6. COMPUTED TOMOGRAPHY

In developed countries, over 10% of diagnostic radiological procedures are CT examinations. In the USA, the total number of CT examinations per year for all age groups is about 60 million, of which 7 million are paediatric [1, 10]. Paediatric CT is a valuable imaging tool, the use of which has been increasing at a rate of about 10% per year recently. An eightfold increase has occurred over the past 20–30 years [7, 10]. The rate of increase in examination numbers may be even greater in special cases.

Given the evidence of CT (over)utilization in recent years, in particular in the USA, there are organized efforts to increase radiation awareness and promote safety in paediatric imaging [10, 119]. Availability of alternative imaging modalities that do not require the use of ionizing radiation and careful review of body CT requests in US paediatric hospitals contributed to a significant decrease of CT utilization in 2006 and 2007 [119]. Some authors believe that many of these examinations may not be necessary or justified (see Section 6.1). The dose for each individual examination is relatively high. CT is not the most frequent examination but it contributes the largest component of the collective dose from medicine, 50–67% in some US tertiary referral centres [120–122].

While the situation in paediatric CT is not fully documented, it has led to increasing concern about the exposure of children, particularly as adult scan settings were used in paediatric CT for many years. Consequently, much comment and advisory material addressing the area has been developed. This includes that from the US Food and Drug Administration, the US National Cancer Institute (NCI), the National Council for Radiation Protection, and the increasingly visible Image Gently Campaign, in addition to that from professional bodies [7, 10, 20, 123].

6.1. JUSTIFICATION IN COMPUTED TOMOGRAPHY

The references in the previous section generally include advice that paediatric CT has to be justified. This is not surprising as some authors have estimated that between a third and half of the examinations occurring may not be necessary, and many are conducted using inappropriate technical factors [32, 124]. At the extreme, Oikarinen et al. [32] report that 77% of lumbar spine examinations in their study of a population under 30 years of age were not justified.

This issue has also been given added impetus by a growing active press and media interest in the area, since about 2007. Government and professional bodies

in the USA now have a consistent response which includes justification [7, 10, 15, 17, 123]. Some specific approaches would have an immediate impact in reducing paediatric doses. Examples are summarized from these and other sources in Table 24. While many of these are generic, they are included here as they are necessary when planning an operational response and for ease of reference and/or completeness.

It is required that each CT examination be rigorously justified. In this regard, tools such as the evidence based referral guidelines mentioned earlier are helpful, and those published by the EC are reproduced in Appendix II with the caveats already noted (see Sections 2, 4 and 5) [27–31]. Some workers have developed or added local guidelines or referral protocols. These are helpful where they are well understood and well incorporated into a local practice [9]. For example, Broder discusses the value of rules and guidelines in limiting CT overutilization in the emergency room setting [125]. The following paragraphs

TABLE 24. IMMEDIATE STEPS TO REDUCE PAEDIATRIC COMPUTED TOMOGRAPHY DOSES [7, 9, 123]

Immediate steps to reduce paediatric CT doses
CT examination is required to be rigorously justified and inappropriate referrals eliminated.
Only necessary CT examinations are to be performed.
The number of multiple scans with contrast material needs to be reduced.
The referring practitioner, patient and/or family needs to be asked about previous procedures.
Referral guidelines need to be used where appropriate.
Alternative approaches, such as ultrasound or MRI, need to be used where appropriate.
Information needs to be provided to the patient in accordance with the BSS or national standards.
Justification needs to be included in clinical audit.
Some specific measures to assist with these objectives
Age specific pathology and its prognosis need to be respected.
Individual paediatric questions need to be respected.
The potential contribution of the scan to patient management and outcome needs to be considered.
The patient's record and previous radiology examinations need to be considered.
Cost and radiation exposure need to be respected.
CT needs to be replaced by an examination with no or with lower radiation exposure (e.g. ultrasound or MRI).
The follow-up examination needs to be delayed unless a decision based on the scan is needed at the time.

will be helpful in establishing local guidelines and/or in practically implementing those from the literature.

