第 26 卷　第 1 期　　CT 理论与应用研究　　Vol.26, No.1
2017 年 2 月（99-106）　　CT Theory and Applications　　Feb., 2017

田执南，龙世亮，赵越，等. 探讨超低剂量前瞻性冠脉 CTA 成像技术在低体重指数患者中的应用价值[J]. CT 理论与应用研究，2017，26(1)：99-106. (英). doi:10.15953/j.1004-4140.2017.26.01.13.
Tian ZN, Long SL, Zhao Y, et al. Feasibility of 80 kVp ultra-low dose scan protocol in prospective coronary CT angiography[J]. CT Theory and Applications, 2017, 26(1): 99-106. doi:10.15953/j.1004-4140. 2017.26.01.13.

Feasibility of 80 kVp Ultra-low Dose Scan Protocol in Prospective Coronary CT Angiography

TIAN Zhi-nan, LONG Shi-liang✉, ZHAO Yue, TAN Hong-wen

CT\MR Room, Zhanjiang Central People's Hospital of Guangdong Province, Zhanjiang 524033, China

Abstract: Objective: To investigate the feasibility of prospective coronary computed tomography angiography (CTA) using tube voltage of 80 kVp in patients with low body mass index (BMI). Methods: Eighty-four patients with suspected coronary artery disease (CAD) underwent prospective ECG-gate coronary CTA. The cases were divided into two groups based on BMI: One group (BMI ≤ 22 kg/m^2) was examined with 80 kVp, and the other group (22 < BMI ≤ 25) with 100 kVp. If heart rates < 65beats/min, pulse exposure time was set at 200 ms, otherwise 380ms. The imaging qualities of coronary artery segments with diameter ≥ 1.5 mm were evaluated. Image quality and radiation dose were compared between groups. Results: The age, height, and heart rate were insignificantly different between groups. In the 80 kVp and 100 kV groups, the EDs were 0.56 ± 0.21 and (1.43 ± 0.58) mSv, respectively. There were significant differences in CT dose index volume (CTDIvol), dose length product (DLP) and ED between groups. The image quality rates (score of 3 or 4) were 92.2% and 91.8% in the 80 kVp and 100 kVp groups, respectively. In image quality scores, aortic SNR and coronary trunk CNR had no significant differences between two groups. Conclusion: Prospective coronary CTA using tube voltage of 80 kVp in low-BMI patients can provide adequate coronary diagnostic information; while significantly reduce the radiation dose.

Keywords: tomography; X-ray computed; coronary angiography; tube voltage; radiation dosage

doi:10.15953/j.1004-4140. 2017.26.01.13.　　**CLC number:** R 812；R 445　　**Document code:** A

Coronary computed tomography angiography (CTA) brings potential carcinogenic risk to subjects, especially women and young people[1]. Radiologists and clinicians should adopt the radiation dosage "as low as reasonably achievable" (ALARA), which can reduce the radiation dosage of coronary CTA while satisfying diagnostic needs. The BMI-based individualized selection of scanning scheme (BMI: body mass index) is able to prevent young subjects from excessive radiation[2]. The radiation dosage of prospective scanning is reduced by about 80% compared with retrospective scanning. For normal-weight subjects, the 100 kVp coronary CTA is sufficient to satisfy diagnostic needs in clinic[3-5]. So far, there is rare report about the use of 80 kVp prospective coronary CTA without heart rate control. In this study, we used 80 kVp prospective coronary CTA to examine small-BMI patients (BMI ≤ 22 kg/m^2) and used CARE

Date of Receiving: 2016-06-27.

Dose 4D for auto-regulation of tube current, aiming to discuss the feasibility of low-dose prospective coronary CTA.

1 Materials and methods

1.1 Clinical data

Totally 84 patients (43 males, 41 females, aged 28 ~ 65 years old, mean 50.6 ± 14.5) with suspected coronary artery disease (CAD) and BMI ≤ 25 kg/m^2 were treated with prospective coronary CTA between March 2012 and March 2013.

A Somatom Definition double-source CT (DSCT) scanner (Siemens Medical Solutions, Forchheim, Germany) was used here. At 3 min before scanning, 0.25 mg of nitroglycerine was put sublingually into each patient. The scan range was from 1 cm below the trachea carina to the heart diaphragmatic surface.

