ORIGINAL ARTICLE

CT RADIATION DOSE REDUCTION IN PEDIATRIC CARDIOVASCULAR ANOMALIES - CLINICAL AUDIT IN A SINGLE CENTRE

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ABSTRACT

PURPOSE: To reduce radiation dose from Multidetector computed tomography (MDCT) using techniques with low tube voltage and modified image parameters without significant degradation of image quality. **AUDIT TARGET:** Radiation dose reduction using 80 kV and 100 kV protocols for MDCT. **MATERIALS AND METHODS:** This is a prospective analysis with single blind selection of cardiac anomaly patients referred to radiology department of Rehman medical institute Peshawar for cardiac CT scan during Jan 2013 to Dec 2015. Total of 100 patients with age range of 1 week to 16 years were selected with echocardiographic suspicion of cardiovascular anomalies. It was probability sampling. Scan was performed on 128 multislice Toshiba scanner. ECG gated retrospective and prospective scanning was performed using modified tube voltage (80 kVp, 100 kVp and 120 kVp) and with adjustment of low tube current. Radiation dose measurement was done by multiplying conversion factor with dose length product (DLP), which was provided by the CT scanner. Data was processed using Microsoft Excel 2010. Images were reviewed on 5.1 Vitrea workstation using multiplanar and 3D reconstruction. Two radiologists independently assessed subjective quality of the CT images to assess cardiac anomalies and normal anatomical structures. **RESULTS:** Prospective ECG gating significantly reduced the radiation dose 22 mSv (retrospective) to 13.96 mSv (prospective) with standard inbuilt 120 kVp setting. Reducing the kVp to 100 further reduced dose to 10.3 mSv and dropped down to 5.46 mSv with 80 kVp and no significant image distortion. Manually adjusting and reducing the mAs with added filtration reduced the radiation dose to 3.64 mSv. **CONCLUSION:** We conclude from our results that prospective ECG gated cardiac CT, low kVp and mAs values show great potential for substantially reducing radiation dose of cardiac CT angiography. By using different radiation lowering dose techniques i.e. prospective ECG gating technique, low kVp and mAs, we were able to reduce radiation dose by 83.45% (22 to 3.46 mSv)

Keywords: Cardiac scan, Computed tomography, Cardiac anomaly scan, CT Radiation dose, pediatric cardiac scan.

Introduction

Computed tomography (CT) has established itself as a primary diagnostic imaging modality in cardiac anomalies.[1] With its fast scanning speed and isotropic spatial resolution at 0.3 - 0.4 mm, CT allows diagnosis safely and accurately than alternative more invasive or less sensitive imaging techniques. It is because of this tremendous value of CT that its use is now pervasive in modern medical practice.[1] With high quality CT imaging being performed more frequently, patients can benefit from a quicker and more accurate diagnosis and precise anatomic information for planning therapeutic procedures. However, inspite of

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the tremendous contributions of CT to modern healthcare, some attention must also be given to the very small health risk associated with the ionizing radiation received during a CT exam.[2]

The radiation dose associated with a typical CT scan (1 - 14 mSv depending on the exam) is comparable to the annual dose received from natural sources of radiation, such as radon and cosmic radiation (1 - 10 mSv), depending on where a person lives.[3] Hence, the health risk to an individual from exposure to radiation from a typical CT scan is comparable to background levels of radiation. One study suggested that as much as 0.4% of all current cancers in the United States may be attributable to the radiation from CT studies based on CT usage data from 1991 - 1996.[4]

