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Original Research

Split-bolus computed tomography urography (CTU) achieves more than half of radiation dose reduction in females and overweight patients than conventional single-bolus computed tomography urography

Li-Jen Wang, ConceptualizationMethodologyWriting – original draftProject administrationFunding acquisition [a,b,*], Yon-Cheong Wong, InvestigationValidationWriting – review & editing [b,c], Yi-Shuan Hwang, SoftwareData curation [a,b], See-Tong Pang, ResourcesSupervision [d], Cheng-Keng Chuang, ResourcesVisualization [d], Ying-Hsu Chang [d,e]

[a] *Department of Medical Imaging and Intervention, New Taipei Municipal Tucheng Hospital, Chang Gung Medical foundation, New Taipei City, Tucheng District, No. 6, Section 2, Jincheng Road, Taiwan*
[b] *Department of Medical Imaging and Radiological Sciences, College of Medicine, Chang Gung University, Taoyuan, Taiwan*
[c] *Department of Medical Imaging and Intervention, Linkou Chang Gung Memorial Hospital, Taoyuan, Taiwan*
[d] *Department of Urology, Linkou Chang Gung Memorial Hospital, College of Medicine, Taoyuan, Taiwan*
[e] *Department of Urology, New Taipei Municipal Tucheng Hospital, Chang Gung Medical foundation, New Taipei City, Taiwan*

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ABSTRACT

Objective: To compare radiation dose between single-bolus and split-bolus computed tomography urography (CTU).

Materials and methods: We prospectively enrolled patients undergoing single-bolus and split-bolus CTU from 2019 June to 2020 June. The age, sex and body mass index (BMI) of each patient was recorded and categorized into BMI classes. The radiation dose indices including volumetric computed dose index, size-specific dose estimate, dose length product and effective dose of each patient were compared between 2 CTU groups with calculation of dose reduction proportions (DRPs).

Results: Seventy-six patients underwent single-bolus ($n = 39$) and split-bolus ($n = 37$) CTU. Single-bolus CTU had higher radiation doses than split-bolus CTU and there were statistically significant differences of all radiation dose indices between two CTU groups without and with stratification by sex and BMI classes. The DRPs of volumetric computed dose index, size-specific dose estimate, dose length product and effective dose using split-bolus CTU were 49%, 49%. 50%, and 45%, respectively. Multiple linear regression with an effect size (f^2) as 2.24 showed females ($p = 0.027$) and higher BMI classes ($p = 2.38 *10^{-9}$) were associated with higher effective doses; and split-bolus CTU, lower effective doses ($p = 5.40 *10^{-15}$). Using split-bolus CTU, females had consistently higher DRP of all radiation dose indices than males (54–55% versus 40–42%). Overweight patients had the largest DRP as 55% of effective dose.

Conclusions: Split-bolus CTU could be preferred by its significant radiation dose reduction effect in regard to single-bolus CTU, which was most profound in females and overweight patients.

Introduction

Recently, single-bolus computed tomography urography (CTU) has become a one-stop imaging examination for evaluating the whole urinary tract [1]. Although single-bolus CTU has shown a high sensitivity, specificity, and accuracy for diagnosing urothelial carcinomas (UC) [2], it takes 3 scanning of the whole range of the urinary tract for obtaining the information of unenhanced, nephrographic phase and excretory phase, which inevitably increases radiation dose to the patients. The nephrographic and excretory phases of single-bolus CTU are performed

* Corresponding author at: Department of Medical Imaging and Intervention, New Taipei Municipal Tucheng Hospital, Chang Gung Medical foundation, New Taipei City, Tucheng District, No. 6, Section 2, Jincheng Road, Taiwan.
E-mail address: lijenwang0918@gmail.com (L.-J. Wang).

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at 70–90 s and 10 min after contrast medium administration, respectively, for obtaining renal parenchymal enhancement and contrast excretion information [1, 2]. On the other hand, the principle of “ALARA” (i.e.: as low as reasonably achievable) should be followed for imaging studies using X-ray. Thus, split-bolus CTU is designed for diagnosing urinary tract diseases, which include only two phases: 1st pre-contrast, and 2nd post-contrast which contains combined information from the nephrographic and excretory phases using two timings after contrast medium administration [1,3]. Although split-bolus CTU could reduce radiation dose in theory, the true proportion of radiation reduction effect of split-bolus CTU has not been fully evaluated, especially in relation to patients’ sex and body mass index (BMI). Thus, the aim of this study is to elucidate the association between sex and BMI categories with radiation dose reduction using split-bolus CTU rather than single-bolus CTU.

