Low tube voltage protocol for prospective ECG-gating coronary CT angiography in Japanese people

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Coronary CT angiography (CCTA) is a less-invasive, time-saving method, and can be used to avoid invasive angiography for diagnosis of coronary artery disease (1, 2). Despite of its non-invasive nature, the associated radiation exposure is of particular concern (3, 4). We use prospective gating method (5, 6) for reduction of radiation dose in particular patients according to SCCT guideline. In 2011 new guideline, 100kV scan is recommended for the patients weighing < 90kg, and most Japanese fit in these criteria (7).

In this study, we evaluated the clinical effect of combination of 100kV scan with prospective ECG-gating CCTA by 64MDCT in Japanese people.
Methods and Materials

Instrumentation and Imaging parameters

All coronary CT angiography (CCTA) examinations were performed with 64-detector row CT scanner (LightSpeed™ VCT: GE Healthcare). First we performed two phantom studies to examine the effect of tube voltage on CT numbers, radiation dose, and image quality. Then, on the basis of phantom studies, we introduced 100kV to our conventional CCTA protocol.

Phantom experiments

Evaluation of the effect of various tube voltage on CT numbers, radiation dose and image quality

Investigation of the effect on CT numbers

To examine the effect of tube voltage on CT numbers, seventeen different iodine concentration solution homemade phantoms of 0 to 4700 HU, adjusted at 120 kV tube voltage, were used. Mean CT number of 4.0-cm$^2$ region of interest (ROI) of seventeen phantoms was measured at 80kV, 100 kV, 120 kV and 140kV on fixed tube current at 300mA.

Investigation of the effect on radiation dose and image quality

To investigate the effect of tube voltage on radiation dose and image quality, calibration phantom attached to CT (QA phantom reference 21CFR 1020.33 (d)(1)) was used. Radiation dose index (DLP) and standard deviation (SD) of CT numbers in a ROI placed on water area of the calibration phantom (Fig. 1 on page left) were measured at 80kV, 100 kV, 120 kV and 140kV with various tube current-time product from 300 mA to 800 mA. Radiation dose was assessed by the dose-length product (DLP), and image quality was assessed by SD of CT number in the ROI.

Scan parameters
The scan parameters were: rotation time of 0.5 second, beam collimation of 20 mm, table feed per rotation of 27.5 mm, beam pitch of 1.375:1, field of view of 13 cm, and reconstruction type of standard. Tube current-time product was varied from 300 mA to 800 mA.

**Clinical study**

**Patients**

Consecutive 78 patients without arrhythmia, whose sinus rhythm became less than 65 b.p.m. after premedication of β-blocker, underwent prospectively ECG-gated CCTA. Thirty-two (41.1%) were male and forty-six (58.9%) were female with an average age of 73.8 years (range: 46 - 94 years). An average body weight was 57.7 kg (range: 37 - 86 kg). There were no significant differences of patients in terms of sex, age, and body weight. With 78 patients, 30, 38 and 10 underwent 100 kV, 120 kV and 140 kV scan protocol, respectively.

**Scan protocol**

Prospective gating method was applied only when the heart rate is less than 65 b.p.m. without arrhythmia. Patients were divided into three different tube voltage scan groups (group of 100 kV, 120 kV or 140 kV) according to the existence of coronary calcification or stent detected at pre-scan for calcium scoring. The 100 kV scan was applied for the case that neither coronary calcification nor stent were detected. Contrast material usage was determined by the body weight of each patient: the proportion to body weight was varying depending on the tube voltage (Table 1 on page 6).

**Scan parameters**

Scan type of Axial cardiac pulse cine, padding of 150msec (center at 77%), rotation of 0.35/s, detector coverage of 40mm, snapshot pulse thickness of 0.625 mm, SFOV of cardiac small, DFOV of 18cm, reconstruction type of standard. Tube current and voltage were variable depending on each patient, and determined as shown on Table 1 on page 6.

**Evaluation of image quality and radiation dose**
To examine image quality, we measured mean CT number and SD with 4.0 cm$^2$ rectangular ROI placed in the aortic root immediately cranial to the left coronary artery (Fig. 1 on page right). Image quality was assessed by image noise and contrast to noise ratio (CNR). Image noise was defined as the SD of CT number, and CNR was defined as dividing the mean CT number by image noise. Radiation dose was referred to DLP of the dose report of VCT. SD, CNR and DLP were compared among three different tube voltage groups.