Special attention is needed for age specific pathology, its prognosis, individual paediatric questions, the costs and the radiation exposure involved in an examination. Previous examinations are required to be considered [2], and their consideration is implied by the proposed IAEA Smart Card project and the Image Gently Campaign [10, 20]. This may render the procedure under consideration unnecessary or allow it to be replaced by a less dose intensive one. Likewise, the potential contribution of the scan to the management and outcome of the patient's condition needs to be considered. Follow-up examinations need to be delayed unless therapeutic decisions based on them are needed immediately.

CT examinations need to be replaced, where appropriate, by others without radiation or with lower exposure (e.g. ultrasound, MRI or conventional radiography). In children, ultrasonography has to be the first line imaging study of the abdomen since their slim body habitus allows access even to the deeper abdominal structures. In experienced hands, ultrasonography can provide substantial clinical information and may obviate the need for CT.

Ultrasonography has to be the examination of choice in children suspected of acute appendicitis. CT need not be performed without a preceding clinical examination by an experienced surgeon. When ultrasonography and radiography are unlikely to provide the answer, the choice of examination is often between CT and MRI. The severity of the suspected disease, the study duration, radiation exposure, side effects of anaesthesia and contrast agents, and specific information required all need to be evaluated.

Problems requiring detailed information on soft tissues, the nervous system or bone marrow are often best evaluated, in the first instance, with MRI. A large body volume, time and anaesthetic restrictions under emergency conditions, such as multiple trauma or the need for information about cortical bone, favour CT. Malignant disease with a poor prognosis renders the potential detriment from radiation exposure less important. Where there is a probability of curative treatment, the added risk of many follow-up studies during and after treatment has to be carefully assessed.

In all of these circumstances, it is important to reduce the number of multiple scans with contrast material. Often, CT scans are done before, during and after intravenous contrast injections. Radiation exposure may be reduced by eliminating pre-contrast images. Repeated scanning of identical areas needs to be minimized and non-enhanced scans need to be avoided unless specifically justified. Where practical, the protocols may allow all, or as much as possible, of the information required to be obtained during one scan.

A lower dose needs to be used for non-enhanced or repeat scans unless high quality is needed. Follow-up CT scans are not to be performed too prematurely

when, according to the known biology of the disease, one cannot yet expect a response to treatment. Of the children that have undergone CT scans, approximately one third have had at least three scans [122]. Justification for repeat scans needs to be as rigorous as for the first examination, and alternative investigations may suffice.

There is also evidence suggesting how dependent usage is on the physician's environment. This is often felt to be driven by concerns about litigation, heavy workload and pressure to make a rapid diagnosis. As mentioned in earlier sections, clinical audit of justification can be an effective tool in providing an incentive to reduce overutilization. The case for development and use of guidelines and for clinical audit of justification has recently been reviewed [17, 21].

As mentioned earlier, a programme of informing parents about the radiation risks associated with relatively high dose procedures and the benefits of the procedure is advisable. With the higher doses involved in many CT examinations, providing adequate information to the patient, parents and carers and comforters takes on much greater importance. In addition, the question of an appropriate level of information is not trivial. It is worth noting that there have been studies in which parents are given information regarding the risks and benefits of CT. This did not result in reduced acceptance but it did result in more informed questions being put to the care providers [10, 23, 24]. In the long run, while time consuming, this is beneficial.

6.2. OPTIMIZATION IN COMPUTED TOMOGRAPHY

Many aspects of the acquisition of a study affect radiation dose and image quality. These are required to be optimized. Some of the measures necessary to achieve this are relatively simple, as indicated in the recommendations summarized from various sources in Table 25 [7, 9, 10].

Optimization is facilitated if the patient is well prepared, so that the examination can proceed smoothly. Renal function needs to be checked and confirmed, and hydration verified where relevant. Intravenous lines need to be placed well in advance. Whatever steps are desirable to reduce anxiety and to restrict movement need to be taken, including avoiding pain and, where valuable, the use of medication, sedation, anaesthetics, and immobilization and positioning aids, etc. Appropriate information needs to be provided to both the patient and accompanying persons.