Materials and methods

This study has been approved by the institutional review board of our hospital before the start of enrollment of participating patients (CGMH IRB no: 201701984A3C602). Informed consent of each patient has been obtained after full explanation of the study protocol as well as potential benefit and harm of this study. This study was performed on CT radiation dose indices comparing two CTU protocols as a part of an interim report of a clinical trial protocol investigating the use of single-bolus and split-bolus CTU randomized in patients presenting with hematuria or histories of urothelial carcinomas (ClinicalTrials. gov Identifier: NCT04113603). From 2019, June to 2020, June, there were 182 patients referred to our department for undergoing CTU, who were candidates of this study. Each patient has been evaluated for eligibility for this study by fitting all the inclusion criteria and without violating any exclusion criteria. The inclusion criteria were (1) age ≧ 40 years old, (2) presenting with gross hematuria or with UC history, (3) normal renal function (i.e. estimated glomerular filtration rate ≧ 60 ml/min/1.73 m^2) and (4) no allergic history of iodinated contrast medium. The exclusion criteria were (1) pregnant or lactating woman, (2) withdrawal of informed consent, (3) not undergoing or completing the whole CTU examination, and (4) no established final diagnosis or follow up duration < 6 months. All patients fitting inclusion criteria were randomized for undergoing single-bolus or split-bolus CTU. For radiation dose comparisons between two CTU protocols aimed in this study, the patients with additional chest CT scan requested by referring physicians were excluded by additional radiation dose from other body region. Of each patient, his or her age, body weight in kilograms (kg) and height in meters (m) were recorded, and body mass index (BMI) of each patient was calculated using his or her body weight over $heights^2$ [4]. The BMI of all patients of this study was classified as underweight (< 25 kg/m^2), overweight (25.0–29.9 kg/m^2) and obesity (≧30.0 kg/m^2) [5,6]. The final diagnoses (FD) of presence of UC of all eligible patients were established by histological diagnosis or findings endourological procedures (i.e.: cystoscopy, nephro-ureteroscopy) and absence of UC, by no evidence of UC on follow-up imaging studies, endourological procedures and clinical symptoms and signs for at least 6 months follow-up duration.

All CTU studies were acquired on the Hitachi Scenaria CT scanner using spiral mode (120 kVp, rotation time of 0.5 s, beam collimation of 64 × 0.625 mm, slice thickness of 5 mm, pitch of 0.83, table feed of 33.1 mm per rotation and tube current with current modulation). In this study, patient doses were simulated using CT-Expo software (version 2.5.1, *G.* Stamm, Hannover and H.D. Nagel, Buchholz, Germany) to determine volume CT dose index, dose length product, size-specific dose estimate and effective dose (Fig. 1), as recommended by the International Commission on Radiologic Protection [7] and the American Association of Physicists in Medicine [8]. CT-Expo is a Microsoft Excel based application for patient CT dose calculation, and uses the dose evaluation methods mentioned in CT exposure surveys in Germany. The software allows the computation of age- and sex-specific radiation doses on the basis of the inputted scanner model, manufacturer, scanning

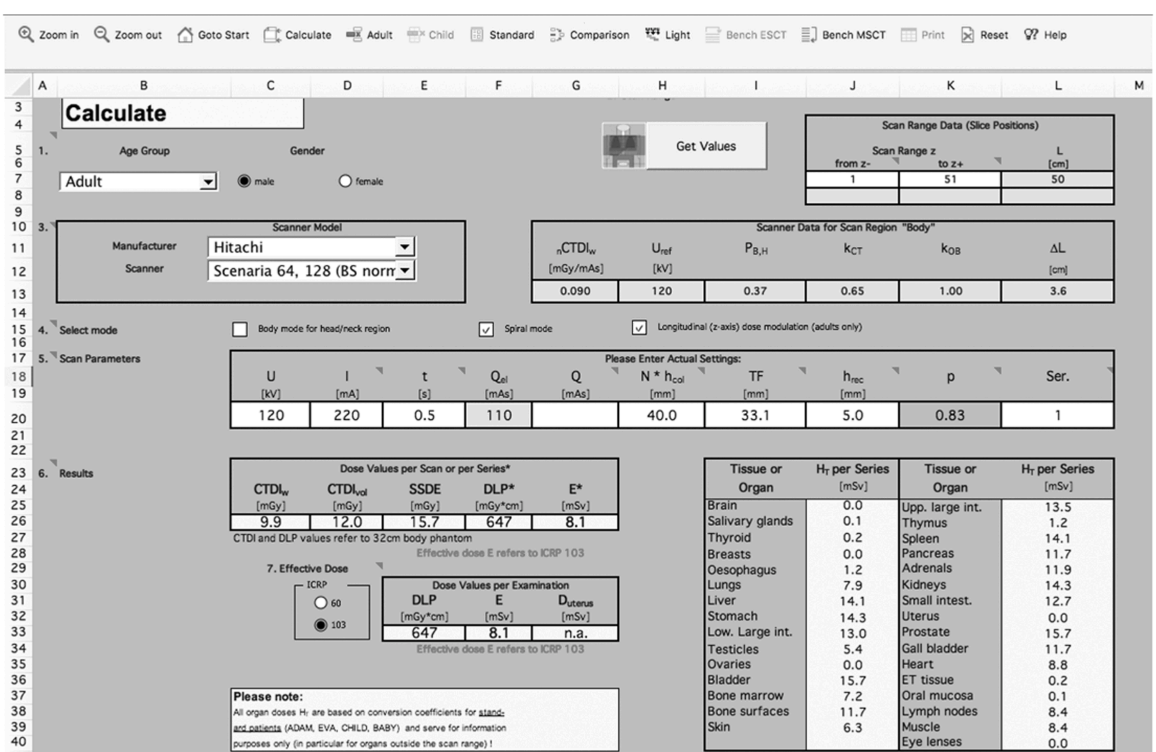

Fig. 1. Spreadsheet of the “Calculate” module in CT-Expo software. Patient dose could be calculated after selecting patient type, defining scan range, selecting scanner model and scanning mode, as well as inputting scan parameters.

