body weight of patients. Based on the study by Luo, the volume of CM can be reduced to 30 mL (300 mg I/mL) without compromising diagnostic image quality. Thirty millilitres was the lowest CM protocol; a study by Cho, presented a protocol with 70 mL (300 mg I/mL), and a study by Zhang reported a CM of above 50 mL (270 mg I/mL) and 25–40 mL (350 mg I/mL) was reported in the study by Xia. Though different indices were used to compare the radiation dose among all studies, the radiation dose in the study by Lu was much reduced. These findings require confirmation with a larger patient cohort.

3.2 | Chest

3.2.1 | Pulmonary CTA (Table 2) and coronary CTA

One disadvantage of low tube voltage protocols is that image noise is increased due to the decreased X-rays in soft tissues. Low X-ray body weight (BW) or body mass index (BMI) to avoid image noise, which leads to decreased image quality. Zhang et al. reported that a number of clinical studies utilizing double low CT are focused on pulmonary CTA (Table 3).

Protocols at 100 kVp tube voltages have been shown to provide similar image quality as the formerly used 120 kVp techniques at a significantly lower radiation dose in pCTA and cCTA.

A number of studies have been performed to compare the protocols of 80–120 kVp or 100 kVp to explore additional radiation dose reductions. Applications with 80 kVp were limited to patients with a lower BW or BMI to avoid image noise, which leads to decreased image quality. Zhang et al. reported that a protocol of 70 kVp combined with 30 mL cCTA can be applied to selected patients (BMI < 23 kg/m²) to obtain high quality diagnostic images. In cardiac CT, prospective electrocardiograph gating reduces the radiation dose to quantum leap because the X-ray tube is only turned on at a predefined time point in the cardiac cycle. This technique is not mentioned in Table 3 but was widely applied in the current studies.

TABLE 2 Summary of pulmonary computed tomography angiography (pCTA) studies in humans (2011–2015)

| Author, year | No. (study group) | Mean age (years) | Mean weight (kg)/BMI (kg/m²) | CT scanner, vendors | Iodine concentration (mg/mL) | CT protocol (study vs control) | Contrast media protocol (study vs control) | Mean ED (mSv) | Radiation dose reduction | Iodine load reduction |
|--------------|-------------------|------------------|-----------------------------|---------------------|-----------------------------|-------------------------------|---------------------------------|----------------|------------------------|---------------------|
| Szucs-Farkas Z & 2014 | 246 | 57.4 | 70.6/24.9 | 16-MDCT, Siemens | 300 | 80 kVp/150 mAs vs 100 kVp/100 mAs | 75 mL vs 100 mL, 4 mL/s | SSDE (mGy); 4.8 vs 6.8 | 30% | 25% |
| Faggioni L², 2012 | 23 | 66 | -/≥23 | 64-MDCT, GE | 320/400 | 80 kVp/50–300 mAs | 40 mL, 5 mL/s vs 40 mL, 4 mL/s | - | 20% |
| Sodickson A³, 2012 | 53 | - | <80³/- | 128-MDCT, Siemens | 370 | 100 kVp/200 mAs vs 120 kVp/200 mAs | 50 mL, 4 mL/s vs 75 mL, 5 mL/s | 33% | 33% |
| Viteri-Ramírez G & 2012 | 35 | 62.7 | 68.7/24.6 | DSCT, Siemens | 300 | 80 kVp/150 mAs vs 100 kVp/150 mAs | 60 mL, 4 mL/s vs 80 mL, 4 mL/s | 1.1 vs 2.7 | 60% | 25% |
| Godoy MCB & 2011 | 10 | 67 | <10⁴/- | DSCT, Siemens | 300 | 80 kVp/370–480 mAs vs 140 kVp/56–80 mAs | 50 mL, 4 mL/s vs 100–150 mL, 4 mL/s vs 100 mL, 2.5–3 mL/s | - | - |

