Session 5

Radiation protection in medical exposures of children and pregnant women

REVIEW ARTICLE ON: RADIATION PROTECTION

OF COMPUTED TOMOGRAPHY IN PEDIATRICS

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Abstract

Imaging studies that use ionizing radiation are an essential tool for the evaluation of many disorders of childhood. CT is of particular interest because of its relatively high radiation dose and wide use with increasing the cancer risk. The medical community tries to decrease radiation exposure by using radiation doses as low as reasonably achievable and by performing studies when necessary. *The aim* of this study is to raise the awareness between the medical team and provide information needed in decision-making and in discussions with the health care team, patients, and families. There is wide agreement that the benefits of an indicated CT scan far outweigh the risks. Pediatric health care professionals' roles in the use of CT on children include deciding when a CT scan is necessary and discussing the risk with patients and families. Radiologists should be consulted when forming imaging strategies and should create specific protocols with scanning techniques optimized for pediatric patients. Families and patients should be encouraged to ask questions about the risks and benefits of CT scanning. However, The IAEA has a big role in assessing the state of practice, providing guidance to counterparts in various countries, and improving practice.

1. INTRODUCTION

Paediatric patients have a higher average risk of developing cancer compared with adults receiving the same dose. The longer life expectancy in children allows more time for any harmful effects of radiation to manifest, and developing organs and tissues are more sensitive to the effects of radiation ⁽¹⁵⁾. Computed tomography (CT) is a valuable and essential addition to the array of imaging modalities for children. It uses x-rays to provide rapid, consistent, and detailed information about virtually any organ system in infants and children that leads to an obligatory radiation exposure during examination. Moreover, recent reports have discussed the potential risk of cancer that results from the lower radiation exposure from CT examinations and can be used to raise the concerns on the part of pediatricians, patients, and families. However, these reports show widely differing opinions concerning the cancer risk of diagnostic imaging studies. The principle supported that the estimated risk of a CT scan is far less than the likely benefit to the patient for indicated examinations ⁽⁴⁾.

This review study is intended to serve as a resource for pediatric health care professionals regarding the radiation protection measures and to improve understanding of pediatric CT radiation and its potential risk in the development of cancer. It also includes suggestions for an informed discussion of this issue between those who provide and those who receive care. The purpose is to summarize current opinions about the risks of cancer from exposure to radiation from imaging studies and to provide pediatricians with information that will be helpful in discussions with patients and families/caregivers regarding the radiation risks of CT examinations and the important clinical advantages of these studies.

2. DIAGNOSTIC IMAGING AND RADIATION DOSE:

Medical radiation can be measured several different ways. For example, the exposure to radiation from diagnostic radiologic procedures can be described as the dose that strikes the surface of the body, or entrance dose. However, the entrance dose is higher than the average dose to which the entire body is exposed. This entrance dose will not necessarily reflect the risk, because different parts of the body vary in their sensitivity to the effects of ionizing radiation. Radiation energy deposited in an individual organ is the organ dose (measured in grays). When several organs are irradiated, the effective dose (measured in sieverts) is used to quantify the total patient risk and is computed by considering the dose to each organ as well as that organ's relative radiosensitivity (eg, lungs are more susceptible than skin) ⁽⁴⁾. For a given dose, there is a difference in cancer risk from radiation exposure to children compared with adults. There are several reasons for this difference. *First*, for the most part, tissues and organs that are growing and

developing are more sensitive to radiation effects than those that are fully mature.^(25,9) *Second*, the oncogenic effect of radiation may have a long (for example, decades) latent period. This latent period varies with the type of malignancy. An infant or child, therefore, has a longer life expectancy in which to manifest the potential oncogenic effects of radiation compared with older adults. *Pierce et al* ⁽²⁵⁾ summarized the radiation cancer risk at different ages and stated that those exposed at 50 years of age have approximately one third of the risk of a 30-year-old and that projection of lifetime risks for those exposed at age 10 is more uncertain. Because the risk varies with age, the increased pediatric risk compared with adults will also vary depending on exactly which age groups are compared ⁽²⁵⁾. *Third*, in the case of CT scanning, the radiation exposure from a fixed set of CT parameters results in a dose that is relatively higher for a child's smaller cross-sectional area compared with an adult ⁽¹⁰⁾. The dose of X-rays in CT depends on patient factors (such as age and size), technical factors (equipment settings and procedure length), and equipment model. Nevertheless, it is helpful to be familiar with some representative doses for common imaging studies (Table 1).