parameters, and scanned area using one of four anthropomorphic mathematical phantoms: adult male (ADAM), adult female (EVA), children at age of seven (CHILD), and infants (BABY) [9,10] (Fig. 2). To calculate the doses, the scan parameters were used: tube current, tube voltage, anatomic region, scan length, pitch, beam collimation, table feed, rotation time, and slice thickness for each patient selected. The doses for 31 organs and tissues generated by Monte Carlo simulation were then available. The weighted computed dose index was determined by the settings of tube voltage and current-time product. The volumetric computed dose index was calculated as dividing weighted computed dose index by pitch factor. Dose length product was determined by the product of volumetric computed dose index and scan length. Effective doses reported in this study were calculated using the calculated organ doses and the tissue weighting factors of the ICRP No. 103 Publication [7].

Descriptive statistics were expressed using counts and proportion for categorical variables and expressed as mean and standard deviation for continuous variables fitting normal distribution or median and interquartile range (IQR) for continuous variables not fitting normal distribution using Shapiro–Wilk test for testing normality [11]. The dose reduction proportions (DRPs) of radiation doses were calculated and defined as median values of single-bolus CTU minus median values of split-bolus CTU divided by median values of single-bolus CTU and expressed as percentages (%). Comparisons between two or more groups of categorical variables were done using chi-square test. Comparisons of radiation dose indices between two CTU groups without and with stratification by sex and BMI classes were done using Mann Whitney U test. Based on biological and clinical grounds, we chose sex, BMI classes and CTU groups to perform multiple linear regression for effective dose. The statistically significant difference levels were set at p values < 0.05 using two tailed tests.

Results

There were 76 patients eligible for CTU radiation dose comparisons, including 39 patients undergoing single bolus and 37 patients undergoing split-bolus CTU (Fig. 3). Their ages ranged from 45 to 92 years old. The body weights, heights and BMI of all patients ranged from 41 to 115 kg, 1.48–1.80 m and 14.2–39.4 kg/m^2. Thirty-five (46%) of the 76 patients had FD of UC of the urinary bladder ($n = 25$), upper urinary tract ($n = 7$) and both urinary bladder and upper urinary tract ($n = 3$). The demographic features, BMI and final diagnoses of all patients and two CTU groups were listed in Table 1. There were no significant differences of the age, sex, BMI and BMI classes as well as FD of UC between two CTU groups (Table 1).

Their medians (IQRs) of volumetric computed dose index, size-specific dose estimate, dose length product and effective dose were 32.00 (22.36) mGy, 41.96 (29.06) mGy, 1728.95 (1178.49) mGy*cm and 22.93 (14.90) mSv, respectively. There were statistically significant differences of volumetric computed dose index, size-specific dose estimate, dose length product and effective dose between all patients, males and females undergoing single-bolus and split-bolus CTU alone (all $p <$ 0.001, Table 2), respectively. There are no significant differences of all radiation indices between males and females using either single-bolus and split-bolus CTU (all $p > 0.05$).

There were statistically significant correlations between volumetric computed dose index, size-specific dose estimate, dose length product, effective dose and BMI as 0.545, 0.545,0.549, 0.541, respectively (all p < 0.001, Fig. 4). Table 3 shows statistically significant differences of volumetric computed dose index, size-specific dose estimate, dose length product and effective dose between patients undergoing single-bolus and split-bolus CTU alone of all BMI classes (all $p < 0.05$). Multiple linear regression model using sex, BMI classes and CTU types showed female patients (coefficient=4.215 with 95% confidence