These steps reduce or eliminate movement of the patient and the associated degradation of image quality. Image noise, contrast and artefacts have an important influence on study quality. Factors such as scan time and pitch, which

TABLE 25. GENERIC AND SPECIFIC REQUIREMENTS FOR OPTIMIZATION IN COMPUTED TOMOGRAPHY

Generic requirements
The patient and accompanying person(s) need to be informed and prepared.
It is necessary to be familiar with CT dose descriptors.
It needs to be realized that noise reduction means high doses; noise is acceptable if the scan is diagnostic.
It needs to be ensured that operating conditions balance image quality and radiation exposure.
Scan parameters within the axial plane need to be considered in optimization.
A set of tube current settings for paediatric examinations needs to be considered in optimization.
Scan parameters for volume coverage need to be optimized.
A minimal length needs to be scanned, and repeated scanning of identical areas needs to be minimized.
Specific measures that assist these objectives
mAs/baseline mA needs to be reduced according to body weight and/or diameter or composition.
x–y-plane dose modulation needs to be used.
Tube filtration needs to be increased (if available).
A maximal slice thickness appropriate for specific diagnosis needs to be used.
The X ray tube voltage (kVp) needs to be decreased for thin patients.
Normally, the shortest rotation time available needs to be used.
A representative volume sample needs to be used when the entire volume is not needed.
A spiral scan with a pitch greater than 1 (e.g. 1.5) needs to be used, provided this does not automatically increase the mA.
Thicker collimation with overlapping reconstruction needs to be used when thin slices are not needed.
z axis dose modulation needs to be used.
It is necessary to be restrictive in defining uppermost and lowermost limits.
A localizing projection scan extending just minimally beyond scan limits needs to be used.
Additional thick noise-reduced slices need to be reconstructed without an increase in exposure.
Major overlap needs to be avoided when scanning adjacent areas with different protocols.
Non-enhanced scans need to be avoided unless specifically justified.
The protocol needs to be optimized to obtain all of the information requested during one scan.
The number of scans in multiphase scanning needs to be minimized.
In the case of multiphase scanning, a shorter scan length needs to be used for additional scans.
A lower dose needs to be used for non-enhanced or repeat scans unless high quality is needed.
A minimal number of additional sequential functional scans needs to be used.
Length of scans and fluoroscopy time need to be minimized in interventional applications.
Test bolus and/or bolus triggering needs to be replaced by standard scan delay unless timing is very critical.
Additional protection devices need to be used where indicated (lens, thyroid, breast, gonads).

can be chosen, may affect the presence or absence of artefacts from motion. With faster table speed and gantry rotation, breathing artefacts in children may be reduced.

In addition to the absolute quality of the image, it is necessary to be attentive to both the requirements of the diagnostic problem being posed and the natural contrast levels available in the area being imaged. For example, the image quality and dose necessary to visualize large bony structures may be less than those required to demonstrate fine vascular structure. Alternatively, more image noise may be acceptable in skeletal or lung parenchymal examinations than in brain or abdominal examinations, owing to the higher contrast differences in the former. Thus, a chest examination with higher noise may have the same diagnostic quality as a lower noise abdominal study.

Abdominal organs, such as the liver, kidney and pancreas, may show only minimal density differences between normal tissues and pathological lesions, and will consequently require higher doses to provide the signal to noise ratio required for acceptable differentiation. Thus, acceptable scan quality will be influenced by the clinical indication for the study. Smaller, low-contrast lesions require higher contrast resolution. For example, more image noise may be tolerated in a follow-up study to assess a fracture of the liver than in a study to assess the presence of small metastases.