About 60 ~ 80 mL of 370 mg/mL iopamidol (a nonionic iodinated contrast agent) was injected via the right cubital vein through a double-cylinder high-pressure syringe. For BMI ≤ 22 (22 < BMI ≤ 25) kg/m^2, the tube voltage was 80 (100) kVp, and the injection speed 4.5 (5.0) mL/s. Then 40 mL of normal saline was injected at the same rate. Pulse exposure time was 200 ms for patients with heart rate < 65 beats/min, and otherwise 380 ms. The tube current was adjusted by the CARE Dose 4D technique, with reference at 370 mAs. Then 0.75-mm-thick layers were reconstructed at the interval of 0.5 mm and with the convolution function B26f.

1.2 Image reconstruction and analysis

The images were post-processed on a Siemens DSCT Syngo workstation, including maximum intensity projection (MIP), curved planar reconstruction (CPR), volume representation (VR) and vessel axial reconstruction. The 16-segment method for coronary arterial tree segmentation from American Heart Association (AHA) was used here. The images were analyzed by two observers (principal physicians or above level) independently with experience in cardiovascular diagnostic imaging and without knowing the grouping.

The coronary segments with diameter ≥ 1.5 mm were scored as follows: 4: complete coronary continuity, very uniform density, clear edges; 3: slightly staggered artifacts, uniform density, clear edges, no impact on diagnosis; 2: visible stair-shaped artifacts, not very uniform density, slightly blur edges, diagnosis basically not impacted; 1: staggered artifacts, non-uniform density, blur edges, impossible diagnosis. The images with score ≥ 3 were considered as eligible.

The average CT value after reinforcement at the horizontal aortic root was measured on the starting part of left coronary artery, and its standard deviation (SD) was used as image noise, with region-of-interest (ROI) = 1 cm^2. The CT values and SDs in the vascular cavity and nearby fat tissues after reinforcement were measured at the starting parts of right coronary artery (RCA) and left main coronary artery (LM). The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were computed as follows: SNR = lumen reinforced CT value /SD; CNR = (RCA or LM reinforced CT value - CT value in nearby fat tissues)/SD.

1.3 Analysis of CT radiation dosage

The CT dose index volume (CTDIvol) and dose length product (DLP) of coronary CTA were recorded. Effective dose (ED) was computed as $ED = DLP \times k$, $k = 0.014$.

1.4 Statistical analysis

Statistical analysis was performed on SPSS 17.0 (IBM Corporation, Armonk, NY, USA). Measuring data were expressed as mean ± SD. The age, heart rate, BMI, noise, SD, SNR, CNR and radiation dosage were all compared between groups via *t*-test with paired independent samples. The image quality scores of coronary CTA were compared between groups via χ^2-test. The between-observer consistency was examined by kappa test (kappa < 0.4: low; 0.4 ~ 0.8 high; > 0.8: very high), with significance level at $P < 0.05$.

2 Results

2.1 Clinical data

The 80 kVp group involved more females than males. No significant difference between groups were found in age, height or heart rate ($P > 0.05$), but in weight and BMI ($P < 0.05$) (Table 1).

2.2 Radiation dosage

No significant differences between groups were found in scanning range or pulse exposure time ($P > 0.05$). The 80 kVp group showed significantly lower ED and radiation dosage reduction ~ 60% versus the 100 kVp group; the EDs in the 80 kVp and 100 kVp groups were 0.56 ± 0.21 and (1.43 ± 0.58) mSv, respectively. The CTDIvol, DLP and ED were all significantly different between groups ($P < 0.001$) (Table 2).

Table 1　Patient characteristics

Groups	*n*	Gender /(F/M)	Age /year	Height /cm	Weight /kg	BMI /(kg/m2)	HR /(b/min)
80 kVp	38	27/11	48.2 ± 13.8	161.5 ± 9.1	51.6 ± 8.4	20.5 ± 1.6	70.9 ± 8.4
100 kVp	46	14/32	51.9 ± 15.3	165.3 ± 8.8	62.2 ± 9.7	23.3 ± 2.2	73.5 ± 9.7
t	-	-	0.263	1.360	2.807	3.635	0.636
P	-	-	0.431	0.178	0.036	0.021	0.524

