ORIGINAL RESEARCH PAPER

Volume - 11 | Issue - 08 | August - 2022 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

COMPARISON OF LOW KVP SIZE BASED LOW DOSE CT PROTOCOL AND LOW KVP AUTOMATED EXPOSURE CONTROLLED BASED LOW DOSE CT PROTOCOL, FOR EVALUATION OF CONGENITAL HEART DISEASE IN PAEDIATRIC POPULATION IN A TERTIARY CARE TEACHING HOSPITAL OF WESTERN RAJASTHAN.

Radio-Diagnosis

Dr. Sunil Vishnoi	3rd Year PG Student, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India
Dr. Kirti Chaturvedy	Professor and Head, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India
Dr. Ramanand Gehlot	Senior Professor, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India
Dr. Divyangi Mishra*	Assistant Professor, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India *Corresponding Author
Dr Girja Nandvanshi	3rd Year PG Student, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India
Dr Anish H. P	3rd Year PG Student, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India
Dr Abhishek Kaushik	3rd Year PG Student, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India
Dr Asaf Ali kammar	3rd Year PG Student, Department of Radio-diagnosis, Dr. S. N. Medical College, Jodhpur, Rajasthan, India

ABSTRACT

Introduction: Evaluation for CHD lead to inadvertent radiation exposure to children. With objective of minimising radiation exposure, we developed a size based (SB) novel low kVp low dose CT protocol for pediatrics population. **Material and methods:** All CT chest examinations performed on PHILIPS Ingenuity core 64-slice multi detector CT machine. A total of sixty children with suspected/diagnosed CHD were randomized to either novel SB protocol or machine's default AEC based low dose pediatric chest CT protocol . Our protocol consisted of keeping tube voltage 80 kVp in all patients and tube current (mA) being modulated according to size of subjects (chest circumference). All CT dose parameters (ED, CTDI vol, DLP and mA) were recorded for comparison. Image quality of the two methods compared by two radiologists blinded to the method. **Results:** After analysing and comparing with other studies for all the CT dose variables we concluded that all CT radiation exposure values as measured by ED, CTDI vol, SSDE, DLP were lower in SB protocol as comparison to default AEC based protocol in those corresponding to <12 months age group. In 1-5 year- ED, SSDE, CTDI vol and DLP was equivalent in both size based and AEC based low dose protocols. In 6-18 year ED, SSDE, CTDI vol and DLP was slightly higher in size based low dose protocol. **Conclusion:** In younger age group (<12 months of age) SB protocol should be preferred as compared to default machine protocol. In children with >1 years of age , low dose AEC protocol is better from perspective of radiation exposure.

KEYWORDS

CHD- Congenital heart disease, AEC - Automated exposure controlled, SBLD- size based low dose, ED- Effective dose, SSDE- Size specific dose estimate, CTDI-CT dose index, kVp -Kilovoltage peak, mAs- Milliamperage- seconds, mGy-Milli-gray, mSv-Milli-sivert, DLP-Dose length product, CT- Computed tomography

INTRODUCTION

CHD is the most frequently occurring congenital disorder, 28% of all congenital birth defects [1]. The birth prevalence of CHD is 8-12/1000 live births in India.

CT has the advantages of widespread availability and short acquisition times in evaluation of congenital heart disease. The development of 64-section CT, with increased scanning speed, higher spatial resolution, and enhanced capabilities for simultaneous evaluation of cardiovascular structures and lung parenchyma, has increased the clinical application of CT for the evaluation of patients with congenital heart diseases.[1,2].

