Image Gently Development of Pediatric CT Protocols 2014

Introduction

In 2001, several scientific articles[1-3] in the radiology literature received considerable media attention by pointing out that using adult CT protocols for pediatric patients resulted in estimated radiation doses to the smallest children as much as three times that given to an adult. Since then, articles have been published on protocols to reduce dose to children undergoing CT examinations [4-17]. However, these protocols are scanner manufacturer and scanner model specific, provided for a limited number of scanner models, and in general are not transferable between two similar CT scanners. In fact, these protocols may not be transferrable between two CT scanners of the same manufacturer and model if the revision of software being run on the two scanners is different. Since 2012, the American Association of Physicists in Medicine (AAPM) has published on their website, www.aapm.org/pubs/CTProtocols/, routine scanner specific *adult* protocols for a broad range of scanner manufacturers and models. This group is now in the process of adding pediatric protocols to their website.

In 2008, to address the limited information on pediatric CT protocols, Image Gently published on this website, suggestions for either developing CT protocols for children or verifying that your current pediatric protocols are appropriate regardless of the scanner manufacturer and model in your department. That document provided suggested technique parameters applicable only to manual techniques. The guidance was limited to suggested changes in the product of tube current and rotation time (mAs) as a function of patient age for any scanner manufacturer or model. Recommendations were provided for scans of the abdomen, thorax, and head. However, these recommendations provided no guidance for scanning children with automatic tube current modulation (mA), reduced tube voltage (kV) techniques, and iterative reconstruction. Therefore, the protocol guidance of 2008 is now replaced with this document entitled "Image Gently Development of Pediatric CT Protocols 2014" to address the additional innovative features of CT scanners since 2008.

Reducing patient dose in CT increases the quantum mottle or background "noise" in CT images. Since increased quantum mottle affects low contrast image quality more than high contrast image quality, dose reductions for low contrast images may be limited. For example, soft tissue differentiation (low contrast) may require lower noise in the image than studies of bone detail or lung parenchyma (high contrast) for diagnostic performance. *Radiologists should work closely with their department's Qualified Medical Physicist (QMP)* [18, 19] (one who is board certified in diagnostic radiological physics) anytime CT technique factors are changed to reduce patient dose to ensure that image quality is not compromised.

No universal CT technique can be used with a variety of vendors' CT scanners for either an adult or a given size pediatric patient. Protocols from one scanner to the next are not transferable unless the scanner's design, configuration and software revision are identical. Differences in CT scanner design (e.g. bow tie filters, focal spot-to-detector distance, detector efficiency, etc.) also *make it impossible to estimate patient radiation dose based on technique factors (kV, mAs, and pitch) alone*. In addition, CT radiation technique protocols should be based on the thickness of the body part imaged. Protocols based on patient weight or age produce greater variability into the development of radiographic techniques [20] since the correlation of patient thickness to age or weight is poor.

Radiologists, technologists, and QMPs who would benefit from more detailed information about patient dose during CT scanning are encouraged to read additional information not in this web document. "Dose Indices: Everybody Wants a Number" [21] defines and explains CTDI, DLP, E dose, and SSDE. It explains that the *$CTDI_{vol}$ displayed at the conclusion of every CT scan is not and was never intended to be a patient dose!* It concludes with examples of how Size Specific Dose Estimate (SSDE) [22] provides an estimate of the patient dose that some thought $CTDI_{vol}$ provided. If the reader desires a more in depth explanation of CT dose indices, Task Group Report No 96 [23], "The Measurement, Reporting, and Management of Radiation Dose in CT" is an excellent source of additional information. Once a fundamental understanding of CT patient dose is developed, "Developing Patient-Specific Dose Protocols for a CT Scanner and Exam Using Diagnostic Reference Levels" [24] was written to help the reader understand the application of dose indices to assist in developing appropriate CT protocols for children on any CT scanner.