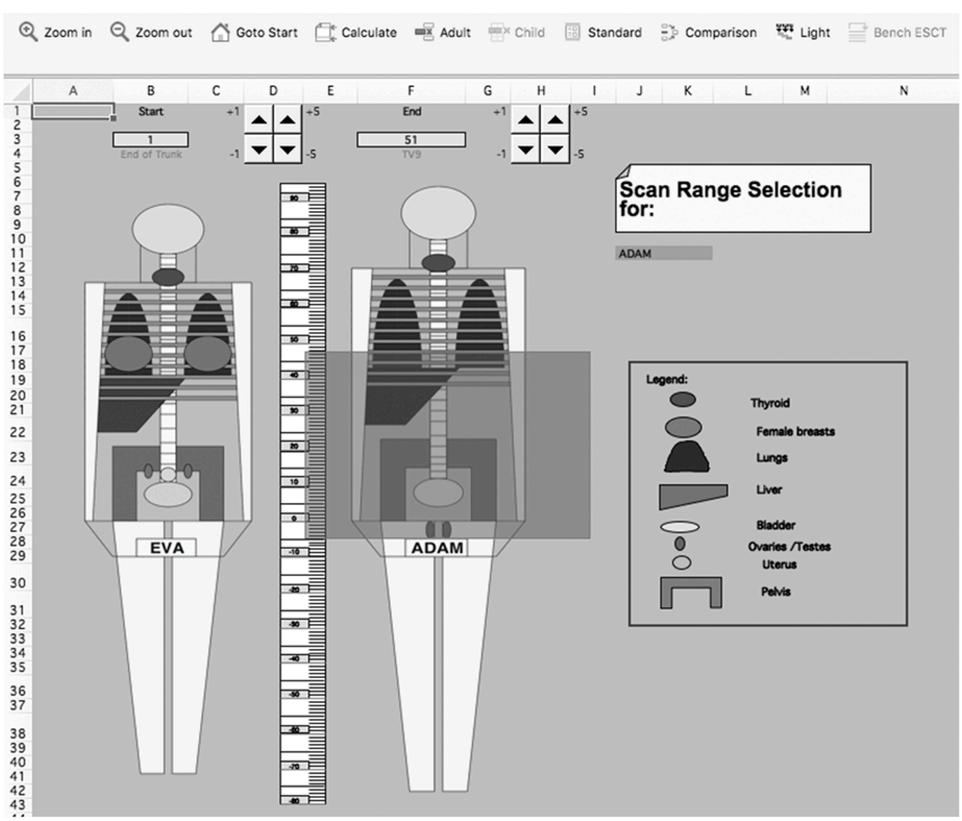

Fig 2. Examples of scan region on the ADAM phantoms implemented in CT-Expo. The region to be set was defined by selecting images archived in our Picture Archiving and Communication System (PACS). The resulting scan range is indicated by the semi-transparent blue area (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

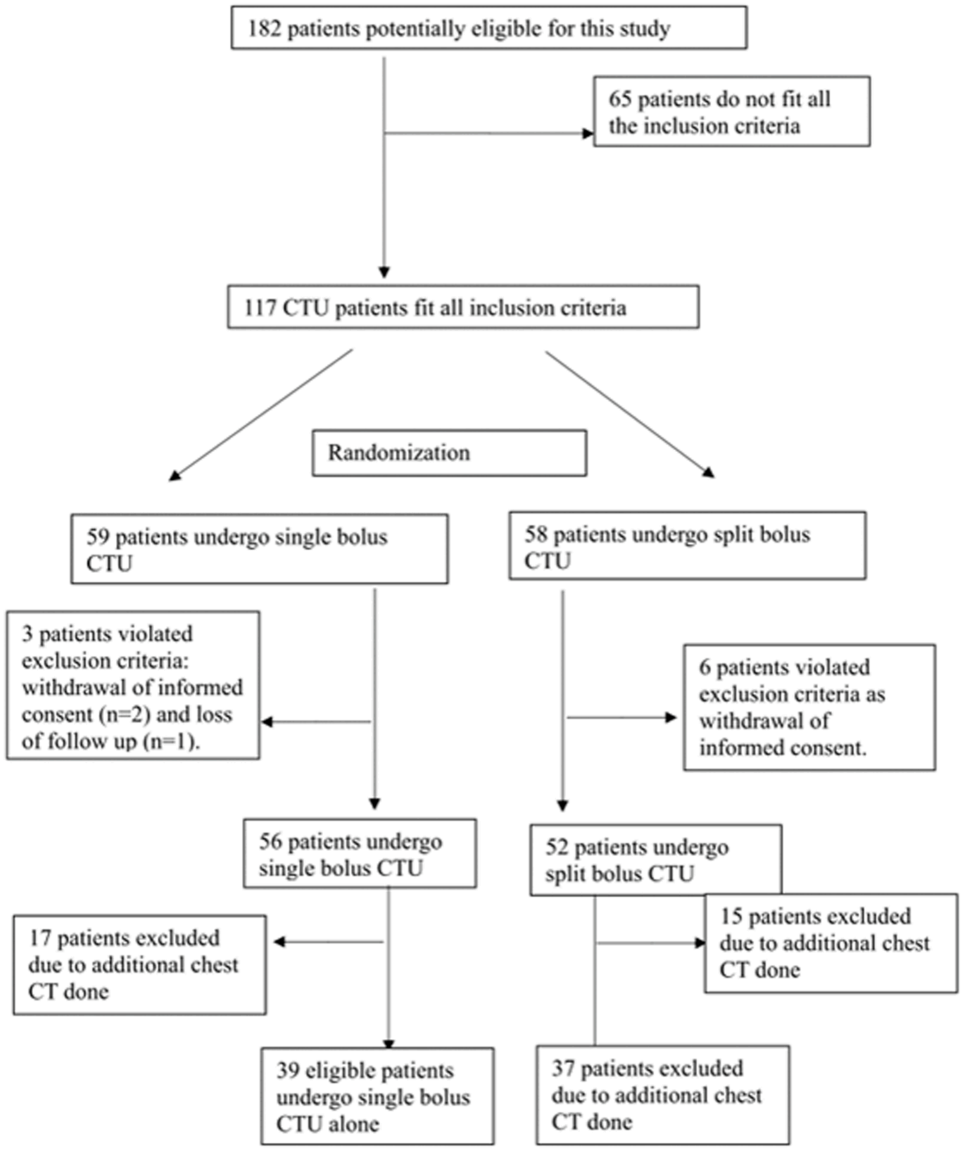

Fig. 3. Flow diagram of eligible patients undergo two types of CTU examinations alone without additional chest CT.

Table 1
Demographic features and body mass indices of the 76 patients.