Low dose cardiac CT angiography is more beneficial for paediatrics patients as compared to conventional CT scans due to the children are at greater risk of radiation exposure than adults because the rapidly dividing cells of children tend to be more radiosensitive and they have a longer expected life time in which to develop potential radiation injury. The risk of radiation-induced cancer development should be a concern in paediatrics patients because it can develop after a long-latency period [3,4]. In contrast to adults low dose CT protocols in children are not standardized. In adults the low dose automated exposure-controlled CT protocol is standard of imaging . The same is often applied to the pediatric patients . Its well known that due to nutritional status there is wide variability of size in children . A low kVp size base (chest circumference) protocol independent to age has been suggested for children to reduce radiation dose , without compromising diagnosis. [5-7]. In this study, we discussed and described about comparison of radiation exposure of the low dose CT scan protocols and CT imaging findings (extra cardiac abnormalities, cardiac abnormalities and connection problems) in paediatrics patients with CHD, and the advantages and disadvantages of low dose CT protocols in this setting and the principal indications in clinical practice.

Methods and material

The study was conducted in Department of Radio diagnosis, Dr. S.N. Medical College and Associated Group of Hospitals, Jodhpur on subjects (<18 years of age) suspected or diagnosed of having CHD require sectional imaging for clarification/comprehensive evaluation of all suspected cardiac and extra cardiac lesion. Those who were hemodynamically unstable patients, Surgically repaired, deranged creatinine were excluded The procedure was explained to the child and his parents and informed consent was taken. Detail history for contraindication of CT was specifically taken, specific allergic reactions of contrast history also taken. The subjects were randomized to either SB or AEC protocol. The SB protocol was conceptualised by one of the authors (KC) and permission for its use in subjects taken from appropriate authorities. The principle is to reduce the kilovoltage to 80 kVp in all patients and modulate tube current according to size based on chest circumference of subject. The exact mA depending on chest circumference as detailed in table 1. Chest circumference was measured in infra-axillary region at the level of nipple. Initially NCCT scan was taken at level of heart (approx. level of right ventricle), ROI

 PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

was placed in right ventricle lumen. Then contrast injection (non-ionic contrast material with iodine concentrations 240–300 mg/mL, dose of 1- 2 mL/kg, rate of 2-2.5 mL/sec) was followed by saline flush. FOV- 5-12 cm (from upper border of manubrium up-to upper abdomen). Then arterial and venous phase scan were taken. We recorded CT radiation variables (DLP, CTDI vol, kVp and mAs) in our patient data sheet in arterial phase of the study for both low kVp low dose CT protocol and statistical analysis done accordingly. Three-dimensional reconstructions (idose4) were formed and analysed for all patients [3]. Subjective image quality analysis was done by two experienced radiologists (experience- 2-3 years and >15 years) and they are blinded about the protocol used. European Guidelines on Quality Criteria for Computerized Tomography document is used for image quality assessment [4,5, 13] with three-point scale grading- minimal, mild and unacceptable image noise [14]. PHILIPS Ingenuity core 64-slice multi detector CT machine was used for the study. The study was approved by Institutional Ethics Committee. (IEC)

Table 1- mA values for size based low dose protocol according to subject's chest circumference

S.N	Average chest circumference (cm)	kVp	mAs
1	30-35 cm	80	40
2	35-40 cm	80	60
3	40-50 cm	80	80
4	50-55 cm	80	100
5	55-60 cm	80	120
6	60-65 cm	80	140

CT dose calculations: -

1. Tube voltage- 80 kVp
2. Tube current (mAs) – In AEC low dose protocol- Default protocol of the CT machine. In size based low dose protocol, it is according to table 1.
3. CTDI vol (mGy) (CT dose index volume) and DLP (dose length product)- (mGy x cm)- as measures by machine.
4. Mean effective diameter of chest- (cm)- for estimate SSDE (size specific dose estimate) Mean effective diameter of chest = √AP diameter of chest x transverse diameter of chest (cm) [measured in the axial CT image at the level of nipple].
5. SSDE= CTDI vol x Conversion factor {conversion factor as per report of AAPM (American association of physicists in medicine 2011) task group 204 and image gently}[3,15].
6. Effective dose (ED)- mSv; ED= DLP x 0.016 {Conversion factor for paediatric chest angiography is ~0.016} [3,5,7,9,15,16].