Purpose

The goal of the current protocols is to provide guidance to departments on how to set up techniques for all size patients, newborns to adults, which provide diagnostic image quality at well managed radiation dose levels to the patients regardless of the manufacturer and model of the department's CT scanners. This process is simpler for departments with only one CT scanner. However, by carefully following these steps, radiologists and CT technologists of large departments in consultation with their department's QMP can achieve similar image quality on their multiple CT scanners usually by matching the SSDE for patients of the same size. These individual steps are more carefully discussed elsewhere [24] for medical imaging professionals who need more than the limited information provided here. Here is a brief outline of the basic objectives necessary to develop pediatric size specific protocols to:

1. Establish acceptable scan parameters, $CTDI_{vol}$ and Size Specific Dose Estimate (SSDE) for adult size patients on department's primary CT scanner.

2. Match image quality of all CT scanners in department to department's primary CT scanner.

3. Establish pediatric patient abdominal and abdominal/pelvic Diagnostic Reference Levels (DRLs) and scan parameters for all CT scanners in department.

4. Establish pediatric patient thorax DRLs for all CT scanners in department.

5. Establish pediatric head DRLs for all CT scanners in department.

6. Establish pediatric DRLs for all CT scanners in department with iterative reconstruction.

7. Establish reduced tube voltage (kV) techniques for all CT scanners in department.

8. Achieve established DRLs with CT scanners using Automatic Exposure Control (AEC).

Some radiologists and technologists may find the above eight tasks overwhelming. If this is the case, please seek the guidance of your department's QMP and read the above suggested reference materials. If you are not familiar with the concept of DRL, additional information can be found elsewhere. [25]

Some fundamental choices are necessary. In time, the AAPM's website listed above may have detailed pediatric techniques for your department's specific CT scanners which you can adopt. If this is not the case, you will need to develop appropriate DRLs for your scanners. If you occasionally scan children, you may elect to develop pediatric DRLs and have your technologists adjust techniques to achieve the desired DRL when the pediatric patient arrives in your department. If you scan children daily or weekly, you may elect to create detailed technique charts for children on each of your department's CT scanners that are used to scan children. *Whichever choice you make, you are strongly encouraged to contact your department's QMP for consultation and assistance.* A QMP should be able to assist you in applying the principles explained in these references.[24, 26] If your medical physicist primarily works as a radiation therapy physicist, s(he) may need assistance from your technologists to understand the design features of your department's actual CT scanners.

Procedure

A. *Establish scan parameters, $CTDI_{vol}$ and Size Specific Dose Estimate (SSDE) for adult size patients on practice's primary CT scanner.*

1. All the measured dose data and scan parameters necessary to establish a standard estimated dose for adult-sized abdomen and head exams on the department's primary scanner should be available within the department. These should be measured by the department's QMP annually to maintain the scanner's accreditation.

2. Verify that the measured $CTDI_{vol}$ values for head and abdomen CTDI phantoms are less than published DRL limits of accreditation bodies. For example, the American College of Radiology's published DRLs for $CTDI_{vol}$ is one source of applicable DRLs. [27, 28]

3. Calculate SSDE.

4. This first step establishes that baseline scan parameters

   a. Are appropriate for the unique design of the site's primary CT scanner

   b. Are appropriate for the site's radiologists' tolerance of noise (quantum mottle) in the CT images for both adult sized head and abdomen exams.

B. *Match image quality of all CT scanners in department to department's primary CT scanner*.

1. If a department uses more than one CT scanner, the image quality for a given size patient for a given type of exam should be similar regardless which CT scanner is used.

2. While matching the radiation dose delivered to the patient for all scanners in the department does not guarantee similar image quality among all possible scanners, it should be a good first step. It should result in similar image quality in departments with a limited number of scanners especially if the design of the department's scanners is not significantly different.

3. Matching radiation dose for a given size patient does not mean that the scan parameters used on each CT scanner will be similar. This occurs due to unique design characteristics of CT scanners from different vendors or even of different models of CT scanners from the same vendor.

4. End users cannot accurately estimate differences in patient dose between two different CT scanners by simply comparing the product of tube current and rotation time (mAs).

