

宽体探测器CT冠状动脉血管成像中应用三低扫描成像技术的可行性分析

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【摘要】目的:分析不同扫描参数及对比剂注射方案,研究应用低辐射剂量、低注射速率及低对比剂用量的三低扫描成像技术在宽体探测器CT冠状动脉血管成像中的可行性。**方法:**招募210例行冠状动脉血管成像的患者,并随机分为A组(常规组, $n=105$)和B组(三低组, $n=105$),宽体探测器CT采用美国GE公司的Revolution CT。A、B组的管电压分别为120、100 kV;对比剂注射速率和注射用量分别依据身体质量指标及心率的计算。通过测量图像CT值、图像信噪比及对比噪声比来客观评价图像质量;利用Likert 5分法进行主观图像质量评价。**结果:**两组基本资料信息比较,差异无统计学意义($P>0.05$);A和B两组所得冠脉图像主动脉窦口CT值为 (442.70 ± 58.26) 、 (454.11 ± 62.36) HU,两组图像CT值、图像评分、图像信噪比及对比噪声比的差异无统计学意义($P>0.05$),对比剂注射速率、对比剂用量、管电流、有效辐射剂量的差异有统计学意义($P<0.05$),B组相比A组减少33.89%的有效辐射剂量。**结论:**基于患者身体质量指标及心率的个性化定制对比剂注射方案,常规组及三低组均能获得满足影像诊断的图像质量,且三低组图像质量更优,即三低方案可在获得更优质图像质量的前提下降低患者受照剂量和减少对比剂的使用,从而使患者获益更多。

【关键词】冠状动脉;三低扫描;辐射剂量;注射速率;对比剂用量

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Feasibility analysis of wide-detector CT coronary angiography using three-low scanning technology

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Abstract: Objective To analyze various scanning parameters and contrast agent injection schemes, and explore the feasibility of three-low scanning technology characterized by lower radiation dose, slower injection rate and reduced contrast agent dosage in coronary angiography with wide-detector CT. **Methods** A total of 210 patients who underwent coronary angiography were recruited and randomly divided into group A (routine group, $n=105$) and group B (three-low group, $n=105$), and all of them were examined using the Revolution CT from the American GE company. Group A and group B adopted 120 and 100 kV tube voltages, respectively. The contrast injection rate and contrast agent dosage were calculated using formulas based on body mass index and beat per minute. Image quality was objectively evaluated using CT number, signal-to-noise ratio and contrast-to-noise ratio, and subjectively scored using Likert 5-point method. **Results** No statistical differences were found in the basic data between two groups ($P>0.05$). The CT numbers of the aortic sinus orifice in coronary artery images obtained from group A and group B were (442.70 ± 58.26) and (454.11 ± 62.36) HU, respectively. The differences between two groups in CT number, image score, signal-to-noise ratio, and contrast-to-noise ratio were trivial ($P>0.05$), while statistically significant differences were noted in injection rate, contrast agent dosage, tube current, and effective radiation dose ($P<0.05$). Group B reduced the effective radiation dose by 33.89% as compared with group A. **Conclusion** Based on the patient's body mass index and beat per minute, a personalized contrast agent injection scheme can be developed. Both routine group and three-low group can obtain image quality that meets imaging diagnosis requirements, and the latter has better

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image quality, demonstrating that the three-low scheme benefits the patients more for it can reduce the patient's radiation dose and contrast agent dosage while achieving higher image quality.

Keywords: coronary artery; three-low scanning; radiation dose; injection rate; contrast agent dosage