Notes: ¹ Non-random control study & prospective study. ² Retrospective study. ³ Round after unit conversion. MDCT, multidetector computer tomography; DSCT, dual source CT.
| Author, year | No. (study group) | Weight (kg) | BMI (kg/m²) | CT scanner, vendors | Iodine concentration (mg/mL) | CT protocol (study vs control) | Contrast media protocol (study vs control) | Mean ED (mSv) | Radiation dose reduction | Iodine load reduction |
|--------------|------------------|-------------|-------------|---------------------|-----------------------------|--------------------------------|--------------------------------|---------------|------------------------|----------------------|
| Oda S, 2015  | 30               | 56.5        | 22.6        | 320-MDCT, Toshiba   | 370                          | 80 kVp/738.6±118.4 mAs       | 210 mg I/kg, 4 mL/s              | 1.5           | 38%                    | 25%                  |
|              | 30               | 54.6        | 22.2        |                     |                             | 80 kVp/727.3±146.3 mAs       | 140 mg I/kg, 4 mL/s              | 1.5           | 38%                    | 50%                  |
|              | 30               | 57.7        | 23.0        |                     |                             | 120 kVp/356.0±151.0 mAs      | 280 mg I/kg, 4 mL/s              | 2.4           |                        |                      |
| Sun G, 2015  | 92               | 28.0        | 22.6        | 320-MDCT, Toshiba   | 270                          | 100 kVp/408.79±33.08 mAs     | 0.9 mL/kg, 5 mL/s               | 3.19          | 45%                    | 27%                  |
|              | 87               | 29.9        | 22.2        |                     |                             | 120 kVp/391.25±37.19 mAs     | 5.81          |                        |                      |
| Wang H, 2015 | 40               | 70.2        | 25.2        | 128-DSCT, Siemens   | 270                          | 80 kVp (BMI≤24)/330–370 mAs vs 100 kVp (BMI>24)/330–370 mAs | 66.3 mL, 3.5 mL/s (BMI≤24) vs 65.0 mL, 4.5 mL/s (BMI>24) | 3.27          | No significant difference | 20.3%               |
|              | 40               | 70.5        | 25.0        |                     |                             | 100 kVp/300 mAs              | 1 mL/kg, 5 mL/s                 | 0.26          | 54%                    | 27%                  |
|              | 87               | 62.3        | 22.2        | 128-DSCT, Siemens   | 370                          | 80 kVp/300 mAs               | 1 mL/kg, 5 mL/s                 | 0.57          |                        |                      |
|              | 83               | 63.7        | 22.6        |                     |                             | 100 kVp/300 mAs              | 1 mL/kg, 5 mL/s                 | 0.57          |                        |                      |
| Zheng M, 2015| 50               | 62.3        | 22.2        | 128-DSCT, Siemens   | 270                          | 80 kVp/300 mAs               | 1 mL/kg, 5 mL/s                 | 0.26          | 54%                    | 27%                  |
|              | 50               | 63.7        | 22.6        |                     |                             | 100 kVp/300 mAs              | 1 mL/kg, 5 mL/s                 | 0.26          | 54%                    | 27%                  |
| Andreini D, 2014 | 84               | 27          | 25          | VCT, GE             | 320                          | 100 kVp/500 mAs (BMI<20)     | 80 mL, 5 mL/s                    | 105.2 mGy·cm   |                        |                      |
|              | 87               | 26          | 22          |                     |                             | 100 kVp/550 mAs (20≤BMI<25)  | 80 mL, 6.2 mL/s                  | 108.6 mGy·cm   |                        |                      |
|              | 83               | 26          | 22          |                     |                             | 100 kVp/600 mAs (25≤BMI<30); 120 kVp/650 mAs (30≤BMI<35) | 80 mL, 5 mL/s                    | 104.5 mGy·cm   |                        |                      |
| Kido M, 2014 | 50               | 61.4        | 23.9        | 256-MDCT, Philips   | 370                          | 100 kVp/827 mAs              | 49.1±8.2 mL, 3.3±0.5 mL/s        | 21.7          | 20%                    |                      |
|              | 50               | 57.2        | 22.9        |                     |                             | 120 kVp/669 mAs              | 57.2±10.9 mL, 3.8±0.9 mL/s       | 21.8          |                        |                      |
| Kido M, 2014 | 30               | 60.1        | 22.9        | 256-MDCT, Philips   | 370                          | First phase:120 kVp/669 mAs, Second phase: 80 kVp/725 mAs | 60.1±9.6 mL                     | 23.5          | 30%                    | 35%                  |
|              | 30               | 61.2        | 22.9        |                     |                             | 120 kVp/669 mAs              | 91.8±22.6 mL                     | 33.4          |                        |                      |
| Zhang LJ, 2014 | 51               | 22.1        | 22.1        | DSCT, Siemens       | 370                          | 70 kVp/320 mAs               | 30 mL, 4 mL/s                    | 0.18          | 75%                    | 50%                  |
|              | 44               | 22.3        | 22.3        |                     |                             | 80 kVp/320 mAs               | 60 mL, 4 mL/s                    | 0.32          | 56%                    | (calculated)        |
|              | 55               | 22.2        | 22.2        |                     |                             | 100 kVp/320 mAs              | 60 mL, 4 mL/s                    | 0.72          |                        |                      |
Interestingly, the effective radiation dose in the studies of Kidoh is the highest among all the studies. These authors attempted to combine CTA with a serial low kVp scan of the whole chest to rule out the main cause of chest pain (pulmonary embolism, acute coronary syndrome and acute aortic syndrome). Retrospective electrocardiographic (ECG) gating was also employed with their protocol. Additional evidence-based studies are needed to confirm the findings of Kidoh prior to adopting this protocol in the clinic. The other studies successfully limited the effective radiation dose to 3 mSv or lower, which is also CT platform dependent.