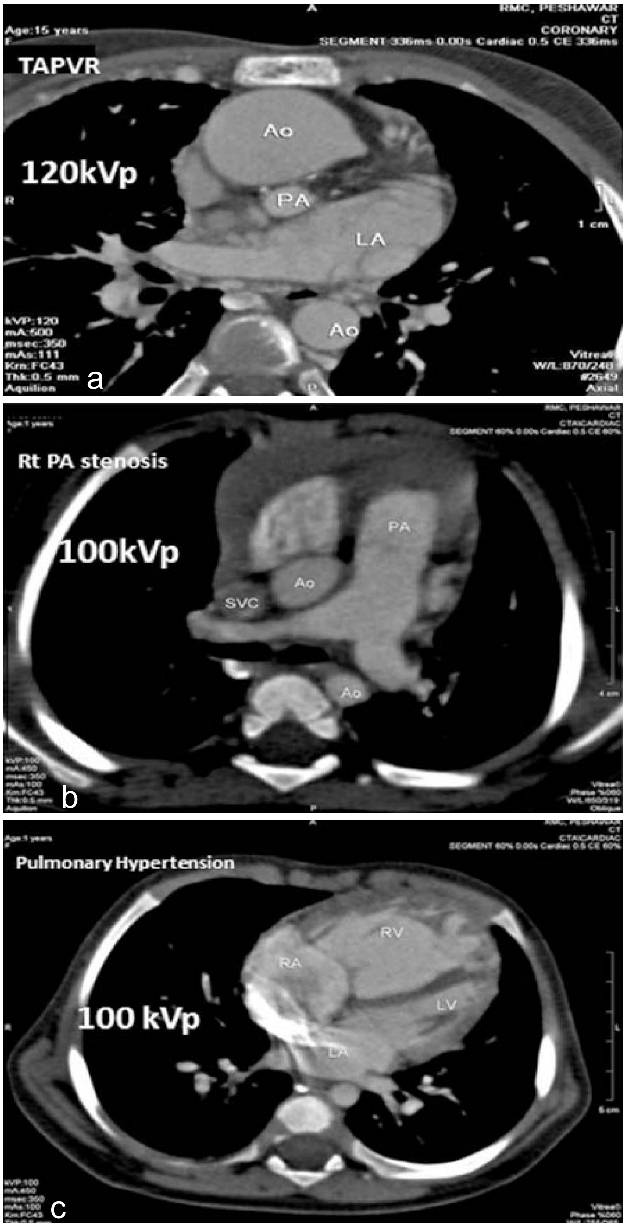
Magnetic Resonance Imaging (MRI) is a better modality but since it is not readily available in Pakistan and where available, requires patient sedation due to longer scan duration. So in many cases CT has to be done at the cost of radiation, which is still less dose than conventional angiography.

There is no question that the benefit of an appropriately indicated CT scan far exceeds the associated estimated risk or that CT providers need to prescribe the minimal amount of radiation required to obtain images adequate for evaluating the patient's condition.[2]

Although the radiation dose can be reduced by decreasing the tube current - time product settings, this alteration also reduces the contrast-to-noise ratio (CNR).[5]

The concern about the potential carcinogenic effects of diagnostic levels of radiation has recently been heightened by reports suggesting that some patients may incur substantial cumulative radiation doses due to repeated CT scans, radionuclide testing, and/or fluoroscopy over the course of their lifetimes.[6] Although the rate of occurrence of cancer induction from diagnostic radiation remains controversial, it is generally accepted that even very low radiation doses have some cancer-inducing potential.[7] We conducted a clinical audit at our department, the goal of which was to reduce the radiation dose of CT with minimal or no compromise in image quality. Different cardiac CT techniques were modified and planned protocols were made for pediatric patients. Implementing these techniques is a practical challenge for radiologists and technologists trying to achieve optimal diagnostic image quality.[8]

Two guiding principles must be followed,[2] which we implemented in our trial too. First, CT examinations must be appropriately justified for each individual patient.[9] The requesting clinicians and radiologists share the major responsibility to direct patients to the most appropriate imaging modality for the required diagnostic task. Second, for each CT examination, all technical aspects of the examination must be optimized, such that the required level of image quality can be obtained while keeping the doses as low as possible. (Fig. 1).