The perception of study quality is also related to the display of the data. Three dimensional reconstruction to determine bony outlines for surgical planning may be achieved at relatively low doses [9]. As with all digital studies, the quality and adjustment of the display can have a significant impact on the quality of the final image displayed. A study viewed on the CT console may look inferior when viewed on a monitor which is not set up for viewing examinations. The ambient environment for image review will also be reflected in the perceived study quality [102].

In reducing dose while maintaining diagnostic image quality, the presence of noise needs to be accepted as long as diagnostic quality is not lost. Some suppliers now provide advice on noise levels and suggest values which can be suitable for initial examinations, and different values which may be appropriate for follow-up or repeat procedures. Extra technical information on how to approach these possibilities is provided in Appendix V.

From a different perspective, breast tissue has to be protected in children, without interfering with image quality. Bismuth breast shields are now available for all paediatric age groups, from neonate to young adult. When used in an appropriate setting, the bismuth shielding technique is still a valid and valuable tool for reducing radiation risk in children [126]. Bismuth breast shields need to be routinely used for examinations involving breast tissue. When z axis modulation is used, it is desirable for them to be positioned after the localizer has

been performed [127]. However, caution is raised based on recent results which need to be kept in view to rationalize use of shielding [128].

The recommendations in Tables 24 and 25 are summarized from a number of sources [7, 10, 123]. While many are technically simple and could well be applied to radiology in general, they are repeated here because their importance in CT has sometimes been missed, and because they are important for those planning a practical approach to dose reduction. Giving effect to them as a matter of institutional policy requires a broad commitment and team approach on behalf of the many professionals and individuals involved.

The Image Gently Campaign emphasizes and draws attention to this; its recommendations for successful widespread application are summarized in Table 26 [10]. In the long term, additional initiatives are required and some of these are summarized in Table 27. Table 27 was developed from an NCI original but has a number of additional recommendations [7].

6.3. COMPUTED TOMOGRAPHY AND DIAGNOSTIC REFERENCE LEVELS

The area of CT dose measurement is unsatisfactory, in that it lacks transparency for many end users. Among the reasons for this are the many different metrics used for CT dose. At least three are commonly employed by the medical physics community. These are CT dose index over the entire volume scanned ($CTDI_{vol}$), dose length product (DLP given in mGy · cm) and absorbed

TABLE 26. ADVICE FOR RADIOLOGISTS, MEDICAL PHYSICISTS AND TECHNOLOGISTS FROM THE IMAGE GENTLY CAMPAIGN [10]

Awareness of the need to decrease CT radiation dose to children needs to be improved.
It is necessary to be committed to making a change in daily practice through teamwork between radiologists, medical radiation technologists, referring doctors and parents.
Medical physicists, radiologists and medical radiation technologists need to review CT protocols and ‘down-size’ them for children.
Single phase scans are often adequate. Pre- and post-contrast or delayed scans rarely add additional information in children but can double or triple the dose.
Only the indicated area needs to be scanned. If a patient has a possible dermoid on ultrasound, there is rarely a need to scan the entire abdomen and pelvis.
It is necessary to be involved with the patients and to be their advocate. It is necessary to ask the questions required to ensure that the scan is ‘child-sized’, and only the area required needs to be scanned.

TABLE 27. LONG TERM STRATEGIES TO MINIMIZE PAEDIATRIC COMPUTED TOMOGRAPHY RADIATION *(based on National Cancer Institute recommendations [7])*

Further development of referral and/or appropriateness criteria needs to be encouraged.
Further development and adoption of paediatric CT protocols need to be encouraged.
Clinical audit for justification needs to be encouraged.
The use of selective strategies for paediatric imaging, such as for the pre-surgical evaluation of appendicitis, needs to be encouraged.
Industry and technical standards organizations need to be encouraged to produce innovative standardized designs that address the issues of dose management for children.
Further research needs to be conducted to determine the relationship between CT quality and dose, to customize CT scanning for individual children, and to clarify the relationship between CT radiation and cancer risk.
Journal publications and conferences need to be used to educate within and outside radiology specialties to manage exposure settings for optimization purposes and to assess the individual need for CT.
Information needs to be disseminated through associations, organizations or societies involved in health care of children.
Readily available information sources on the Image Gently Campaign, IAEA Radiation Protection of Patients and other relevant web sites need to be provided [10, 20].

dose (mGy). Other metrics are also often used. In addition, effective dose (given in millisieverts) is frequently quoted, as it conveniently relates to risk, but there are some reservations about this in the measurement community.