The reduced volume of CM varied from 50–75 mL (300 mg I/kg) to 40–50 mL (320/370/400 mg I/kg) for pCTA. In comparison, the contrast infusing protocols of cCTA are very complicated among the studies. To date, no agreement exists as to the optimal iodine concentration for pCTA and cCTA.

3.3 | Body

3.3.1 | Aorta and branches CTA (Table 4), CT venography of deep vein (Table 5), Abdominal parenchymal organs (Table 6)

Applications of low tube voltage in the body were divided into vascular disease (Tables 4–5) and parenchymal organs (Table 6). Compared to the studies in the chest, similar protocol discussions between low tube voltages of 100 kVp or 80 kVp have occurred among studies of aorta CTA and deep vein CT Venography (CTV). The volume of CM is markedly decreased to 30 mL in the studies of Ippolito and Chen. In regards to solid organs, the feasibility of the double low strategy has been reported mainly in the liver,1–3,6,9,11–13 kidneys,14–16 and pancreas.17–20 The iterative reconstruction technique combined with the low tube voltage protocol can decrease image noise, which greatly improves image quality in abdominal studies.21–23 Patients from the previously published studies (Tables 2–4) were primarily Asian with a lower mean body weight compared to other clinical studies. To date, no agreement exists as to the optimal iodine concentration for PCA and CTA.

4 | DISCUSSION

Low tube voltage can be a powerful tool for radiation dose reduction and the feasibility of such protocols has been examined in virtually all body regions. Another advantage of this technique is the increased attenuation values of vessels, which leads to a lower iodine CM burden in patients in two ways: either a lower volume of CM or a lower concentration in patients with a higher BMI. In this case, the lower tube voltage can be conducted to confirm the usage of low tube voltage in abdominal applications.

TABLE 3 (Continued)

| Author, year | No. (study group) | Weight (kg) | BMI (kg/m²) | CT scanner, vendors | Iodine concentration (mg/mL) | CT protocol (study vs control) | Contrast media protocol (study vs control) | Mean ED (mSv) | Radiation dose reduction | Iodine load reduction |
|--------------|-------------------|------------|------------|---------------------|-----------------------------|-------------------------------|---------------------------------|-------------|-------------------------|-------------------|
| Zheng M, 2014 | 50 | 65.5 | 22.3 | 128-DSCT, Siemens | 270 | 80 kVp/150 mAs (BMI<25) | 100 kVp/150 mAs (BMI≤25) | 1 mL/kg body weight, 5 mL/s. | 0.41 (BMI<25) vs 0.94 (BMI≤25) | 56.4% | 27% | Calculated from the paper. |
| | 50 | 64.6 | 23.7 | | | | | | 1.14 (BMI<25) vs 2.37 (BMI≤25) | | |
| Patel AR, 2011 | 20 | 29.3 | | 256-MDCT, Philips | 370 | 100 kVp/600–1000 mAs | 120 kVp/600–1000 mAs | 55–70 mL 4–5 mL/s | 1.9 | 74% | 28% |
| 20 | | | | | | | 80–90 mL 5–6 mL/s | 7.4 | |
| Zhang C, 2011 | 40 | 22.3 | | 320-MDCT, Toshiba | | 100 kVp/400–450 mAs (BMI<22) | 100 kVp/450–500 mAs (22≤BMI<25) | 45 mL 4.0 mL/s | 2.12 | 54% | 15% |
| 67 | | 27.8 | | | | 120 kVp/400–500 mAs (25≤BMI<30) | 120 kVp/500–580 mAs (BMI≥30) | 55 mL 5.0 mL/s | 4.61 | |

ED, effective radiation dose.

