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Simplified split-bolus intravenous contrast injection technique for pediatric abdominal CT: Comparison of image quality and radiation dose with that of single bolus technique

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Simplified split-bolus intravenous contrast injection technique for pediatric abdominal CT: Comparison of image quality and radiation dose with that of single bolus technique

Directed by Professor Mi-Jung Lee

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ABSTRACT

Simplified split-bolus intravenous contrast injection technique for pediatric abdominal CT: Comparison of image quality and radiation dose with that of single bolus technique

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Objectives: To investigate image quality and radiation dose for pediatric abdominal CT using a split-bolus intravenous contrast injection technique.

Methods: This retrospective study included two groups of pediatric abdominal CT with the split-bolus (Split group) or the single bolus (Control group) intravenous contrast injection technique. Radiation dose, image quality and diagnostic accuracy were evaluated.

Results: Between the Split group (n = 114) and Control group (n = 100), mean age (10.6 vs. 9.9 years, p = 0.344) and body weight (36.6 vs. 33.9 kg, p = 0.284) were not different. On age-matched comparison for subgroup analysis with 60 patients in each group, the mean effective dose was lower in the Split group (2.46 vs. 2.85 mSv, p = 0.002). Noise level was lower in the Split group in aorta (17.8 vs. 19.9, p < 0.001), liver (11.1 vs. 14.2, p < 0.001), and portal vein (17.4 vs. 19.8; p = 0.014). Nine studies (8%) in the Split group and 12 studies (12%) in the Control group were diagnostically suboptimal.

Conclusion: The split-bolus intravenous contrast injection technique is a simple

method to obtain adequate and homogeneous enhancement without need for bolus tracking radiation dose in pediatric abdominal CT.

Key words : contrast materials, computed tomography, pediatrics, radiation dosage, image quality enhancement

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I. INTRODUCTION

As pediatric patients demonstrate significant variation in age and body habitus, determining the adequate scan timing in contrast enhanced CT of these patients has been difficult[1], resulting in various enhancement study protocols depending on hospitals, patient age, and body weight. Likewise, in the recently published studies investigating the application of 'split-bolus' intravenous contrast injection protocols in pediatric patients, CT scanning protocol was modified according to patient age and body weight, which made the technique complicated[2,3].

The idea of splitting the volume of intravenous contrast into two consecutive bolus injections for body CT was first initiated in the field of aorta imaging[4]. And the utility of this 'split-bolus' technique has been most studied in genitourinary imaging[5-7]. Application of this technique for the evaluation of pancreatic or hepatic lesions has been limited[8-10]. Moreover, until recently, the split-bolus technique has been little described in the literature regarding pediatric CT examination[11,12], and only a few studies dealing with split-bolus technique in pediatric body CT have been reported[2,3,13].

We thought that if the split bolus technique is simplified, it could have the potential to provide generally applicable CT scan protocol in pediatric patients, with ease of routine use in clinical practice. Therefore, we implemented a simple method of the split-bolus technique in pediatric abdominal CT protocol and designed a retrospective case-control study to compare image quality and radiation dose of the split-bolus protocol with that of single bolus hepatic venous phase abdominal CT.

II. MATERIALS AND METHODS

1. Patients

This retrospective study was approved by our institutional review board, and informed consent was waived. However, written informed consent for iodine contrast injection and CT scan was received before each scan as routine clinical practice.

In our hospital, we introduced the split-bolus contrast injection technique for pediatric abdominal CT in April 2014, established the technique in August 2014, and have since used this technique as routine protocol. In this study, we included patients who underwent split-bolus contrast injection for abdominal CT from August 2014 to March 2015 as the Split group. We also selected patients who underwent single bolus contrast injection for abdominal CT from August 2013 to March 2014 as the Control group. In each group, consecutive patients younger than 18 years of age who underwent abdominal CT with intravenous contrast injection were included. We excluded patients who underwent non-contrast enhancement CT, body CT with both chest and abdomen, or dynamic enhancement CT for an initial tumor or transplanted liver evaluation. Age, gender, and body weight of each patient were recorded at the time of CT study. Indications for abdominal CT and diagnoses based on imaging findings were also recorded. Final diagnoses were concluded from the medical records based on operative findings or clinical follow-up results until July 2015.

