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Relative dose reduction in CT thorax with employment of AEC technique as compared to fixed tube current technique

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ABSTRACT

The article aims to demonstrate the variation in tube current and dose delivered to the patients with the employment of AEC (Automatic Exposure Control) technique as compared to fixed tube current technique in CT thorax performed on multi-detector row CT. The study conducted on 200 subjects of age group 14- 30 years by performing CT chest, using Automatic Exposure Control technique in 1st group (100 subjects) and fixed tube current technique in 2nd group (100 subjects) for comparing dose. Height and weight of each subject was also noted down for finding Body Mass Index (BMI).The subjects with BMI range of 16 – 22 kg/meter2 were included in the study. The data was evaluated for percentage volume dose reduction in terms of CTDIvol in 1st group as compared to 2nd group depending on Body Mass Index of the patients. The image quality with regard to the detection of pathology been compared in both the groups. Data was also analyzed retrospectively for clavicular ossification staging. Volume dose index (CTDIvol) reduced inversely to BMI in 1st group as compared to 2nd group. A significant reduction in dose delivered to patient in terms of volume dose index (CTDIvol) was achieved using AEC technique and correlation of percentage dose reduction and BMI was found to be statistically significant ($p \leq 0.01$).

KEYWORDS CT (computed tomography), ALARA (as low as reasonably achievable) concept, CTDI (CT dose index), BMI (body mass index), AEC (Automatic Exposure Control).

Introduction:

The attention of CT scan users all over the world has now driven on the doses from CT with regard to children and young adults and the potential cancer risk, as the use of CT is increased due to upcoming noninvasive advanced techniques in CT such as angiography, virtual bronchography, enterography, colonoscopy, perfusion CT and multiphasic CT etc. Dose delivered to the patient in CT is relatively high, but CT is more sensitive in earlier detection and characterization of the disease in chest region [1, 2]. The introduction of spiral CT and multi-detector-row CT scanner has facilitated the rapid acquisition of images and completion of scanning of a particular region in single breath- hold (few seconds). The ability to acquire thinner slice collimation and overlapping sections has advanced the clinical applications of CT and raised the patient throughput [3].

But the major drawback of this frequently used technique is increased dose delivered to the patient for producing good quality scans. The most important and misleading fact in using CT parameters is that there is no adverse effect on image quality in CT for increasing patient dose with increased technical factors like conventional radiography, thus upper range of these factors is not bothered by the operators. The image quality of CT mage is defined by 3 components: 1) spatial resolution 2) contrast and 3) mottle or noise [4,5]. These technical factors might not been of much concern if quality would have been the only issue, but understanding how CT image quality is related to these factors should ensure that diagnostic information is not lost while reducing the corresponding radiation dose [6].Image quality and dose delivered to the patient in CT scan is actually a balancing act which is to be performed by the operator.

The conditions of exposure dose are quite different in CT from other conventional x-ray examinations. Thus specific techniques of dose measurement have been developed to assess patient doses in CT. CT is a unique modality in using a narrow beam of x-ray to expose the patient from multiple angles with multiple exposures along the length of the patient to cover a volume. Keeping in view, all these modality-specific parameters a dose descriptor, CTDI (CT Dose Index) was developed to measure the radiation dose distribution in CT from single slice and then to calculate dose from multiple slices [7-9].The CTDI is the integral of the dose distribution profile in z-axis (axis of table translation) of single slice i.e. (1)

$$CTDI = 1/T \int_{-\infty}^{\infty} D(z)\, dz \quad (1)$$

Where T is slice thickness and D(z) is dose as a function of position along z-axis .