**Adopting evidence-based studies was also employed with their protocol.** Additional evidence-based studies are needed to confirm the findings of Kidoh prior to adopting this protocol in the clinic. The other studies successfully limited the effective radiation dose to 3 mSv or lower, which is also CT platform dependent. The reduced volume of CM varied from 50–75 mL (300 mg I/kg) to 40–50 mL (320/370/400 mg I/kg) for pCTA. In comparison, the contrast infusing protocols of CTA are very complicated among the studies. To date, no agreement exists as to the optimal iodine concentration for pCTA and CTA.
| Author, year | Examination | No. (study) | Mean weight (kg)/Mean BMI (kg/m²) | Mean age (years) | CT scanner, vendor | Protocol (study vs control) | Radiation dose reduction | Iodine load reduction | Radiation dose |
|-------------|-------------|-------------|---------------------------------|----------------|-------------------|-------------------------|-------------------------|------------------------|---------------|
| Ippolito D, 2015 | CTA of thoracic and abdominal aorta | 67 | -/24.6 | 65.4 | 256-MDCT, Philips | 100 kVp – 350 mg I/mL, 30 mL, 4 mL/s vs 120 kVp – 350 mg I/mL, 80 mL, 4 mL/s | 61% in the thoracic aorta examination | 69.9% in the abdominal aorta examination | 62.5%<sup>a</sup> | DLP (mGy·cm): 490 vs 1032 (thoracic aorta examination); 324 vs 1078 (abdominal aorta examination) |
| Shen Y, 2015 | CTA of aorta | 50 | 70.33/24.24 | 52.66 | 128-DSCT, Siemens | 100 kVp, 350 mAs – 270 mg I/mL, 1 mL/kg, 4 mL/s vs 120 kVp, 350 mAs – 370 mg I/mL, 1 mL/kg, 4 mL/s | 34.3% | 27.3% | ED (mSv): 4.4 vs 6.7 |
| Chen C, 2014 | CTA of aorta | 48 | 63.9/23.7 | 70.2 | 320 Toshiba/ 64-MDCT, Toshiba/ 16-MDCT, Siemens/ GE Brightspeed | 80 kVp – 350 mg I/mL, 40 mL, 3 mL/s vs 120 kVp – 350 mg I/mL, 40 mL, 3 mL/s | 37% reduction in ED | 48% reduction in CTDIvol | – | ED (mSv): 12.1 vs 19.2; CTDIvol (mGy): 10.1 vs 19.5 |
| Kanematsu M, 2014 | Whole body CTA | 37/34 (240 mg/mL–80 kVp/300 mg/mL–80 kVp) | 62.0–63.8/– | 72.9/70.9 | 64-MDCT, GE | 80 kVp – 240 mg I/mL, 89.9 mL, 4 mL/s vs 80 kVp – 300 mg I/mL, 89.3 mL, 4 mL/s vs 120 kVp – 370 mg I/mL, 91.8 mL, 4 mL/s. | 4% (Thorax); 17.9% (Abdomen); 24.1% (Pelvis) | (80 kVp – 240 mg I/mL group vs 120 kVp – 370 mg I/mL group)<sup>a</sup> | 36.5% (80 kVp – 240 mg I/mL group vs 120 kVp – 370 mg I/mL group)<sup>a</sup> | ED (mSv): 4.3 vs 4.2 vs 4.5 (Thorax); 2.3 vs 2.4 vs 2.8 (Abdomen); 4.1 vs 4.0 vs 5.4 (Pelvis) |
| Cho E, 2012 | CTA of the renal arteries | 25 | 72.7/24 | 21.4 | 64-MDCT, Philips | 80 kVp, 585 mAs – 300 mg I/mL, 110 mL, 5.0 mL/s vs 120 kVp, 200 mAs – 370 mg I/mL, 110 mL, 5.0 mL/s | 8.2% | 18.9% | ED (mSv): 4.5 vs 4.9 |
| Iezzi R, 2011 | CTA of abdominal aorta | 30<sup>b</sup> | 80/28.16 | 76.7 | 64-MDCT, Siemens | 80 kVp, 100 mAs – 400 mg I/mL, 90 mL, 3 mL/s vs 120 kVp, 130 mAs – 300 mg I/mL, 120 mL, 3 mL/s | 74% | – | ED (mSv): 1.97 vs 7.56 |

<sup>a</sup>Calculated according to the data in the article. <sup>b</sup>Patients underwent two consecutive MDCTA scans 6 months apart. ED, effective dose; CTDIvol, CT dose index volume; DLP, dose length product.
development of low tube voltage protocols combined with lower CM burden based on original research related to ‘double low’ protocols.