2. CT image acquisition with contrast injection techniques

All scans were obtained after injection of 300 mg iodine/ml of the intravenous contrast iobitridol (Xenetix, Laboratoires Guerbet, Roissy, France). Total contrast volume was determined in proportion to the patient's body weight (2 ml/kg with the maximum contrast volume of 100 ml).

The split-bolus technique used an initial half bolus, followed by another half bolus and a single acquisition (Figure 1). Half of the total intravenous contrast was injected manually, followed by same volume of saline injection. Thirty seconds after the start of the initial half bolus injection, the second half bolus was injected using the same method and was followed by saline infusion. CT scanning was started 25 seconds after the start of the second bolus injection, resulting in a merged late-arterial phase and hepatic venous phase (HVP) image without use of bolus tracking.

In the single bolus technique, the full volume of intravenous contrast was injected at once, followed by saline infusion. Using bolus tracking, CT scanning was performed 35 seconds after enhancement in the abdominal aorta reached 100 Hounsfield units (HU). This was the routine technique of single-phase HVP scan in our institution before the introduction of the spit-bolus technique.

All CT scans were obtained using one of two CT units (SOMATOM Definition Flash and SOMATOM Definition AS+; Siemens Healthcare, Forchheim, Germany) without using the dual energy acquisition technique. Acquisition parameters were 64 x 0.6 mm detector collimation and 0.28 second gantry rotation. We used tube voltage of 70 kVp for patients with less than 10 kg, 80 kVp for patients with 10-30 kg, 100 kVp for patients with 30-50 kg, and 120 kVp for those with more than 50 kg. Tube current were calculated automatically using CARE Dose 4D (Siemens Healthcare, Forchheim, Germany). This system proposed optimized settings for tube current based on the patient's topogram and reference settings[14]. Reference tube current was 100 mAs and the strength curve was 'very strong' for children. Reconstructed slice thickness and increment were 2 mm each. Original images were reconstructed using Sinogram-affirmed iterative reconstruction (SAFIRE, Siemens Healthcare, Forchheim, Germany) level 3 and a medium-smooth convolution kernel (B30f).

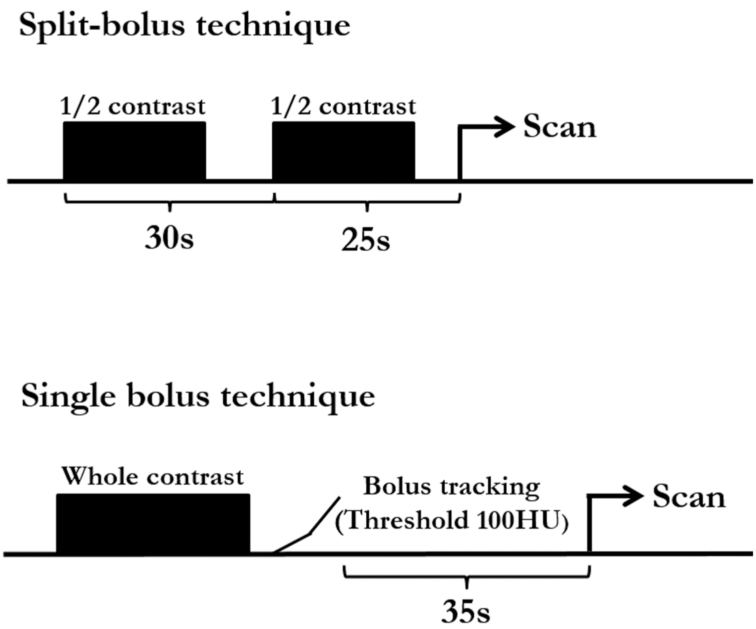

Figure 1. Scan protocols of split-bolus technique and single bolus technique with bolus tracking.