Table 2　Radiation dose

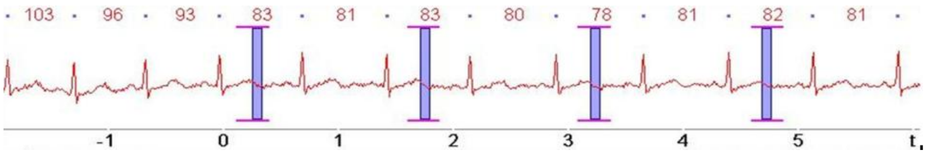
The scanning parameters	80 kVp(n = 38)	100 kVp(n = 46)	*t*	*P*
Scan range(cm)	12.1 ± 0.6	11.6 ± 0.9	1.321	0.472
Pulse exposure time(ms)	286.3 ± 47.8	278.5 ± 52.1	2.253	0.558
CTDIvol (mGy)	3.5 ± 1.22	8. 6 ± 3.5	8.835	0.000
DLP (mGy*cm)	40.2 ± 13.6	102.5 ± 41.1	6.474	0.000
ED (mSv)	0.6 ± 0.2	1.4 ± 0.6	6.896	0.000

2.3 Image quality

The 80 kVp prospective coronary CTA without heart rate control significantly reduced radiation dosage and improved image quality (Fig.1). The low-dose prospective coronary CTA clearly displays a small amount of non-calcified plaques (Fig.2). The 80 kVp and 100 kVp groups had 538 and 663 coronary segments with diameter ≥ 1.5 mm, respectively, and the eligible rates satisfying diagnostic needs were 92.2% and 91.8%, respectively, but the image quality scores were not significantly different between groups (Table 3). The between-observer consistency was very high (kappa = 0.85).

Table 3 Qualitative evaluation of image quality

image quality score	80 kVp (n = 38)	100 kVp (n = 46)	χ^2	P
the number of segments	538	663	-	-
4 分	289 (53.7%)	387 (58.4%)	0.13	> 0.05
3 分	207 (38.5%)	221 (33.4%)	0.05	> 0.05
2 分	32 (5.9%)	37 (5.6%)	0.07	> 0.05
1 分	10 (1.9%)	18 (3.6%)	0.28	> 0.05
percent of pass	92.2%	91.8%	-	-



(a)

(b)

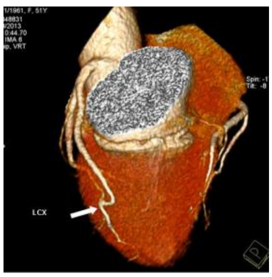
(c)

(d)

(e)

(f)

(g)



(h)

Fig.1 Female, 51 years old, BMI = 20.3 kg/m^2, tube voltage 80 kVp. (a) scanned ECG, average heart rate = 80 beats/min. (b) statistics of scan parameters and radiation dosage; DLP = 36mGy • cm, ED = 0.5 mSv. (c) CT value at aortic root (707.3 + 43.6) Hu. (d) ~ (h) showed the CPR, MIP and VR, continuity in the RCA and LM and their main branches, uniform density, clear edges, image quality score = 4