前 言

各种原因引起的冠状动脉管腔狭窄或闭塞是冠心病的原发因素之一,早发现、早治疗冠状动脉狭窄情况能为患者带来极大的健康获益^[1-3]。数字减影血管造影技术是目前临床诊断和排除冠状动脉疾病的金标准,但因其是有创侵入性的影像学检查手段,且存在检查费用高、并发症风险大等问题,使其临床使用有一定局限性^[4]。近年来,随着CT设备的不断发展,利用CT进行冠状动脉血管成像(Coronary Computed Tomography Angiography, CCTA)可以三维立体评估动脉斑块性质,分析测量血管狭窄程度,不仅检查流程便捷、成像速度快、检查费用低,更能进行冠状动脉血管病变的无创筛查及治疗前后的评估等^[5-6]。宽体探测器CT因其16 cm的探测器宽度,加上0.28 s超高转速,时间分辨率可达29 ms,轴扫一圈便能对整个心脏血管进行冻结成像,无需患者控制心率及呼吸,这使得CCTA在临床中发挥越来越重要的作用,但CCTA仍存在对比剂的不良反应和CT的辐射剂量问题等,如何减少患者对比剂的使用并降低受照剂量成为CCTA领域的研究热点。通常情况下,CCTA扫描仅是依据患者心率快慢作为注射造影剂速率及用量的参考^[7],本研究尝试结合患者心率及身体质量指数(Body Mass Index, BMI)来探索更低注射速率、更低对比剂使用量以及更低辐射剂量(三低扫描方案)在CCTA中的可行性。

1 资料与方法

1.1 研究对象

根据预设的入组标准招募2022年9月到2023年12月在南方医科大学南方医院进行CCTA检查的患者共210例,并随机分为A组(常规组, $n=105$)和B组(三低组, $n=105$),其中A组男72例、女33例,平均年龄(57.4 ± 9.7)岁;B组男76例、女29例,平均年龄(55.5 ± 9.4)岁。入组标准:年龄为18~80岁,均无碘对比剂禁忌证、三级高血压、心律不齐、严重哮喘、心肌梗急性期、重度心功能不全、心脏相关手术后、硝酸甘油禁忌证等患者^[8]。

1.2 方法

获取患者身高、体质量及心率,A组和B组分别依据式(1)~式(4)计算获得对比剂注射速率 v 及对比剂注射用量 N ,计算公式参考中国医师协会放射医师分会对于CCTA扫描专家共识中针对不同心率患者

推荐的注射速率并结合临床使用的经验^[9]。对比剂总量由式(4)计算求得,注射时间 t 设置为12 s^[10-11],A、B两组管电压分别采用120 kV及100 kV,监测层面为定位像中气管分叉下1 cm层面的降主动脉层面,监测点为血管管腔中心^[12]。

$$v_a = \frac{0.05 \times \text{心率} + 0.25 \times \text{BMI}}{2} \tag{1}$$

$$v_b = \frac{0.05 \times \text{心率} + 0.25 \times \text{BMI} + 0.5}{3} \tag{2}$$

$$\text{BMI} = \frac{\text{体质量}}{\text{身高}^2} \tag{3}$$

$$N = v \times t \tag{4}$$

1.3 设备及扫描参数

采用美国GE公司的Revolution CT进行扫描,探测器宽度为16 cm,固定kV,自动mA调制控制,mA选择区间为500~690 mA,球管转速0.28 s/r,SFOV选择Cardiac Small,上限为32 cm,自动触发扫描,监测触发阈值设置为200 HU,前门控轴扫,触发延迟时间:4 s;扫描范围为气管分叉处至心尖下1 cm,前后包括整个心脏,扫描长度16 cm^[13-15]。对比剂:37℃碘佛醇,浓度为350 mgI/mL^[16],扫描期相分为3个Part,30%最大mA剂量扫描(0~90%),全mA剂量扫描期相:收缩期(40%~55%)、舒张期(70%~80%)^[17-18],矩阵大小为512×512,重建图像层厚:0.625 mm,层间距:0.625 mm;迭代重建系数ASIR-V:60%^[19-21],智能冠脉追踪冻结平台(SnapShot Freeze, SSF)默认为ON^[22]。