3. Radiation dose

Volume CT dose index (CTDIvol) and dose length product (DLP) values were recorded on the dose page for each study. In the Control group, the recorded DLP was the sum of DLP from the bolus tracking and CT scan. Additionally, the dose of bolus tracking was separately evaluated only in the Control group. We calculated CTDIvol values with the size-specific dose estimation (SSDE) method with reference to the American Association of Physicists in Medicine report #204[15] in a subgroup analysis of 60 patients from each age-matched group. Effective radiation doses were estimated by multiplying DLP by age-specific conversion factors[16].

4. Objective image quality assessment

We evaluated image quality on the picture archiving and communication system (PACS) at our institution (Centricity; GE Healthcare, Milwaukee, WI). The objective assessment of image quality was performed in the subgroup analysis with 60 age-matched patients from each group. Circular regions-of-interest (ROIs) were placed on the aorta, liver, right kidney, and right renal artery at the level of the right renal hilum and on the hepatic artery and portal vein at the level of the hepatic hilum on axial images for the measurement of CT attenuation value in mean Hounsfield units (HU) and the noise level as the standard deviation of the attenuation value. ROIs were positioned in the homogeneous portions of the structures. We included only renal cortex for the evaluation of right kidney enhancement.

5. Image acceptability and diagnostic accuracy

For subjective image quality assessment, we retrospectively reviewed each exam and graded images using a three-point scale of image acceptability (3 good, 2 suboptimal, and 1 unacceptable). Two radiologists with 3 and 12 years of experience in pediatric abdominal CT reviewed whole images of each exam and graded in a consensus fashion. A CT scan was considered to have good quality if none of the following were present: inadequate vascular enhancement or artifact, artifact from renal excretion, and inadequate or inhomogeneous enhancement of solid organs. A suboptimal grade was assigned if one of the above-mentioned problems was present without influence on the image interpretation. When the problem compromised image interpretation, the image was considered unacceptable.

Diagnostic accuracy of the abdominal CT exams was evaluated based on medical records and/or pathology report, if available. Indications for CT, diagnoses based on imaging findings, and final diagnoses were reviewed. Final diagnoses were classified into true-positive, false-positive, true-negative, and false-negative only for clinically important findings.

6. Statistical analysis

Statistical analyses were performed using SPSS version 20.0 (IBM Corporation, Armonk, NY). Independent two-sample t-test was used for comparison of continuous variables between the two groups. Paired t-test was used for evaluation of radiation dose and objective image quality in subgroup analysis. Descriptive analysis was used for the results of subjective image quality and diagnostic accuracy. All tests were two-sided, and a *p*-value less than 0.05 was considered to be statistically significant.

III. RESULTS

1. Patient demographics and radiation dose

A total of 114 patients in the Split group and 100 patients in the Control group were included in our study. Among these, 120 patients were male (64 in the Split group and 56 in the Control group). The major indications for CT were non-angiographic in both groups including pain (n = 74) or tumor evaluation (n

= 32) in the Split group and pain (n = 72) or tumor evaluation (n = 23) in the Control group. There was only one angiographic indication for the evaluation of renovascular hypertension in the Split group. Patient age ranged from 1-17 years with a mean of 10.6 ± 5.2 years in the Split group and 9.9 ± 4.5 years in the Control group, without significant difference (p = 0.344). Body weight ranged from 8-77 kg with a mean of 36.6 ± 19.7 kg in the Split group and 6-78 kg with a mean of 33.9 ± 16.9 kg in the Control group. Mean body weight was also not significantly different between the two groups (p = 0.284).

Table 1 demonstrates the results of subgroup analysis. The mean SSDE of the Split group was 3.1 ± 1.6 mGy, and the mean SSDE of the Control group was 3.3 ± 1.9 mGy, without significant difference (p = 0.287). The radiation dose of bolus tracking was present only in the Control group. The mean effective dose of bolus tracking was 0.20 ± 0.17 mSv with a range of 0.03-0.94 mSv. The mean total effective dose was lower in the Split group (2.46 ± 1.27 mSv with a range of 0.6-4.9 mSv) compared with the Control group (2.85 ± 1.46 mSv with a range of 0.8-7.9 mSv) (p = 0.002).