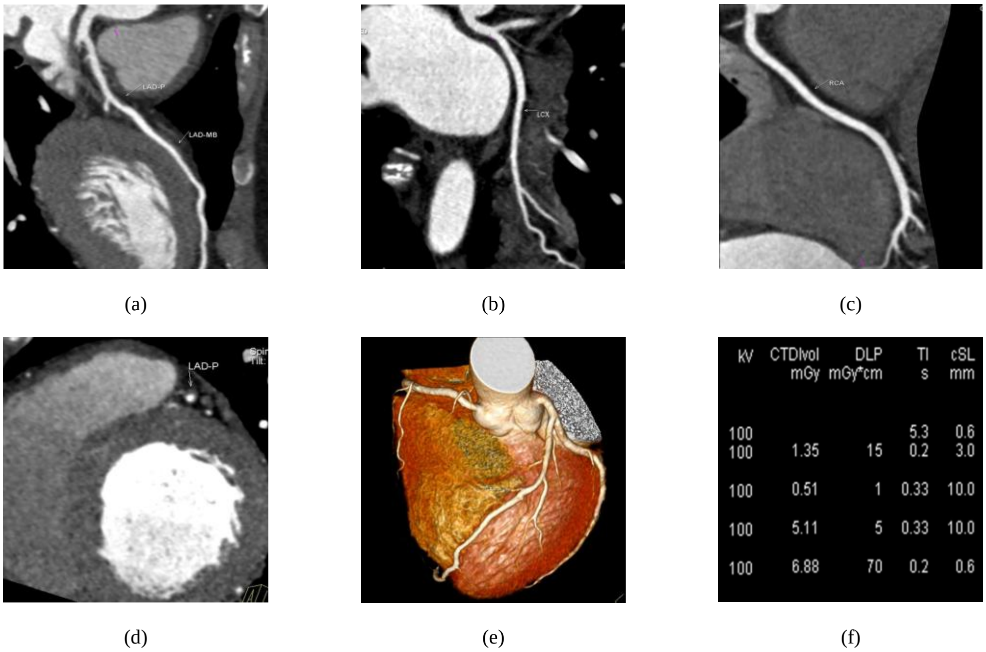


Fig.2　Female, 49 years old, BMI = 23.5 kg/m^2; tube voltage 100 kVp. (a) ~ (c), and (e) showed CPR, VR, uniform vascular density in RCA and LM, clear edges, no staggered artifacts, image quality score = 4. (a) and (d) clearly showed a small amount of non-calcified plaques in the middle segment of the anterior descending coronary artery. (f) statistics of radiation dosage; DLP = 70 mGy • cm, ED = 0.98 mSv

The CT values in the aorta root, RCA, and LM in the 80 kVp group were all significantly higher versus the 100 kVp group (all $P < 0.001$). The aortic image noises in the 80 kVp group were higher than in the 100 kVp group. The aortic SNR, RCA CNR, and LM CNR were not significantly different between groups (P > 0 05) (Table 4).

Table 4　Quantitative measurement of image quality

image quality indexes	80 kVp (*n* = 38)	100 kVp (*n* = 46)	*t*	*P*
Aortic CT value/Hu	677.2 ± 166.3	479.8 ± 85.3	-1.893	0.000
RCA CT value/Hu	689.4 ± 164.2	503.6 ± 95.7	-4.245	0.000
LM CT value/Hu	653.6 ± 144.8	477.6 ± 85.3	-2.728	0.000
Coronary fat around the CT value/Hu	-105.3 ± 28.4	-93.4 ± 20.1	-1.653	0.036
Aortic SD	42.7 ± 6.5	25.3 ± 5.4	-2.217	0.002
Aortic SNR	21.6 ± 4.3	22.7 ± 4.8	0.822	0.550
RCA CNR	24.3 ± 5.1	26.8 ± 5.2	0.734	0.630
LM CNR	23.7 ± 5.6	28.3 ± 6.6	0.659	0.420

3　Discussion

Coronary CTA is widely used into diagnosis and follow-up of CAD and gradually applied into screening of high-risk CAD populations. Moreover, the concern that coronary CTA may induce radiation injury has attracted high attention, and low-dose coronary CTA already becomes a hotspot[1-3].

3.1 Prospective coronary CTA without strict heart rate control

DSCT provides high time resolution (83 ms), while retrospective coronary CTA does not require heart rate control in principle[6]. Compared with retrospective coronary CTA, the prospective coronary CTA can reduce ~ 80% of radiation dosage[4,7]. As reported, novel DSCT large-helical-pitch scan could reduce the ED of coronary CTA to 0.9 mSv, but it is only feasible to patients with stable heart rate lower than 65 beats/min[8]. Thus, exploring the potential of DSCT will help to reduce the radiation dosage received by people undergoing coronary examination.

A part of young, female and reexamined patients should use prospective scanning under the condition of high heart rate, which ensures to significantly reduce radiation dosage. DSCT prolongs the pulse exposure time of prospective scan from 200 to 380 ms, or namely the Flex Padding technique, which is feasible to high-heart-rate patients receiving prospective coronary CTA[9,10]. The reason is that the prolonging of pulse exposure time helps to transform the previous reconstruction time phase from "nonadjustable" to "adjustable". Appropriate selection of acquisition phase and electrocardiogram (ECG) editing contribute to the elimination of motion artifacts due to heart rate variation. In this study, the 84 patients finished prospective coronary CTA successfully without restrict heart-rate control. This examination not only largely reduced the radiation dosage received by the subjects, but also shortened the waiting time.

3.2 Tube voltage and radiation dosage

Reducing the tube voltage can significantly decrease the radiation dosage received by the subjects[11]. As reported, the 100 kVp coronary CTA significantly reduced the radiation dosage, but did not significantly change the image quality compared with the 120 kVp one[12]. The 100 kVp coronary CTA significantly reduced the radiation dosage among patients with BMI = 25.0 ~ 30.0 kg/m^2, and provided image quality satisfying diagnostic needs[13]. For people with smaller BMI, the 80 kVp coronary CTA can provide image quality that meets diagnostic needs[14].