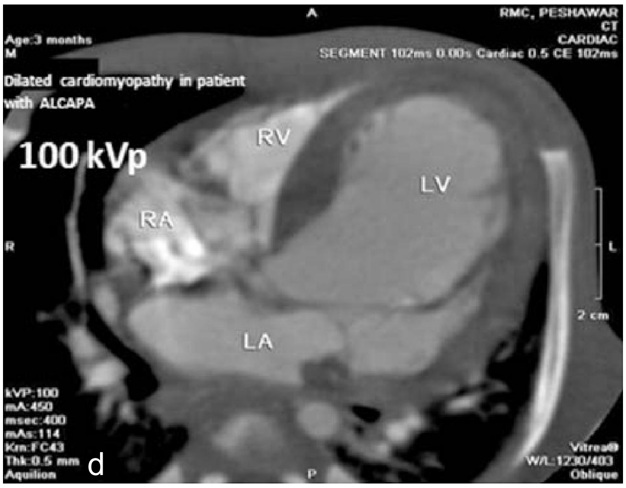


Figure 1 (a, b, c & d): Cardiac CT axial images of different patients show no remarkable difference in image quality and resolution in scans done with 120 kVp **(a)** and with 100 kVp **(b, c & d)**.

This article will focus on the second guiding principle and summarize the general technological strategies that we used for radiation dose reduction in cardiac anomaly MDCT. Some perspectives on future CT dose-reduction techniques are presented.

Materials and Methods

This is a prospective analysis with single blind selection of cardiac anomaly patients referred to radiology department of Rehman medical institute Peshawar for cardiac CT scan during Jan 2013 to Dec 2015. Total of 100 patients with age range of 1 week to 16 years were selected with echocardiographic suspicion of cardiovascular anomalies. It was probability sampling. Scan was performed on 128 multislice Toshiba scanner. ECG gated retrospective and prospective scanning was performed using modified tube voltage (80 kVp, 100 kVp and 120 kVp) and with manual adjustment of low tube current. Pre-procedure beta blocker was not given. Mild sedation was given to patients under 10 years of age under anesthetist supervision. Radiation dose measurement was done by multiplying conversion factor with dose length product (DLP), which was provided by the CT scanner. Images were reviewed on 5.1 Vitrea workstation using multiplanar and 3D reconstruction. Two radiologists independently assessed subjective quality of the CT images to assess cardiac anomalies and normal anatomical structures.We assessed the effects of modified general image quality and scan parameters on visual impression of image noise, texture, sharpness and artifacts in CT.

Results

Prospective ECG gating significantly reduced the radiation dose 22 mSv (retrospective) to 13.96 mSv (prospective) with standard inbuilt 120 kVp setting. Reducing the kVp to 100 further reduced dose to 10.3 mSv and dropped down to 5.46 mSv with 80 kVp and no significant image distortion. (Tab. 1) shows radiation dose reduction by prospective ECG gating and decreasing kVp and mAs. Manually adjusting and reducing the mAs with added filtration reduced the radiation dose to 3.64 mSv.

Study	kVp	mAs	DLP mGycm	mSv
Retrospective	120	166	1250	22
Prospective	120	166	622	13.96
Prospective	100	166	397	10.3
Prospective	80	166	210	5.46
Prospective	80	111	140	3.64

Table 1: Radiation dose reduction by prospective ECG gating and decreasing kVp and mAs in Pediatric Cardiac CT anomalies scan.

Discussion

The use of CT in pediatric patients has grown dramatically, reaching at least 4 million examinations in the USA in 2006 4. Minimization of radiation dose associated with pediatric CT examinations is of particular importance because the risk to children due to radiation exposure is two- to three-times greater than the risk to adults.[10] This is because children's organs are more sensitive to radiation exposure and they have a much longer life expectancy relative to adults, thereby allowing more time for a potential radiation-induced cancer to develop.

