Application of 70kVp in abdominal CT angiography to reduce both radiation and contrast dosage and improve patient comfort for children

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Abstract

Objective

To evaluate the application of 70kVp in pediatric abdominal CT angiography (CTA) to reduce radiation and contrast dose and improve patient comfort.

Methods

Forty-six children needing abdominal CTA were enrolled in the study group using low-dose scanning protocol with 70kVp and 0.7-1.1ml/kg contrast dose, and reconstructed with 50%ASIR-V. They were compared with another 46 children (control group) with matching body weight who underwent conventional CT scans with 100kVp, 1.2-1.8ml/kg contrast dose and reconstructed using 50%ASIR. The image quality of large vessels was evaluated using a 5-point scale, and the number of superior mesenteric artery branches identifiable by CAD was recorded. The CT value and standard deviation of descending aorta (Ao) was measured, and signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) calculated. Radiation dose, contrast dose, the maximum injection pressure, correlation between flow rate and injection pressure were compared between the two groups.

Results

The score for displaying large vessels by 70kVp images was 3.91±0.28, and up to 3 superior mesenteric artery branches could be identified, all of which met the diagnostic requirements. The CT value of Ao was 390.87±86.79HU in the study group, higher than 343.93±49.94HU in the control group, while no difference in SNR and CNR between the two groups; the radiation dose, contrast dosage and injection pressure of the study group were 1.23±0.39mGy, 12.67±7.27ml and 43.83±17.16psi respectively, significantly lower than the 1.95±0.37mGy, 22.67±7.39ml, and 77.59±19.68psi of the control group. The correlation coefficients between flow rate and injection pressure were 0.82 and 0.86 in 70kVp group and 100kVp group.

Conclusion

70kVp scanning meets the diagnostic requirements in pediatric abdominal CTA while providing significant radiation dose, contrast dose and injection pressure reduction.

Background:

CT angiography (CTA) is a common examination for children. It can clearly show the morphology of blood arteries and can be used for the diagnosis of various vascular malformations, thrombosis and other diseases [1−4]. It is widely used in clinic, and has the characteristics of fast detection, safety and less trauma comparing with conventional angiography. However, for children, especially infants, the placing of peripheral venous cannulas before CTA is also a challenge because the children’s peripheral vein is tiny and not obvious. At the same time, the injection rate and the gauge of the venous cannulas are directly proportional to the dosage of contrast medium (CM). The high dosage would inevitably increase the injection rate and size of cannulas and makes it more difficulty for nursing care. Therefore, reducing the dosage of contrast medium could reduce not only renal injury [5] but also the flow rate and the difficulty of venipuncture operation, thus reducing the risks of CTA in children [6]. Many studies have confirmed that low-tube voltage scanning could improve the CT attenuation value of contrast medium, so as to improve the image quality or ensure image quality while reducing the amount of contrast medium. Most of the previous studies focused on the use of 80kVp or 70kVp for imaging the heart or chest to reduce radiation dose and/or contrast dose [7–13]. On the other hand, due to the small body size, children may benefit more from the use of lower tube voltage scanning without losing too much detection efficiency or producing too many beam hardening artifacts, even in imaging the abdomen. Thus, the purpose of our study was to evaluate the application of 70kVp scanning protocol in pediatric abdominal CTA to reduce both the radiation and contrast medium dosage and by doing so to reduce the potential kidney damage caused by contrast medium, and to improve comfort for children.

Methods:

General information: This was a prospective clinical study and was approved by the Ethics Committees of our institution. The informed consent was signed by children's parents. From Feb 26th, 2018 to Mar 30th, 2018, the patients undergoing abdominal CTA were continuously collected into the study group. Exclusion criteria included: the body weight greater than 28.0 kg. Children with matching age and weight who underwent abdominal CTA using the conventional CT scan protocol before June 1st, 2015 were selected from hospital database into the control group for comparison purpose.