TAF	BLE	1: Estimated	Medical	Radiation	Doses for	r a 5-Y	Year-Old	Child
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Imaging Area	Effective Dose,	Equivalent No. of
	mSv	CXRs
3-view ankle	0.0015	1/14 th
2-view chest	0.02	1
Anteroposterior and lateral abdomen	0.05	2 1/2
Tc-99m ² radionuclide cystogram	0.18	-9
Tc-99m radionuclide bone scan	6.2	310
FDG PET ³ scan	15.3	765
Fluoroscopic cystogram	0.33	16
Head CT	4	200
Chest CT	3	150
Abdomen CT	5	250

However, CT has considerable benefits in the diagnosis of disease, but, unlike most general diagnostic radiology, involves relatively high doses. Newer techniques such as multislice CT and CT fluoroscopy can result in even higher doses. It is important that these potentially very high doses be kept to a minimum through careful assessment of protocols, strict referral criteria for patients, use of automatic exposure controls and choice of scan techniques ⁽¹¹⁾. ICRP forecasted and 'sounded the alarm' on increasing patient doses in CT, and recommended actions for manufacturers and users (29). Three factors have made CT scanning the focus of much of the recent interest in ionizing-radiation exposure from diagnostic imaging. First, CT scanning provides a disproportionately higher amount of the radiation exposure from diagnostic imaging. In 2000, Mettler et al ⁽²⁰⁾ reported that CT scanning accounted for 11% of procedures that used ionizing radiation in a large academic radiology department but accounted for 67% of the radiation exposure. Second, indications for CT scanning and the number of CT scans are increasing rapidly. In a more recent, CT scanning accounted for 15% of the procedures and 75% of the dose ⁽³⁰⁾. Third, CT scanning can be performed by using a wide range of techniques with variable radiation exposures that produce very similar image quality. With conventional ("plain") radiographs, an increase in radiation dose makes the image darker, and most individuals will recognize that the film was overexposed. However, changing the amount of radiation for a CT study affects the amount of mottle (or image noise) with little other effect on the appearance of the image. Above a level of diagnostic quality, this decrease in mottle with increasing radiation will have no effect on diagnostic accuracy of the CT study and may not even be appreciated, but the exposure may have been unnecessarily high, especially in children ⁽²⁶⁾. Until recently, the same CT-examination parameters were used for children and adults. In fact, a change in these parameters with a resultant reduction in dose, ranging from approximately 50% to 90%, has been shown to be satisfactory for a child's CT study.

3. THE PRINCIPLES OF RADIATION PROTECTION IN MEDICINE

Although individual risk associated with radiation exposure from medical imaging is generally low and the benefit substantial, the large number of individuals being exposed has become public health issue. In medical exposures, the dose limits are not applied in the radiation protection principles because they may reduce the effectiveness of the patient's diagnosis or treatment, thereby doing more harm than

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good ⁽¹³⁾. So, the radiation protection system is based on the two fundamental principles: Justification and optimization as follows: (a) Medical exposures shall be justified by weighing the expected diagnostic or therapeutic benefits against the potential radiation detriment, with account taken of the benefits and the risks of available alternative techniques that do not involve exposure to radiation. The procedure should be judged to do more good than harm. (b) The justification of a particular radiologic medical procedure is generally endorsed by national health authorities and professional societies (e.g. to recommend a procedure for those at risk of a particular condition). (c) The responsibility of justifying a procedure for a patient falls upon individual professionals directly involved in the health-care delivery process (referrers, RMPs). Imaging referral guidelines help health-care professionals make informed decisions by providing clinical decision-making tools created from evidence-based criteria. Justification of an exam must rely on professional evaluation of comprehensive patient information including: relevant clinical history, prior imaging, laboratory and treatment information. (d) When indicated and available, imaging media that do not use ionizing radiation, e.g. ultrasonography (sound waves) or MRI (radiofrequency and electromagnetic waves) are preferred, especially in children. The final decision may also be influenced by cost, expertise, availability of resources and/or patient values. In the context of the system of radiation protection, optimization signifies keeping doses "as low as reasonably achievable" (ALARA). In particular for medical imaging, ALARA means delivering the lowest possible dose necessary to acquire adequate diagnostic data images: best described as "managing the radiation dose to be commensurate with the medical purpose" (13,14)

3.1. Possible reasons for inappropriate ionizing-radiation procedures in children

(a) Appropriateness criteria/imaging referral guidelines not available or ignored. (b) Insufficient, incorrect or unclear clinical information provided for justification. (c) Lack of confidence in clinical diagnosis & over-reliance on imaging. (d) Consumer's demand (patient's and/or family's expectations). (e) Self-referral, including requesting inappropriate additional imaging studies. (f) Concern about malpractice litigation (defensive medicine). (g) Pressure to promote and market sophisticated technology. (h) Lack of dialogue/consultation between referrers and radiologists. (i) Not considering or aware of more appropriate imaging modalities that do not use ionizing radiation (e.g. ultrasound or MRI, when available). (j) Too frequent or unnecessary repeat examinations. (k) Pressure from referring clinicians or other specialists. (l) Reliance on personal or anecdotal experience not supported by evidence-based medicine. (m) Pressure to perform (e.g. quickly processing patients in the emergency department). (n) Lack of availability of alternate imaging resources-expertise and/or equipment (e.g. to perform ultrasonography beyond regular working hours). (o) Inappropriate follow-up imaging recommendations from imaging expert reports ⁽³¹⁾.