To avoid the difficulty of measuring dose over an infinite distance Food and Drug Administration (FDA) decided to measure the dose over the distance of 7 CT slices on either side of the center and is defined as $CTDI_{FDA}$ in FDA code regulations. [10-12]

$$CTDI_{FDA} = (1/nT) \int_{-7T}^{7T} D(z)\, dz \quad (2)$$

Where n = number of slices per scan,

The limitation of this index was the dose profile to be integrated over 14 slice widths (changeable with slice thickness). To overcome this, the International Electro-technical Commission defined a new dose descriptor, $CTDI_{100}$ in 1991 to measure the dose over fixed length 10-cm pencil ionization chamber (CT dose chamber). [7.11]

$$CTDI_{100} = (1/nT) \int_{-5cm}^{5cm} D(z)\, dz \quad (3)$$

Another dose descriptor, $CTDI_W$ (the weighted index) was later

on introduced to get a weighted average of the center and peripheral contribution to dose within the scan plane [7] as dose was not uniformly distributed within the object.

$$CTDI_W = (1/3)(CTDI_{100})_{center} + (2/3)(CTDI_{100})_{peripheral}$$

$CTDI_{vol}$ (final dose descriptor) used in helical CT

$$CTDI_{vol} = CTDI_W /pitch,$$

These CTDI descriptors are obviously meant to serve as an index of radiation dose, not an accurate estimate of the dose [12].

Several techniques are available to reduce the dose delivered to the patient in CT such as reducing kVp, increasing pitch, reducing tube current, scan time/rotation time (sec), scan length, beam collimation etc., but each one of these involves some tradeoff in image quality of the image quality. Energy factor 'kVp' is generally kept constant in most of applications and optimized to ensure an adequate contrast to noise ratio for a given imaging task [3]. The radiation dose is linear with mAs, if all other factors are kept constant (phantom measurements and simulations). Thus reducing mAs by 50% results in the dose reduction in similar way, but the noise will increase by 41% ($1/\sqrt{(mAs)}$[13]. Depending on the requirement of clinical applications, this reduction may be readily accepted [13]Pitch is another method to reduce radiation dose, but with limited use, as it results in increased effective slice thickness [13].

The most genuine technique of dose reduction in CT is varying mAs (mille Amperes x seconds) with patient size. The small size adult patients are mostly imaged on CT using full-sized adult techniques (to minimize noise in the thickest body part), as the image quality is not affected adversely with increased exposure factors, but dose to the patient is increased. Therefore, significant efforts have been put to develop size and weight-based imaging protocols to reduce radiation dose to pediatrics and small-sized adult patients, while still obtaining sufficient diagnostic image quality [12,14]. Modern multi-detector CT scanners are provided with this software named Automatic Exposure Control system (AEC).

Present study has been carried out to show how the values of $CTDI_{vol}$ and effective mAs are affected, while scanning the patients of different body built using *Care-dose4D* technique (AEC in Siemens 16-slice CT scan [12]). Reference mAs were kept constant for all the patients, so as to get consistency in quality of resultant images. Medial clavicular ossification status of the subjects included in this study was also analyzed retrospectively from CT chest examination, as all subjects were in the age group of 14 to 30 years who presented with all infective, inflammatory and malignant diseases.

Material and method:

Material:

200 subjects included were in the study in the age range of 14- 30 years and BMI range of 16-22kg/m^2 with all kind of infective, inflammatory or malignant disease. Their CT examinations were performed for their respective diagnostic purpose and were retrospectively analyzed for finding the ossification status of medial clavicular epiphyseal cartilage for age estimation in addition to the basic purpose of their examination.

Method:

Total number of subjects divided into two groups and examined with two different techniques.

❖1st Group using AEC technique:

Thorax CT of 100 subjects was performed using AEC (Care-dose4D) technique with reference mAs=150, on Siemens sensation -16 (16 slice) CT scan. All the other parameters were kept constant KVp—120, Pitch—1.15, and slice collimation-16x1.5. The parameter of reference mAs (150) was kept constant for all the subjects of this group. Height and weight of each subject noted to find out BMI in each case and then corresponding values of effective mAs and $CTDI_{vol}$ were noted down for each subject.

❖2nd Group using fixed tube current technique:

Thorax CT of 100 other subjects was performed on same machine with fixed mAs technique using parameters, KVp—120, mAs—150 (fixed), Pitch Factor—1.15 and slice collimation-16x1.5. Height and weight of each subject noted here also to find out BMI in each case.