Instruments and equipment: For the study group, a 256-row CT scanner (Revolution CT, GE Healthcare, USA) was used with the following scan parameters: tube voltage of 70kVp, helical pitch of 1.375:1 and tube rotation speed of 0.35 s, A set of fixed tube currents were used and were adjusted to obtain the following patient weight-dependent radiation dose (calculated as CTDIvol) [15]: 0.92 mGy for 0–12 kg with 260 mA; 1.22 mGy for 12.1–20 kg with 345 mA; and 1.52 mGy for 20.1–28 kg with 430 mA. The images were reconstructed at 0.625 mm slice thickness using the second-generation adaptive statistical iterative reconstruction (ASIR-V) at 50% strength (50%ASIR-V) and a standard reconstruction kernel. For the control group, a 64-row CT scanner (Discovery CT750HD, GE Healthcare, USA) was used with the conventional scan protocol: tube voltage of 100 kV, helical pitch of 1.375:1 and tube rotation speed of 0.4 s. The tube current was set by using the automatic tube current modulation (ATCM) in the range of 10–700 mA during the scan to obtain age-based image noise index (NI) settings: NI = 11HU for children with age of 0–12 months; NI = 13HU for 1–2 years old, and NI = 15HU for 3–14 years old. The images in the control group were reconstructed at 0.625 mm slice thickness using ASIR algorithm with 50% strength (50%ASIR) and a standard reconstruction kernel. For those children who were too young to cooperate, sedation with oral chloral hydrate (10%, 0.5 ml/Kg) was applied before the scanning in both groups.

Enhanced CT protocol: A peripheral venous cannula was pre-placed in the superficial vein of dorsum of the hand. A 22G needle was used for children with body weight > 15.1 kg and a 24G needle was used for children with weight < 15.0 kg. An iodinated contrast agent (270 mg I/ml iodixanol; GE healthcare, American) was administered in both groups using a single-head power injector. The contrast medium dosage in the control group was calculated according to the body weight of each child: 1.8 ml/kg for 3–5 kg, 1.6 ml/kg for 5–10 kg, 1.4 ml/kg for 10–15 kg and 1.2 ml/kg for 15–28 kg, while the contrast medium dosage in the study group was reduced by 40%: 1.1 ml/kg for 3–5 kg, 1.0 ml/kg for 5–10 kg, 0.8 ml/kg for 10–15 kg and 0.7 ml/kg for 15–28 kg. Flow rate was adjusted according to a fixed injection time of 15 s and contrast enhanced scan started at 17 s after the start of contrast injection.

All images were transmitted to a GE AW4.7 workstation (GE Healthcare, WI, USA) for data measurement and image analysis. All children related information and scanning parameters were hidden during the image analysis process, and 3D post-processing images, such as multi-planner reformation (MPR), and Volume Rendering (VR), were generated and used to display the vessels. Two pediatricians (with 14 years and 7 years of CT diagnostic experience) evaluated the image quality according to the scoring standard together with consensus, and they could adjust the image display window width and window level to the level deemed appropriate. Image evaluation included the subjective scoring for vessel display and objective measurement of CT attenuation value and noise value of image.

Subjective image quality evaluation: The subjective image quality assessment focused mainly on the sharpness and clearness of the edges of large vessels and the ability to display branches of small mesenteric arteries. The subjective quality evaluation of the large vessels including the descending aorta and its first and second branches was performed on a 5-point scale as follows (with 3–5 stands for a satisfying imaging quality): 5 point, the edge of the vessel is clearly displayed, with a very good contrast; 4 point, the edge is clear, with a good contrast; 3 point, the blood vessel is clear, but not smooth enough, the diameter of the lumen can be accurately measured; 2 point: the diameter of the lumen cannot be accurately measured, but the shape of the blood vessel can be judged; 1 point: the shape of the blood vessel cannot be judged. The ability for vascular display was evaluated by the observed number of branches of small mesenteric arteries. The number of small mesenteric artery branches were observed on the VR images (more than 50% of the branch to be displayed), and the smallest branch (with at least 2 branches displayed) could be observed. The image quality was jointly evaluated by two readers. In case of any inconsistency, the final score was given after consultation.