DISCUSSION

On detailed study of this subject group, it was found that since this group (>50 cm) is very large and variable type of study population ranging from (5-18 year), incidentally the mean age of subjects in AEC based protocol was ~10 year and mean age of subjects in size based low dose CT chest protocol was ~ 11.75 year and number of subjects in each group was very less.

We found strong positive correlation between the radiation exposure indices (like ED, CTDI vol, SSDE and DLP) and chest circumference of the subjects in size based low dose protocol in comparison to AEC based low dose protocol. The correlation between SSDE and chest circumference in size based low dose CT chest protocol is very high specially in lower chest circumference range as compared to correlation coefficient between SSDE and chest circumference of subjects in AEC based low dose CT chest protocol, with lot of scatter specially in lower chest circumference range.

Since SSDE is best method of radiation exposure measures as per size of patient, this difference in r value in two protocols suggest that size based low dose protocol is best suited for paediatric patients, especially those with lower chest circumference range.

We compared radiation dose parameters of the automated exposure based low dose CT protocol with size based low dose CT protocol to derived either size based low dose CT chest protocol was just equally effective or better than AEC protocol for the evaluation of congenital heart disease in paediatric population.

Comparison done under following two sub-headings:

(I) CT radiation dose parameters
(II) Image quality subjective assessment

[I] CT radiation dosimetry calculations-

(a) Effective dose- In all chest circumference groups (<35, 35-50 & >50 cm group); in size based low dose CT protocol (respectively for each CC groups- 0.26, 0.38, 0.98 mSv) delivered lower mean effective dose (ED) in comparison to AEC based low dose CT protocol (respectively for each CC groups- 0.36, 0.47, 1.03 mSv).
Overall mean effective dose (ED) value was lower in size based CT protocol (0.53 mSv) compared to AEC low dose CT protocol (0.56 mSv).

In comparison with study done by Ibrahim et al[20], we had 65% effective dose reduction; however, they studied on adult population and mean age in their study was 40.9 years and mean age in our study was 3.49 (mean chest circumference 42 cm). Comparison of 70 kVp low dose protocol, we got similar results in near adult age groups (n= 5, ED- 1.5 mSv) of our study.

(b) Volume CT dose index [CTDI vol]- CTDI is specification of the amount of radiation in CT examinations.

The CTDI measured by placing cylindrical acrylic phantom at the scanner isocentre. In our study 32 cm phantom of Phillip's 64 slice CT machine used in chest angiography protocol for evaluation of CHD.

We observed statistically significant difference in CTDI vol values of SB protocol (0.92 mGy) and AEC based low dose protocol (1.24 mGy) for infants with normal chest circumference group (35 cm) (p value <0.05).

We found lower mean CTDI vol values in chest circumference groups (<35 cm, 35-50 cm), except in >50 cm chest circumference group for the SB low dose CT chest protocol (mean-1.43+0.58 mGy) in comparison to AEC protocol (mean-1.45+0.60 mGy). However, this result was not statistically significant (p value-0.883).

Lower CTDI vol value (~55-60%) in our AEC based low dose CT protocol in comparison with the AEC based low dose protocol of siegel et al study. [17]

Most accurate method for setting up low dose CT protocol and radiation exposure calculation calculating is based on chest circumference and SSDE. Since in our study r value in AEC based protocol is lower in comparison to SB protocol. It shows AEC based protocol do not perform so well to reducing radiation dose. [3-5, 7,14]. Likely because they are depending on effective implication by expert radiographers, proper centring of patients, assumption that patients have not moved, the scout had been taken and the fact that is depend upon tomogram which is 2D estimate of chest measures.

(c) SSDE (Size-specific Dose Estimation)-
SSDE= CTDI vol x conversion factor.
It estimates the dose at the centre of a certain CT scan range and does not take scan length account in variations of dose[5,18].