**Measurement of CT number**

**CT numbers on phantom studies and clinical study were measured by Osirix 3.0 system.**

**Statistical analysis**

**All data were expressed as means ± SD. Student T test was performed to examine the differences of CNR, SD and noise on 100 kV scan group against 120 kV group.**
Fig. 1: Determination of image noise by measurement of SD of CT number within ROI in examples of QA phantom and CCTA scan from patient. Left: ROI placed on water area of QA phantom to investigate the effect of tube voltage on image quality. ROI (green rectangular) shows image noise is 13.5. Right: A ROI placed in the aortic root immediately cranial to the left coronary artery. ROI (green rectangular) shows image noise is 24.7.

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Table 1: New CCTA scan protocol with 100 kV. Patients are divided by the existence of coronary stent or calcification.

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Results

Phantom experiments

The effect of various tube voltage on CT numbers, radiation dose and image quality

The effect on CT numbers

Fig. 2 on page 10 shows the measured CT numbers of seventeen different iodine solution phantoms at 80 kV, 100 kV, 120 kV and 140 kV with various tube current. On the same tube voltage, CT number increased proportional to iodine concentration. On the same concentration phantom, CT numbers increase as the tube voltage decrease. Moreover, the lower the tube voltage was, the more the increasing rate was observed.

These results indicate that the CT number is tube voltage dependent, and we postulated that enhancement contrast could be decreased if lower tube voltage were used. On the line chart, to attain 300 HU on 100 kV, iodine solution of 240 HU at 120 kV is sufficient. From this results, we hypothesized that contrast material usage could be reduced to 0.48 ml / body weight on 100kV from 0.6 ml /BW used on 120 KV scan.

The effect on radiation dose and image quality

Fig. 3 on page 10 shows DLP and SD of the water area of the QA phantom measured at 80 kV, 100 kV, 120 kV and 140 kV tube voltage. As the tube voltage decreased, SD increased while DLP decreased.

Fig. 4 on page 11 shows the change of DLP of the QA phantom measured at various tube current at 80 kV, 100 kV, 120 kV and 140 kV tube voltage. On the same tube current, DLP at 100 kV reduced by 40% in comparison to that 120kV. Those results were compatible with the theoretical X-ray intensity calculated according to the formula; X-ray energy$\#K\#v^2 \#i$, where "$K$" is defined as constant, "$v$" is defined as tube voltage, and "$i$" is defined as tube current.

Relationship between DLP and SD were further examined. SD was in an inverse correlation with DLP. The change in SD was only 5 even if DLP halved 250 from 500 (Fig. 5 on page 12).
Fig. 6 on page 12 shows the change of SD on QA phantom at 80 kV, 100 kV, 120 kV and 140 kV on various tube currents. To keep SD constant, more tube current was required on lower tube voltage. SD increasing rate at 80kV was greater than other tube voltages especially on lower tube current. Thus, because loss of image quality and more skin surface dose were concerned, 80 kV scan was not integrated to new CCTA protocol (Table 1 on page 13).

Clinical study on new CCTA protocol

Combination of 100 kV with prospective gating method was evaluated with respect to image quality and radiation dose. Image quality and radiation dose of 100 kV group were compared with 120 kV group. Image quality and radiation dose were assessed by CNR, SD and DLP/weight.

Fig. 7 on page 14 shows CNR, SD and DLP/weight of the group of 100 kV, 120 kV and 140 kV, respectively. The differences of CNR (left top) of 100 kV group compared to 120kV group was not significant. Considerable reduction of contrast material usage as 0.48 ml/weight for 100 kV in comparison to 0.6 ml/weight for 120 kV was attained without significant change of CNR. Slight increase of SD (right top) at 100kV compared to 120 kV was not significant, and did not negatively influence for diagnosis. DLP/weight (bottom) of 100kV group was significantly lower compared to 120kV group (mean = 7.3 and 4.9 for 120kV and 100kV respectively, \( p < 0.0001 \)). Examples of an image on three tube voltage groups are shown on Fig. 8 on page 15.
**Fig. 2:** Top: A plot of CT numbers of tube voltage at 80 kV, 100 kV, 120 kV and 140 kV. On the same tube voltage, CT number increases proportional to iodine concentration. The lower the tube voltage is, the more increasing rate is observed, and CT number increases as the tube voltage decrease (corresponding images of dot lines are on the bottom). Bottom: Examples of phantom images. Axial slices of iodine solution phantom of 500 HU adjusted at 120 kV, were scanned at 100, 120 and 140 kV. CT numbers varies dependant on tube voltage.