5. Radiologists, radiologic technologists, and QMPs at the site must work as a team after matching patient radiation doses on all scanners to validate that similar image quality was achieved. The QMP should obtain appropriate phantom images that allow evaluation of low contrast resolution. Provided the phantom images are acceptable, the radiologists should carefully evaluate initial clinical images to assess that low contrast resolution and level of quantum mottle in the clinical images are acceptable.

C. *Establish pediatric patient abdominal DRLs and scan parameters for all CT scanners in department.*

1. Recommendations are for general study indications.

2. Table 1 contains more data than the data found in the 2008 web protocols.

   a. Column 5: same age groups used in 2008

   b. Columns 1 and 2: Average AP and LAT thickness of patient of specified age.[20]

c. Column 3: Effective Diameter calculated from AP and LAT dimensions. [22]

d. Column 4: Patient mass. [29]

e. Columns 6 – 8: Reduction factors function of patient size.

   i. Column 6: Same as 2008 protocol; pediatric patient dose ~ adult dose.

   ii. Column 8: Newborn patient dose half of adult patient dose. [30]

   iii. Column 7: Newborn patient dose 75% of adult patient dose.

f. Columns 9 – 11: SSDE of pediatric patients corresponding to reduction factors respectively used in Columns 6 – 8.

g. Columns 12 -14: Estimated 'mAs' values (in blue) to use as a function of patient size and degree of reduction chosen (column 6 – 8) relative to the mAs required to image a standard size adult patient.

3. The operator is encouraged to use size (cm) or thickness of the body part being imaged opposed to patient age or weight to select protocols.

TABLE 1: Technique and CT Dose (SSDE) Reduction for Abdominal Studies
In this example, 120 kVp and 200 mAs with a pitch = 1 used for a standard adult *abdominal* scan which delivers a SSDE of 23 mGy.

Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp 120	mA 200	Time (sec) 1	Pitch During Measured CTDIvol 1.0	Pitch During Clinical Exam 1.0	Adult SSDE 23					
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggres-sive* mAs SSDE (mGy)	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
10	14	11.8	4	newborn	0.52	0.39	0.25	23	17	11	104	77	50
11	16	13.3	10	1 yr	0.55	0.42	0.29	23	18	12	110	84	59
14	20	16.7	18	5 yr	0.62	0.50	0.39	23	19	15	123	100	78
16	25	20.0	33	10 yr	0.70	0.62	0.53	23	20	18	140	123	106
19	29	23.5	54	15 yr	0.80	0.74	0.68	23	21	20	160	148	137
22	32	26.5	65	20 yr	0.89	0.86	0.83	23	22	22	179	172	165
25	35	29.6	75	md adult	1.00	1.00	1.00	23	23	23	200	200	200
31	41	35.7	110	lg adult	1.21	1.28	1.35	23	25	27	242	256	270

4. The values in the table automatically populate when the data is entered in the green boxes in a down loadable excel spreadsheet: mA, Rotation Time, Adult SSDE calculated in step A above, and Pitch during clinical exam.

   a. All correction factors in table only apply to 120 kV scans. The user cannot change the kV value in down loadable spreadsheet.

   b. The QMP should have calculated the $CTDI_{vol}$ with a Pitch of 1. This value also is fixed in the table.

c. Changing the pitch during the clinical scan to a value other than 1.0 will not alter the SSDE of the clinical scan. Rather the mAs values in the last three columns change will change as required to result in the targeted patient dose expressed as SSDE.

D. *Establish pediatric patient thorax DRLs for all CT scanners in department.*

1. X-ray attenuation is not as pronounced in the thorax as in the abdomen due to the presence of air in the lung fields.

2. Technique factors for the thorax relative to the abdomen should be modified to avoid an increase in patient dose.

   a. Assume, for example, a 20% reduction in technique factors.

      i. Tube current (mA) or rotation time reduced 20% and placed in fifth or sixth column in second row of Table 1.

      ii. Above reduction reduces Adult SSDE 20%. Reduced value input into column 9, second row of Table 1. Table will calculate reduced 'mAs' (in blue font, columns 12 – 14) and SSDE values for three reduction models (columns 6 – 8), see Table 2.