Discussion of these quantities and measurement systems is beyond the scope of this volume but they are reviewed at length and summarized in many sources [129–133].

Some typical paediatric CT effective doses in millisieverts and organ doses in milligrays from the US NCI are reproduced in Table 28. The latter refers to the absorbed doses in particular organs (mGy) and the former to effective dose, which is a marker for whole body risk. Reference doses and typical doses from various sources are available in a series of publications [7, 10, 134–139].

The NCI makes the following observations:

> “Effective doses from a single paediatric CT scan can range from about <1 to 30 mSv. Among children who have undergone CT scans, approximately one-third have had at least three scans. Multiple scans present a particular concern. In addition, more than one scan ‘phase’ may be done during a single examination, further increasing the radiation dose. A single scan

TABLE 28. TYPICAL COMPUTED TOMOGRAPHY DOSES [7]

Examination type	Relevant organ	Range of absorbed organ dose (mGy)	Range of effective dose (mSv)
Head unadjusted (200 mAs)	Brain	23–49	1.8–3.8
Head adjusted (100 mAs)	Brain	11–25	0.9–1.9
Abdomen unadjusted (200 mAs)	Stomach	21–43	11–24
Abdomen adjusted (50 mAs)	Stomach	5–11	6–12
Chest X ray PA	Lung	0.04–0.08	0.01–0.03
Chest X ray lateral	Lung	0.04–0.10	0.03–0.06

Note: 'Unadjusted' refers to using the same settings as for adults; 'adjusted' refers to settings adjusted for body weight; PA: postero-anterior.

during paediatric CT may be sufficient in the vast majority of cases. The highest lifetime risks estimated in the literature are less than 1 in 1000, and most estimates are substantially lower than that. The public health issue is the increasingly large paediatric population being exposed to these small risks. The benefits of properly performed CT examinations must always outweigh the risks for an individual child" [7].

In practice, in potentially life threatening situations, multislice CT can be an excellent tool. Good protocols are needed to ensure that the study is both justified and optimized [139].

Table 29 provides information on CT doses in terms of the equivalent period of natural background. There are also representations in terms of equivalent number of chest X rays for each examination [20]. It can be seen that this has considerable value in communicating with both patients and physicians. Some radiologists have questioned the use of these scales on the grounds that patients or guardians may find it frightening to have a scan that is equivalent to several hundred chest X rays or many years of natural background radiation. However, in the interests of patients, it is essential that a readily comprehensible measure of dose and risk be available, as well as a sense of the real benefit to be derived from the scan.

In Table 30, examples of United Kingdom national reference doses for paediatric patients from various age groups and for different examinations are provided [138], which are a valuable benchmark for practitioners. The weighted CT dose index ($CTDI_w$) values are provided for the purpose of comparison with historical values as this index has largely been replaced by $CTDI_{vol}$ as a reference dose quantity. The reader is referred to the original publication for the full detail of the conditions that prevailed for the various measurements reported [138].

TABLE 29. TYPICAL DOSES FROM VARIOUS EXAMINATIONS, EXPRESSED AS EFFECTIVE DOSE AND IN EQUIVALENT PERIOD OF NATURAL BACKGROUND WITH ASSOCIATED INCREASED CANCER RISK [20]

Procedure	Effective dose (mSv)	Increased risk of cancer	Equivalent period of natural background
No dose (MRI, ultrasound)	Not defined and/or applicable	Not known	Not equivalent
Low dose (chest X ray, extremities)	<0.1	1 in 1 million	Few days
Intermediate dose (intravenous pyelogram, lumbar spine, abdomen, head and neck CT)	1–5	1 in 10 000	Few months to a few years
Higher doses (chest or abdomen CT, nuclear cardiogram, cardiac angiogram, barium enema)	5–20	1 in 2000	Few years to several years
Natural background	2.4	1 in 5000	—