Applications in the head and neck were limited for clinical reasons. Studies included in the current analysis cover the vascular system and abdominal solid organs. Compared to the conventional tube voltage of 120–140 kVp, 100 kVp tube voltage protocols have been widely applied in the head, chest and whole body. Body weight or BMI is one factor known to impact the clinical application of the low tube voltage protocol. The protocol involving an 80 kVp tube voltage is feasible and reliable in lean patients. Both low tube voltage protocols can be combined with a CM reduction strategy.

Another factor that should be taken into account is the image reconstruction technique after data acquisition. This review chose not to overlap with the work of Padole, who recently reviewed the clinical applications of iterative reconstruction techniques.

In contrast to the consistency in reported low tube voltage protocols, the CM reduction strategies varied from a lower concentration of iodine CM to a reduced volume of a constant concentration of CM. The attempt to combine lower concentration and volume of CM simultaneously has not yet been achieved.

5 | CONCLUSION

Overall, this review demonstrates that the low tube voltage CT protocol is a powerful tool to reduce the radiation dose in CT examinations. Currently, this technique is widely applicable for all body regions and can be combined with a contrast media reduction strategy.

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DISCLOSURES

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AUTHOR CONTRIBUTIONS

Guarantor of the integrity of the entire study, Zhen Li; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important

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**TABLE 5** Summary of CTV in deep veins (2011–2015)

| Author, year | No. (study) | Mean weight (kg)/Mean BMI (kg/m²) | Mean age (years) | CT scanner, vendor | Protocol (study vs control) | Radiation dose reduction | Indicative CM reduction | Radiation dose CTDIvol (mGy) | DLP (mGy·cm) |
|--------------|-------------|----------------------------------|------------------|-------------------|---------------------------|-------------------------|-----------------------|-----------------------------|----------------------|
| Ichikawa S, 2014 | 63 | 56.7/29.7 | 65.4 | 320-MDCT, Toshiba | 80/120 kVp – 370 mg I/mL, 450 mAs, 400 mAs vs 80/120 kVp – 370 mg I/mL, 450 mAs | 30% | – | 10.4 vs 14.9 | – |
| Cho E, 2013 | 44 | 61.2/59.4 | 61.2 | 64-MDCT, Siemens | 100 kVp – 300 mg I/kg, 300 mL I/kg, up to 50 seconds vs 120 kVp – 300 mg I/kg, 300 mL I/kg, up to 50 seconds | – | – | 18.9% | – |
| Oda S, 2011 | 44 | 56.5/23.2 | 71.9 | 64-MDCT, Philips | 80 kV, 250 mAs vs 120 kV, 370 mAs, 450 mAs | 53% | – | 602.2 vs 1131.7 | 33% |