When a CT examination is deemed necessary for a pediatric patient, scanning protocols specifically designed for children must be used. Following the wide realization of inappropriate use of adult techniques for children and small adults[11], a recent survey found that 98% of radiologists used weight-based tube current adjustments.[12] Adapting the dose level to different patient size has become a common practice in the CT community, which is further endorsed by the special requirement on pediatric CT technique in ACR accreditation.[13]

CT radiation dose quantification:
Radiation dose in CT can be quantified in a variety of ways. Scanner radiation output, organ dose and effective dose are several of the more common dose metrics. Scanner radiation output is represented by the **volume CT dose index** ($CTDI_{vol}$), which describes the radiation output of the scanner in a very standardized way, making use of two standardized acrylic phantoms[14] and organ dose specific risk data patients undergoing CT examinations.[15]
Effective dose[16] typically expressed in the units of mSv, is a quantity representing a 'whole-body equivalent' dose that would have a similar risk of health detriment as that due to a partial body irradiation.[17] Effective dose allows an approximate comparison of radiation-induced risk among different types of examinations. Effective dose allows an approximate comparison of radiation-induced risk among different types of examinations.[18]

Dose-reduction strategies
1. Optimal tube potential: Peak kilo voltage (kVp) is the single most powerful tool for radiation dose reduction because it is related to the dose in a non-linear fashion. A number of recent physics and clinical studies have demonstrated various levels of dose reduction or image quality improvement by using lower tube potentials (kV) in CT imaging. Siegel et al suggested that the image quality improvement of lower kV increases with the decrease of the phantom size.[19] The standard kVp setting for adults and pediatric population is 120. In selected group of patients by reducing kVp from 120 to 100, we observed a 26% decrease in radiation dose (13.96 to10.3 mSv) and 61 % decrease from 120 to 80 kVp. Using low kVp technique has few added benefits other than radiation dose reduction like higher contrast enhancement, better visualization of vessels & vascular anomalies and lesser amount of contrast is required to get the same diagnostic image quality (Fig. 1 & 2). The underlying principle is that iodine has an increased attenuation (CT contrast) at lower tube potentials than at higher tube potentials in the tube potential range available on clinical CT scanners.

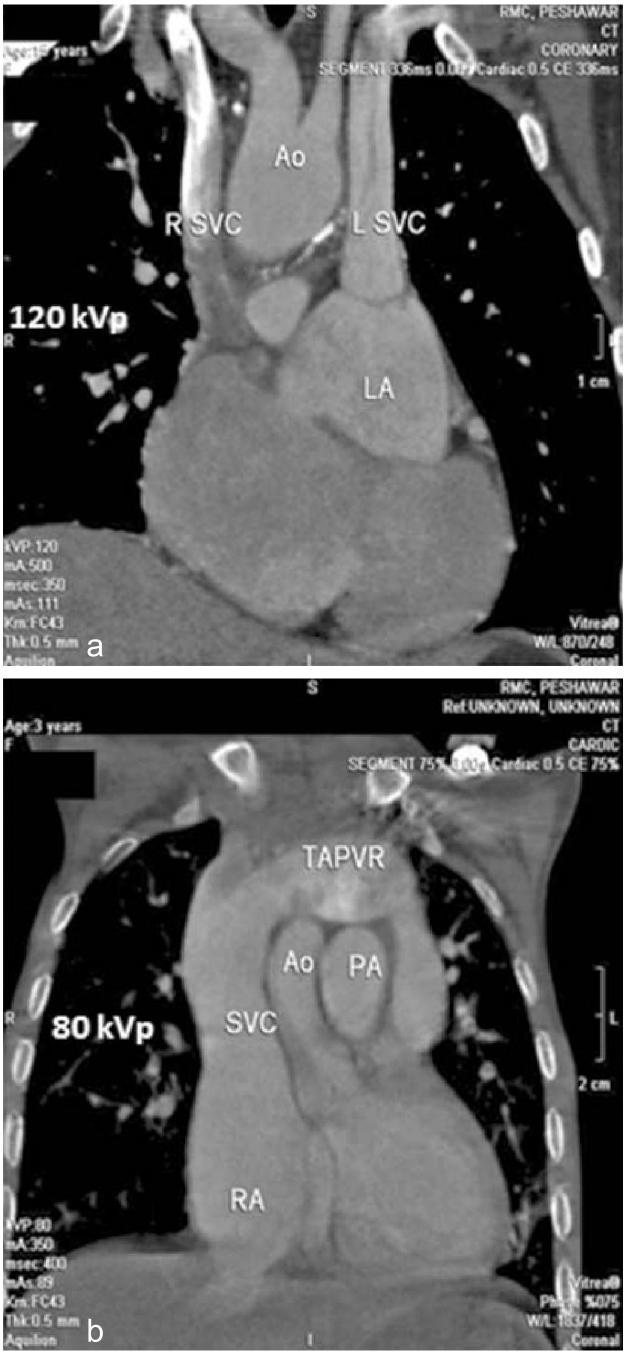


Figure 2 (a, b): Coronal sections of cardiac CT of two different patients acquired at 120 kVp **(a)** and 80 kVp **(b)** show similar contrast resolution.