The value of tube current has been selected as 150mAs for fixed current technique, because all the routine CT of thorax region are usually performed at this value in our department and this quality is readily accepted by all the radiologists for reporting. The same value of reference mAs in AEC technique is therefore selected for comparison purpose. Another reason is based on the reference of several published studies which have shown not much improvement in quality above 140 mAs used in CT protocols for CT chest examination [15,16].

Automatic exposure control (AEC) technique: It is x-ray beam modulation technique based on patient's size. It is now equipped in almost all MDCT scanners. Care-dose4D (in Siemens, Malvern, Pennsylvania), Smart Scan (in General Electric, Milwaukee, Wisconsin), and SURE Exposure (Toshiba, New YORK) are commercial versions of this current modulation [12]. Based on a user's defined Image Quality Reference mAs, Care-dose4D modulates the tube current on-line during each tube rotation according to the patients angular attenuation profile [Application Guide, Siemens Medical Solution,Sensation-16].

Evaluation criterion: The present study has been conducted to show the relationship of $CTDI_{vol}$ and mAs with BMI of the patients in thorax CT scan performed using AEC technique and percentage dose reduction in this technique with respect to BMI of the patient as compared to fixed tube current technique. BMI is a statistical measure which compares a person's weight and height.BMI is defined as individual's body weight divided by the square of his or her height. The formulae universally used in medicine produce a unit of measure of kg/m^2 [17].

SI unit of BMI= mass (kg)/ (height (m))^2

Results and discussion:

Results: BMI range = 16-22 kg/meter for N= 200 subjects
Age range = 14 – 30 years for N= 200 subjects
CTDIvol range = 4.29-10.04 for group 1st
10.50(fixed) for group 2nd

The corresponding values of CTDIvol, mAs and BMI of both the groups recorded for comparing percentage volume dose index reduction in AEC technique (1st group) as compared to fixed current technique (2nd group) with respect to BMI of subjects. The values of mAs automatically reduced with reduction in BMI of subjects in 1st group(AEC technique) and similarly the dose delivered in terms of CTDIvol, but remained unchanged in 2nd group(fixed mAs technique) and are well shown for some subjects in the table 1. The corresponding values of these parameters for 1st group are also given in table 2 for comparison with 2nd group. The statistical derivations carried out for data set of 1st group (AEC used subjects) to show the relationship of CTDIvol with BMI of the subjects. **The relationship (Pearson Correlation) between $CTDI_{vol}$ and BMI of the subjects was found to be positive and highly significant ($p \leq 0.01$) and shown in table 3**. Percentage reduction of dose in terms of $CTDI_{vol}$ in each subject of 1st group was calculated as compared to that of 2nd group (fixed value of CTDIvol= 10.50mGy) and given in **9th column of table 2**.

Table 1: Corresponding values of mAs, CTDIvol and BMI in 2nd group (fixed mAs):

S. No.	Age/ Sex	KVp	mAs (fixed)	CTDIvol (mGy)	Weight (Kgs)	Height (meters)	BMI= wt(Kgs)/ Ht(meters)^2
1.	20/M	120	150	10.5	55	1.60	21.48
2.	16/M	120	150	10.5	45	1.50	20.00
3.	14/M	120	150	10.5	45	1.60	17.57

4.	21/F	120	150	10.5	42	1.57	17.04
5.	19M	120	150	10.5	57	1.75	18.61

Table 2: Corresponding values of mAs, CTDIvol, BMI in 1st group (AEC) and percentage reduction in CTDIvol in this group as compared to 2nd group(fixed mAs):

S.No.	Age/Sex	KVp	mAs (AEC)	CTDIvol (mGy)	Weight (kg)	Height (meters)	BMI= wt(kg)/Ht(meter)^2	%Reduction(CTDIvol) in this group(1st) in comparison with fixed mAs technique group(2nd) (10.5mGy)
1.	28/M	120	140	9.89	54	1.62	20.57	5.8%
2.	17/M	120	78	5.51	40	1.55	16.64	47%
3.	15/M	120	93	6.51	45	1.66	17.41	38%
4.	22/F	120	78	5.48	40	1.55	16.64	47.8%
5.	20/M	120	88	6.18	52	1.75	16.97	41.1%