Table 1. Comparison between the Split group and the Control group in age-matched subgroup analysis.

		Split group (n=60)	Control group (n=60)	*p*-value
Demographics	Age (years)	10.0± 5.1		
	Body weight (kg)	36.2 ± 20.7	35.2 ± 18.7	0.183
Radiation dose	Size-specific dose estimate (mGy)	3.1 ± 1.6	3.3 ± 1.9	0.287
	Effective dose of bolus tracking (mSv)		0.20 ± 0.17	
	Total effective dose (mSv)	2.46 ± 1.27	2.85 ± 1.46	**0.002**
CT attenuation (HU)	Aorta	340.1 ± 89.2	223.9 ± 65.7	< **0.001**
	Liver	116.4 ± 19.4	139.8 ± 28.1	< **0.001**
	Hepatic artery	259.3 ± 63.2	201.2 ± 54.2	**<0.001**
	Portal vein	214.0 ± 52.3	235.4 ± 61.2	**0.017**
	Right kidney	225.9 ± 43.2	224.5 ± 57.2	0.858
	Right renal artery	278.2 ± 63.2	206.6 ± 55.3	**<0.001**
CT noise	Aorta	17.8 ± 5.1	19.9 ± 6.4	< **0.001**
	Liver	11.1 ± 2.5	14.2 ± 4.0	< **0.001**
	Hepatic artery	15.6 ± 6.3	14.7 ± 5.4	0.446
	Portal vein	17.4 ± 5.6	19.8 ± 5.4	**0.014**
	Right kidney	15.2 ± 5.2	16.8 ± 6.4	0.119
	Right renal artery	15.9 ± 6.7	14.0 ± 5.9	0.123

The data are mean ± standard deviation.

2. Objective image quality

On age-matched subgroup analysis, the age range was 1-17 years with a mean of 10.0 ± 5.1 years. Body weight was not different between the two groups (36.2 ± 20.7 kg in the Split group vs. 35.2 ± 18.7 kg in the Control group; p = 0.183).

On ROI measurements, the mean attenuation of the liver was significantly lower in the Split group (mean of 116.4 ± 19.4 HU) than in the Control group (mean of 139.8 ± 28.1 HU) (p < 0.001). The mean attenuation of the portal vein was also lower in the Split group than in the Control group (214.0 ± 52.3vs. 235.4 ± 61.2 HU; p = 0.017). The mean arterial attenuation was significantly higher in the Split group than in the Control group for the aorta (340.1 ± 89.2 vs. 223.9 ± 65.7 HU; p < 0.001), hepatic artery (259.3 ± 63.2 vs. 201.2 ± 54.2 HU; p < 0.001), and right renal artery (278.2 ± 63.2 vs. 206.6 ± 55.3 HU; p < 0.001). The mean attenuation of the right kidney was not different between the two groups (225.9 ± 43.2 vs. 224.5 ± 57.2 HU; p = 0.858).

In the comparison of noise, the mean noise level was lower in the Split group for the aorta (17.8 ± 5.1 vs. 19.9 ± 6.4; p < 0.001), liver (11.1 ± 2.5 vs. 14.2 ± 4.0; p < 0.001), and portal vein (17.4 ± 5.6 vs. 19.8 ± 5.4; p = 0.014) compared with the values of the Control group. There was no significant difference in the noise level of the hepatic artery and right renal between the two groups. Mean noise level (15.2 ± 5.2 vs. 16.8 ± 6.4, p = 0.119) of the right kidney was not different between the two groups.

3. Subjective image quality and diagnostic accuracy

For subjective image quality, the majority of images in both the Split group (105/114, 92%) and the Control group (88/100, 88%) demonstrated good quality. Nine images (9/114, 8%) were diagnostically suboptimal in the Split group due to inadequate portal vein enhancement (n=6) or vena cava artifact (n=3). In the Control group, 12 images (12/100, 12%) were suboptimal due to renal excretion (n=10) or inadequate enhancement of solid organs (n=2). There was no case with unacceptable image quality in both groups.