Since SSDE is best method of radiation exposure measures as per size of patient in our study the correlation coefficient between SSDE and chest circumference is very high specially in lower chest circumference range as compared to correlation coefficient of AEC, which shows lot of scattered specially in lower chest circumference range this is likely because AEC based take consideration of transverse diameter of scout image[4-7,9,18].

In our study conversion factor for SSDE calculation was derived by taking consideration in anteroposterior diameter and transverse diameter of chest both (effective diameter of chest), hence the calculation of SSDE was more precise in our study as per size of patient hence size based (according chest circumference) protocol is better in younger paediatric subjects (<35 cm chest circumference and <12 months age)

In our study we found that SSDE values are lower in <12 months age group for both normal and abnormal ranges of chest circumference in size based low dose protocol (2.36±0.25 mGy) in comparison to AEC based low dose protocol (2.98±1.16 mGy), this result was statistically significant (p value-0.038).

In 1-5 years and 6-18 years groups we found that SSDE values were higher in size based low dose CT chest protocol as comparison to AEC based low dose protocol respectively (2.71±0.83, 3.63±0.77 in AEC based protocol and 3.27±0.69, 4.12±0.60 in size-based protocol).

In AEC based protocol scatter graph shows more random scatters SSDE values from reference line according to corresponding chest circumference ranges in comparison to size-based scatter plot which shows SSDE values near to reference line according to their chest circumference.

d) DLP dose length product- (mGy*cm)
DLP is Product of CTDI vol and scan length (in cm). A measure of the total amount of radiation used to perform any CT examination [3-7,17,18].

Chest circumference value <35 cm group, mean DLP in our study was 25.4 mGy*cm (for AEC based protocol), 16.17 mGy*cm (for size based low dose CT chest protocol) and this correlation was found to be statistically significant (p value 0.016).

Comparison of DLP values with khalid mohammed salim et al study, we obtained lower DLP values in both of low dose CT protocol grouped according to age. In our study ~50-60% reduction of DLP in each age group. [7].

e) Tube current (mA)-
Relationship between tube current and patient dose is linear, with increases in mAs resulting in a comparable percentage increase in patient dose, however improved image quality, decreased image noise[].

Although tube current can be manually controlled, most operators use automated tube current modulation (in AEC protocol) for most scans. Similarly, in our AEC based protocol tube current modulation by automated tube current modulation and for size based low dose CT chest protocol tube current was given according to their chest circumference ranges as shown previous[15,16].

Our study we found that mean delivered tube current (mA) was lower in size based low dose protocol (74.00 mAs) in comparison to AEC based low dose Ct protocol (76.2 mAs).

Our study population and radiation indices were comparable with the study done by Jae-Yeon Hwang, et al[3].

They did a survey of paediatric CT protocols and radiation doses in South Korean hospitals to optimize the radiation dose for paediatric CT scanning. We compared all paediatric chest CT data of their study (N-105) with our study (N- 60). Since the Jae-Yeon Hwang, et al standardised their radiation dose indices based on 16 cm phantom whereas in our study it was based on 32 cm phantom [3]. Hence, we multiplied the DLP and CTDI vol by 2 to make these two studies comparable.

In <12 months age group, ED, CTDI vol and DLP values in our study were lower in comparison to study done by Jae-Yeon Hwang et al but it was vice versa for SSDE. The conversion factor for SSDE calculation used in both the studies were adopted from "AAPM report (American association of physicists in medicine 2011) task group 204". The conversion factor in the AAPM report shows decreasing trend with increase in effective chest diameter which in turn depends on age of the subjects. As higher number of subjects belonging to ≤ 1 month age group were present in our study (N-13 out of total 28 subjects) as compared to the study done by Jae-Yeon Hwang et al (N-3 out of 21 subjects), SSDE values were slightly higher in our study as compared to the study done by Jae-Yeon Hwang et al for <12-month age group.

