Feasibility study of low tube voltage CTA for bronchial artery imaging in patients with hemoptysis

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Abstract

To investigate the application of low tube voltage CTA in bronchial artery (BA) imaging in patients with hemoptysis. 119 patients with hemoptysis in our hospital from January 2017 to December 2021 were studied, including 31 patients in the 80kV group (tube voltage: 80kV), 39 patients in 100kV group (tube voltage: 100kV) and 49 patients in the control group (tube voltage: 120kV). The mean CT dose index (CTDIvol, mGy) and effective radiation dose (ED, mSv) of each group were compared and analyzed, and the image quality was evaluated by objective noise measurement: signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) and subjective 5-score method. The differences of CTDIvol, ED, SNR, CNR and image scores between the groups were compared, and the matching rate was analyzed with the blood vessels displayed by DSA. There were significant statistical differences in CTDIvol, ED, SNR, CNR, and image quality scores among the three groups (P<0.05). The comparison results between the groups showed that there was no statistical difference in CTDIvol, ED, and image quality scores between the 80kV and 100kV groups. The matching rates between the images of the three groups and DSA angiography were 96.80%, 97.40%, and 95.90% respectively. It is feasible to use low tube voltage CTA in BA imaging of patients with hemoptysis. The tube voltage of 100kV has the better image quality and lower radiation dose.

Introduction

Hemoptysis is a common clinical emergency with high mortality. The effect of conservative treatment in internal medicine is poor and easy to relapse. Bronchial artery embolization (BAE) is favored by clinicians because of its minimally invasive, safe, and effective characteristics[1]. Studies have shown that about 90% of hemoptysis comes from the BA, but 10% is caused by non-bronchial systemic arterial (NBSA) or pulmonary circulation bleeding[2]. Even if it comes from the bronchial artery (BA), there are many variations in the number, opening position, and course of the BA. The opening, shape, and distribution of the BA cannot be completely found by DSA alone[3]. Therefore, the effectiveness of interventional embolization in hemostasis is limited. With the development of CTA technology, researchers have applied thoracic aorta CTA to image the BAs before operation. Some studies have shown that the preoperative thoracic aorta CTA examination can effectively and consider the situation of the BAs or NBSA as the blood vessel responsible for bleeding, significantly shorten the interventional operation time, improve the efficiency of interventional hemostasis and reduce the recurrence rate[4-6].

However, the patients received conventional scanning CTA examination before operation and interventional treatment under fluoroscopy. The superposition of the two led to a significant increase in the X-ray radiation dose of the patients, which undoubtedly increased the physical burden and side injury of the patients. Therefore, there is an urgent need for the improved CTA examination method that can not only clearly show the number, opening position, and course of BAs, but also minimize the patient's X-ray radiation dose.

At present, there is no clinical report on the application of low tube voltage scanning to examine BAs. This study hopes to prospectively apply the improved CTA under different tube voltages to hemoptysis patients in our department, evaluate the radiation dose received by each group of patients and the image quality of the CTA, analyze the matching rate between CTA and DSA image, and finally screen out the scanning parameters more suitable for BAE anterior the CTA.

Materials And Methods

1. Research object

Taking the hemoptysis patients who visited our department from January 2017 to December 2021 as the research object, all patients signed the informed consent of interventional surgery before operation, and this experimental study has been approved by the ethics committee of Qinhuangdao Municipal No.1 hospital.
Inclusion criteria: 1. Repeated hemoptysis or massive hemoptysis (hemoptysis volume in one time > 300 ml, or hemoptysis volume within 24 hours > 500 ml); 2. The effect of internal medicine hemostasis is poor; 3. Improve routine examinations such as laboratory examination, ECG, and the chest CT before operation; 4. Conscious, no need for endotracheal intubation or incision.

Exclusion criteria: 1. Unconsciousness, excessive airway secretions, and obstruction of discharge; 2. Hemodynamic instability; 3. Severe heart, brain, lung, and other organ dysfunction or blood system diseases; 4. Allergic to iodine contrast medium.

A total of 119 patients were included in this study. 119 patients were randomly divided into three groups by the random number table method. There were 31 cases in 80kV group (tube voltage: 80kV), 39 cases in 100kV group (tube voltage: 100kV) and 49 cases in control group (tube voltage: 120kV). See Table 1 for general information on all patients.

2. CTA scanning method

CTA inspection equipment: Philips brilliance 256 iCT, layer thickness 0.90mm, layer spacing 0.45mm, matrix 512×512, tube voltage 80-120kV (80kV and 100kV for low dose group and 120kV for conventional dose), tube current 250mas. The patient took the supine position, the scanning range was from the lung tip to the L1 vertebral body level, and the scanning was completed with one breath-hold. A stellent double-barrel high-pressure syringe was used. The non-ionic isotonic contrast agent iodixanol (320mgI/ml) was injected from the right elbow vein. The injection flow rate was 4.5-5 ml/s. The dosage of the contrast agent was 1.2ml/kg in the conventional-dose group, and then 40ml of normal saline was injected at the same rate. Use artificial intelligence trigger (trigger threshold is set to 100HU).