Shrimpton et al. compare some of these reference levels with those that previously prevailed in Europe. In commenting on their findings, they have many useful observations to make and conclude in respect of paediatric practice that:

> "For examinations on children, typical values of the dose descriptors…, $CTDI_{vol}$ and DLP decrease with decreasing age (and size), whereas the corresponding effective dose increases. Indeed, effective doses to children aged 0–1 years from examinations of the head and the chest were typically higher than those for adults" [138].

Other recent national surveys of paediatric CT doses are available, together with some experience of the potentially positive impact of introducing reference levels [134, 136, 139]. Table 31 reproduces the recommendations of Verdun et al. for DRLs in Switzerland. They also usefully compare their findings with recent work and/or recommendations from the United Kingdom and Germany [138, 140]. It is not clear that, in all cases, like is being compared with like, but nonetheless the comparisons are reassuring and useful. Additional information on conversion of DLP to effective dose is provided in Appendix V.

A recent large scale multinational study by the IAEA investigated the frequency of CT examinations of paediatric patients below 15 years of age in 28 countries of Africa, Asia and Eastern Europe, and assessed the magnitude of

TABLE 30. NATIONAL REFERENCE DOSES FOR COMPUTED TOMOGRAPHY OF PAEDIATRIC PATIENTS IN THE UNITED KINGDOM *(published in 2006 following a 2003 review, compared with European Commission values from 1999 [138, 139])*

Examination	Region	$CTDI_w$ (mGy)[a]		$CTDI_{vol}$ (mGy)[a]	Dose length product (mGy · cm)[a]	
		United Kingdom 2003 [138]	Europe [139]	United Kingdom 2003 [138]	United Kingdom 2003 [138]	Europe [139]
Chest (detection of malignancy)	Whole examination					
0–1 year old		23	20	12	200	200
5 year old		20	30	13	230	400
10 year old		26	30	20	370	600
Head trauma (including non-accidental injury)	Post-fossa	35	—	35	—	—
	Cerebrum	30	—	30	—	—
0–1 year old	Whole examination	—	40	—	270	300
Head trauma (including non-accidental injury)	Post-fossa	50	—	50	—	—
	Cerebrum	45	—	45	—	—
5 year old	Whole examination	—	60	—	470	600
Head trauma (including non-accidental injury)	Post-fossa	65	—	65	—	—
	Cerebrum	50	—	50	—	—
10 year old	Whole examination	—	70	—	620	750

Note: $CTDI_w$: weighted CT dose index; $CTDI_{vol}$: CT dose index divided by volume scanned.
[a] Relates to the 16 cm diameter CT dosimetry phantom.

CT doses. Radiation dose data were available from 101 CT facilities in 19 countries [141].

The results show that, on average, the frequency of paediatric CT examinations was 20, 16 and 5% of all CT examinations in participating centres in Africa, Asia and Eastern Europe, respectively. The mean frequencies of paediatric CT examinations ranged from 0.5 to 38% among different countries. The survey data indicated a relatively higher paediatric CT frequency in a majority of African countries than in Asia and Eastern Europe. In the countries included in this study, the paediatric CT frequency in Asian countries is also relatively higher than in Eastern Europe. This situation is likely to be due to the

TABLE 31. DIAGNOSTIC REFERENCE LEVELS (mGy FOR COMPUTED TOMOGRAPHY DOSE INDEX AND mGy · cm FOR DOSE LENGTH PRODUCT) FOR DIFFERENT PATIENT GROUPS AND EXAMINATIONS IN SWITZERLAND, GERMANY, THE UNITED KINGDOM AND THE EUROPEAN UNION *(adapted from Verdun [134])*