In the analysis of diagnostic accuracy, 40 studies in the Split group were true-positive, and 73 studies were true-negative. A representative case of split-bolus protocol is presented in figure 2. There was only one false-negative case in the Split group, which did not demonstrate cavernous transformation from chronic portal vein obstruction (Figure 3). There were no false-positive studies in the Split group. In the Control group, there were 42 true-positive studies and 56 true-negative studies. There were two false-positive studies in the Control group due to inhomogeneous or inadequate enhancement (Figure 4). There were no false-negative studies in the Control group. The sensitivity, specificity, positive predictive value, and negative predictive value were 97.6%, 100%, 100%, and 98.7% in the Split group, and 100%, 96.6%, 95.5%, and 100% in the Control group, respectively. The reference standard used for diagnostic accuracy was follow-up medical record in most of the cases (n=201), with the other 13 cases based on pathology report (n=12) or diagnostic angiography (n=1).

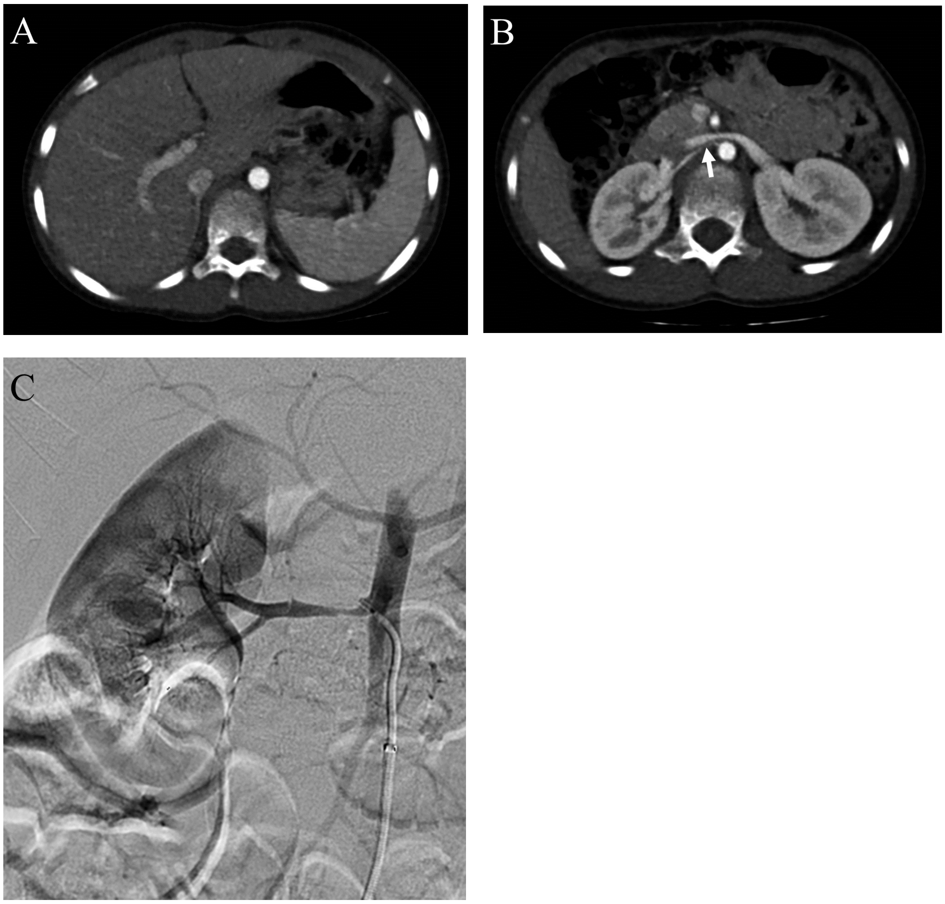

Figure 2. Representative abdominal computed tomography (CT) images obtained from an 8-year-old boy with hypertension using the split-bolus technique. (A) Adequate aortic, inferior vena caval, and portal venous opacification is achieved, as is good hepatic and renal parenchymal enhancement. (B) A stenosis (arrow) at the right proximal renal artery is well depicted, which was the cause of the patient's hypertension. (C) Renal artery stenosis was confirmed on conventional angiography for balloon angioplasty.