Objective measurement: the CT value and standard deviation (SD) of the interested area of descending aorta (Ao) and back muscle (Mu) of hepatic hilar section were measured by the two observers together after the subjective evaluation, SD values were used to represent image noise. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the descending aorta were calculated using the following formula: $SNR = \text{CT density}_{(Ao)} / SD_{(Ao)}$, $CNR = (\text{CT density}_{(Ao)} - \text{CT density}_{(Mu)}) / ((SD_{(Ao)} + SD_{(Mu)})/2)$.

Statistical analysis: the general information for the patients including height, weight, gender and age were recorded in detail. The scanning and contrast agent parameters including radiation dose (volumetric CT dose index (CTDIvol), dose-length-product (DLP)), contrast medium volume, iodine dose, contrast injection rate and IV pressure were recorded. The objective noise and subjective score data including CT and SD values of Ao and Mu, SNR, CNR, and subjective scores were represented as mean ± standard deviation. Paired t-test was performed to assess for the continuous data that followed normal distribution to evaluate whether there were differences between the two groups, Mann-Whitney U test was performed for the discrete data such as the subjective image quality scores and for the continuous data that did not follow the accord with normal distribution. The spearman correlation coefficients between flow rate and injection pressure in two group were evaluated. All the statistical analyses were performed using SPSS17.0 software, $P < 0.05$ was considered as statistically significant.

Results

The general information of children, contrast medium doses and radiation doses are shown in Table 1. The subjective scores and objective measurements are shown in Table 2. There was no significant difference between the two groups in patient general information. The contrast medium dose, injection pressure, flow rate and radiation dose in the 70kVp group were significantly lower than those in the control group with the contrast medium dose being reduced by 44.20%, injection pressure by 43.51%, flow rate by 43.71%, and CTDIvol by 36.92%. The spearman correlation coefficients between flow rate and injection pressure were 0.82 and 0.86 in 70kVp group and 100kVp group (Fig. 1). The objective measurement values showed that the CT value of blood vessel in the 70kVp group was higher than that in control group, but there were no significant differences in SNR and CNR between the 70kVp group and control group. Subjectively, images in both groups were acceptable for diagnosis (Fig. 2), however, the subjective scores in the control group were better than those in the 70kVp group, as demonstrated in Table 2.

Table 1
Patient information and scan parameters for the two groups

Parameters	Study group (70kVp)	Control group (100kVp)	t value	p value
Male: female	28:18	24:22	0.71*	0.26
Age (years)	3.20 ± 3.11	2.92 ± 2.58	0.49	0.62
Weight (kg)	15.09 ± 10.81	15.09 ± 10.81	N/A	N/A
Height (cm)	92.61 ± 27.11	95.13 ± 19.57	0.56	0.58
CM flow rate (ml/s)	0.85 ± 0.43	1.51 ± 0.49	7.82	0.00
CM volume (ml)	12.65 ± 7.27	22.67 ± 7.39	7.74	0.00
Iodine (g)	3.42 ± 1.96	6.12 ± 1.99	7.74	0.00
IV pressure (psi)	43.83 ± 17.16	77.59 ± 19.68	7.95	0.00
CTDIvol (mGy)	1.23 ± 0.39	1.95 ± 0.37	9.95	0.00
DLP (mGy.cm)	31.80 ± 22.74	50.82 ± 11.98	6.00	0.00

CM: contrast medium; Psi: Pounds per square inch; CTDI: computed tomography dose index (volume); DLP: dose-length product.

*: Chi-square test was performed

Table 2
subjective and objective evaluation results

Parameters	Study group (70kVp)	Control group (100kVp)	t /H value	p value
CT value (Ao)	390.87 ± 86.79	343.93 ± 49.94	3.36	0.00
SD value (Ao)	10.33 ± 4.84	9.71 ± 5.92	0.49	0.63
CT value (Mu)	64.37 ± 6.75	53.59 ± 8.22	7.31	0.00
SD value (Mu)	8.97 ± 3.37	6.40 ± 1.27	4.68	0.00
SNR	45.97 ± 22.45	42.84 ± 17.31	0.61	0.54
CNR	37.18 ± 13.42	39.25 ± 13.78	0.63	0.53
Quality of the large vessels	3.91 ± 0.28	4.17 ± 0.38	3.47*	0.00
The ability for vascular display	2.22 ± 0.42	3.00 ± 0.00	7.65*	0.00
The number of artery branches	3.07 ± 0.39	4.72 ± 0.46	8.58*	0.00
Ao: aorta; Mu: muscle				
*: Mann-Whitney U test was performed because the data did not accord with normal distribution				