Radiation indices- ED, CTDI vol_{16}, and DLP values were lower in our study in comparison to the study done by Jae-Yeon Hwang et al for 1-5 year and 6–18-year age groups. The SSDE values in our study were lower in AEC based low dose CT protocol and slightly higher in size based low dose protocol as compared to the study done by Jae-Yeon Hwang et al for 1–5-year group. For 6–18-year age group SSDE values were lower in our study (in both CT protocols) as compared to the study done by Jae-Yeon Hwang et al [14].

After analysing and comparing with other studies for all the CT dose variables we concluded that all CT radiation exposure values in term of ED, CTDI vol, SSDE, DLP were lower in size based low dose CT chest protocol as comparison to AEC based low dose protocol for <12 months of age with corresponding <35 cm chest circumference group.

In 1-5 year/ 35-50 cm chest circumference range- ED, SSDE, CTDI vol and DLP was equivalent in both size based and AEC based low dose protocols.

In 6-18 year/ >50 cm chest circumference range- ED, SSDE, CTDI vol and DLP was slightly higher in size based low dose protocol.

(II) Image quality assessment (subjective assessment) –
Qualitative Image quality assessment- in all 60 patients, diagnostic image quality was assessed by two observers, first observer had >15 year of experience and 2nd observer had 2 year of experience were blinded to the image techniques (blinded about which protocol is used).

All observations were recorded with consensus of both observers at the time of reporting and analysis of study.

Subjective evaluation of aorta and pulmonary artery opacification after contrast injection and about the beam hardening artifact due to contrast injection into the SVC was recorded and found that 76.67% of scan in both CT protocols shows minimal image noise (minimal motion related artifact) which shows no effect on diagnostic accuracy for chest CT angiography for evaluation of CHD. Only 23.33% scan shows mild noise (beam hardening artefact +/ motion artefact /metallic artefact /IV lines and clothes artefact), however none of scan shows unacceptable noise (0%) for diagnostic quality in both low dose CT protocols.

In our study we used iDose4 Iteration reconstruction performed on both raw-data space with statistical noise modelling and in image space to avoid an artificial appearance. The window level and width were freely changed to visualize CT images in both protocols [].

In our study we found many of complex congenital heart diseases likely hetero taxy syndrome, DORV, TA, COA, TOF, MAPCAS, coronary artery abnormalities, ASD, VSD, PDA, DOLV and multiple venous abnormalities in both the protocol with very minimal image noise in (90%).

RESULTS:
The radiation exposure (as measured in term of ED/SSDE/CTDI vol) was relatively lower in <35 cm chest circumference and <12 months age in SB protocol. All radiation dose parameters were almost equivalent in both protocols in 1–5-year age, 35-50 cm chest circumference group and these parameters was slightly higher in >50 cm chest circumference and 6–18-year age group in SBLD CT chest protocol. There was no difference in image quality in two protocols.

In addition, it was found that reduced radiation exposure as measured by SSDE, CTDI vol indices between the two low dose CT protocols were statistically significantly low in subject groups of <35 cm chest circumference (which correlated with <12 months of age as per IAP standard), with size based low dose CT protocol.

In the subject group of 35-50 cm chest circumference the radiation exposure was equivalent with both protocols suggesting that either can be used for this group, especially if trained radiographers are available. In study group >50 cm chest circumference the radiation exposure by all indices (ED, SSDE, CTDI vol), was slightly more in SB protocol in comparison to AEC based low dose CT protocol but this was not statistically significant.

CONCLUSION
Low and fixed tube voltage (80 kVp) in both study group, reduced radiation exposure significantly as well as increased image contrast. Image contrast was also increased by the k -Edge of iodine, in contrast angiography study without compromising image quality.

Both protocols used low kVp (80 kVp) but in pediatric patients due to more variations in body size and anthropometry as per their age, size based low dose CT protocol may be a better alternative of the low dose CT protocol based on AEC. Younger age group (<35 cm chest circumference, <12 months of age) had lower radiation exposure as measured by SSDE and CTDI vol in SB CT protocol However no reduction in radiation exposure was found in middle age children (1-5 yrs.) Thus or LD CT protocol is specially recommended in pediatric chest CT examination if child has <35 cm chest circumference and /or <12 months age.