3.2. Unnecessary procedures

Overuse of diagnostic radiation results in avoidable risks and can add to health costs. In some countries, a substantial fraction of radiologic examinations (over 30%) are of questionable merit and may not provide a net benefit to patient health care $^{(8,22)}$. The real magnitude of unjustified risk resulting from inappropriate use of radiation in paediatric imaging remains uncertain; for example, it has been estimated that perhaps as many as 20 million adult CTs and more than one million paediatric CTs are performed unnecessarily in the USA each year ^(3,31). On the other hand, Radiation Medical Practitioner responsible for overseeing the radiological exposure make the ultimate decision to perform or reject each individual radiological procedure. The Radiation Medical Practitioner should base that decision on knowledge of the: a) hazard associated with the radiological exposure; and b) clinical information that the referrer supplies. Accordingly, the Radiation Medical Practitioner may need to liaise closely with the referrer about the merit of performing a particular examination. Any decision to proceed or not should be made after consideration of the timely availability of alternative tests, which involve less or no exposure to ionizing radiation. The Radiation Medical Practitioner has particular responsibility to optimize the conduct of a CT examination by balancing the clinical need against the radiation dose. CT has the capacity to deliver a large radiation dose rapidly to the patient: a) at a level that may cause deterministic and stochastic effects; and b) without limitation by tube heat capacity ⁽²⁾.

4. RISKS OF IONIZING RADIATION FROM DIAGNOSTIC IMAGING

Fortunately, the relationship between radiation exposure and cancer risk from low-dose radiation is less clear ⁽²¹⁾. On the other hand, no published studies have directly attributed cancer to CT scanning, and

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it is important to recognize how difficult it would be to perform such a study. CT scanners and other diagnostic imaging equipment use low-dose radiation, which is defined as a dose of less than approximately 100 mSv. There are numerous studies of populations receiving high doses of radiation above 500 mSv that have demonstrated an increased risk of cancer. These studies, reviewed in the 2005 report of the Biological Effects of Ionizing Radiation (BEIR) Committee of the National Academy of Sciences ⁽²¹⁾. provided widely accepted evidence that, at higher exposures, the risk of cancer increases linearly with increasing dose until extensive cell killing takes place at very high exposures. Additionally, Pediatric patients have a higher average risk of developing cancer compared with adults receiving the same dose. The longer life expectancy in children allows more time for any harmful effects of radiation to manifest, and developing organs and tissues are more sensitive to the effects of radiation ⁽¹⁵⁾. Because of the diversity of opinion and the many different studies that have been performed, a broad range of estimates of the risk of ionizing radiation from diagnostic imaging can be supported by selecting specific publications from the peer-reviewed literature. In 2005 the BEIR Committee of the National Academy of Sciences concluded that "the risk of cancer proceeds in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increased risk to humans."(21) The United Nations Subcommittee on Atomic Radiation 2000 report stated that "an increase in the risk of tumor induction proportionate to the radiation dose is consistent with developing knowledge and that it remains, accordingly, the most scientifically defensible approximation of low dose response."(1) The International Commission on Radiation Protection recommendations (2005) stated that "the weight of evidence on fundamental cellular processes supports the view that in the low dose range up to a few tens of mSv, it is scientifically reasonable to assume that in general and for practical purposes cancer risk will rise in direct proportion to absorbed dose in organs and tissues."⁽¹²⁾ In the absence of definitive evidence of the effects of low-level radiation, these consensus statements provide useful guidance. They suggest that it is reasonable to act on the assumption that the low-level radiation used in diagnostic imaging may have a small risk of causing cancer. If one assumes that radiation from a CT examination may cause cancer, it is reasonable that the medical community seek ways to decrease radiation exposure. Two ways to achieve this reduction are to use radiation doses that are as low as reasonably achievable (ALARA), which means that no more radiation should be used than is required to achieve the necessary diagnostic information, and to perform these studies only when they are necessary⁽⁴⁾.