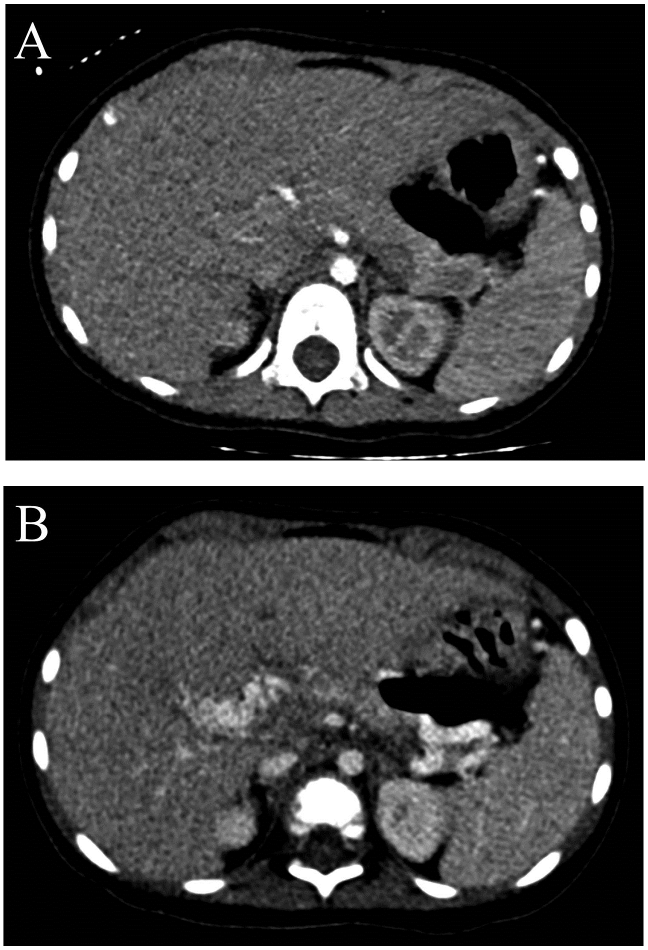

Figure 3. A case of false-negative diagnosis in a CT scan using the split-bolus technique. This 4-year-old girl has underlying chronic portal vein obstruction, (A) which is not properly depicted in the abdomino-pelvic CT using the split-bolus technique. (B) The previous abdominal CT of the portal venous phase of the same patient demonstrates enhancing tubular structures along the hepatoduodenal ligament, suggestive of portal vein obstruction and cavernous transformation.