Small-BMI subjects are not uncommon in clinical practice, so it is necessary to set a specific group with BMI < 25 kg/m^2, thus largely reducing the radiation dosage. In this study, the patients with BMI < 22 kg/m^2 were examined by 80 kVp scan. Results show the EDs of the 80 kVp group and 100 kVp group were (0.56 ±0.21)mSv and (1.43 ±0.58)mSv, respectively, with radiation dosage reduction of 60% in the 80 kVp group. The image qualities were not significantly different between groups, with image eligibility rates of 92.2% and 91.8%, respectively. The image noise increased in the 80 kVp group, because the tube voltage reduction eliminated the X-ray penetration and thus decreased the number of X-ray photons from the detector[15]. The SNR in the 80 kVp group did not decrease with the increase of noise. The aortic SNR, LM CNR, and RCA CNR were not significantly different between groups, because the low voltage enhanced the photoelectric effect of iopamidol and increased the vascular CT value. The use of low-dose (80 kVp) coronary CTA is feasible for small-BMI patients.

3.3 Tube current and radiation dosage

Tube current and radiation dosage are linearly correlated, and tube current reduction is a main method to decrease the radiation dosage of coronary CTA[14,16]. The use of CARE Dose 4D can reduce the radiation dosage by 30% ~ 40%[13]. In our sample, the 80 kVp technique reduced the radiation dosage by about 60%, which is related to the tube current reduction in CARE Dose 4D.

This study has some limitations. First, the number of patients with coronary artery stenosis is not large enough for comparison of digital subtraction angiography (DSA) data and is unable to evaluate the accuracy of coronary stenosis diagnosis. Second, we did not divide groups by heart rate, which is a main factor affecting the image quality. Thus, the sample size should be enlarged in the future, which makes the findings more convincing.

In conclusion, the 80 kVp prospective coronary CTA combined with CARE Dose 4D with tube current regulation and without strict heart rate control is feasible to low-BMI patients. The radiation dosage is reduced to the level of DSCT large-helical-pitch scan, and the image quality is high enough to meet diagnostic needs.

Referencces

[1] Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography[J]. The Journal of the American Medical Association, 2007, 298(3): 317-323.

[2] Yerramasu A, Venuraju S, Atwal S, et al. Radiation dose of CT coronary angiography in clinical practice: Objective evaluation of strategies for dose optimization[J]. European Journal of Radiology, 2012, 81(7): 1555-1561.

[3] Van der Bijl N, Joemai RM, Mertens BJ, et al. Effect of dose reduction on image quality and diagnostic performance in coronary computed tomography angiography[J]. International Journal of Cardiovascular Imaging, 2013, 29(2): 453- 461.

[4] Stolzmann P, Leschka S, Scheffel H, et al. Dual-source CT in step-and-shoot mode: Noninvasive coronary angiography with low radiation dose[J]. Radiology, 2008, 249: 71-80.

[5] Blankstein R, Bolen MA, Pale R, et al. Use of 100 kVp versus 120 kVp in cardiac dual source computed tomography: Effect on radiation dose and image quality[J]. International Journal of Cardiovascular Imaging, 2011, 27(4): 579-586.

[6] Scheffel H, Alkadhi H, Plass A, et al. Accuracy of dual-source CT coronary angiography: First experience in a high pretest probability population without heart rate control[J]. European Journal of Radiology, 2006, 16(12): 2739-2747.

[7] 古今, 吴晟, 史河水, 等. 低剂量冠状动脉 CTA: 前瞻性与回顾性心电门控扫描的对比分析[J]. 放射学实践, 2011, 26(7): 716-720.
Gu J, Wu S, Shi HS, et. al. low dose coronary CTA: Prospective and retrospective heart switch control scanning analysis[J]. Radiology Practices, 2011, 26(7): 716-720. (in Chinese).

[8] Sommer WH, Albrecht E, Bamberg F, et al. Feasibility and radiation dose of high pitch acquisition protocols in patients undergoing dual-source cardiac CT[J]. American Journal of Roentgenology, 2010, 195(6): 1306-1312.

[9] Labounty TM, Leipsic J, Min JK, et al. Effect of padding duration on radiation dose and image interpretation in prospectively ECG-triggered coronary CT angiography[J]. American Journal of Roentgenology, 2010, 194(4): 933-937.