3. 'Aggressive' [30] reduction factors may be too severe in the lung field. If pediatric image quality is not sufficient for CT images of thorax, the 'moderate' factor should be a good substitute.

4. As in Section C above, the values in the table automatically populate when the data is entered in the green boxes in a down loadable excel spreadsheet: mA, Rotation Time, Adult SSDE calculated in step A above, and Pitch during clinical exam.

TABLE 2: Technique and CT Dose (SSDE) Reduction for Studies of Thorax
In this example, 120 kVp and 160 mAs with a pitch = 1 used for a standard adult *thorax* scan which delivers a SSDE of 18 mGy.

Abdomen/	Abdomen/	Abdomen/	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE					
Pelvis:	Pelvis:	Pelvis:	120	160	1	1	1	18					
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor (1)	*Moderate* mAs Reduction Factor(0.75)	*Aggressive* mAs Reduction Factor(0.5)	*Limited* mAs SSDE	*Moderate* mAs SSDE (mGy)	*Aggres-sive* mAs SSDE	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
10	14	11.8	4	newborn	0.52	0.39	0.25	18	13	9	83	62	40
11	16	13.3	10	1 yr	0.55	0.42	0.29	18	14	10	88	67	47
14	20	16.7	18	5 yr	0.62	0.50	0.39	18	15	12	99	80	62
16	25	20.0	33	10 yr	0.70	0.62	0.53	18	16	14	112	99	85
19	29	23.5	54	15 yr	0.80	0.74	0.68	18	17	16	128	119	109
22	32	26.5	65	20 yr	0.89	0.86	0.83	18	17	17	143	138	132
25	35	29.6	75	md adult	1.00	1.00	1.00	18	18	18	160	160	160
31	41	35.7	110	lg adult	1.21	1.28	1.35	18	19	21	194	205	216

a. The user cannot change the kV value in down loadable spreadsheet.

b. The QMP should have calculated the $CTDI_{vol}$ with a Pitch of 1. This value also is fixed in the table.

c. Changing the pitch during the clinical scan to a value other than 1.0 will not alter the SSDE of the clinical scan. Rather the mAs values in the last three columns change will change as required to result in the targeted patient dose expressed as SSDE.

E. *Establish pediatric head DRLs for all CT scanners in department.*

1. Table 3 is similar to Table 1.

a. First five columns of Table 3 identical to Table 1.

b. Column 5: Only 5 patient sizes used since 5 yr-old head is ~ 90% of the size of the patient's adult head.

b. Column 6 – 7: Reduction factors function of patient size.

i. Column 6: Same as 2008 protocol; pediatric patient dose ~ adult dose.

ii. Column 7: 1 yr old patient dose ~ half of adult patient head dose. [24] No aggressive reduction model provided due to lack of data.

c. Reduced mAs values are printed in blue in columns 12 – 14.

2. The operator is encouraged to specify the size of the pediatric patient as opposed to their age.

3. SSDE is not defined for the patient's head, only the patient's thorax, abdomen, and pelvis.

TABLE 3: Technique for Head Studies; in this example, 120 kVp and 340 mAs with a pitch = 1 used for a standard adult *head* scan.

Head Baseline:	Head Baseline:	Head Baseline:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	
			120	340	1.00	1.0	1.0	
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	Limited Estimated mAs	Moderate Estimated mAs
14	12	13	4	newborn	0.74	0.38	252	129
16	13	14.5	10	1 yr	0.80	0.47	272	160
17	14	15.5	13	2 yr	0.86	0.62	292	211
19	15	17	21	6 yr	0.93	0.79	316	269
20	16	18	75	md adult	1	1	340	340

4. As in Section C, data can be entered in the green cells of the down loadable work sheet. Changing the pitch during the clinical scan to a value other than 1.0 alters the required mAs, but leaves the targeted SSDE unchanged.