DSA angiography: 1250ma large C-arm angiography machine of American GE company is used, and the contrast medium is also iodixanol (320mgI/ml).

3. Radiation Dose.

The evaluation indexes include the mean CT dose index (CTDlvol) and effective radiation dose (ED). CTDlvol is automatically generated by the computer, and ED = dose length product (DLP) × Conversion factor (using the average chest value proposed by the European CT quality standard guidelines, i.e. 0.014msv•mGy⁻¹•cm⁻¹) [7], and the DLP is generated by computer.

4. Image quality evaluation.

Objective evaluation: Following the random and double-blind method, two senior radiologists (visiting staff) reviewed and evaluated the images (including the objective and subject evaluation) of all the patients independently. The circular ROI was selected in the thoracic 4-5 horizontal descending aorta (100mm²). Then, we measured the enhanced CT value (CTv) of the ROIs, avoiding touching the vascular wall and calcified plaque. The image noise was defined as the standard deviation value (SDv) of the ROIs. (2) We measured the mean CT values (CTm) of the bilateral pectoralis major muscle of the abovementioned ROI levels. (3) The SNR and CNR were calculated by the following formulas: signal-to-noise ratio (SNR) = CTv/SDv and contrast-to-noise ratio (CNR) = (CTv−CTm)/SDv.

Subjective evaluation: The subjective evaluation of the image quality (vascular delineation of arterial vessels, visibility of small arterial detail and image artifacts), lesion detection, and normal structure visualization followed the double-blind method and was performed using the 5-score method. The details of the 5-score method were as follows: 5-excellent image quality and contrast ratio, good vascular delineation, no artifacts, easy to diagnose; 4-good image quality and contrast ratio, normal vascular delineation, with a few artifacts, but adequate to diagnose; 3-satisfactory image quality and contrast ratio, some artifacts, the artery was not clearly displayed but was sufficient for the diagnosis; 2-weak image quality and contrast ratio, obvious artifact, the artery was not clearly displayed and was not sufficient for the diagnosis; 1-
poor image quality and contrast ratio, severe artifacts, very hard to distinguish the small artery and could hardly make a diagnosis. More than 3 scores of the image quality were considered for the clinical diagnosis[8]. See Supplementary figure for details.

5. Statistical analysis

SPSS 21.0 statistical software was used for data analysis. The measurement data is expressed by X±S, and the counting data is expressed by frequency and percentage. The basic situation of patients among the three groups and the comparison of ED, noise, and image scores were analyzed by one-way ANOVA, and the comparison of ED, SNR, CNR, and image quality scores among the three groups were analyzed by one-way ANOVA and LSD. The consistency of image quality score of two experts using Cohen's kappa statistic. Kappa values less than 0.20 were interpreted as poor agreement; 0.21–0.40, as fair; 0.41–0.60, as moderate; 0.61–0.80, as good; and 0.81–1.00, as very good agreement. P values less than 0.05 were considered statistically significant[9]. Bland-Altman plot analysis was used to analyze the consistency of results between CTA and DSA.

Results

Comparison of basic conditions of three groups of patients

There was no significant difference in age, proportion of men and women, cause composition and BMI index among the three groups, which was comparable. See Table 1 for details.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Male / Female</th>
<th>Etiological composition</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bronchiectasia</td>
<td>Malignant tumor</td>
</tr>
<tr>
<td>80kV(n = 31)</td>
<td>67.35±9.25</td>
<td>24/7</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>100kV(n = 39)</td>
<td>63.69±14.91</td>
<td>30/9</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>120kV(n = 49)</td>
<td>61.29±11.54</td>
<td>37/12</td>
<td>29</td>
<td>10</td>
</tr>
<tr>
<td>F/X^2</td>
<td>2.331</td>
<td>0.045</td>
<td>7.615#</td>
<td>0.185</td>
</tr>
<tr>
<td>P</td>
<td>0.102</td>
<td>0.978</td>
<td>0.422</td>
<td>0.832</td>
</tr>
</tbody>
</table>

#Fisher's exact test.