Discussion

How to reduce the radiation dose and contrast dose in CTA is always the focus for radiologists. Reducing radiation dose for reduced ionizing damage and reducing contrast medium dose for reduced renal damage to patients are especially important for children that are in the growth and development period. According to the previous research results, reducing tube voltage improves the CT attenuation value of contrast medium, thus improving the CNR of images, making it possible to reduce the amount of contrast medium [15]. However, low-voltage scanning could also increase the beam hardening artifacts in images [13] and decrease the x-ray detection efficiency due to the higher portion of soft x-rays. Therefore, the International Commission on Radiological Protection (ICRP) committee has advised that different levels of low-voltage scanning should be used according to patient weight and size to maximize the benefit between contrast and image quality [16]. However, most of the previous systematic studies used 80 kV scanning, and the application of 70 kV was focused mainly on the heart and chest. We have studied the use of 80kVp for abdominal CT of children with body weight under 28 kg to obtain high CNR while preventing beam hardening artifacts caused by low-voltage scanning to impact image quality [14]. Therefore, the patients included in the current study were strictly limited to within 28 kg for the body weight. Our study indicated that for pediatric patients with weight less than 28 kg, the use of 70kVp tube voltage could reduce about 37% radiation dose and 44% contrast dose while obtaining images that meeting the diagnostic requirement in abdominal CT imaging. Our results are an extension to the results of previous studies for cardiac CT imaging showing that the use of 70kVp could provide images that satisfy the diagnosis requirements with a CM dose reduction of 25%-56% [17–19].

Patient comfort is a very important aspect that pediatric radiologists need to worry about besides patient safety in performing CTA for children, especially infants and very young children. Intravenous injection of contrast medium might result in sensory changes, heat, even pain in children, and it is difficult for young children to control their own activities due to their poor tolerance and sense of cooperation. Therefore, oral sedatives are normally used for younger children, and examinations are performed after they fell asleep. And yet, the contrast injection may awake up the children, causing motion during the CT scans. In order to improve the success rate, some scholars investigated the application of hand injection [20] to complete the examination. Meanwhile, in order to ensure the degree of enhancement, contrast medium must be injected in a certain period of time and sometimes rapid injection is required dependent on the total contrast medium volume. The rapid injection rate will increase the discomfort, so the requirements for sedation are further increased. Moreover, higher flow rate requires a larger size of IV catheters making it more uncomfortable for the patients. Our experience suggested the use of 22G for children over 15 kg, but larger size needles will increase the operation difficulty for nurses. Our research showed that the flow rate was positively correlated with injection pressure (Fig. 1), reducing the total amount of contrast agent can reduce the flow rate which makes the use of finer needles possible, thus reducing the work difficulty for nurses, and the IV injury to children. Furthermore, with the reduced contrast medium flow rate, the injection pressure is reduced, and children discomfort can be reduced, so as to improve the compliance of children and lower the requirement for sedation.

Our results showed that there was no significant difference in the baseline data of the children. However, compared with the control group, the volume of contrast medium, contrast injection flow rate in the study group decreased more than 43%, and the injection pressure decreased 44% to 43.83 psi from 77.59 psi in the control group. Because the average flow rate of the study group was 0.85 ml/s, with the maximum flow rate less than 1.1 ml/s, we were able to use the 24G needle for all pediatric patients in the future protocol, significantly reduce the risks of injury. The objective image quality showed that although the amount of contrast agent was decreased, the CT value of the descending aorta was increased by 14% in the study group, benefiting from the effect of using low voltage. Recent researches showed that 80kVp scanning could increase the CT value by 49%, compared with the use of 120 kVp, and the research results of Yu et al. [15] indicated that the increase of the CT value of contrast agent by using 70kVp was more obvious. In our study, radiation dose was further reduced by 37% in the study and images were reconstructed using ASIR-V with matched strength with ASIR in the control group. ASIR-V at the same strength as ASIR had better noise reduction ability [21]. There was only 6% increase in the noise of the descending aorta in the study group. Although the average background noise in the study group was increased, the CT value also increased, resulting in similar SNR and CNR values of the images in both groups, which was consistent with the results of previous research [22].