Limitations of our study-
1. Small study group
2. Comparison of the both protocols was not possible in same subjects due to ethical issues, enhance subject population had comparison for variation.

3. The third study group of 6-18 year of age and >50 cm chest circumference was very large with variable subject population so comparison between these two protocols was in appropriate in this age group.

Therefore, size-based protocol is a recommended if -
a) If AEC is not available
b) Radiographers is not well trained/inexperienced for AEC based low dose CT protocol
c) Children <1 year of age group

This study attempts towards reduction of radiation dose which needs further studies and refined subject selection to consolidate the findings.

REPRESENTATIVE CASES

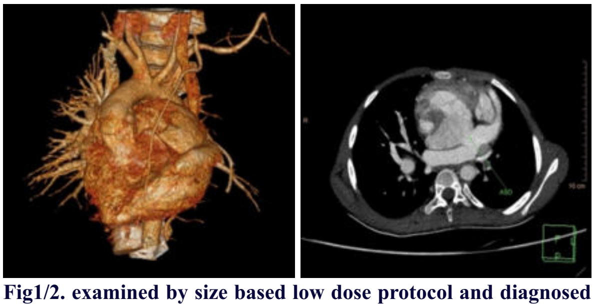

Fig1/2. examined by size based low dose protocol and diagnosed DORV (both MPA and aorta arising from RV) with ASD, multiple VSD, hypoplastic LPA (? less likely PDA), PAPVC, persistent left svc, right ventricle is enlarged with right atrial appendages enlarged, D10 hemivertebra with 12 ribs on right and 11 ribs on left side, MPA is narrowed, few MAPCAS present

OBSERVATION AND RESULTS

Dose							
#	Scan Label	Scan Mode	mAs	KV	CTDIvol [mGy]	DLP [mGy*cm]	Phantom Type [cm]
		Helical	92	80	1.8	58.6	BODY 32 CM

Fig -3 (56 cm chest circumference) size based protocol, arterial phase CT dose parameters

Dose							
#	Scan Label	Scan Mode	mAs	KV	CTDIvol [mGy]	DLP [mGy*cm]	Phantom Type [cm]
		Helical	81	80	1.5	39.9	BODY 32 CM

Fig- 4 (56.3 cm chest circumference) AEC protocol, arterial phase CT dose parameters

TABLE 2: Over all mean values of all dose variables in both low dose CT protocols-

Radiation dose variables	Automatic exposure control low dose CT protocol (Mean ± SD)	Size based low dose CT protocol (Mean ± SD)	p value
Effective dose (ED)	0.56±0.35 mSv	0.53±0.36 mSv	0.744
CT dose index (CTDI vol)	1.45±0.60 mGy	1.43±0.58 mGy	0.883
Size specific dose estimate (SSDE)	3.11±1.02 mGy	3.13±0.90 mGy	0.943
Tube current (mA)	76.2±31.26 mAs	74.00±32.44 mAs	0.79
Dose length product (DLP)	35.83±22.50 mGy*cm	33.98±22.86 mGy*cm	0.752

TABLE 3 :- Over all mean values of all dose variables according to their age groups in both low dose CT protocols-

Age of subjects	Type of protocol	ED (Mean± SD)	mA (Mean± SD)	SSDE (Mean± SD)	CTDI vol (Mean±SD)	DLP (Mean± SD)
<12 Month	AEC	0.35±0.16	59.35±22.21	2.98±1.16	1.17±0.45	22.87±10.44
	Size based	0.27±0.05	46.15±9.60	2.36±0.25	0.94±0.12	17.45±3.46
1-5 year	AEC	0.48±0.18	71.57±24.06	2.71±0.83	1.3±0.43	30.58±11.78
	Size based	0.46±0.09	75.00±14.14	3.27±0.69	1.43±0.28	29.53±5.94
6-18 years	AEC	0.94±0.38	106.00±28.16	3.63±0.77	2.02±0.57	60.07±23.98
	Size based	0.98±0.36	113.33±22.36	4.12±0.60	2.14±0.45	61.8±22.63