5. ROLE OF PEDIATRIC HEALTH CARE PROFESSIONALS

Pediatric health care professionals have an important role in the use of CT on children ⁽⁶⁾. The health care professional ultimately decides whether a CT examination is necessary. With this important role comes a responsibility to recognize both the value of CT and its risks. He should also be able to discuss these risks in a manner that is informative and understandable to patients and families. One must recognize that the decision regarding a CT examination will often depend on the combination of the interaction with consultants, such as radiologists, and the family. The pediatric health care professional should be in a position to be able to answer questions and address concerns. He is usually the first, and often the only, source of direct communication with the child and the family. This relationship carries with it an opportunity to inform and educate the family. There were two reviews that covered CT technology and its role in the imaging armamentarium ^(23,5) and are salient for pediatric health care professionals. Additionally, an important role of the pediatric health care professional is to communicate with the radiologist to decide whether CT is the best study to perform. This consultation will vary from practice to practice, but it should be the goal of both parties to facilitate discussions on imaging strategies. These discussions provide an opportunity to share information, such as the number of studies using ionizing radiation to which the patient has been exposed. In addition to the pediatric health care professionals and radiologists, the integration of other care providers, such as surgical consultants or emergency department physicians, in decisions regarding pediatric CT policy or practice should also be fostered. Other imaging techniques such as ultrasonography or MRI may be suitable alternatives to CT examination, and they do not use ionizing radiation. If the CT examination is indicated and the radiology department uses a low-dose technique, another way to reduce CT dose is to limit the number of times (or phases) the child is scanned for the individual examination. It is very common for adult CT protocols to involve multiple scans through the same body part, which can double or triple the radiation dose to the patient. For most indications for pediatric CT scans, a single pass through the body part of interest is usually sufficient for diagnostic purposes ⁽⁴⁾. Additionally, CT has an increasingly recognized role as the first, if not only, imaging

examination for a wide variety of disorders that affect infants and children. The use of CT for common problems such as trauma (closed head injury, skeletal evaluation including cervical spine assessment, and blunt abdominal trauma), appendicitis, and renal calculi has increased the frequency of CT examinations in adult and pediatric populations. Most clinicians believe that CT studies on children prevent hospitalization for head injuries and that negative findings in patients with acute onset of abdominal pain can obviate surgical explorations. Currently, approximately 11% of CT examinations are performed on children, ⁽²⁰⁾ which could account for more than 7 million pediatric CT examinations per year in the United States. (7,19) Another review study indicated that CT use has increased substantially over the last 1 to 2 decades, including estimates of at least 10% growth per year. ⁽⁷⁾ These studies provide information that leads to earlier and more definitive diagnosis. This increased use, however, must be based on a firm understanding that the CT study is the best study for the clinical situation being evaluated and that the possibility of a very small risk of cancer is considered when making the decision to order the study. The possible cancer risk is not clearly understood by many health care professionals, as concluded by 2 studies. In the first one, Lee et al (18) surveyed emergency department patients, physicians, and radiologists. He found that only 7% of patients indicated that there was any discussion outlining the radiation risks and benefits from an abdominal CT examination. Only 9% of emergency department physicians believed that the lifetime risk of cancer was potentially increased by CT scanning. And, 75% of physicians surveyed underestimated the accurate range for the equivalent number of chest radiographs for a CT examination. In another investigation, Jacob et al ⁽¹⁶⁾ surveyed physicians in the United Kingdom and found that only 12.5% were aware of the potential association of CT radiation and cancer. Less than 20% correctly identified the relative radiation dose of CT examinations. ⁽¹⁶⁾ These studies support a continued and compelling need for radiation safety education for health care professionals and the public. The pediatric health care professional should also be able to provide summary information to families on local practice patterns of radiology colleagues. It is reasonable to have information immediately available from the radiology practice in addition they must have an Appropriate pediatric head and body CT protocols consisting of size- or age-based adjustments in scanner settings; and additional expertise of the practice (e.g. having a pediatric radiology fellowship training, American Board of Radiology Certificate of Added Qualification, and current Maintenance of Certification in pediatric radiology).

6. ROLE OF THE RADIOLOGIST

The importance of the role of consultation between the pediatrician and the radiologist-should not be understated. The decision whether CT imaging should be obtained is determined, in large part, by the pediatric health care professional. However, the radiologist also has a responsibility to perform only those examinations that are appropriate. Any question by either party should trigger communication to be mutually certain about optimizing the child's care. The radiologist also has a responsibility to create protocols and adjust scanning techniques on the basis of special considerations of pediatric patients. ⁽²⁴⁾ These technical considerations have been reviewed for chest and abdomen CT ⁽⁵⁾. In short, the exposure factors, many of which contribute to the radiation dose, must be adjusted. The amount of radiation necessary for diagnostic CT examinations in infants and young children is less than that in adults. If the same settings are used for both children and adults, children will receive an unnecessary and excessive amount of radiation. Many manufacturers now provide at least some basic pediatric guidelines, but it is still the decision of the radiology practice if these are to be used. ⁽⁴⁾ Additional expertise in pediatric imaging may be available in certain practice settings. Although this is not requisite for appropriate CT examinations on children, it would be unusual for a practice with this expertise not to align with the current recommendation of size-adjusted pediatric CT. Radiologists, regardless of whether they are fellow-shiptrained pediatric radiologists, should be able to provide either health care professionals or families with information on the CT protocols and techniques used and be able to discuss the radiation equivalent of CT, potential risks, and any additional techniques (such as breast shields) used in the practice. In addition, radiologists must keep up to date with rapidly evolving CT technology. For example, the multidetector array CT scanners are extremely fast (a complete infant chest examination is possible in approximately 1 second). This fast technology is accompanied by expanded uses in current applications as well as new applications. Furthermore, the radiology practice should also be able to keep pace with potential changes in radiation exposure from this technology as well as new technology to help manage radiation doses ⁽¹⁷⁾.