*Patients were randomised into three groups and administered contrast medium of either 600, 500 or 400 mg of iodine per kilogram. CTDIvol, CT dose index volume; DLP, dose length product.
| Author, year | Parenchymal organs | No. (study) | Weight (kg)/Mean BMI (kg/m²) | Mean age (years) | CT scanner, Vendors | Protocol (study vs control) | Radiation dose reduction | Iodine load reduction | Radiation dose |
|-------------|-------------------|------------|----------------------------|------------------|---------------------|------------------------|----------------------|----------------------|-----------------|
| Kanematsu M, 2015 | kidney | 37/39 | 61.1–58.1/–60.7/60.2 | 64-MDCT, GE | 80 kVp, <700 mA – 300 mg I/mL, 400 mg I/kg (saline flushing: 20 mL at 4 mL/s), vs 80 kVp, <700 mA – 300 mg I/mL, 400 mg I/kg vs 120 kVp, <835 mA – 300 mg I/mL, 600 mg I/kg | – | 51%/30% | CTDIvol (mGy): 8.5 vs 7.7 vs 6.5; DLP (mGy-cm): 256.4 vs 238.0 vs 207.0 |
| Hwang I, 2015 | CT urography | 32 | /23.8 | 52.9 | 64-MDCT, Philips | 80 kVp – 240 mg I/mL, 1.5 mL/kg, 2.4–4.5 mL/s vs 120 kVp – 350 mg I/mL, 500 mg I/kg vs 120 kVp – 350 mg I/mL, 600 mg I/kg | 39.6% in excretory phase, 20.4% in whole study | 31.4% | ED (mSv): 3.44 vs 5.70 in excretory phase, 10.17 vs 12.79 in whole study |
| Noda Y, 2015 | liver | 170<sup>a</sup> | 58.7/– | 67.7 | 64-MDCT, GE | 80 kVp – 350 mg I/mL, 150 mg I/kg vs 80 kVp – 350 mg I/mL, 1.5 mL/kg, 2.4–4.5 mL/s vs 120 kVp – 350 mg I/mL, 600 mg I/kg | – | 33% | ED (mSv): 4.1 vs 3.8 vs 3.3 |
| Takahashi H, 2014 | liver | 55 | 55/22 | 71 | 64-MDCT | 100 kVp – (320, 370, 300, 240) mg I/mL, 480 mg I/kg vs 120 kVp – (320, 370, 300, 240) mg I/mL, 600 mg I/kg | 37% | 20% | CTDI (mGy): 6.38 vs 4.04 DLP (mGy-cm): 124.57 vs 194.54 |
| Nakaura T, 2012 | liver | 35 | 54.1/– | 67.8 | 256-MDCT, Philips | 80 kVp, 557–922 mAs – (300, 350, 370) mg I/mL, 360 mg I/kg vs 120 kVp, 320–852 mAs – (300,350,370) mg I/mL, 600 mg I/kg | 51% lower during HAP and 48% lower during PVP | 40% | ED (mSv): 5.6 vs 11.6 (HAP); 5.8 vs 11.2 (PVP) |
| Namimoto T, 2012 | liver | 25<sup>b</sup> | 57.2/22.4 | 70.3 | 64-MDCT, Philips | 80 kVp, 357 mAs – 300 mg I/mL, 450 mg I/kg, 2.8 mL/s vs 120 kVp, 357 mAs – 300 mg I/mL, 600 mg I/kg | 28.8% | 25% | CTDIvol (mGy): 9.0 vs 12.7 mGy |
| Nakaura T, 2011 | liver | 34 | 54.3/– | 77.0 | 256-MDCT, Philips | 80 kVp, 550–1000 mAs – (300,350,370) mg I/mL, 360 mg I/kg vs 120 kVp, 160–593 mAs – (300,350,370) mg I/mL, 600 mg I/kg | 20% | 40% | ED (mSv): 8.2 vs 10.2 |
| Yanaga Y, 2011 | liver | 55 | 55.0/– | 69.1 | 64-MDCT, Philips | 80 kVp, 600 mAs – 370 mg I/mL, 444 mg I/kg vs 120 kVp, 300 mAs – 370 mg I/mL, 600 mg I/kg | 12.9%<sup>c</sup> | 25% | ED (mSv): 2.97 vs 3.41 |

<sup>a</sup>Patients were randomised into three groups. <sup>b</sup>All underwent standard tube voltage (120 kVp) CT before low tube voltage (80 kVp) CT (mean±SD interval, 148±137 days). <sup>c</sup>Calculated according to data in the article. ED, effective dose; CTDIvol, CT dose index volume; DLP, dose length product; HAP, hepatic arterial phase; PVP, portal venous phase.
REFERENCES

1. Huda W, Scalzetti EM, Levin G. Technique factors and image quality as functions of patient weight at abdominal CT. Radiology. 2000;217:430–435.

2. Luo S, Zhang LJ, Meinel FG, et al. Low tube voltage and low contrast material volume cerebral CT angiography. Eur Radiol. 2014;24:1677–1685.

3. Xia W, Wu JT, Yin XR, Wang ZJ, Wu HT. CT angiography of the neck: value of contrast medium dose reduction with low tube voltage and high tube current in a 64-detector row CT. Clin Radiol. 2014;69:e183–e189.

4. Zhang WL, Li M, Zhang B, et al. CT angiography of the head-and-neck vessels acquired with low tube voltage, low iodine, and iterative image reconstruction: clinical evaluation of radiation dose and image quality. PLoS ONE 2013;8:e81486.

5. Cho ES, Chung TS, Oh DK, et al. Cerebral computed tomography angiography using a low tube voltage (80 kVp) and a moderate concentration of iodine contrast material: a quantitative and qualitative comparison with conventional computed tomography angiography. Invest Radiol. 2012;47:142–147.

6. Sodickson A, Weiss M. Effects of patient size on radiation dose reduction and image quality in low-kVp CT pulmonary angiography performed with reduced IV contrast dose. Emerg Radiol. 2012;19:437–445.