The subjective evaluation of images showed that for large vessels, the image quality in the study group was not affected by the 70 kV scanning, and there was no statistically significant difference between the two groups. For small blood vessels, especially terminal arterioles, CAD software was used to segment images in order to avoid subjective judgment bias. Taking the small mesenteric artery as the evaluation object, its branches were displayed specifically. It was found that the 70kVp images could typically display 2nd – 3rd branches of the superior mesenteric artery and as far as the 4th branch, and all images in the control group could display the 3rd branch and as far as the 5th branch. Our results showed that the ability of displaying small artery branches was affected by the use of 70kVp scanning with low radiation dose and low dosage of contrast medium, which was similar to the results of previous research [23]. The reason may be due to the increased image noise caused by the combination of low dose scanning and 70kVp and the increased beam hardening artifacts at 70kVp [13]. Another reason may be that we set the same scan start time for CTA in both groups, the slower injection rate in the study group delays the opacification of the distal branches, which may be compensated with a delayed scan for the study group to make sure the distal branches have adequate contrast filling. Even though the reduced display of vascular branches did not affect the diagnosis of cases in the study group, it did indicate the importance of ensuring the applicability of using lower tube voltage such as 70kVp in CT application.

There are some deficiencies in this study: First, the sample size was rather small. Second, the patient weight limitation for using 70kVp in the study group was based on our previous experience with the 80kVp study. Further studies are needed to extend the limit. Third, because the included children in the study group were too young and were all examined under sedation, we were unable to quantify the effect of low flow rate injection scheme on improving patient comfort and reducing in-scan motion artifacts. Future studies are needed to evaluate the benefit of reduced injection flow rate and pressure in reducing the need for using sedations on children.

Conclusion:

70kVp scanning provides acceptable image quality that meets the diagnostic requirements in abdominal CTA for children with body weight under 28 kg while providing significant reduction in radiation dose, contrast dose and injection pressure, compared with the conventional scan protocol using 100kVp.

Abbreviations

Ao Aorta

ASIR-V Adaptive statistical iterative reconstruction-v

CHD Congenital heart disease

CM Contrast medium

CNR Contrast-to-noise ratio

CTA CT angiography

CTDIvol CT dose index

MPR Multiplanar reconstruction

Mu Muscle

SD Standard algorithm

SNR Signal-to-noise ratio

VR Volume rendering

Declarations

Ethics approval and consent to participate:

This retrospective study was approved by the Ethics Committees of Beijing Children's Hospital for using the data, and the informed consent was signed by children's parents.

Consent for publication:

Not applicable.

Competing interests:

The author of this manuscript declares relationship with the following companies: GE Healthcare (JL). Authors with no financial ties to GE Healthcare (JS, LY, HL1, Z., WY, HL2 and YP)

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Authors' contributions:

JS, LY, HL1, and WY carried out the studies, participated in collecting data, and drafted the manuscript. JL, ZZ, HL2 and YP helped to draft the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials:

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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Figures