Variables	All patients (n = 76)	Single bolus CTU (n = 39)	Split bolus CTU (n = 37)	p values
Age	66.26 ± 8.98	66.77 ± 9.49	65.67 ± 9.42	0.553
Sex				0.550
Male	53 (70%)	26 (67%)	27 (73%)	
Female	23 (30%)	13 (33%)	10 (27%)	
Body mass index (BMI)	25.33 (5.6)	26.48 (5.6)	24.91 (6.5)	0.291
BMI classes				0.765
Normal	36 (47%)	17 (44%)	19 (51%)	
Overweight	28 (37%)	15 (39%)	13 (35%)	
Obesity	12 (16%)	7 (18%)	5 (14%)	
Final diagnosis				0.467
Absence of urothelial carcinoma (UC)	41 (54%)	20 (50%)	21 (58%)	
Presence of UC	35 (46%)	20 (50%)	15 (42%)	

interval= 0.494–7.935, p = 0.027) and the increase of BMI class (coefficient=6.929 with 95% confidence interval= 4.904–8.955, $p = 2.38 * 10^{-9}$) were associated with higher effective doses; and in contrast, the use of split-bolus CTU was associated with lower effective dose (coefficient=−16.873 with 95% confidence interval= −20.286 to −13.461, $p = 5.40 * 10^{-15}$). It means females have a higher effective dose than male as 4.215 mSv when the BMI class and CTU types are fixed, the increase of each BMI class would increase 6.929 mSv in effective dose for patients of the same sex using the same CTU type; and the use of split-bolus CTU would have a decrease of 16.873 mSv of effective dose as compared with the use of single-bolus CTU. This regression model explains 69% of the variance (R^2=0.691, adjusted R^2=0.678, F (3, 72) =53.644, $p = 2.52 * 10^{-18}$) and has an effect size (f^2) as 2.24.

Using split-bolus CTU, the DRPs of volumetric computed dose index, size-specific dose estimate, dose length product and effective dose using split-bolus CTU of all patients were 49%, 49%. 50%, and 45%, respectively (Table 2). The DRPs (54–55%) of volumetric computed dose index, size-specific dose estimate, dose length product and effective dose using split-bolus CTU of females were consistently higher than those (40–42%) of males for 10.0% or more. Among 3 BMI classes, normal BMI patients had the largest DRPs (43–46%) of volumetric computed dose

Table 2
Comparisons of radiation doses between patients undergoing single-bolus and split-bolus CTU alone stratified by sex.

Radiation dose indices	Sex	Single bolus CTU ($n = 39$)	Split bolus CTU ($n = 37$)	p value	DRPs
Volumetric computed dose index (mGy)	All	44.54 (20.94)	22.79 (10.41)	1.48×10^{-11}	49%
	Male	45.52 (23.42)	26.21 (10.71)	2.09×10^{-8}	42%
	Female	39.75 (19.73)	18.38 (4.74)	2.00×10^{-6}	54%
Size-specific dose estimate (mGy)	All	58.91 (27.35)	30.30 (12.99)	8.94×10^{-12}	49%
	Male	59.69 (30.72)	34.37 (14.09)	2.09×10^{-8}	42%
	Female	54.80 (27.13)	25.36 (6.54)	2.00×10^{-6}	54%
Dose length product (mGy*cm)	All	2319.57 (1344.31)	1158.09 (577.85)	1.82×10^{-10}	50%
	Male	2378.30 (1467.71)	1430.02 (635.82)	1.39×10^{-7}	40%
	Female	2019.97 (916.56)	932.44 (317.49)	1.20×10^{-5}	54%
Effective dose (mSv)	All	32.43 (17.33)	17.82 (6.84)	8.32×10^{-12}	45%
	Male	30.48 (18.33)	17.88 (8.13)	1.15×10^{-7}	41%
	Female	36.29 (15.90)	16.31 (4.86)	2.00×10^{-6}	55%

Table 3
Comparisons of radiation dose parameters between patients undergoing single-bolus and split-bolus CTU alone stratified by BMI classes.

Radiation dose indices	BMI classes	Single-bolus CTU	Split-bolus CTU	p value	DRPs
Volumetric computed dose index (mGy)	Normal	34.21 (11.56)	18.76 (4.40)	2.33×10^{-10}	45%
	Overweight	48.05 (25.10)	28.50 (5.52)	5.34×10^{-8}	41%
	Obesity	51.72 (24.31)	34.10 (12.29)	0.004	34%
Size-specific dose estimate (mGy)	Normal	46.63 (14.35)	25.39 (5.63)	2.33×10^{-10}	46%
	Overweight	66.27 (31.20)	37.36 (7.26)	5.34×10^{-8}	44%
	Obesity	67.83 (34.83)	44.71 (15.38)	0.004	34%
Dose length product (mGy*cm)	Normal	1839.26 (664.35)	1044.36 (290.20)	6.98×10^{-9}	43%
	Overweight	2707.92 (1565.45)	1583.03 (372.11)	2.14×10^{-7}	42%
	Obesity	3018.01 (1391.84)	1947.20 (782.45)	0.012	36%
Effective dose (mSv)	Normal	28.52 (10.22)	14.26 (3.30)	9.31×10^{-10}	50%
	Overweight	43.78 (20.17)	19.73 (4.26)	1.07×10^{-7}	55%
	Obesity	42.87 (25.43)	24.31 (8.36)	0.004	43%