F. *Establish pediatric DRLs for all CT scanners in department with iterative reconstruction.*

1. Pediatric techniques that provide reduced doses associated with iterative reconstruction are best determined using the technique reduction tables found in Tables 1 and 3

   a. Assume, for example, a 30% reduction of dose provides acceptable diagnostic CT images when iterative reconstruction is used.

      i. Tube current (mA) or rotation time reduced 20% and placed in fifth or sixth column in second row of Table 1 or 3.

      ii. Above reduction reduces Adult SSDE 30%. Reduced value input into column 9, second row of Table 1. Table will calculate reduced 'mAs' (columns 12 – 14) and SSDE values for three reduction models (columns 6 – 8), see Table 1.

2. 'Aggressive'[30] reduction factors may be too severe when using iterative reconstruction. If pediatric image quality is not sufficient, the 'moderate' factor should be a good substitute.

3. As in Section C, data can be entered in the green cells of the down loadable work sheet. Changing the pitch during the clinical scan to a value other than 1.0 alters the required mAs, but leaves the targeted SSDE unchanged.

TABLE 4: Technique and CT Dose (SSDE) Reduction for Abdomen with Iterative Reconstruction; in this example, 120 kVp and 140 mAs with a pitch = 1 used for a standard adult *thorax* scan which delivers a SSDE of 16 mGy.

Abdomen/	Abdomen/	Abdomen/	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE					
Pelvis:	Pelvis:	Pelvis:	120	140	1	1	1	16					
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor (1)	*Moderate* mAs Reduction Factor(0.75)	*Aggressive* mAs Reduction Factor(0.5)	*Limited* mAs SSDE	*Moderate* mAs SSDE17	*Aggres-sive* mAs SSDE	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
10	14	11.8	4	newborn	0.52	0.39	0.25	16	12	8	73	54	35
11	16	13.3	10	1 yr	0.55	0.42	0.29	16	12	9	77	59	41
14	20	16.7	18	5 yr	0.62	0.50	0.39	16	13	10	86	70	54
16	25	20.0	33	10 yr	0.70	0.62	0.53	16	14	12	98	86	74
19	29	23.5	54	15 yr	0.80	0.74	0.68	16	15	14	112	104	96
22	32	26.5	65	20 yr	0.89	0.86	0.83	16	16	15	125	120	116
25	35	29.6	75	md adult	1.00	1.00	1.00	16	16	16	140	140	140
31	41	35.7	110	lg adult	1.21	1.28	1.35	16	17	19	169	179	189

G. *Establish reduced tube voltage (kV) techniques for all CT scanners in department.*

1. Decreasing the voltage decreases the energy carried by each photon, which leads to a less penetrating beam, increased quantum mottle in the image, and less dose to the patient if no other scan parameters are adjusted. [31]

2. The degree of change in radiation dose and quantum mottle caused by changes in voltage may be reduced by changing the mAs in the opposite direction of the change in tube voltage. [32]

3. The choice of voltage should be made based on the need for subject contrast in the image. [33-36]

4. Use methods of appropriate previous sections to identify appropriate mAs reduction at 120 kVp. Reduce voltage (kV) and

   a. Increase mAs to maintain the *original radiation dose* with *improved* contrast in the image.

   b. Increase mAs to a lesser degree to maintain the *original image quality* (contrast to noise ratio, CNR) with some reduction in radiation dose.

H. *Achieving established DRLs with CT scanners using Automatic Exposure Control (AEC).*

1. CT operator must know how to adjust the:

   a. Tube current, rotation time, or pitch in the manual mode or

   b. Level of desired quantum mottle in the image in the automatic mode

   to deliver the department's standard DRL dose to the patient as a function of the patient size and the type of CT examination.

<u>Summary</u>

The Alliance acknowledges that the above reductions in pediatric CT doses may be less aggressive than those that some institutions have currently achieved. If your current pediatric protocols use mAs values that are lower than those derived from the above protocols, you are commended for achieving this reduction and encouraged to continue with your current program.

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