2. Tube Current Modulation: Automated exposure control (AEC) systems for multidetector CT scanners are now available from all major scanner manufacturers. This technology potentially saves dose because instead of using a fixed tube current optimized for the thickest part of the patient, the scanner will produce fewer x-ray photons in regions of lower attenuation (caudal chest for example) and modulate higher values of tube current in regions of higher attenuation (shoulders). The commercial names of tube current modulation software include Auto-mA 3D (GE Healthcare), Care Dose 4D (Siemens Healthcare), Z-DOM (Philips Healthcare), and Sure Exposure (Toshiba Medical Systems). Modulating tube current has been reported to provide up to 40% dose reduction per examination and should be used in most CT protocols.

3. Modified tube current (mAs): The relationship of mA and radiation dose is directly proportional, meaning if mA is reduced by half, the corresponding dose is reduced by half. In cardiac CT, dropping mA during systole can significantly reduce dose to the patient. Numerous investigators have shown that the manner in which mA should be adjusted as a function of patient size should be related to the overall attenuation, or thickness, of the anatomy of interest as opposed to patient weight. It is a fundamental responsibility of the CT operator and the radiologist to take patient size into account when selecting the parameters that affect radiation dose, the most basic of which is the mAs.[20] Lowering KVp automatically enables the machine to adjust the mAs maintaining the image quality. We further manually reduced mAs according to patient's habitus and age which was upto 100 mAs in neonates and 50 mAs in older children. By lowering mAs, we were able to reduce radiation dose by further 33%. The major disadvantage of this method was increased image noise which was compensated by applying *Adaptive Iterative Dose Reduction* - AIDR thus maintaining the acceptable image quality. This advanced iterative reconstruction algorithm works in two parts. The first part adaptively removes photon noise in the 3D raw data domain. This is followed by the second part, model-based iterative noise reduction in the reconstruction process. AIDR is able to eliminate up to 50% of image noise. (Fig. 2 & 3) show that by reducing kVp to 80 kVp and lowering the mAs, no significant effect seen on image quality.

4. Prospective vs. Retrospective ECG gated scan: Currently, retrospectively ECG-gated helical scan is the most commonly used scanning mode in adult