Table 3: Correlation of CTDIvol with BMI in group 1st (AEC used):

		CTDIvol in mGy	BMI
CTDIvol in mGy	Pearson Correlation	1	.983(**)
	Sig. (2-tailed)		.000
	N	100	100
BMI	Pearson Correlation	.983(**)	1
	Sig. (2-tailed)	.000	
	N	100	100

** Correlation is significant at the 0.01 level (2-tailed).

Then percentage reduction of dose in terms of $CTDI_{vol}$ in each subject of 1st group was calculated as compared to that of 2nd group i.e. fixed value of $CTDI_{vol}$= 10.50mGy and Pearson correlation of percentage dose reduction with BMI of the subjects was found to be significant (p = 0.01) and linear(fig: graph). The percentage dose reduction is inversely proportional to the BMI of the patient in this study and in a patient with BMI value of 16.00 kg/m^2, the dose in terms of $CTDI_{vol}$ has been found reduced to almost half (5.30 mGy) as compared to fixed tube current technique (10.50mGy), no reduction was achieved beyond BMI= 22kg/m^2.

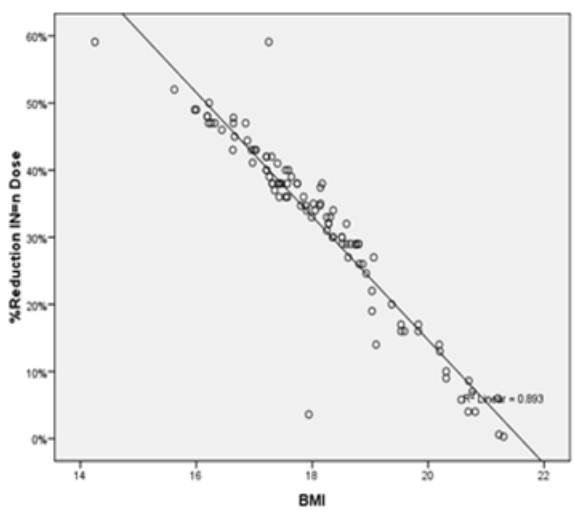
Fig. Graph*: Showing percentage reduction in $CTDI_{vol}$ with respect to BMI of the subjects performed with AEC (Care-Dose 4D) technique: Reduced volume dose index with AEC Technique in group 1st patients as compared to group 2nd patients is calculated and percentage of reduction was also calculated and shown in 9th column of table 2 in each patient of group 1st. Percentage reduction in CTDIvol in each patient is plotted in this graph against BMI of that patient i.e**.** fig. graph and table 4 show the correlation of percentage reduction with respect to BMI in all 100 patients of group 1st.

Table 4 and fig graph*: Shows the correlation of percentage volume dose index (CTDIvol) reduction in group 1st with respect to BMI:
Table 4:

		BMI	%Reduction IN=n Dose
BMI	Pearson Correlation	1	-.945**
	Sig. (2-tailed)		.000
	N	100	100
%Reduction IN=n Dose	Pearson Correlation	-.945**	1
	Sig. (2-tailed)	.000	
	N	100	100

**. Correlation is significant at the 0.01 level (2-tailed).

Figure graph*



Foot note:* BMI in terms of kg/m2 is plotted along X-axis with range 16-22 kgs/m2. Percentage reduction in volume dose index (CTDIvol measured in mGy) of AEC (1st) group than original / fixed dose index (10.5mGy of 2nd group) is plotted along Y-axis with the range o% -60%. The figure shows the relationship of percentage reduction in volume dose index (CTDIvol) in the subjects performed with AEC (Care-Dose 4D) technique as compared to subjects performed with fixed current technique with respect to their BMI.

Discussion:
Today with the capability of performing rapid multi-phasic studies, and increased use of CT, cumulative patient dose is rising up. Now the focusing of the users has been drawn on implementation of as-low-as-reasonably–achievable (ALARA) [18] concept into CT protocols. Absorbed dose in tissues from CT are among the highest observed in the diagnostic radiology and can often approach or exceed levels known to increase the probability of cancer [19].