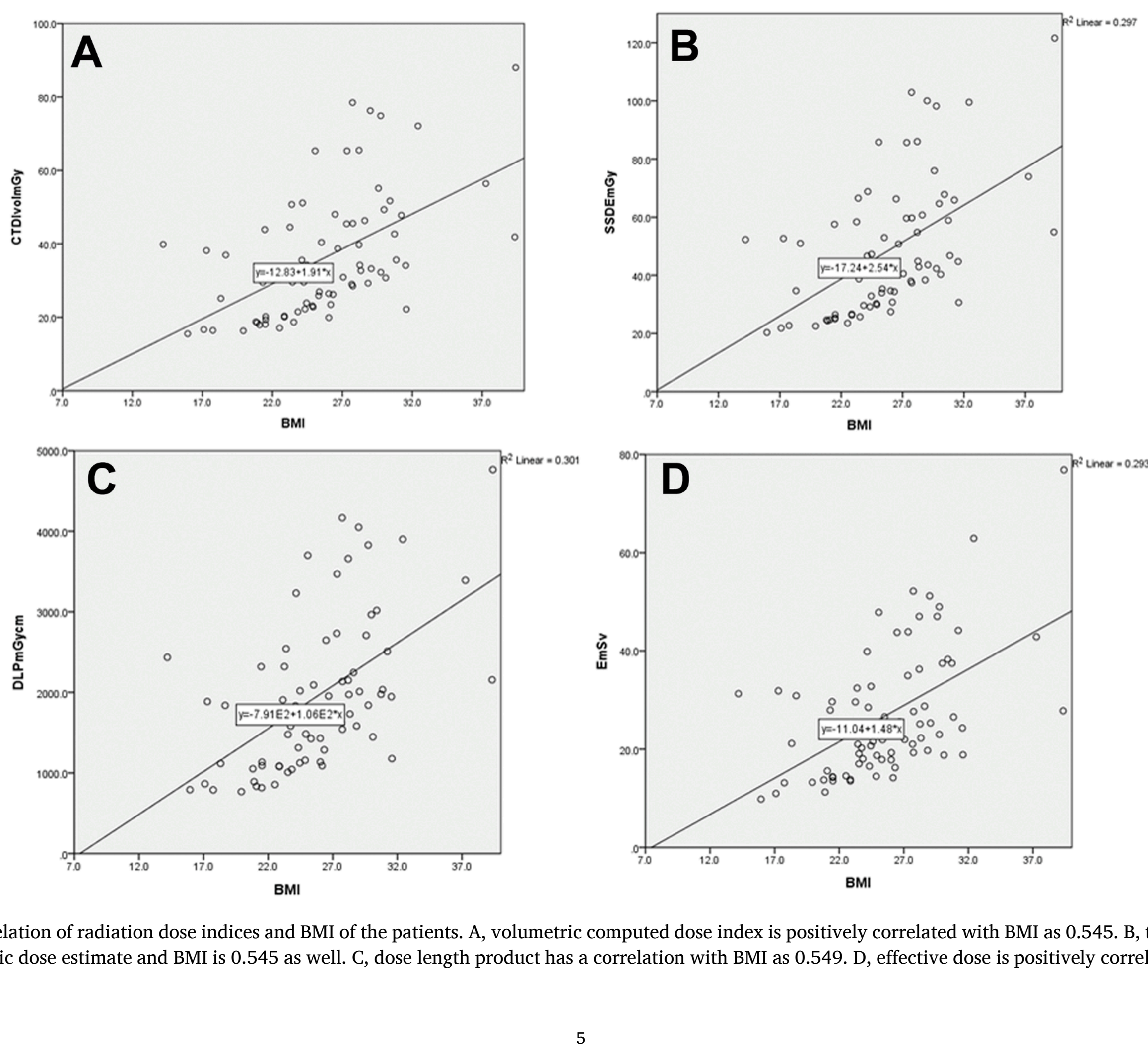

Fig. 4. Correlation of radiation dose indices and BMI of the patients. A, volumetric computed dose index is positively correlated with BMI as 0.545. B, the correlation of size-specific dose estimate and BMI is 0.545 as well. C, dose length product has a correlation with BMI as 0.549. D, effective dose is positively correlated with BMI as 0.541.

index, size-specific dose estimate, and dose length product. On the other hand, overweight patients had the largest DRP (55%) of effective dose.

Discussion

Diagnostic X-ray utilizing ionizing radiation has a potential to induce cancer [12,13], and among all imaging studies using diagnostic X-ray, CT is most commonly used nowadays. The rapid growth of CT use is multifactorial, which includes the effect of defensive medicine applies to clinical practice [12]. The radiation doses of CT examinations are affected by imaging protocols, including tube current and voltage parameter [12,14]. Imaging reconstruction techniques also affect radiation dose of CT examinations and newly developed iterative reconstruction has shown lower radiation exposure to patients than filtered back projection [12,15–18]. It is difficult to measure cancer risk of the individual undergoing one CT scan. Risk of cancer upon one time of CT scanning [12]. However, according to the estimation done by a multicenter study, one in 330 females at the age of 20 undergoing CT pulmonary angiography potentially develops radiation induced cancer later [12,19]. The lifetime attributable risk of developing cancer mortality is estimated as 8/100,000 for males and females at 80–90 years old and 57/100,000 for females at 17–19 years old [12,20], which indicates females exposed to ionizing radiation at younger age have higher estimated cancer mortality risks. However, in clinical practice, the benefit and harms for the CT use should be assessed regarding clinical scenarios. CTU has been widely accepted as a rapid and widely used imaging protocol by its diagnostic performance with high sensitivity, specificity and accuracy for diagnosing urinary tract abnormalities [1–3], in regard to wide range of diseases encountered in hematuria patients. Nonetheless, efforts focusing on reduction of CTU radiation doses remain important if similar diagnostic performance could be achieved by lower dose CTU protocols [1–3].