Age group (a)[a]	Quantity	Examination			
		Brain			
		Switzerland [134]	Germany	United Kingdom	European Union
<1	$CTDI_{vol}$	20	33	30	—
	DLP	270	390	270	300
1–5	$CTDI_{vol}$	30	40	45	—
	DLP	420	520	470	600
5–10	$CTDI_{vol}$	40	50	50	—
	DLP	560	710	620	750
10–15	$CTDI_{vol}$	60	60	65	—
	DLP	1000	920	930	—
		Chest			
		Switzerland [134]	Germany	United Kingdom	European Union
<1	$CTDI_{vol}$	5	3.5	12	—
	DLP	110	55	200	200
1–5	$CTDI_{vol}$	8	5.5	13	—
	DLP	200	110	230	400
5–10	$CTDI_{vol}$	10	8.5	20	—
	DLP	220	210	370	600
10–15	$CTDI_{vol}$	12	6.8	14	—
	DLP	460	205	580	—
		Abdomen			
		Switzerland [134]	Germany	United Kingdom	European Union
<1	$CTDI_{vol}$	7	5	20[a]	—
	DLP	130	145	170[a]	—
1–5	$CTDI_{vol}$	9	8	20[a]	—
	DLP	300	255	250[a]	—
5–10	$CTDI_{vol}$	13	13	30[a]	—
	DLP	380	475	500[a]	—
10–15	$CTDI_{vol}$	16	10	14	—
	DLP	500	500	560	—

Note: $CTDI_{vol}$: CT dose index divided by volume scanned; DLP: dose length product.

[a] For the United Kingdom, adult values were taken for the age group 10–15 years, as values for this age group were not available in the report.

non-availability of alternative imaging modalities, such as MRI or high resolution ultrasound, and/or possibly limited experience in justifying CT procedures for children.

The $CTDI_w$ variations ranged up to a factor of 55 (Africa), 16.3 (Asia) and 6.6 (Eastern Europe). The corresponding DLP variations ranged by a factor of 10, 20 and 8, respectively. Eleven CT facilities in six countries were found to use adult CT exposure parameters for paediatric patients. This single factor has great implications for the individual dose, collective dose and risk of lifetime radiation induced cancer. Variations in $CTDI_w$ and DLP across countries are not unexpected as similar variations have been presented in earlier studies from a number of developed countries and are attributable to different techniques used for CT examinations.

The typical mean $CTDI_w$ and DLP values with associated ranges in three regions are presented in Table 32. In this study, CT equipment dose characteristics are reported in terms of $CTDI_w$ because the majority of centres reported this quantity in view of older CT scanners. For those reporting in $CTDI_{vol}$, the values of $CTDI_w$ were computed using pitch factors.

TABLE 32. MEAN WEIGHTED COMPUTED TOMOGRAPHY DOSE INDEX AND DOSE LENGTH PRODUCT VALUES WITH ASSOCIATED RANGES FOR SELECTED PAEDIATRIC COMPUTED TOMOGRAPHY EXAMINATIONS IN THREE REGIONS [141]

Region	Weighted CT dose index (mGy)				
	Chest	Chest — high resolution	Lumbar spine	Abdomen	Pelvis
Africa	10 (4–17.1)	9.8 (3.5–14)	14 (4.2–14)	8.5 (4.2–20)	8.3 (4.9–17)
Asia	10 (5.5–16)	13 (5.2–19)	13 (8.7–18)	14 (8.7–20)	14 (8.7–18)
Europe	8.7 (3.3–16)	6.5	11 (7.1–22)	9.2 (3.5–14)	9.3 (3.9–14)
	Dose length product (mGy · cm)				
Africa	153 (85–272)	137 (49–371)	201 (121–277)	180 (43–320)	131 (50–382)
Asia	269 (134–216)	139 (64–260)	274 (150–397)	413 (150–821)	189 (150–240)
Europe	194 (76–326)	145 (96–194)	182 (115–385)	246 (115–613)	255 (82–487)

The study indicated a stronger need in many developing countries to justify CT examinations in children and for their optimization. As an example, implementation of suitable dose reduction methods and follow-up of the facilities that use CT exposure parameters for children's CT examinations were applied in Sudan and Thailand in consultation with radiologists. Consequently, based on the reported new scan parameters, a $CTDI_w$ reduction in the range of 38–50% was reported for chest CT in Sudan, and 53% for the same type of CT procedure in Thailand.