Comparison of radiation dose among three groups of subjects

The comparison of radiation dose showed that the CTDIvol of 80kV group was (4.68±1.75)mGy and that of 100kV group was (6.28±1.89)mGy, which was significantly lower than that of the control group (20.97±4.44)mGy (F = 339.4, P < 0.0001). There was no significant difference between 80kV and 100kV groups (adjusted P value = 0.0970), 80kV vs. 120kV (adjusted P value < 0.0001), 100kV vs. 120kV (adjusted P value < 0.0001). See Fig. 1A.
For ED value, it was \((1.67 \pm 1.19)\) mSv in 80kV group and \((2.70 \pm 1.07)\) mSv in 100kV group, which was significantly lower than that in the control group \((13.00 \pm 3.17)\) mSv, the difference was statistically significant \((F = 342.5, P < 0.0001)\), 80kV vs. 120kV (adjusted P value < 0.0001), 100kV vs. 120kV (adjusted P value < 0.0001). There was no significant difference in ED between 80kV and 100kV groups (adjusted P value = 0.1284). See Fig. 1B.

Comparison of three groups of image quality

The SNR of CT images of the three groups were \(13.64 \pm 4.16\), \(17.48 \pm 4.38\) and \(26.18 \pm 6.16\) respectively. The SNR of 80kV group was significantly lower than that of 100kV group and control group \((F = 63.70, P < 0.0001)\), 80kV vs. 100kV (adjusted P value = 0.0067), 80kV vs. 120kV (adjusted P value < 0.0001), 100kV vs. 120kV (adjusted P value < 0.0001), see Fig. 2A.

The CNR of CT images of the three groups were \(12.33 \pm 3.82\), \(15.08 \pm 3.75\) and \(22.07 \pm 5.68\) respectively. The CNR of 80kV group was significantly lower than that of 100kV group and control group \((F = 47.58, P < 0.0001)\), 80kV vs. 100kV (adjusted P value = 0.0415), 80kV vs. 120kV (adjusted p value < 0.0001), 100kV vs. 120kV (adjusted P value < 0.0001), see Fig. 2B.

The comparison of CT image quality scores among the three groups showed that the image quality scores of 80kV, 100kV and control groups were \(4.24 \pm 0.85\), \(4.32 \pm 0.69\) and \(4.87 \pm 0.38\) respectively, the difference was statistically significant \((F = 12.28, P < 0.0001)\), the kappa values of the two experts for the three groups of image quality scores were 0.949, 0.790 and 0.699 respectively, but there was no significant difference between 80kV and 100kV groups \((p value = 0.8640)\), 80kV vs. 120kV (Adjusted P Value = 0.0001), 100kV vs. 120kV (Adjusted P Value = 0.0003), see Fig. 2C. In addition, the proportion of images with quality score \(\leq 3\) in 80kV, 100kV and control groups were 22.6\% (7/31), 12.8\% (5/39) and 0\% (0/49) respectively. There was significant difference in image defect rate between the three groups \((X^2 = 12.401, P < 0.001)\), but there was no significant difference in image defect rate between 80kV and 100kV groups \((X^2 = 1.158, P = 0.282)\).

Comparison of matching rate between three groups of images and DSA

The matching rates of CTA and DSA images in the 80kV group, 100kV group, and control group were 96.80\%, 97.40\%, and 95.90\%, respectively.

Results of Bland-Altman plot analysis showed that the two methods had high consistency for enhancement of the bronchial arteries in each group. The deviation value of the two methods in 80kV by two radiologists was \(-0.03226\), the standard deviation was 0.1796, the 95\% limits of agreement= -0.3843, 0.3198 (Fig. 3A). The deviation value of the two methods in 100kV by two radiologists was \(-0.02564\), the standard deviation was 0.1601, the 95\% limits of agreement= -0.3395, 0.2882 (Fig. 3B). The deviation value of the two methods in 120kV by two radiologists was \(-0.04082\), the standard deviation was 0.1999, the 95\% limits of agreement= -0.4326, 0.3510 (Fig. 3C).

Discussion

The BAs are the nutrient vessel of lung tissue, which starts from the descending aorta and takes shape along the bronchial vascular bundle. When patients have bronchiectasis, tuberculosis, lung cancer, and other diseases, the repeated injury and repair of lung tissue lead to the reconstruction of anatomy and hemodynamics of pulmonary circulation, the compensatory number of BAs increases, the lumen thickens, and finally evolves into the responsible artery of hemoptysis[10, 11]. In addition, the extracorporeal circulation artery may also participate in the blood supply of hemoptysis lesions and form communication with the intrapulmonary circulation. BAE for hemoptysis patients has a definite therapeutic effect. Some data show that about 95\% of the responsible arteries for hemoptysis come from the external pulmonary circulation arteries such as the BAs or internal thoracic artery, phrenic artery, and thyroid carotid trunk artery, and the success rate of embolization and hemostasis is about 70\%-95\%[12]. Selective arterial intubation is the key to BAE, but the multi-source of diseased vessels and the complexity of blood supply make it difficult to complete
embolization[13]. CTA is not only used to show the responsible arteries of hemoptysis but is also helpful to evaluate the etiology of hemoptysis, the relationship between lesions and surrounding tissues, and the differentiation of benign and malignant tumors. CTA has high tissue resolution. Combined with post-processing technology, CTA can observe the responsible arteries of hemoptysis intuitively and stereoscopically, to reduce the blindness of selecting target vessels in BAE. Preoperative identification of the etiology of hemoptysis can also guide individualized treatment, such as regular anti-tuberculosis treatment for pulmonary tuberculosis patients, and infusion of chemotherapy drugs for lung cancer patients.