Applying (AEC) technique to thorax CT can reduce patient dose up to 20% and helps in individualizing the scanning protocol(children and small adults) by dynamic modulation of tube current[20,21]. A considerable reduction of patient dose in the range of 35-60% and 53-65% can be achieved by AEC technique in CT especially in young adults and pediatric patients [22,23]. A consistency in image quality can also be achieved using this technique while doing CT scan of varied thickness body part, such as neck region, because drastic

change in attenuation profile is adjusted by online tube current modulation. Gomi et al. (2008) achieved improved image quality by using AEC in low chest CT for screening purpose without increasing collective dose [24].

Namasivayam et al. (2006) [25] compared the results of two study groups performing MDCT of neck using z-axis AEC and with fixed-current technique (300 mA). They concluded that z-axis AEC resulted in similar subjective noise and diagnostic acceptability with considerable dose reduction compared with those of fixed tube current.

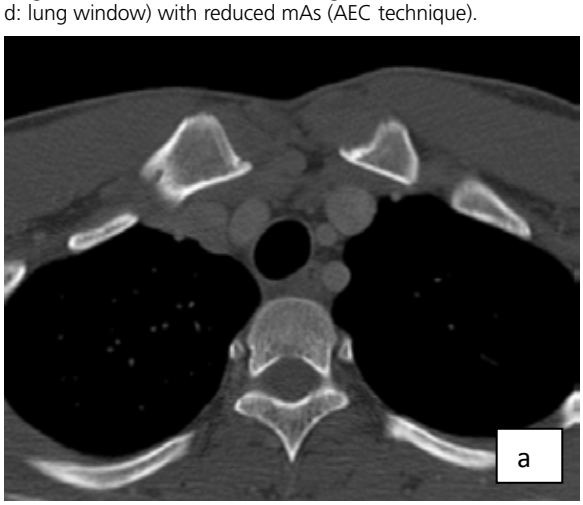
The present study has been conducted on 200 patients for chest CT-examinations using Care-dose4D[12]technique(AEC in Siemens sensation-16 MDCT system) in 100 subjects and fixed tube current in another 100 subjects. BMI of all patients was calculated from their height and weight, and corresponding mAs and $CTDI_{vol}$ recorded in each case. The subject included in the study were having BMI between 16 to 22 kg/m^2, as no reduction in dose could be found in the subjects having BMI≥ 22 kg/m^2. The relationship of $CTDI_{vol}$ and BMI was found to be highly significant (p≤ 0.001). A considerable reduction in dose (more than 50%) depending upon the BMI of patient has been achieved using this technique without deteriorating quality of scans. The correlation of percentage dose reduction and BMI was also found significant (p≤ 0.01). The technique has been proved beneficial in reducing patient dose in terms of $CTDI_{vol}$ for performing CT examination of young adults and adolescents and that is very important in this age, as normal body tissues are more sensitive to dose effects in growing age.

Conclusion:

No difference was found in the quality of scans, as all the images acquired, permitted the evaluation of diagnosis in chest CT as well as the staging of clavicular ossification in bone window and no information was obscured due to noise in the image. The patient's volume dose index (CTDIvol) was reduced considerably especially in small size young adults. This technique reduces dose to the subject in terms of CTDvol, without compromising the quality of scans with consistency in image quality due to constant reference mAs used in all subjects.

Image Quality comparison in both the techniques with regard to diagnostic acceptability for reporting purpose:

The radiologists were unable to distinguish which technique has been used to perform the scan, while reviewing a blinded set of images. The noise in the image depends on mAs used. But it is not reduced blindly in AEC technique but managed depending on the attenuation profile of body tissue, as reference mAs was kept constant. The image quality was consistent in the resultant image with reference mAs constant. Practically it can be seen in the Fig. 1 and Fig. 2, as ossification stage is well demonstrated on fig 1: a, b with fixed mAs and fig 2: a, b with reduced mAs. Similarly soft tissue lesions in the lung are also seen with same quality in both the technique fig 1 (c: mediastinal window; d: lung window) with fixed mAs and fig 2 (c: mediastinal window; d: lung window) with reduced mAs (AEC technique).