7. ROLE OF IAEA

The International Atomic Energy Agency, on the other hand, has been instrumental in assessing the state of practice at grassroots level, identifying lacunae in justification and optimization, providing guidance to counterparts in various countries, and improving practice. The results from approximately 50 less-resourced countries for adult and paediatric CT studies have become available, and some have been published. The concerted efforts and actions by the international organizations have contributed to better awareness and improvement of patient protection in CT in adults and children in many countries⁽²⁸⁾.

8. SUMMARY AND CONCLUSIONS

Concerns about radiation exposure are understandable, and questions should be encouraged, particularly when scientific communications are reported in the lay press. ⁽²⁷⁾ There is wide agreement that the benefits of an indicated CT scan far outweigh the risks. The amount of radiation that CT provides is low-level and depends on many factors, especially the protocols used and equipment settings for the individual examination. No direct connection between CT examinations and subsequent development of cancer has been demonstrated, so the risks of CT scans must be estimated, and these estimates vary depending on the information used. It is the responsibility of those health care professionals who use CT scanning to ensure that each CT scan is indicated. It is the responsibility of radiology personnel to ensure that radiation risk is minimized by using the ALARA principle to determine the correct technique. The information provided in this study is offered to aid in decision-making and discussions with the health care team, patients, and families.

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DERIVING AGE-SPECIFIC DIAGNOSTIC REFERENCE LEVEL (DRL) FOR PEDIATRIC CT PROCEDURES IN SAUDI ARABIA: AN APPROACH TO DOSE OPTIMIZATION

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Abstract

Establishment of a national diagnostic reference level (DRL) for different diagnostic imaging procedures has been recommended to evaluate the practices and to optimize radiation safety of patients. The study attempts to establish the DRL for pediatric CT procedures covering age groups 0, 1, 5 and 10 years old. The DLP values taken from patient records were used and analyzed for dose variation and in establishing the DRL. The DRL value was calculated using the third quartile of all the DLP values. The aim of the study is to recommend a national diagnostic reference level for four age groups in common pediatric CT procedures as an approach for dose optimization.

1. INTRODUCTION

The use of computed tomography (CT) for imaging has increased with the development of new and modern technologies. The US survey performed in 2006 showed that CT contributes to 24% of the collective dose due to medical exposure [1]. The use of CT increases as multi-slice technology proliferates and the increasing trend contributes to the increase of collective effective doses by about 40 to 60% [2-4]. Since year 2000, the use of CT on children has increased and 500 fatal cancers were attributed to computed tomography procedures [5].

The frequency of CT procedures may vary from country to country and from locality to locality. About 40 to 50 % of diagnostic imaging collective dose can be attributed to CT imaging in developed countries. It has been estimated that about 8-10% of the CT procedures were performed on children in the US, 4% in Japan and and 2% in Switzerland and Germany respectively [6-7]. The increase in medical use of radiation now becomes the source of the rapidly increasing dose to the population. The realization of the need for optimization of protection especially on children are becoming the initiatives of many countries to reduce patient doses [8].

The use of CT is a choice for better imaging of both adult and children. In the US, CT of the abdomen, pelvis and spine comprises about 58% of the total CT procedures and 17% for chest [1]. The percentage of CT procedures performed on children for examination of the head, abdomen, thorax and spine is about 20% [9]. The increase in the use of CT imaging is due to the emergence of new technologies such as the multi detector CT (MDCT), multi slice and dual energy CT units. These new developments have made scanning rapid and obtaining high resolution images through fast reconstruction. Advances in CT technology have made gantry motion faster and use thinner detector sizes with the ability to acquire larger volumes of data for the entire body. This innovation in CT technology becomes an advantage to pediatric patients because of the small structure sizes that can be well imaged for a very short scan time eliminating motion artifact or lessens the use of anesthesia. Most of pediatric CT imaging procedures is done for diagnostic purposes and for emergency cases such as trauma and pulmonary embolism. Added to the technological advances, the exponential growth in the use of CT is also attributed to the accessibility of CT units even in Emergency Department [10-12].

The use of CT in pediatric patients has undergone various studies due to the radiation doses with the associated risks of exposure and reported radiation incidents. Pediatric patients receive higher organ doses than adults due to the small anatomy size of the patient and the state of the body development with a sensitivity of

about 10 times more than that of adults [5, 12-13]. The 2013 UNSCEAR report states that for chest CT imaging the effective dose in mSv for infant is about 1.5 and for the 7 year old children, it is about 4.2. In modern conventional radiography units, the adult chest x-ray procedure will deliver a dose of only about 0.3 mSv. The study of KE Thomas and B Wang shows that for head CT imaging the estimated effective dose for neonates , 1, 5 and 10 years old are 4.2, 3.6, 2.4 and 2 mSv respectively and for abdomen /pelvis they are 13.1, 11.1, 8.4 and 8.9 mSv respectively [14]. The concern about the high radiation doses and risks on exposure of pediatric patients is under scrutiny because 20% of all CT procedures in well developed countries are performed on infants and children [1].