This study showed higher effective doses of males than females using split-bolus CTU in contrast to higher effective doses of females than males using single-bolus CTU. Nagpal et al. observed that male patients have significant higher mean effective doses than females when pulmonary computed tomography is done which is estimated as 25.5% more [12]. Nonetheless, males have been considered as less radiosensitive than females because females have higher cancer risk when exposed to similar radiation dose as males [12]. This study used CT-Expo for assessing radiation doses which were based on the calculated organ doses with regard to the tissue weighting factors [9,10]. In assessing females, two radiosensitive organs (i.e.: breast and ovary) were included in organ radiation calculations whereas testicles in males was the only radiosensitive organ included for organ dose evaluation [9,10]. Nonetheless, the default setting of CT-Expo is actually to reflect the higher radiation sensitivity and risk of females, especially for breast, potentially induced by ionizing radiation. Although this study showed no differences of radiation doses between females and males either using single-bolus and split-bolus CTU, a higher radiation dose reduction for more than 10% or has been achieved in females than males. This result suggested the use of split-bolus CT rather than single-bolus CTU in females was particularly meaningful in reducing radiation doses and lifetime risk of radiation induced cancers.

The effect of BMI on radiation dose regarding examinations using ionizing radiation has not been comprehensively studied [21]. There has been little information regarding patient's characteristics affecting radiation dose on real patients because most of studies have been done in phantoms [12]. A recent study of interventional cardiac procedures showed positive correlation of dose area product and BMI [21]. The higher radiation dose received in patients with higher BMI was contributed to greater scattered radiation during fluoroscopic examinations as recommended by the investigators [21]. BMI was shown as associated with radiation dose of CT pulmonary angiography last year and patients of overweight or obesity had an increase of radiation dose as 67.5% compared to normal BMI patients [12]. This study showed similar positive correlation relationship between CTU and BMI, supporting higher radiation dose exposure of higher BMI patients. Nonetheless, the dose reduction effect using split-bolus CTU protocol among 3 BMI classes were analyzed in this study and the result indicated overweight patients had a higher dose reduction proportion than normal BMI patient. Thus, the use of low radiation protocol is valuable in high BMI patients since they are prone to higher radiation doses and could be beneficial by higher radiation decrease.

This prospectively randomized study compared the radiation doses of the patients undergoing two CTU protocols. Most of the studies in the literature compared radiation doses using retrospective designs [12]. Although the factors affecting radiation doses could be compared in retrospective studies, there could be difficult to evaluate the impact of potential confounders in retrospective designs and the potential confounders could be more reliably controlled with the use of randomization technique to make two groups with similar demographics and similar distributions. This study showed a higher expected radiation dose reduction using split-bolus CTU rather than single-bolus CTU because in theory there were 2 phases of split-bolus CTU and 3-phases of single-bolus CTU and the expected dose reduction proportions would be around 33%. This result suggested the effort of radiation dose reduction in CT protocol design could be even more effective than estimated.

There were several limitations of this study. First, this study is a part of interim report of our ongoing randomized clinical trials. The patients included in this report was small in number and further validation by larger patient number should be done. Second, the request of additional chest CT scan was a request for clinical evaluation of lung metastasis in patients with UC histories. The ignorance of this request would be inappropriate on clinical decision making. Thus, we excluded these patients with additional CT in the database for comparing radiation doses of two CTU protocols, although it inevitably decreased the patient number and might result in insufficient power of statistical analysis. Third, this study did not include the evaluation of diagnostic performance comparing single-bolus and split-bolus CTU which is another end-point of our study project. It was because the calculated patient number needed for comparing diagnostic performance were about 3 times of the patient number than that included in this study. We are now in the stage of continuing enrollment of more patients for achieving this end point.

In conclusion, in regard of radiation dose, the use of split-bolus CTU is preferred than single-bolus CTU, especially for high BMI patients and females, who have high radiosensitivity and induced cancer risk.

CRediT authorship contribution statement

Li-Jen Wang: . **Yon-Cheong Wong:** . **Yi-Shuan Hwang:** . **See-Tong Pang:** . **Cheng-Keng Chuang:** . **Ying-Hsu Chang:** Data curation.

Declaration of Competing Interest

The authors declare no competing interests.

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References

[1] N.C. Cowan, CT urography for hematuria, Nat. Rev. Urol. 9 (2012) 218–226.

[2] L.J. Wang, Y.C. Wong, C.C. Huang, C.H. Wu, S.C. Hung, H.W. Chen, Multidetector computerized tomography urography is more accurate than excretory urography for diagnosing transitional cell carcinoma of the upper urinary tract in adults with hematuria, J. Urol. 183 (2010) 48–55.

[3] D. Lee, E.S. Cho, J.H. Kim, Y.P. Kim, H.K. Lee, J.S. Yu, J.J. Chung, Optimization of split-bolus CT urography: effect of differences in allocation of contrast medium and prolongation of imaging delay, AJR Am. J. Roentgenol. 209 (2017) W10–W17.