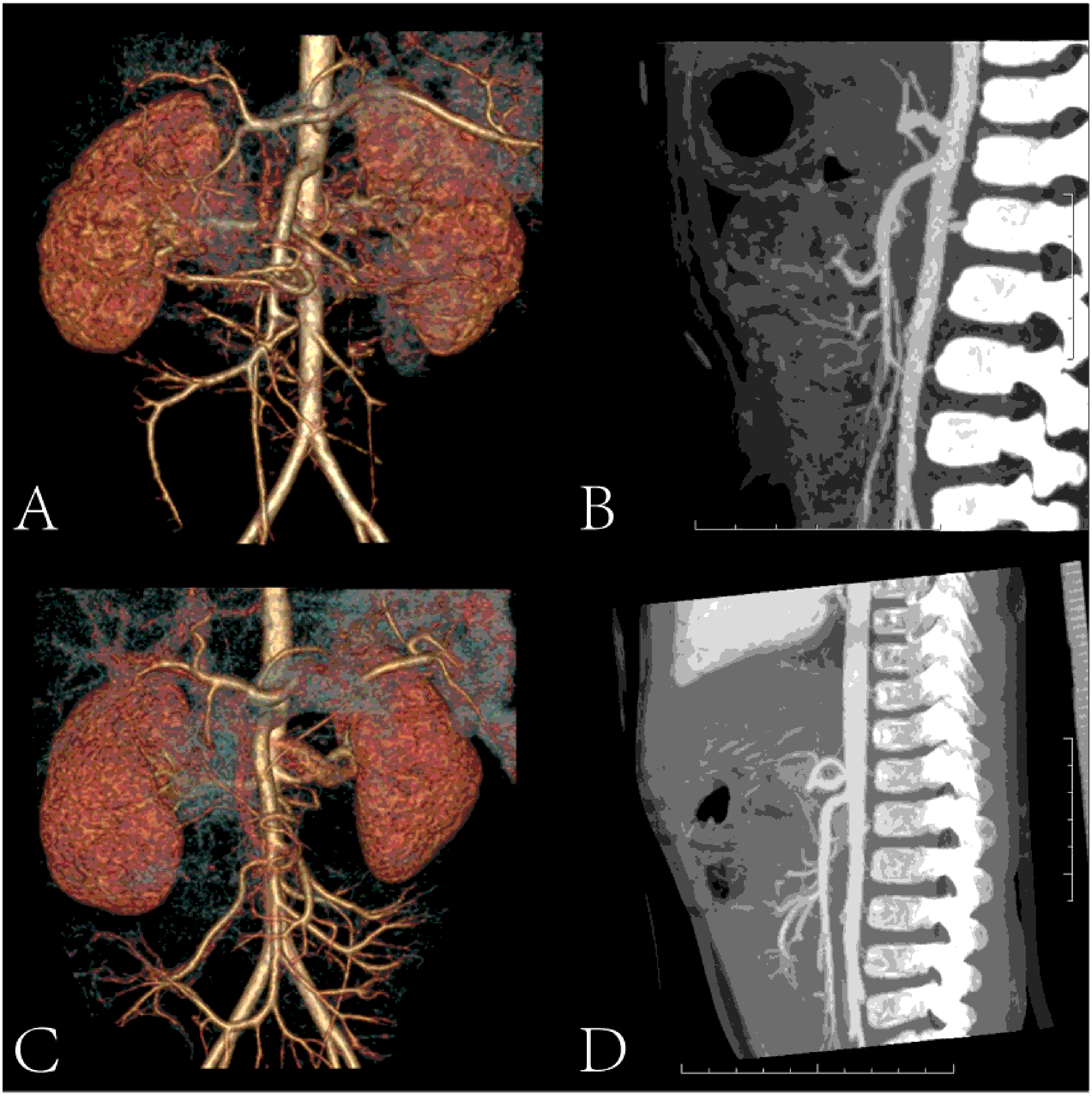

Figure 1

2a and 2b: A 21-month old body with 12kg suffered from neuroblastoma underwent 70kVp CT scan. 1a, a 3D image and 1b, a multi planar reconstruction (MPR) image. The aorta and its branches, celiac trunk, renal arteries and small mesenteric artery (SMA) are displayed well. The 3rd branch of SMA can be seen clearly, and the 4th branch can also be detected, the whole image quality can meet the diagnostic requirement. Fig. 2c and 2d: A 17-month old body with 12kg with a hepatic blastoma, underwent 100kVp CT scan. 1c, a 3D image and 1d, a MPR image. The arteries are displayed very well, especially the small branches of SMA. The display for smaller branches is more abundant, but the main arteries have similar quality as the 70kVp images.