1.4 图像分析及评价

扫描图像均采用期相为(70%~80%)的最佳舒张期SSF图像^[23],应用设备adw4.7版本后处理软件测量工具分别测量主动脉窦口(Aortic Sinus Orifice, ASO)、胸前壁皮下脂肪(Subcutaneous Fat, SAT)、右冠状动脉(Right Coronary Artery, RCA)、冠状动脉左前降支(Left Anterior Descending Branch, LAD)、冠状动脉左回旋支(Left Coronary Circumflex Branch, LCX)血管管腔中心CT值、标准差(Standard Deviation, SD)。将所测得的冠状动脉分支血管的SD值作为图像噪声,SAT的CT值作为背景值,计算各分支血管的信噪比(Signal-to-Noise Ratio, SNR)和对比噪声比(Contrast-to-Noise Ratio, CNR),其中, $\text{SNR} = \text{CT目标血管} / \text{SD}$; $\text{CNR} = (\text{CT目标血管} - \text{CT皮下脂肪}) / \text{SD}$ ^[24-25]。测量感兴趣区域(Region of Interest, ROI)尽可能避开血管壁及管腔斑块^[26],脂肪及各分

支血管测量如图1所示。图像质量分析:依据Likert 5分法,由3名高年资医师分别对图像质量进行评分,1分:极差,血管显示不清,或严重血管搏动伪影,强化不明显,血管无法诊断;2分:不佳,血管中度搏动伪影,或血管中断,血管边缘模糊,图像不清,诊断价值低;3分:可用,血管轻度搏动伪影,血管情况尚能评价;4分:好,图像质量好,有轻微噪声或伪影,与周

围组织对比好;5分:非常好,血管显影好,边界清晰,与周围对比度好^[27-28]。统计的患者受照剂量不包含定位像及钙化积分扫描,记录设备提供的辐射剂量长度乘积(Dose Length Product, DLP)并计算有效辐射剂量(Effective Radiation Dose, ED), $ED=k\times DLP$,其中,胸部吸收系数 k 取 $0.014\text{ mSv}/(\text{mGy}\cdot\text{cm})^{[29-31]}$ 。