[4] Obesity: Preventing and Managing the Global Epidemic. Report of a WHO consultation, 894, World Health Organization Technical Report Series, 2000, pp. 1–253, i-xii.

[5] Physical Status: the Use and Interpretation of Anthropometry. Report of a WHO Expert Committee, 854, World Health Organization Technical Report Series, 1995, pp. 1–452.

[6] F. Javed, E.F. Aziz, M.S. Sabharwal, G.N. Nadkarni, S.A. Khan, J.P. Cordova, A. M. Benjo, D. Gallagher, E. Herzog, F.H. Messerli, F.X. Pi-Sunyer, Association of BMI and cardiovascular risk stratification in the elderly African-American females, Obesity 19 (2011) 1182–1186 (Silver Spring).

[7] The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103, Ann. ICRP 37 (2007) 1–332.

[8] A.A.O.P.I. Medicine., Size-specific dose estimate (SSDE) in pediatric and adult body CT examinations (Report 204). 2011.

[9] Y. Gao, B. Quinn, U. Mahmood, D. Long, Y. Erdi, J. St Germain, N. Pandit-Taskar, X.G. Xu, W.E. Bolch, L.T. Dauer, A comparison of pediatric and adult CT organ dose estimation methods, BMC Med. Imaging 17 (2017) 28.

[10] C. De Mattia, F. Campanaro, F. Rottoli, P.E. Colombo, A. Pola, A. Vanzulli, A. Torresin, Patient organ and effective dose estimation in CT: comparison of four software applications, Eur. Radiol. Exp. 4 (2020) 14.

[11] S. Shapiro, M. Wilk, An analysis of variance test for normality (complete samples), Biometrika 52 (1965) 591–611.

[12] P. Nagpal, S. Priya, A. Eskandari, A. Mullan, T. Aggarwal, S. Narayanasamy, K. Parashar, A.P. Bhat, J.C. Sieren, Factors affecting radiation dose in computed tomography angiograms for pulmonary embolism: a retrospective cohort study, J. Clin. Imaging Sci. 10 (2020) 74.

[13] A. Pijpe, N. Andrieu, D.F. Easton, A. Kesminiene, E. Cardis, C. Nogues, M. Gauthier-Villars, C. Lasset, J.P. Fricker, S. Peock, D. Frost, D.G. Evans, R.A. Eeles, J. Paterson, P. Manders, C.J. van Asperen, M.G. Ausems, H. Meijers-Heijboer, I. Thierry-Chef, M. Hauptmann, D. Goldgar, M.A. Rookus, F.E. van Leeuwen, Genepso, Embrace, Hebon, Exposure to diagnostic radiation and risk of breast cancer among carriers of BRCA1/2 mutations: retrospective cohort study (GENE-RAD-RISK), BMJ 345 (2012) e5660.

[14] R. Smith-Bindman, Y. Wang, P. Chu, R. Chung, A.J. Einstein, J. Balcombe, M. Cocker, M. Das, B.N. Delman, M. Flynn, R. Gould, R.K. Lee, T. Yellen-Nelson, S. Schindera, A. Seibert, J. Starkey, S. Suntharalingam, A. Wetter, J.E. Wildberger, D.L. Miglioretti, International variation in radiation dose for computed tomography examinations: prospective cohort study, BMJ 364 (2019) k4931.

[15] J. Leipsic, G. Nguyen, J. Brown, D. Sin, J.R. Mayo, A prospective evaluation of dose reduction and image quality in chest CT using adaptive statistical iterative reconstruction, AJR Am. J. Roentgenol. 195 (2010) 1095–1099.

[16] P. Rajiah, L. Ciancibello, R. Novak, J. Sposato, L. Landeras, R. Gilkeson, Ultra-low dose contrast CT pulmonary angiography in oncology patients using a high-pitch helical dual-source technology, Diagn. Interv. Radiol. 25 (2019) 195–203.

[17] A. Sauter, T. Koehler, B. Brendel, J. Aichele, J. Neumann, P.B. Noel, E.J. Rummeny, D. Muenzel, CT pulmonary angiography: dose reduction via a next generation iterative reconstruction algorithm, Acta Radiol. 60 (2019) 478–487.

[18] M.K. Kalra, M. Woisetschlager, N. Dahlstrom, S. Singh, S. Digumarthy, S. Do, H. Pien, P. Quick, B. Schmidt, M. Sedlmair, J.A. Shepard, A. Persson, Sinogram-affirmed iterative reconstruction of low-dose chest CT: effect on image quality and radiation dose, AJR Am. J. Roentgenol. 201 (2013) W235–W244.

[19] R. Smith-Bindman, J. Lipson, R. Marcus, K.P. Kim, M. Mahesh, R. Gould, A. Berrington de Gonzalez, D.L. Miglioretti, Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer, Arch. Intern. Med. 169 (2009) 2078–2086.

[20] J.K. Woo, R.Y. Chiu, Y. Thakur, J.R. Mayo, Risk-benefit analysis of pulmonary CT angiography in patients with suspected pulmonary embolus, AJR Am. J. Roentgenol. 198 (2012) 1332–1339.

[21] A. Salah, H.A. Abdel Ghany, A.A. Taha, H.M. Diab, Investiagation of effect of body mass index of patient radiation dose during interventional cardiac process, J. Sci. Res. Sci. 35 (2018) 87–94.