Table 4: Coefficient correlation between low dose CT protocols for various parameters:

Low dose CT protocol	Effective dose mSv	SSDE (mGy*cm)	Tube current (mAs)	CTDI vol (mGy)	DLP (mGy*cm)
	r value	r value	r value	r value	r value
AEC	0.769	0.272	0.626	0.766	0.681
Size Based	0.936	0.883	0.96	0.936	0.979

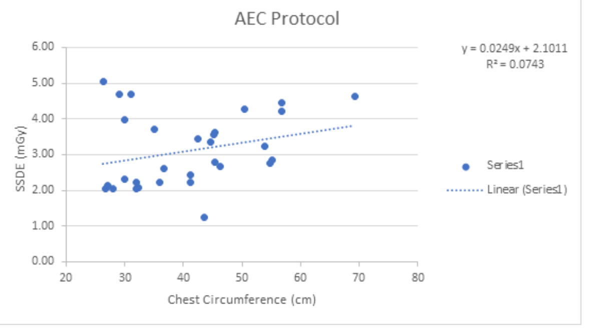

Figure 5 -Scatter plot shows positive correlation between variables in AEC protocol

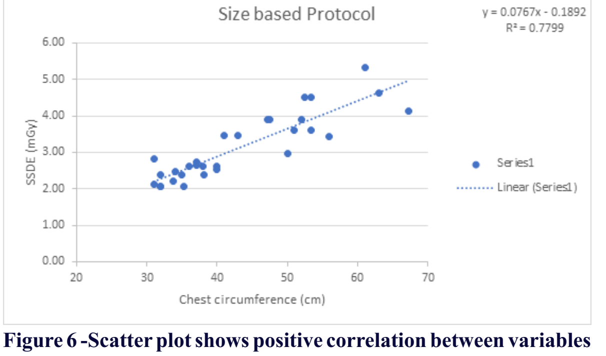

Figure 6 -Scatter plot shows positive correlation between variables in size based protocol