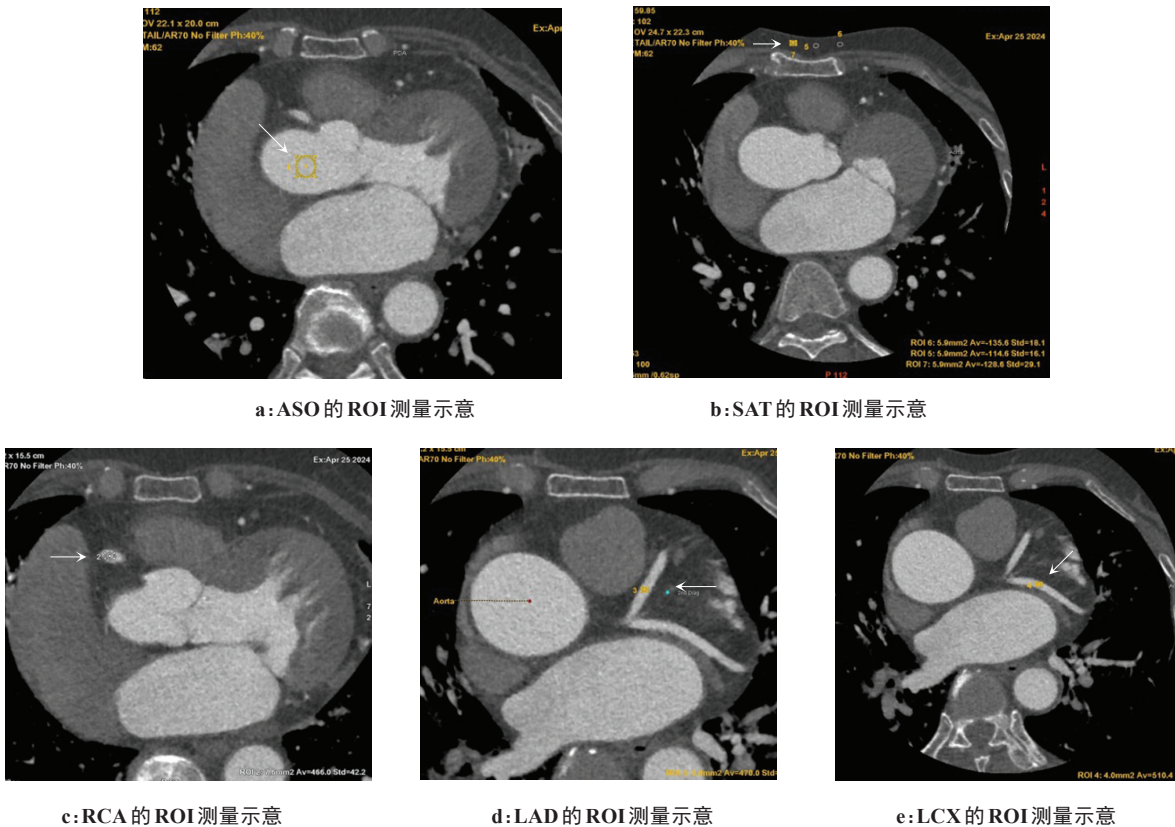


图1 ROI测量
Figure 1 Measurement of regions of interest

1.5 统计学分析

统计学分析利用IBM SPSS21.0软件进行。计量资料采用均数±标准差表示,两组间比较采用t检验;计数资料用例数表示,采用卡方检验。 $P<0.05$ 为差异有统计学意义。

2 结果

2.1 基本临床资料比较

A组和B组的性别、年龄、身高、体质量、BMI及心率差异无统计学意义($P>0.05$)。见表1。

2.2 图像质量评价

2.2.1 图像客观评价 A、B两组ASO、RCA、LAD、LCX的CT值均大于300 HU,可满足临床对于血管管

表1 基本临床资料

Table 1 Basic clinical information

指标	A组	B组	t, χ^2 值	P值
性别(男/女)	72/33	76/29	0.366	0.650
年龄/岁	57.4±9.7	55.5±9.4	1.424	0.156
身高/cm	166.4±8.3	166.6±7.6	-0.177	0.859
体质量/kg	71.0±12.8	70.4±11.4	0.340	0.734
BMI/kg·m ⁻²	25.5±3.3	25.3±3.1	0.526	0.600
心率/次·min ⁻¹	74.5±10.8	74.1±11.2	0.315	0.753

腔情况分析的强化要求。A、B两组在ASO的CT值、SNR、CNR, RCA的CT值、SD值、SNR、CNR, LAD的CT值、SD值、SNR、CNR, LCX的CT值、SD值、SNR、CNR上比较,差异均无统计学意义($P>0.05$),各分支

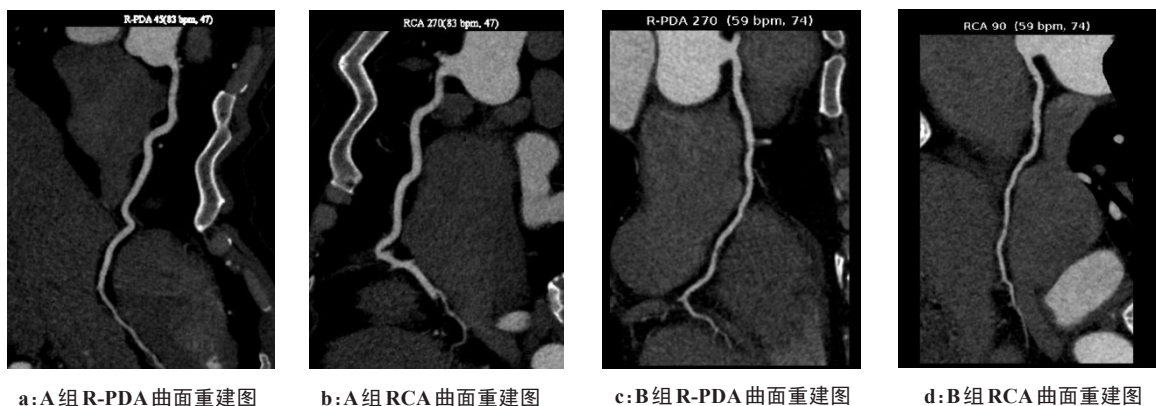


图3 冠状动脉CPR重建图

Figure 3 Curved planar reformation views of coronary artery

表3 注射参数与辐射剂量值

Table 3 Injection parameters and radiation dose

评价指标	A组	B组	t值	P值
注射速率/mL·s ⁻¹	5.05±0.45	3.52±0.36	27.654	<0.05
对比剂用量/mL	60.59±5.50	42.30±4.29	26.879	<0.05
管电流/mA	660.00±26.73	679.10±24.68	-5.295	<0.05
CTDI _{vol} /mGy	21.56±2.89	14.13±1.86	22.139	<0.05
DLP/mGy·cm	343.77±47.59	227.10±29.80	21.292	<0.05
ED/mSv	4.81±0.67	3.18±0.42	21.292	<0.05