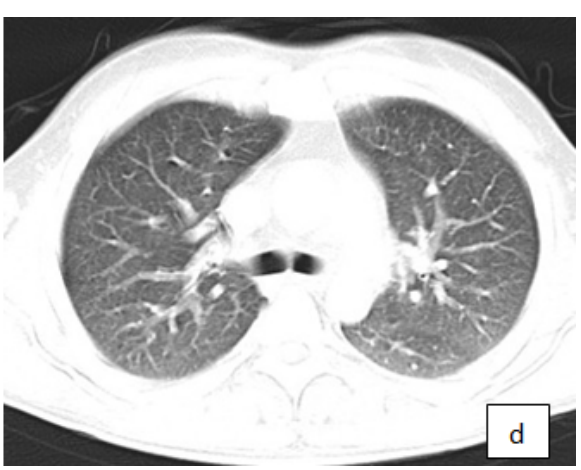
CT image showing quality with fixed mAs{150}



b: CT image showing quality with fixed mAs{150}



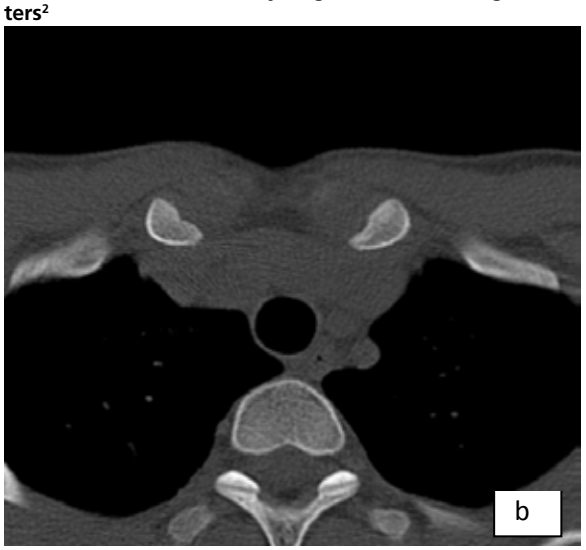
c: CT image showing quality with fixed mAs{150}



CT image showing quality with fixed mAs{150}



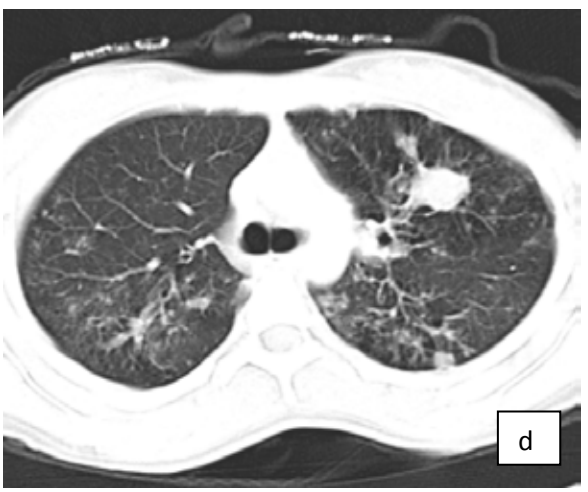
a:mAs-88,CTDIvo– 6.18mGy,stage, BMI – 17.30 Kgms/meters^2



b: mAs-93, CTDIvol –6.51mGy,stage1,BMI– 17.57Kgms/meters^2



c:Mediasinal window showing nodular lesion , mAs-86, CTDIvol – 6.06mGy, BMI – 17.21Kgms/meters^2



d: lung window showing pathology in lung mAs-86, CTDIvol – 6.06mGy, BMI – 17.21Kgms/meters^2