7. Sun G, Hou YB, Zhang B, et al. Application of low tube voltage coronary CT angiography with low-dose iodine contrast agent in patients with a BMI of 26–30 kg/m². Clin Radiol. 2015;70:138–145.

8. Andreini D, Pontone G, Mushagk T, et al. Coronary stent evaluation with coronary computed tomographic angiography: Comparison between low-osmolar, high-iodine concentration iomeprol-400 and iso-osmolar, lower-iodine concentration ioxaglate. J Cardiovasc Comput Tomogr. 2014;8:44–51.

9. Kidoh M, Nakaura T, Nakamura S, et al. Low-dose-contrast-protole injection in cardiac CT: 20% contrast dose reduction using 100 kVp and high-tube-current-time setting in 256-slice CT. Acta Radiol. 2014;55:545–553.

10. Zhou L, Liu Y, Wei M, Wu Y, Zhao H, Li J. Low concentration contrast medium for dual-source computed tomography coronary angiography by a combination of iterative reconstruction and low-tube-voltage technique: feasibility study. Eur J Radiol. 2014;83:e92–e99.

11. Patel AR, Lodato JA, Chandra S, et al. Detection of myocardial perfusion abnormalities using ultra-low radiation dose regadensin stress multidetector computed tomography. J Cardiovasc Comput Tomogr. 2011;5:247–254.

12. Zhang C, Zhang Z, Yan Z, Xu L, Yu W, Wang R. 320-row CT coronary angiography: effect of 100-kV tube voltages on image quality, contrast volume, and radiation dose. Int J Cardiovasc Imaging. 2011;27:1059–1068.

13. Kidoh M, Nakaura T, Nakamura S, et al. Contrast material and radiation dose reduction strategy for triple-rule-out cardiac CT angiography: feasibility study of non-ECG-gated low kVp scan of the whole chest following coronary CT angiography. Acta Radiol 2014;55:1186–1196.

14. Godoy MC, Heller SL, Naidich DP, et al. Dual-energy MDCT: comparison of pulmonary artery enhancement on dedicated CT pulmonary angiography, routine and low contrast volume studies. Eur J Radiol. 2011;79:e11–e17.

15. Oda S, Utsunomiya D, Yuki H, et al. Low contrast and radiation dose coronary CT angiography using a 320-row system and a refined contrast injection and timing method. J Cardiovasc Comput. 2015;9:19–27.

16. Szucs-Farkas Z, Megyeri B, Christe A, Vock P. Very low radiation dose with lower concentration iodixanol 270 ml and iomeprol 400 mg I/mL in cardiac CT angiography at various body weights. Eur Radiol. 2014;24:1868–1877.

17. Faggioni L, Neri E, Sbragia P, et al. Low contrast and radiation dose CT coronary angiography with 40 ml of iodinated contrast material in lean patients: comparison of vascular enhancement with iodixanol (320 mg I/mL) and iomeprol (400 mg I/mL). AJR Am J Roentgenol. 2012;199:1220–1225.

18. Viteneri-Ramirez G, Garcia-Lallana A, Simón-Yarza I, et al. Low radiation and low-contrast dose pulmonary CT angiography: Comparison of 380 kVp/40 ml and 100 kVp/80 ml protocols. Clin Radiol. 2012;67:833–839.

19. Wang H, Xu L, Zhang N, Fan Z, Zhang Z, Sun Z. Coronary computed tomographic angiography in coronary artery bypass grafts: comparison between low-concentration iodixanol 270 and iohexol 350. J Comput Assist Tomogr. 2015;39:112–118.

20. Zheng M, Wu Y, Wei M, Liu Y, Zhao H, Li J. Low-concentration contrast medium for 128-slice dual-source CT coronary angiography at a very low radiation dose using prospectively ECG-triggered high-pitch spiral acquisition. Acad Radiol. 2015;22:195–202.

21. Zhang LJ, Qi L, De Cecco CN, et al. High-pitch coronary CT angiography at 70 kVp with low contrast medium volume. Medicine. 2014;93:e92.

22. Ippolito D, Talei Francesi C, Fior D, Bonaffini PA, Minutolo O, Sironi S. Low kV settings CT angiography (CTA) with low dose contrast medium volume protocol in the assessment of thoracic and abdominal aorta disease: a feasibility study. Br J Radiol. 2015;88:20140140.