Studies have shown that the preoperative CTA examination can effectively clarify the responsible vessels, significantly shorten the interventional operation time, improve the efficiency of interventional hemostasis and reduce the recurrence rate[5, 7]. However, CTA scanning requires a wide range and thin layer, which leads to a large radiation dose to patients. Studies have shown that the probability of dying of cancer increases by 0.08% with each CT scan, and will increase with the increase of the number of CT scans[14]. And the patient needs to be damaged by X-ray radiation again during BAE treatment. Clinically, under the condition of ensuring the accuracy of diagnosis as much as possible, reducing the harm caused by radiation is an important measure to ensure the life safety of patients. At present, reducing the tube voltage is the most direct and effective way to reduce the radiation dose, which can reduce the radiation dose exponentially. The size of the tube voltage determines the penetration ability of the ray, and the irradiation dose is directly proportional to the square of the tube voltage[15]. Jun et al. showed that the radiation dose can be reduced when the tube voltage is reduced from 100 kV to 80 kV during coronary CTA[16].

In this study, when 80kV and 100kV scanning were used, CTDIvol was only 22% and 30% of that in the 120kV group, and ED was only 58% and 67% of that in the 120kV group, which could significantly reduce the radiation dose received by patients. This is the same as the previous research results, and we also found that there was no significant difference in radiation dose between the 80 kV and 100 kV groups. Whether SNR, CNR, or image quality score, the 120kV group is greater than 80kV and the 100kV group. The reason is a low tube voltage scan usually increases the image noise and, therefore, degrades the image quality due to the X-ray low-dose efficiency.

However, the previous results showed that the SNR and CNR of head and neck low-dose CTA images were significantly higher than those of 120kV group. Our analysis may be that previous studies used ECG gating or computer iterative technology for scanning, which can significantly improve the image SNR of low-dose CTA[17, 18], while our experimental research only used conventional technology for image scanning. Although there is no significant difference in image quality score between 80kV group and 100kV group, we consider that the matching rate of low tube voltage CTA and DSA images is higher, and the SNR and CNR of 100kV group are better than those of 80kV group. Therefore, while reducing the radiation dose of patients as much as possible, the images of 100kV group can still have high SNR and CNR, which can play a very important guiding role in clarifying the bleeding responsible vessels before BAE.

In conclusion, as a non-invasive examination method, low tube voltage CTA, especially under the condition of low radiation dose, can also accurately evaluate the characteristics of the BAs. The accuracy and effectiveness of interventional surgery can be significantly improved by displaying the characteristics. The comparative study of different scanning parameters shows that the application of 100kV for CTA has more advantages. However, there are some defects in this experiment. First, this experiment is a single-center small sample size study. Second, there is no long-term follow-up for patients, and the efficacy of patients after BAE is not evaluated. These will be the experimental studies we need to carry out next.

Declarations

Funding
This study was not supported by any funding.

**Conflict of interest**

The authors declare that they have no conflict of interest.

**Ethical Approval**

This study was approved by the ethics committee of Qinhuangdao Municipal No.1 hospital. All experimental participants signed informed consent before the study.

**Consent for publication**

For this type of study consent for publication is not required.

**Author contributions**

JL A and YC D contributed to the design of the study and the development of the study protocol, YC D and JL A coordinated the study. JL A and HT N performed the systematic review, including data collection and data analysis. All authors contributed to data interpretation, manuscript drafting and review. YC D drafted the first version of the manuscript.

**References**


**Figures**

**A**

**CTDlvol**

***

\[80\text{kv} \quad 100\text{kv} \quad 120\text{kv}\]

\[\text{mGy}\]

\[\text{ns} \quad ****\]

**B**

**ED**

***

\[80\text{kv} \quad 100\text{kv} \quad 120\text{kv}\]

\[\text{mSv}\]

\[\text{ns} \quad ****\]

**Figure 1**

1A and 1B show the comparison of CTDlvol and ED among the three groups respectively, * represents statistical difference, and ns represents no statistical difference.
Figure 2

2A, 2B and 2C show the comparison of SNR, CNR and image quality score among the three groups respectively, * represents statistical difference, and ns represents no statistical difference.

Figure 3

3A, 3B and 3C show the three groups of CTA and DSA image matching respectively.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFigure.zip