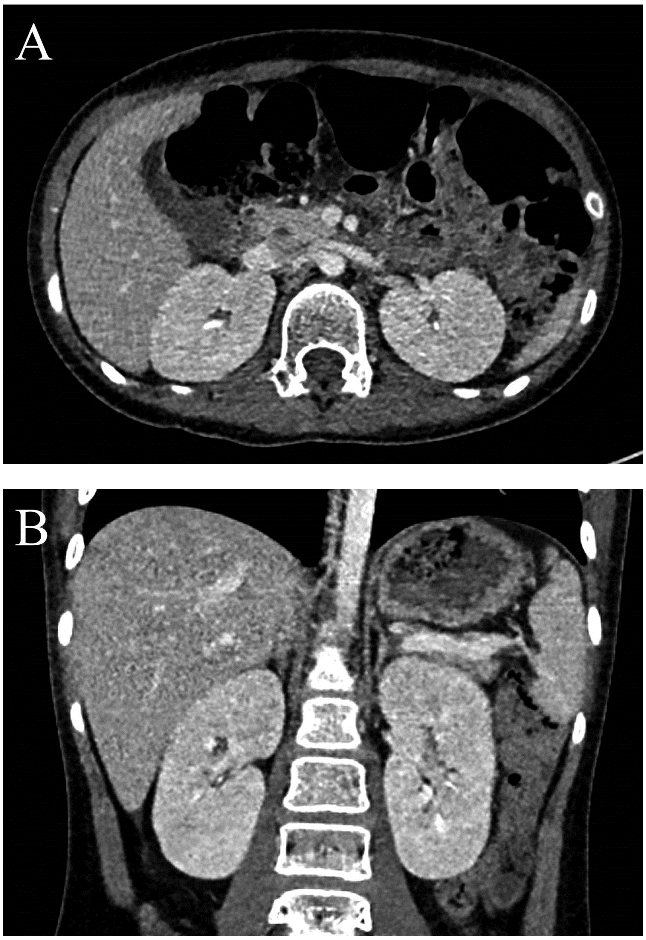

Figure 4. A case of false-positive diagnosis in a CT scan using the single bolus technique. This 12-year-old girl had CT scan for evaluation of the fever that developed during the adjuvant chemotherapy period after removal of brain medulloblastoma. In this CT scan, false interpretation of decreased corticomedullary differentiation of both kidneys on both axial (A) and coronal (B) images and diagnosis of diffuse renal disease was made due to delayed enhancement. Early renal excretion of the contrast is also noted. The serum creatinine level within the period between two weeks before and after the time of the CT scan was not elevated (0.35 – 0.40 mg/dL), indicating normal renal function of the patient.

IV. DISCUSSION

In this study, we established a simple method of split-bolus contrast injection without using bolus tracking for abdominal CT in pediatric patients with variable body size. Images acquired using our split-bolus technique resulted in a statistically significant radiation dose reduction compared to the conventional single bolus technique, while achieving generally acceptable subjective and objective image quality.

The split-bolus protocol in our study differed from that described previously. Prior studies of split-bolus technique for pediatric body CT have modified contrast injection and scan timing according to body weight-based stratification[2] or both body weight-based stratification and bolus tracking[3]. We used a simplified scan protocol with fixed timing of contrast injection and scan start time for ease of use in routine clinical practice. The results demonstrated generally acceptable image quality in the Split group.

Previously reported radiation dose reduction effects of the split-bolus have been based on the technique's capability to reduce multiple phases of dynamic CT scanning into a single-phase study[5,13]. As we developed our split-bolus technique and compared it with the single-phase CT of the single bolus technique, evaluation of the radiation dose reduction effect from merging different phases was not within the scope of this study. Instead, our data demonstrated that adequate and homogenous enhancement can be achieved by the split-bolus technique without applying the bolus-tracking method. The mean total effective dose was significantly lower in the Split group than in the Control group. This might be due to the effect of the dose for bolus tracking, which was about 7% (0.20/2.85) of the mean total effective dose of the Control group. Even though mean radiation dose for bolus tracking was only 0.20 mSv in our study, any small portion of radiation should be reduced to as low as reasonably achievable (ALARA) in consideration of the sensitivity to radiation and long life expectancy in the pediatric age group[17,18].

Our study also evaluated objective image quality. In other studies of the split-bolus protocol, image quality assessment was performed using only subjective grading[2] or lacked direct comparison with the single bolus protocol[3]. We performed ROI measurements of CT attenuation values and noise levels in a subgroup analysis for objective comparison of image quality between the Split group and Control group. Higher attenuation of the arterial structures (aorta, hepatic artery, and right renal artery) and lower attenuation of liver and portal vein was seen in the Split group, which could be attributed to the second bolus resulting in greater arterial enhancement in this technique. This analysis also demonstrated less noise in the aorta, liver parenchyma, and portal vein in the Split group, though the absolute differences in the noise value were small (about 2-3 HU).

In subjective image quality analysis, CT images obtained with the split-bolus technique were generally acceptable for interpretation. Nine of 114 cases (8%) in the Split group demonstrated suboptimal enhancement without influence on image interpretation, whereas 12 of 100 cases (12%) in the Control group were suboptimal. A notable difference between the two groups was that most suboptimal enhancement in the Split group resulted from inadequate portal vein enhancement (6/9), whereas that in the Control group was due to early renal excretion (10/12).