The practice of justification of procedures and optimization of radiation protection is internationally adopted to reduce patient doses and consequently minimize the risks of radiation exposure [15-17]. Although the number of cases per pediatric CT procedure increases annually and patient doses are high, justification provides a net benefit to patient clinical and dose management [18]. Moreover, a big leap in CT dose reduction in pediatric doses is also achieved with the participation of manufacturers in this drive through the use of automated tube potential and current modulation and iterative reconstruction [19-20]. The use of CT dose conversion coefficient in terms of DLP per effective dose that is size, gender and age specific was developed in 1999 for comparison of doses from different procedures and modalities. The conversion coefficient is intended to achieve reduced CT doses for pediatric patients through faster estimation of patient doses [21-22]. The DRL was introduced as an effective tool for dose optimization and management in diagnostic imaging [17, 23- 25]. DRL values are not ideal doses but they identify high dose practices and indicate where dose reduction techniques are to be evaluated and initiated [26-27].

The aim of this study is to determine the variation in the doses in common pediatric procedures using the dosimetric quantities CTDI_{vol} and dose length product (DLP). It also aims to recommend a national diagnostic reference level for four (4) age groups in common pediatric CT procedures.

2. METHODS

Saudi Arabia is geographically divided into five (5) regions comprising the Central, North, South, East and West regions. A cross sectional retrospective study of hospitals and medical centers that have high patient workload in pediatric CT procedures was performed. A total of 7 hospitals equipped with helical CT were included in the study. Three medical centers are located in the central region and one facility each for other regions. One of the medical centers in the central region is a specialized pediatric cancer center. The quality control data and phantom information were verified for all the participating hospitals and medical centers. Three pediatric CT procedures typical to all the selected hospitals were identified. They were chest, head and abdomen plus pelvis.

Pediatric patients with ages ranging from 0 (neonates) to 10 years old were included in the study. Pediatric patients were grouped into age groups 0, 1 (1to less 5 years old), 5 (5 to less than 10 years old) and 10 (10 to less than 15 years old). Patients CT records were retrieved and the age, gender, CT scan parameters, dosimetric quantities $CTDI_{vol}$ and DLP were recorded. The recorded $CTDI_{vol}$ and DLP were software generated for all units. A retrospective analysis of the recorded doses in dose length product (DLP) was performed for all patients because not all participating centers submitted the $CTDI_{vol}$ values. The dose reference levels were calculated using the third quartile (75%) of the DLP values.

3. RESULTS

In the study, the centers use CT multi-slice scanner manufactured by GE, Siemens or Philips. The selected centers use the 16 cm diameter phantom for dose measurements for pediatric patients. The participating facilities have pediatric protocols for chest, head and abdomen plus pelvis. One center in the central region although it has the pediatric protocol, use the adult protocol for chest procedure for patients in the 10 year old age group.

The selected centers in the central region provided the most number (40%) of the total 486 patients. The age group 0 or neonate had a total of 160 (33%) patients and the age group 10 was 25% of the total patient population (Fig. 1). The age group with the lowest number of patients (22%) was the 5 year old group. Pooling

all ages, the chest procedure obtained the highest percentage (41%) of all cases. For the age group 0, 43% of the total number of patients for this group had abdomen and pelvis procedure and 33% for chest. Age group 5 had the lowest number of patients and the chest procedure has the lowest number of cases (Fig. 2).



FIG. 1. Distribution of patients for the chest, head and abdomen and pelvis procedures according to ag group 0, 1, 5 and 10.

The technical exposure parameters for the three procedures are listed in Table 1. The values in the table are the lowest and highest values for the peak kilovoltage (kVp) and tube current-time in milliampere-second (mAs). Exposure parameters for chest procedure showed the high value of 140 for kVp and 300 for mAs for central region compared to other facilities. Pooling all the DLP values from the participating facilities for each age group, the calculated average, standard deviation and third quartile values are listed in Table 2. The DRL was calculated for each age group and procedure using the 75th percentile or the third quartile of the DLP doses. (Table 2).