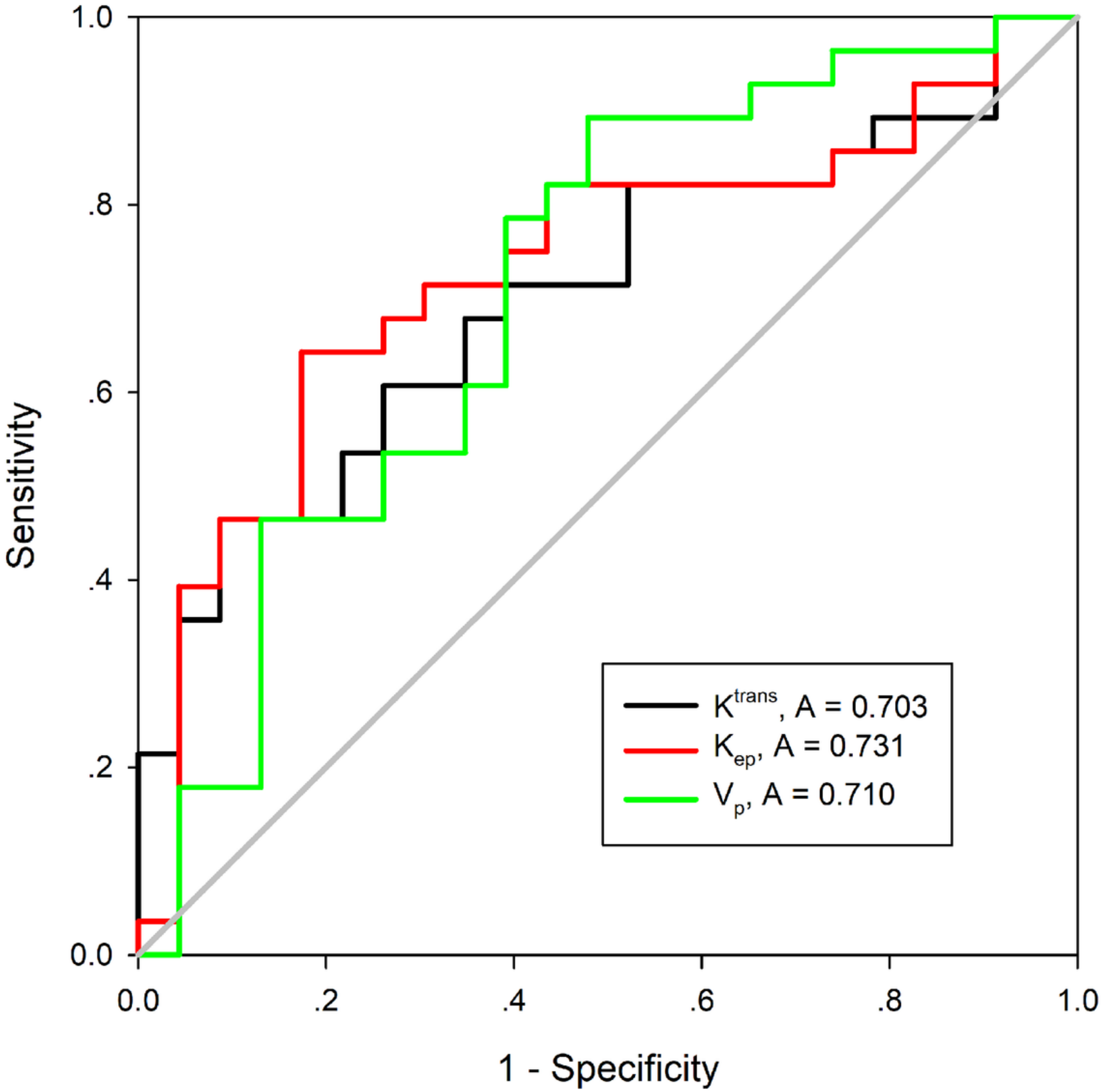

Figure 2

1A was the spearman correlation coefficients between flow rate and injection pressure in study group (70kVp), and 1B was in control group (100kVp), the flow rate of 1A was 0.85±0.43ml/s, lower than 1.51±0.49 ml/s of 1B, and the injection pressure of 1A was 43.83±17.16 psi , lower than 77.59±19.68 psi/s of 1B. the correlation were 0.82 and 0.86 in 70kVp group and 100kVp group respectively, which means the reduction of flow rate could help to decrease the injection pressure, help to make young child comfort when they under CTA.