[10] 孙明利, 吕滨, 吴润泽, 等. 双源 CT 前瞻性心电门控对较高心率患者冠状动脉成像的准确性研究[J]. 中华放射学杂志, 2011, 45(5): 436-440.
Sun ML, Lv B, Wu RZ et. al. Dual-source CT prospective heart switch control the accuracy of the coronary artery imaging in patients with higher heart rate research[J]. Chinese Journal of Radiology, 2011, 45(5): 436-440. (in Chinese).

[11] Leschka S, stolzmann P, Schmid FT, et al. Low kilovoltage cardiac dual-source CT: Attenuation, noise, and radiation dose[J]. European Journal of Radiology, 2008, 18: 1809-1817.

[12] Pnederer T, Rudofsky L, Ropers D, et al. Image quality in a low radiation exposure protocol for retrospectively ECG-gated coronary CT angiography[J]. American Journal of Roentgenology, 2009, 192: 1045-1050.

[13] 何新华, 胡永胜, 王自勇, 等. 双源 CT 低管电压技术在超重患者冠状动脉成像中的应用[J]. 中华

放射学杂志，2011，45(5)：486-491.
He XH, Hu YS, Wang ZY et. al. Low dual-source CT tube voltage technology application in overweight patients with coronary artery imaging[J]. Chinese Journal of Radiology, 2011, 45(5): 486-491. (in Chinese).

[14] Abada HT, Larchez C, Daoud B, et al. MDCT of the coronary arteries: Feasibility of low dose CT with ECG-pulsed tube current modulation to reduce radiation dose[J]. American Journal of Roentgenology, 2006, 186: S387-S39.

[15] Jun BR, Yong HS, Kang EY, et al. 64-slice coronary computed tomography angiography using low tube voltage of 80 kVp in subjects with normal body mass indices: Comparative study using 120 kVp[J]. Acta Radiologica, 2012, 53(10): 1099-1116.

[16] Park YJ, Kim YJ, Lee JW, et al. Automatic tube potential selection with Tube Current Modulation (APSCM) in coronary CT angiography: Comparison of image quality and radiation dose with conventional body mass index- based protocol[J]. Journal of Cardiovascular Computed Tomography, 2012, 6(3): 184-190.

探讨超低剂量前瞻性冠脉 CTA 成像技术在低体重指数患者中的应用价值

田执南，龙世亮✉，赵越，谭宏文

（湛江中心人民医院 CT/MR 室，广东 湛江 524033）

摘要：目的：探讨在低体重指数患者中使用 80 kVp 管电压的前瞻性心脏冠脉 CTA 成像的可行性。方法：对 84 例临床上怀疑冠心病的患者应用 80 kVp 管电压的前瞻性心脏冠脉 CTA 检查。按 BMI 分为 80 kVp（BMI ≤ 22 kg/m^2）和 100 kVp（22 < BMI ≤ 25）2 组。脉冲曝光时间为 200 ms（心率≦65 次/分）或 380 ms（心率 >65 次/分）。分析直径 ≥ 1.5 mm 的冠脉节段的图像质量（1～4 分），比较各组的图像质量及辐射剂量。结果：两组患者的年龄、身高、心率的一致性较好（P > 0.05）。80 kVp、100 kVp 组的 ED 分别为 (0.56 ±0.21)mSv、(1.43 ±0.58)mSv。两组的 CT 容积剂量指数（CT dose index volume，CTDIvol）、剂量长度乘积（dose length product，DLP）、ED 存在显著的统计学差异（（P = 0.000）。80 kVp、100 kVp 组的合格图像分别为 92.2%、91.8%。两组的图像质量评分、主动脉 SNR 及左、右冠主干 CNR 无统计学差异（P > 0.05）。结论：80 kVp 的超低剂量前瞻性冠脉 CTA 可以应用于低体重指数患者，图像质量足以满足诊断需要，辐射剂量显著降低。

关键词：体层摄影术；X 线计算机；冠状血管造影术；管电压；辐射剂量

作者简介：田执南（1962－），男，湛江中心人民医院 CT/MR 室主管技师，主要从事 CT 和 MRI 成像工作，E-mail：13809752432@139.com；龙世亮✉（1968－），男，湛江中心人民医院医学影像中心主任，主要从事医学影像诊断及研究工作，E-mail：13822520222@139.com。