Region	Che	Chest		ead	Abdomen& pelvis	
Region	kVp	mAs	kVp	mAs	kVp	mAs
Central	80-140	25-300	100-120	160-300	100-140	75-300
North	100-120	80-180	100-120	100-250	100-120	75-250
South	100-120	40-200	100-120	150-350	100-120	58-180
East	100-120	50-200	100-120	90-350	120-140	100-300
West	100-120	40-200	100-120	100-250	100-120	50-180

TABLE 1. EXPOSURE PARAMETERS FOR THE CHEST, HEAD AND ABDOMEN AND PELVIS PROCEDURES USED FOR ALL AGE GROUPS

				DLP (1	mGy-cm)				
	0		1		5		10		
CT		3rd		3rd		3rd		3rd	
Procedure	Ave±SD	Quartile	Ave±SD	Quartile	Ave±SD	Quartile	Ave±SD	Quartile	
Chest	42.9±8.8	42	55.7±22.5	59	142.6±126.2	125	230±179	392	
Head Abdomen	366.98±130	480	479.9±168	555.89	458±111	576.54	450.12±258	651.92	
& pelvis	64.3±37.4	73	221±162	196	290±133	389	323.97±190	450	

TABLE 2 AVERAGE DOSE LENGTH PRODUCT WITH STANDARD DEVIATION (SD) AND THE 3rd QUARTILE FOR EACH AGE GROUP

4. DISCUSSIONS

The data in Table 1 showed that some CT technologists in the central region used adult exposure parameters for some patients. The survey made by D. P. Frush [28] on the kVp and mA used by members of the Society for Pediatric Radiology in 2006 showed that for chest the highest mean kVp value is 120 and 140 for mA. Central region has a maximum peak kilovolatage of 140 and 300 mAs. Table 1 shows that for abdomen and pelvis procedure, the kVp used by the centers are within the values stated in the Frush survey. High exposure parameters for pediatric patients can unnecessarily burden the pediatric patients with high doses. The same findings are seen in the study of E. Yakoumakis et al in the Greece survey made in 2009 [5].

All the DLP values provided by the CT scanner have been quantified using the 16 cm diameter cylindrical phantom. Table 2 shows that there is a wide variation of the DLP values for chest for age group 5 and 10 and this is due to the use of adult protocol by some technologists in some centers. All of the participating centers use automatic modulation of the tube current. The data allows investigation to be carried out in terms of the mAs, kVp, beam collimation and pitch used for the patients in this group. Since the automatic modulation of the tube current provides consistent good images, the scan length and the mAs values need to be investigated for each center. CT image quality in a broader sense might include scan region or indication or regional practice standards [29] but for dose reduction, scan length plays a very important role in the investigation.

Age group 1 obtained the highest third quartile value of the DLP for head. This age group should be given preference in optimization of protection for this procedure. There is an increase of almost two fold in the DLP value for the same age, the same procedure but different imaging system. The dose indicators and scan parameters should be investigated for all age groups. Improving the DLP values but maintaining the good image quality should be addressed especially for age group 1 for abdomen + pelvis. Standardization of protocols and image quality should be assessed. Standardization of CT pediatric imaging protocols, dose metrics, image quality, justification and appropriateness criteria should be discussed by the team of pediatric CT radiologists, medical physicists and technologists across the Kingdom. Tube current, tube voltage, pitch and scan length are the most important parameters for dose optimization and image quality [30-31].

The calculated DRL values per age group are comparable with some internationally published data (Fig. 2). Reducing the DLP values but maintaining a good image quality is important to be undertaken by the team of radiologists, technologists and medical physicists. This can be done in the future for improvement of optimization process and for establishing the radiation protection culture in the country. Surveys for other procedures are recommended for establishing the national DRL value.



FIG. 2 The calculated DRL for age groups 1,5 and 10 compared to published data for chest, head and Abdomen & pelvis procedures.

5. CONCLUSIONS

There are some technologists who use of adult protocols for pediatric patients. Training of technologists and radiologists on specific pediatric protocols and on radiation protection should be given a priority. The recommendation of standardizing CT pediatric protocols and image quality needs to be studied at the national level. The process of justification of pediatric protocols should be implemented in all centers. The obtained third quartile values of the DLP for chest, head and abdomen + pelvis are recommended to be the initial national DRL. A regular re-survey and determination of the DRL should be done especially if there are more and new installations are distributed all across the country. The time for re-survey should allow the implementation of corrective actions to take place after the initial DRLs. Periodic review will improve optimization of protection and safety in the Kingdom. A graded approach may be used to select procedures for which DRLs are to be established for children. Optimization of protection for pediatric CT procedures should be a joint effort of CT radiologists, medical physicists and technologists.

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EVALUATION OF PEDIATRIC RADIATION DOSE IN COMPUTED TOMOGRAPHY IN SAUDI ARABIA

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Abstract

Pediatric CT procedure is frequently performed at radiology department due to its ability to diagnose various clinical conditions. The objective of this study was measure the patient dose and to evaluate the imaging protocol during brain and abdomen CT scans with 128 CT machine installed at King Khaled Hospital and Prince Sultan Center for Health Services, Saudi Arabia. A total of 33 patients were investigat ed (12 (36.4%) patient undergone CT abdomen and the rest undergone CT brain). The radiation dose parameters were presented in terms of $CTDI_{vol}(mGy)$ and air kerma length product (P_{KA}). The mean $CTDI_{vol}(mGy)$ and P_{KA} was 34.0 ± 14 mGy and 665 ± 300 mGy.cm for brain and 5.6 ± 1.3 and 233.6 ± 108 for abdomen procedures, respectively. In this study, large variation in patient doses were observed. Pediatric patients exposed to unnecessary radiation compared to previous studies. The radiation dose in brain CT is higher compared to abdomen. The main contributor for this high dose was the use for adult protocol for pediatric patients. Radiation dose optimization is recommended to reduce the patient's dose to its minimal value without affecting the diagnostic findings.