This study has established baseline data on the frequency and dose levels in paediatric CT examinations. This will form a basis for future studies on dose management in paediatric CT examinations. In that sense, the ongoing large scale paediatric CT dose survey organized by the IAEA is an important step in the optimization of paediatric CT practice and for promotion and implementation of dose reduction strategies, while maintaining diagnostic information worldwide. Furthermore, education and training programmes currently being implemented by the IAEA in developing countries, along with focused training on radiation dose management organized by the IAEA for participants in the project, provide key resources directed at increased awareness of radiation dose management methods in CT.

6.4. SPECIAL TECHNIQUES IN COMPUTED TOMOGRAPHY

6.4.1. Computed tomography interventions

Once a diagnostic scan has been performed, the CT dose used for the interventional procedure can be reduced markedly. Repeated imaging has to be limited to the small area of interest directly involved in the procedure. Where possible, a single slice may be used.

6.4.2. Cone beam dental computed tomography

CT based systems are finding significant application in dental practice, and intensive study of the requirements for justification is necessary. These and other developments are the subject of the SEDENTEXCT EC project [142]. The principles for use of dental cone beam CT have been set out by the European Academy of Dental and Maxillofacial Radiology in a consensus document from which an extract is provided in Table 33 [142]. Much of this guidance deals with justification issues but training and optimization issues are also emphasized.

TABLE 33. USE OF DENTAL CONE BEAM COMPUTED TOMOGRAPHY [142]

Cone beam CT examinations need not be carried out unless a history and clinical examination have been performed.
Cone beam CT examinations are required to be justified for each patient to demonstrate that the benefits outweigh the risks.
Cone beam CT examinations need to potentially add new information to aid the patient's management.
Cone beam CT ought not to be repeated 'routinely' on a patient without a new risk–benefit assessment having been performed.
When accepting referrals from other dentists for cone beam CT examinations, the referring dentist needs to supply sufficient clinical information (results of a history and examination) to allow the cone beam CT practitioner to perform the justification process.
Cone beam CT need only be used when the question for which imaging is required cannot be answered adequately by lower dose conventional (traditional) radiography.
Cone beam CT images need to undergo a thorough clinical evaluation ('radiological report') of the entire image data set.
Where it is likely that the evaluation of soft tissues will be required as part of the patient's radiological assessment, the appropriate imaging needs to be conventional medical CT or MRI, rather than cone beam CT.
Cone beam CT equipment needs to offer a choice of volume sizes, and examinations need to use the smallest volume that is compatible with the clinical situation if this provides less radiation dose to the patient.
Where cone beam CT equipment offers a choice of resolution, the resolution compatible with adequate diagnosis and the lowest achievable dose needs to be used.
A quality assurance programme needs to be established and implemented for each cone beam CT facility, including equipment, techniques and quality control procedures.
Aids to accurate positioning (light beam markers) always need to be used.
For dento-alveolar cone beam CT images of the teeth, their supporting structures, and the mandible and the maxilla up to the floor of the nose (e.g. 8 cm × 8 cm or smaller fields of view), a clinical evaluation ('radiological report') needs to be undertaken by a specially trained dental and maxillofacial radiologist or, where this is impracticable, an adequately trained general dental practitioner.
For non-dento-alveolar small fields of view (e.g. temporal bone) and all craniofacial cone beam CT images (fields of view extending beyond the teeth, their supporting structures, the mandible, including the temporomandibular joint, and the maxilla up to the floor of the nose), a clinical evaluation ('radiological report') needs to be undertaken by a specially trained dental and maxillofacial radiologist or by a clinical radiologist (medical radiologist).