The problem of inadequate portal vein enhancement in the split-bolus technique was not encountered in previous studies of this technique in pediatric body CT[2,10]. This might have resulted from differences in the details of the split-bolus protocol. For example, half of the total contrast volume was allocated for the first bolus in our study, compared to about two-thirds of the total volume in other studies[2,10]. In all cases in both groups, inadequate or inhomogeneous enhancement was not considered unacceptable (score 1 in three-point scale) on image interpretation. However, caution is needed in interpreting inhomogeneous enhancement with any enhancement technique.

The diagnostic accuracy achieved by the split-bolus technique was comparable to that of the single bolus technique. The one false-negative case in the Split group was due to inadequate portal vein enhancement, and the two false-positive cases in the Control group were due to inadequate hepatic or renal enhancement. Inadequate portal vein enhancement can be a serious problem for image interpretation in pediatric patients with hepatic tumors or liver transplantation status. Even though liver MRI can be preferable in pediatric patients with hepatic tumors[19] and liver Doppler in patients with liver transplantation[20,21], caution is needed when using the split-bolus technique in patients with suspected portal vein pathology.

There are some limitations in our study. First, we did not perform radiation dose comparison in all patients. However, we included more than half of the total patients in the subgroup analysis. Second, our study was limited to a single body region of abdomino-pelvic CT, in order to compare the radiation dose of split-bolus technique with the single bolus technique by excluding the bolus tracking. Third, inadequate portal vein enhancement limited the split-bolus technique in our study for evaluation of hepatic disease. As studied previously in adults, the smaller number of phases is a good reason to use the split-bolus technique in pediatric abdominal CT, and evaluation of hepatic disease can be a major indication of dual-phase CT in pediatric abdomen. However, the overall subjective image quality and diagnostic accuracy of the split-bolus technique was not inferior to that of the single bolus technique in our study. Fourth, assessment of diagnostic performance might be limited as patient population likely had relatively small number of pathologies. Also, the reference standard used for assessment of diagnostic accuracy was based mainly on medical records during a relatively short follow-up period and there were a limited number of angiographic indications without conventional angiographic confirmation. However, in real clinical practice, the majority of the cases represent medical disease rather than surgical disease.

V. CONCLUSION

In conclusion, the split-bolus intravenous contrast injection technique is a simple method to obtain adequate and homogeneous enhancement without the need for bolus tracking compared to the single bolus technique in pediatric abdominal CT. However, caution is needed when applying this technique in pediatric patients with portal vein pathology.

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ABSTRACT(IN KOREAN)

소아의 복부 전산화 단층촬영(CT)에서 단순화한 정맥내 조영제의 분할 주입법: 일시 주입법과의 영상 품질 및 방사선량 비교

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목적: 정맥내 조영제 분할주입법을 사용한 소아의 복부전산화 단층촬영의 영상품질과 방사선량을 조사하기 위함이었다.
방법: 소아 환자에서 정맥내 조영제 분할주입법을 사용하여 복부전산화 단층촬영을 시행한 환자군(분할주입군)과 조영제 일시주입법을 사용한 대조군(일시주입군)의 방사선량, 영상품질, 진단 정확도를 후향적으로 비교하였다.
결과: 분할주입군(n=114)와 일시주입군(n=100) 사이에 평균연령과 몸무게의 유의한 차이는 없었다. 각 군에서 60명씩 나이로 짝지은 소집단 비교에서 평균 유효선량은 분할주입군이 일시주입군보다 적었다. 대동맥, 간실질, 간문맥에서 측정한 잡음은 분할주입군에서 일시주입군보다 낮았다. 분할주입군 중 9명(8%), 일시주입군 중 12명(12%)에서 영상 품질이 차상위(suboptimal)이었다.
결론: 간단화한 정맥내 조영제 분할주입법을 통해 소아의 복부 전산화 단층촬영에서 덩어리추적법(bolus-tracking)에 필요한 방사선을 사용하지 않으면서도 적절하고 균일한 조영증강을 얻을 수 있다.

핵심되는 말: 조영제, 전산화 단층촬영, 소아, 방사선량, 영상품질향상