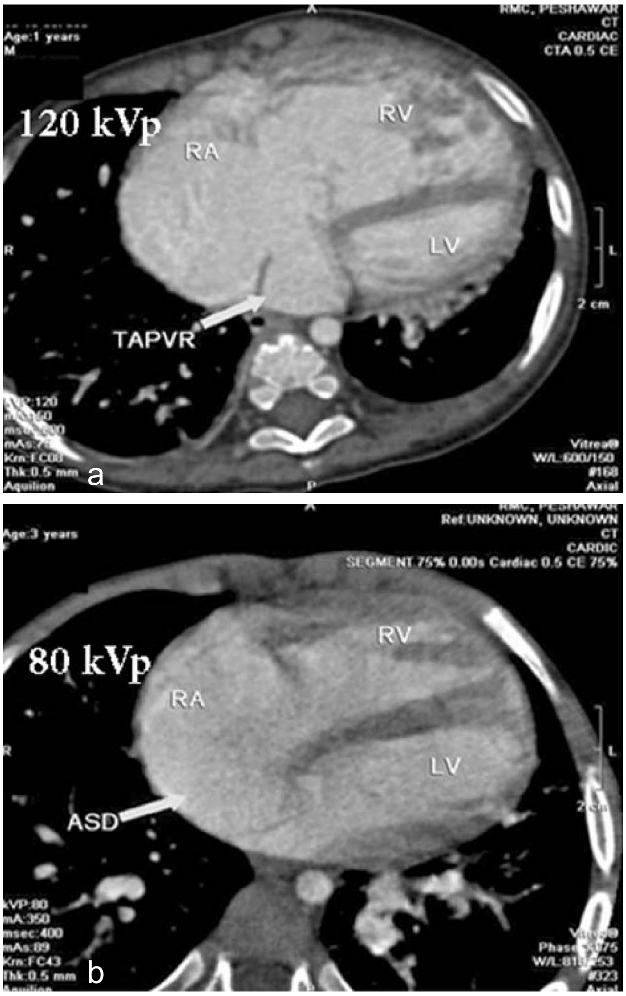


Figure 3 (a, b): Axial scan of cardiac CT **(b)** shows increased image noise with 80 kVp **(b)** as compared to 120 kVp image **(a)** but having no significant effect on diagnostic yield.

cardiac CT mainly due to its clinical stability and flexibility. The x-ray beam is continuously on and the patient is translated through the gantry in a very slow speed (helical pitch - 0.2 - 0.3). The images are reconstructed by retrospectively selecting the data from the phase of the cardiac cycle that has the least motion. In a recent international analysis of 50 institutions performing coronary CT angiography, some sites had an average effective dose of 30 mSv; however, the median dose across all 1965 scans was 12 mSv, which is similar to a scan of the abdomen and pelvis.[21] A prospective ECG-triggered sequential (or step-and-shoot) scan is a more dose-efficient scanning mode for cardiac CT,[22] particularly for single-phase studies. In this scanning mode, the x-ray is only turned on at the preselected phases during the cardiac cycle and therefore the dose is much reduced relative to the retrospectively ECG-gated scan mode. Stolzmann et al. evaluated the dose and image quality with a prospective ECG-triggered step-and-shoot protocol on a DS scanner and found that the mean effective doses were 1.2 and 2.6 mSv for patient groups with a BMI of less than 25 and 25–30 kg/m^2, respectively.[23] Similar results were also obtained by Scheffelet al.[24]

By using different radiation lowering dose techniques i.e. prospective ECG gating technique, low kVp and mAs, we were able to reduce radiation dose by 83.45% (22 to 3.46 mSv).

Pre-procedure beta blockers:

Use of pre-procedural beta blockers in pediatric patients is controversial.[25] Some centers don't favor it as patients with severe pulmonary hypertension and right heart dysfunction or severe aortic stenosis may not tolerate large beta blocker doses. Secondly neonatal heart rate is usually more than 100 beats per minute. Thus it will require high dose of beta blockers to reduce it. It also requires careful patient screening for contraindications, including those patients who are hemodynamically unstable with a compensatory sinus tachycardia. Hence we didn't use beta blockers in our patients.

Image Reconstruction & data processing for noise control:

Many techniques have been developed for controlling noise in CT, operating on the raw projection measurements, the log-transformed sinogram or the images after reconstruction.[27] Image-based filtering techniques usually perform quite well with regards to reducing image noise while maintaining high-contrast resolution. Although some of these techniques have demonstrated some clinical benefit, particularly in vascular applications,[28] image-based filtering usually changes the appearance of the CT image and sacrifices the low-contrast detectability. These techniques are widely available on most commercial scanners, but the performance requires careful evaluation before large-scale clinical use. The image reconstruction method and data utilization are also important factors for optimal noise control.

Conclusion

We conclude from our results that prospective ECG gated cardiac CT, low kVp and mAs values show great potential for substantially reducing radiation dose of cardiac CT angiography. By using different radiation lowering dose techniques i.e.prospective ECG gating technique, low kVp and mAs, we were able to reduce radiation dose by 83.45% (22 to 3.46 mSv).

Clinical Relevance: Cardiac CT is achievable at sub-mSv using modified technique parameters i.e. an image-based safe CT without significant compromise in image quality at 69% dose reduction. Our audit results recommend that low dose CT technique should be performed for cardiac anomaly CT scans.

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