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**Fig. 3:** Example images of QA phantom measured at 80 kV, 100 kV, 120 kV and 140 kV on tube current of 300 mA, slice thickness of 5mm, reconstruction of standard. DLP and SD are measured at the water area of the phantom. As tube voltage decreases, SD increases while LDP decreases.

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**Fig. 4:** A plot of DLP at 80 kV, 100 kV, 120 kV and 140 kV on various tube current. At 100kV, DLP reduces by 40% compared to 120kV.

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**Fig. 5:** A plot of DLP and SD. SD is in an inverse correlation with DLP. Change in SD is only 5 even if DLP halved from 250 to 500.

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Fig. 6: A plot of SD at 80 kV, 100 kV, 120 kV and 140 kV on various tube current. To keep SD constant, more tube current is required on lower tube voltage. SD increasing rate at 80kV is greater than other tube voltages especially on lower tube current.

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Table 1: New CCTA scan protocol with 100 kV. Patients are divided by the existence of coronary stent or calcification.

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Fig. 7: CNR, SD and DLP/weight of the group of 100 kV, 120 kV and 140 kV on our CCTA protocol. The differences of CNR (left top) and SD (right top) of 100 kV group compared to 120kV group are not significant, while DLP/ weight (bottom) of 100kV group is significantly lower (*p < 0.0001).

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Fig. 8: Sample CTA images of left coronary artery obtained by our protocol of tube voltage at 100 kV (left), 120 kV (middle) and 140 kV (right). Left: An image in a 58 year-old female patient (body weight 65 kg) scanned at 100 kV. DLP/weight, SD and CNR were 3.12, 27.1 and 12.5, respectively. Middle: An image in a 66 year-old male patient (body weight 63 kg) scanned at 120 kV. DLP/weight, SD and CNR were 6.1, 22.6 and 17.7, respectively. Right: An image in a 68 year-old male patient (body weight 62 kg) scanned at 140 kV. DLP/weight, SD and CNR were 8.35, 18.9 and 16.6, respectively.

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Conclusion

Discussion

We evaluated the clinical effect of 100 kV in combination with prospective gating CCTA in Japanese people. On SCCT guideline, recommendation for tube voltage is definite, while recommendation for tube current is stated as "based on each individual patient's size and clinical indication, to the lowest setting that achieves acceptable image noise." (7). On another guideline GuLATIC, produced by Japanese society radiological technology, recommends that target SD at Aorta is around 25. Various factors on image quality and radiation dose affect differently on every patient, and we are searching for a solution to attain definite protocol in everyday practice. To figure out the "appropriate" protocol for Japanese people, we first performed phantom studies and then introduced 100 kV scan into our conventional CCTA protocol.

With our new protocol, we could achieve significant reduction of DLP without image quality degradation, as well as significantly less contrast material usage with considerable CNR by combination of 100kV with prospectively ECG-gated CCTA using 64 MDCT without iterative reconstruction. Indication of the scan protocol should be selected carefully with the consideration of arrhythmia, heart rate, body weight, the existence of the cause of partial volume artifact such as calcification or stent, and so on. We used body weight to determine tube current and contrast material usage because of the convenience at CT room before scan, however, there would be more suitable factors such as BMI.

By latest multi-row technology in CT with iterative reconstruction, it became possible to reduce radiation dose (8-10). In real clinical practice, however, immediate introduce of the expensive latest medical equipment is impractical, and large number of facilities use the 64 MDCT for coronary CTA. It is important to understand the performance of the device on our hand and to contrive for full advantage.

Conclusion:

Combination of 100kV with prospective gating CCTA achieved significant dose reduction without image quality degradation in selected Japanese people.
References


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Thank you for your interest in this exhibit. If you have any question or comment, please contact me via email (minori.imura@gmail.com).

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Fig. 10

References: M. Imura and T. Todoroki; Kyoto, JAPAN