注射速率及对比剂用量,可明显减少高流速注射带来的对比剂外渗及对比剂肾病风险^[32]。

由于管电压的降低,B组的管电流为(679.10±24.68) mA,略高于A组的(660.00±26.73) mA,但是在辐射剂量方面,A组的CTDI_{vol}、DLP、ED值均高于B组,A组的ED值为(4.81±0.67) mSv,B组的ED值为(3.18±0.42) mSv,B组的ED值明显低于A组。

3 讨论与结论

对于冠心病的早发现早治疗,CCTA是具有非常重要意义的临床筛查手段之一,CCTA增强检查所用到的碘对比剂通过肾脏代谢,其带来的不良反应、碘对比剂外渗、碘对比剂肾病等不良事件也备受关注^[33]。为了在保证血管强化效果的同时减少对比剂注射速率及对比剂的用量,就需要降低管电压,随着管电压的降低,可使光电效应增强,增加含碘血管与周围组织的对比度。当管电压为100 kV时,个性化计算得到的较低的对比剂注射速率及对比剂用量的扫描方案可有效降低患者因高流速注射带来的对比剂外渗风险,对血管压力耐受程度低的患者可改善患者检查体验,较少的对比剂用量可大大减少对比剂对患者肾脏带来的负担^[34-35]。随着新设备的不断更新迭代,最早64排CT对冠脉成像患者需要心率及

呼吸憋气控制,到如今利用 Revolution CT 进行 CCTA,16 cm 宽体探测器结合 0.28 s 的球管高转速,可在患者自由呼吸状态及任意心率的条件下完成冠脉成像,对于心律失常及呼吸配合度差的患者均能有一个满意的成像效果。随着 CT 设备的普及,电离辐射的危害也逐渐被公众所认识,根据 ALARA(As Low As Reasonably Achievable)原则,在保证图像质量满足临床诊断需求的同时,采用更低的辐射剂量曝光的扫描方案是每一个放射工作者的职责所在,对于低剂量的冠脉成像的研究也是如今研究的重点。Revolution CT 可用到的管电压为 140、120、100、80 及 70 kV,管电压的选择常常是机器自动管电压控制或者技师的经验选择,陈依林等^[36]和陈玉环等^[37]将 70 kV 用于正常 BMI 患者作为研究人群,虽然降低管电压可带来更好的增强效果,但是会导致体型较大患者的图像质量噪声增加,故本研究优先选用适用于多数患者的管电压(120 及 100 kV),后续研究将围绕更低 kV 展开。现有研究中,对于不同 BMI 及心率的患者,CCTA 扫描方案都是依赖技师的技术及经验,对比剂注射方案均是以心率作为参考因素^[38]。本研究是在原本基于心率的对比剂注射方案下结合 BMI 作为对比剂注射速率及对比剂用量的参考,基于患者个体个性化提出有一定临床操作意义的对比剂注射方案。在目前三低扫描方案中,当采用管电压为 100 kV 时,相较于 120 kV,可减少约 33.89% 的 ED,当管电压降低时,图像噪声稍增加,但是整体图像 SNR 及 CNR 无明显差异。利用宽体探测器 CT 进行冠脉成像时,基于 BMI 及心率个性化定制的扫描方案可进一步推动扫描标准化的流程,尽可能减少技术员经验误差,提高冠脉扫描成功率,进一步推动影像同质化的进程。

综上所述,利用较低管电压并结合患者 BMI 及心率的低对比剂注射速率及低对比剂用量的三低扫

描成像技术可在保证图像质量的同时降低辐射剂量,还能减少对比剂使用带来的不良事件的发生,使患者获益。

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