23. Shen Y, Sun Z, Xu L, et al. High-pitch, low-voltage and low-iodine-concentration CT angiography of aorta: assessment of image quality and radiation dose with iterative reconstruction. PLoS ONE 2015;10:e117469.

24. Cho E, Chung J, Kim S, Kim JH, Yu J, Yoon C. CT venography for deep vein thrombosis using a low tube voltage (100 kVp) setting could increase venous enhancement and reduce the amount of administered iodine. Korean J Radiol. 2013;14:183–193.

25. Chen C, Chu S, Hsu M, Liao Y, Tsai H. Low-tube-voltage (80 kVp) CT aortography using 320-row volume CT with adaptive iterative reconstruction: lower contrast medium and radiation dose. Eur Radiol. 2014;24:460–468.

26. Ichikawa S, Ichikawa T, Motosugi U, Imaizumi A, Sano K, Morisaka H. Computed tomography (CT) venography with dual-energy CT: low tube voltage and dose reduction of contrast medium for detection of deep vein thrombosis. J Comput Assist Tomogr. 2014;38:797–801.

27. Kanematsu M, Goshima S, Miyoshi T, et al. Whole-body CT angiography with low tube voltage and low-concentration contrast material to reduce radiation dose and iodine load. AJR Am J Roentgenol. 2014;202:W106–W116.

28. Cho ES, Yu JS, Ahn JH, et al. CT angiography of the renal arteries: comparison of lower-tube-voltage CTA with moderate-concentration iodinated contrast material and conventional CTA. AJR Am J Roentgenol. 2012;199:96–102.

29. Iezzi R, Cotroneo AR, Giammarino A, Spigonardio F, Storto ML. Low-dose multidetector-row CT angiography of abdominal aortic aneurysm after endovascular repair. Eur Radiol. 2011;79:21–28.

30. Oda S, Utsunomiya D, Awai K, et al. Indirect computed tomography venography with a low-tube-voltage technique: reduction in the radiation and contrast material dose—a prospective randomized study. J Comput Assist Tomogr. 2011;35:631–636.

31. Noda Y, Kanematsu M, Goshima S, et al. Reducing iodine load in hepatic CT for patients with chronic liver disease with a combination of low-tube-voltage and adaptive statistical iterative reconstruction. Eur J Radiol. 2015;84:11–18.
32. Takahashi H, Okada M, Hyodo T, et al. Can low-dose CT with iterative reconstruction reduce both the radiation dose and the amount of iodine contrast medium in a dynamic CT study of the liver? Eur J Radiol. 2014;83:684–691.

33. Nakaura T, Nakamura S, Maruyama N, et al. Low contrast agent and radiation dose protocol for hepatic dynamic CT of thin adults at 256-detector row CT: effect of low tube voltage and hybrid iterative reconstruction algorithm on image quality. Radiology. 2012;264:445–454.

34. Namimoto T, Oda S, Utsunomiya D, et al. Improvement of image quality at low-radiation dose and low-contrast material dose abdominal CT in patients with cirrhosis: intraindividual comparison of low tube voltage with iterative reconstruction algorithm and standard tube voltage. J Comput Assist Tomogr. 2012;36:495–501.

35. Nakaura T, Awai K, Maruyama N, et al. Abdominal dynamic CT in patients with renal dysfunction: contrast agent dose reduction with low tube voltage and high tube current-time product settings at 256-detector row CT. Radiology 2011;261:467–476.

36. Yanaga Y, Awai K, Nakaura T, et al. Hepatocellular carcinoma in patients weighing 70 kg or less: initial trial of compact-bolus dynamic CT with low-dose contrast material at 80 kVp. AJR Am J Roentgenol. 2011;196:1324–1331.

37. Kanematsu M, Goshima S, Kawai N, et al. Low-iodine-load and low-tube-voltage CT angiographic imaging of the kidney by using bolus tracking with saline flushing. Radiology. 2015;275:832–840.

38. Hwang I, Cho JY, Kim SY, et al. Low tube voltage computed tomography urography using low-concentration contrast media: Comparison of image quality in conventional computed tomography urography. Eur J Radiol. 2015;84:2454–2463.

39. Noda Y, Kanematsu M, Goshima S, et al. Reduction of iodine load in CT imaging of pancreas acquired with low tube voltage and an adaptive statistical iterative reconstruction technique. J Comput Assist Tomogr. 2014;38:714–720.

40. Padole A, Ali KR, Kalra MK, Singh S. CT radiation dose and iterative reconstruction techniques. AJR Am J Roentgenol. 2015;204:W384–W392.