REFERENCES

1. Huda W. Radiation dosimetry in diagnostic radiology. Am J. Roentgenol. (1997); 167:1487-1488 | 2. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. Report to the General Assembly, UN, New York: UNSCEAR;2000 | 3. Huda W, Ravenel J G, and Scalzetti EM. How do radiographic techniques affect image quality and patient dose in CT? Seminars in ultrasound, CT and MRI (2002); 23(5):411-422 | 4. Dainty JC, Shaw R. (1974); Image Science San Diego, CA, Academic Press. | 5. Hasegawa BH. The Physics of Medical X-ray Imaging, 2nd edition (1990); Madison, WI, Medical Physics Publishing. | 6. Donnelly LF, Emery KH, Brody AS, et al. Perspective minimizing radiation dose for pediatric body application of single-detector helical CT: Strategies at a large children's hospital. Am J. Roentgenol (2001); 176: 303-306 | 7. EUR. European Guidelines on Quality Criteria for Computed Tomography. 16262 EN, May (1999): EUR; 2002 Availability at: www.drs.dk/guidelines/quility/index.htm | 8. AAPM. Standardized Method for measuring diagnostic X-ray exposure. Report No. 31(1990) New York: AAPM; 2002 (Available at www.aapm.org/pubs/reports). | 9. Shope TB, Gange RM, Johnson GC. A method for describing the dose delivered by transmission X-ray computed tomography. Med Phys (1981); 8:488-495 | 10. Department of Health and Human Services. Diagnostic x-ray system and their major components, amendments to performance standard, final rule. CFR 21: 1020(part), Federal Register 49:171. Food and Drug Administration;1984 | 11. Jucius RA, Kambic GX. Radiation dosimetry in computed tomography. Appl Opt Instrum Eng Med (1977); 127:286-295 | 12. Thomas JP. CT Radiation Dose and Image Quality. RadioL Clin N Am (2005); 43:953-962 | 13. McNitt-Gray MF. Radiation issues in computed tomography screening. Seminars in ultrasound, CT and MRI (2003);38(1):87-99 | 14. Rogers LF. Taking care of children: check out the parameters used in helical CT. AJR(2001);176:287 | 15. Mayo JR, Hartman TE, Lee KS, Primack SL, Vedal S, Müller NL. CT of the chest: minimal tube current required for good image quality with the least radiation dose. AJR (1995);164:603 | 16. Ravenel JG, Scalzetti EM, Huda W, Garrisi W. Radiation exposure and image quality in chest CT examinations. AJR (2001); 177:279 –284 | 17. ^ NHLBI. The Body Mass Index Table from the NIH's. | 18. International commission on Radiological Protection. Protection of patient in diagnostic radiology. Publication 34: Pergamon Press, Oxford: ICRP; 1982 | 19. International commission on Radiological Protection. Managing Patient Dose in CT. Annals of the ICRP, Pergamon Press, Oxford: ICRP;2002 | 20. Prakash, P. Modified Chest CT Technique Reduces Patient Radiation Exposure. Paper presented in Annual meeting, San Diego, CA, USA: American Roentgen Ray Society (ARRS); 2010. | 21. Food and Drug Administration. Reducing radiation risk from computed tomography for pediatric and small adult patients. FDA public health notification. Pediatr Radiol (2002); 32:314–316 (also available at www.fda.gov/cdrh/ | 22. Soderberg M, Gunnarsson M. Automatic exposure control in computed tomography – an evaluation of systems from different manufacturers. Acta Radiol (2010); 51(6):625-34 | 23. Shah R,Gupta AK,Rehani MM. et al. Effect of reduction in tube current on reader confidence in pediatric computed tomography. Clinical Radiology(2005); 60(2):224-31 | 24. Gomi S, Muramatsu Y, Tsukagoshi S. et al. Low-dose CT screening for lung cancer with automatic exposure control: phantom study. Radiol Phys Technol (2008); 1:244-250 | 25. Namasivayam S, Kalra MK, Pottala KM. et al. Optimization of z-axis automatic exposure control for multi-detector row CT evaluation of neck and comparison with fixed tube current technique for quality and radiation dose. Am J Neuroradiol (2006); 27:2221-25 |