REFERENCES

1. Tsai IC, Chen MC, Jan SL, et al. Neonatal cardiac multi detector row CT: why and how we do it. Pediatr Radiol 2008; 38:438–451
2. Gaca AM, Jaggers JJ, Dudley LT, Bisset GS 3rd. Repair of congenital heart disease: a primer. Part 1. Radiology 2008; 247:617–631
3. Hwang JY, Do KH, Yang DH, Cho YA, Yoon HK, Lee JS, Koo HJ. A Survey of Pediatrics CT Protocols and Radiation Doses in South Korean Hospitals to Optimize the Radiation Dose for Pediatrics CT Scanning. Medicine (Baltimore). 2015 Dec;94(50) :e2146
4. Greenwood TJ, Lopez-Costa RI, Rhoades PD, Ramírez-Giraldo JC, Starr M, Street M, Duncan J, McKinstry RC. CT Dose Optimization in Pediatrics Radiology: A Multiyear Effort to Preserve the Benefits of Imaging While Reducing the Risks. Radiographics. 2015 Sep-Oct;35(5):1539-54
5. Nagayama Y, Oda S, Nakaura T, Tsuji A, Urata J, Furusawa M, Utsunomiya D, Funama Y, Kidoh M, Yamashita Y. Radiation Dose Reduction at Pediatrics CT: Use of Low Tube Voltage and Iterative Reconstruction. Radiographics. 2018 Sep-Oct;38(5):1421-1440
6. Agarwal S, Jokerst C, Siegel MJ, Hildebolt C. Pediatrics emergency CT scans at a children's hospital and at community hospitals: radiation technical factors are an important source of radiation exposure. AJR Am J Roentgenol 2015;205(2):409–413
7. Al Mahrooqi KMS, Ng CKC, Sun Z. Pediatrics Computed Tomography Dose Optimization Strategies: A Literature Review. J Med Imaging Radiat Sci. 2015 Jun;46(2):241-249
8. Mitchell SC, Korones SB, Berendes HW. Congenital heart disease in 56,109 births. Incidence and natural history. Circulation 1971; 43: 323–332
9. Reid J, Gamberoni J, Dong F, Davros W. Optimization of kVp and mAs for pediatrics low-dose simulated abdominal CT: is it best to base parameter selection on object circumference? AJR Am J Roentgenol. 2010 Oct;195(4):1015-20
10. Leschka S, Oechslin E, Husmann L, et al. Preand postoperative evaluation of congenital heart disease in children and adults with 64-section CT. RadioGraphics 2007; 27:829–846
11. Hollingsworth CL, Yoshizumi TT, Frush DP, et al. Pediatrics cardiac-gated CT angiography: assessment of radiation dose. AJR 2007; 189:12–18
12. Taylor AM. Cardiac imaging: MR or CT? Which to use when. Pediatr Radiol 2008; 38[suppl 3]:S433–S438
13. Fanous R, Kashani H, Jimenez L, Murphy G, Paul NS. Image quality and radiation dose of pulmonary CT angiography performed using 100 and 120 kVp. AJR Am J Roentgenol. 2012 Nov;199(5):990-6
14. O'Connor OJ, Vandeleur M, McGarrigle AM, Moore N, McWilliams SR, McSweeney SE, O'Neill M, Ni Chroinin M, Maher MM. Development of low-dose protocols for thin-section CT assessment of cystic fibrosis in pediatrics patients. Radiology. 2010 Dec;257(3):820-9
15. American Association of Physicists in Medicine. Size Specific Dose Estimates (SSDE)

in Pediatrics and Adult CT Examinations. Report of AAPM Task Group 204. 2011:1–23
16. Singh, Sarabjeet & Kalra, Mannudeep & Moore, Michael & Shailam, Randheer & Liu, Bob & Toth, Thomas & Grant, Patricia & Westra, Sjirk. (2009). Dose Reduction and Compliance with Pediatrics CT Protocols Adapted to Patient Size, Clinical Indication, and Number of Prior Studies. Radiology. 252. 200-8
17. Siegel, M. J., Hildebolt, C., & Bradley, D. (2013). Effects of automated kilovoltage selection technology on contrast-enhanced pediatrics CT and CT angiography. Radiology 289(2), 538–547
18. Huda W, Mettler FA. Volume CT dose index and dose-length product displayed during CT: what good are they? Radiology. 2011 Jan;258(1):236-42
19. Szucs-Farkas Z, Kurmann L, Strautz T, et al. Patient exposure and image quality of low-dose pulmonary computed tomography angiography: comparison of 100- and 80-kVp protocols. Invest Radiol 2008; 43:871–876
20. Weis M, Henzler T, Nance JW Jr, Haubenreisser H, Meyer M, Sudarski S, Schoenberg SO, Neff KW, Hagelstein C. Radiation Dose Comparison Between 70 kVp and 100 kVp With Spectral Beam Shaping for Non-Contrast-Enhanced Pediatrics Chest Computed Tomography: A Prospective Randomized Controlled Study. Invest Radiol. 2017 Mar;52(3):155-162
21. Nakagawa M, Ozawa Y, Sakurai K, Shimohira M, Ohashi K, Asano M, Yamaguchi S, Shibamoto Y. Image quality at low tube voltage (70 kV) and sinogram-affirmed iterative reconstruction for computed tomography in infants with congenital heart disease. Pediatr Radiol. 2015 Sep;45(10):1472-9
22. Siva P. Raman, Mahadevappa Mahesh, Robert V. Blasko, Elliot K. Fishman, CT Scan Parameters and Radiation Dose: Practical Advice for Radiologists; Journal of the American College of Radiology; Volume 10, Issue 11, 2013, ;840-846