1. INTRODUCTION

Diagnostic radiological imaging is effective method for diagnosis may clinical conditions. Computed tomography (CT) become the leading source of medical exposure in diagnostic radiology worldwide since its emergence in 1971. Pediatric CT procedures increased frequently in recent years worldwide due to the technological development due to the short scan time, accuracy, volume imaging and versatility [1]. It was estimated that 10% (\approx 18 million procedures) of CT procedures performed on children with a mean effective dose (*E*) of 5.0 (range (1.0 to 10.0)) mSv per procedure. This dose range is within the first quartile of the estimated dose received by atomic bomb survivors (5.0 to 20. mSv) [2]. Therefore, the international atomic energy agency (IAEA) and other international organizations encouraged adoption of national measures to reduce the radiation dose to its minimal value by proper justification and optimization of the CT procedures, especially in pediatric patients.

According to the world health organization (WHO) [3], the Saudi health care systemis ranked 26th among 190 of the world's health systems. The high quality of health care level classification translates broadly to large number and frequency of X-ray examinations (9 million procedures) [4]. Although diagnostic imaging is important, the patients and specially pediatrics are exposed to high radiation doses with may increase the probability of cancer risk. Pediatric are more vulnerable to radiation compared to adults because they have longer life probability than adults, resulting in a great opportunity for radiation effect to manifest. In addition to that, children have more rapidly dividing cells which more sensitive to radiation the low dividing cells. Furthermore, Pediatric patients may exposed to unnecessary radiation dose, the CT machine settings are not adjusted according to the child weight. As a result, the risk for developing a radiation-related cancer increased in children compared to adults [4-8]. Therefore, measurement of radiation dose to pediatric patients in order to evaluate the current practice for dose optimization is mandatory. Furthermore, few studies were performed in Saudi Arabia compared to the frequency of the procedures [5-9]. In addition to that, with increasing use of CT in pediatric population accompanied with a

lack of use of appropriateness criteria, there is a strong need to implement protocols to avoid unnecessary radiation doses to children [7, 10, and 11]. CT brain and abdomen are the most common CT examination in children. It was estimated that 75% of all pediatric CT procedures are performed in head region [6]. The objectives of the current study are to measure pediatric patient's doses that undergone CT scans (brain and abdomen) and to estimates of organ-specific doses from pediatric CT scans.

2. MATERIAL AND METHODS

2.1 PATIENT POPULATION

A total of 33 patients with different CT examinations were referred to King Khalid Hospital in the period of study. All the procedures were performed using routine departments' protocols. Data were collected to the study the effects of patient-related parameters (e.g. age, gender, body mass index (BMI) diagnostic of examination, and procedure type) and to assess the effect of exposure-related parameters (gantry tilt, tube voltage (kVp), tube current (mA), exposure time, slice thickness, table increment, number of slices, and start and end positions of scans) on patient dose (Table 1).

2.2 CT MACHINES

A CT machine with 128 slice (Philips iCT 128 slice, Philips Healthcare, Best, the Netherlands) was used in this study. The machine was manufactured in 2009 and installed in 2014. Regular quality control tests were carried out for the machines by experts from King Khalid Hospital. All data were within acceptable ranges.

2.3 Imaging protocol

In general the imaging protocols were based on the following steps: first, patient placed in supine position, head first into the gantry, with the head in the head-holder whenever possible. Second, adjust the center the table height such that the external auditory meatus (EAM) is at the center of the gantry. Then, the scan angle was placed parallel to a line created by the supraorbital ridge and the inner table of the posterior margin of the foramen magnum to reduce or avoid ocular lens exposure, this may be accomplished by either tilting the patient's chin toward the chest or tilting the gantry. No protection shields were used to protect the sensitive organs such as thyroid or breast during the entire procedures.

2.3. MEASURING CT RADIATION DOSE

In this study, $CTDI_{vol}$ (mGy) and P_{KA} (mGy.cm) were measured by the scanner software, by using these parameters and conversion factor for brain, the effective dose (mSv) was calculated using conversion factor, equations 1-3 [12-14].

$$CTDI_{vol} = \frac{CTDI_{w}}{pitch}$$
(1)

Where

CTDI_w is the average dose in a slice using a 100 mm pencil ion chamber. Pitch is defined as the table transportation per rotation to the total nominal beam width.

$$P_{KA} = CTDI_{vol} x L$$
 (2)

$$E = P_{\rm KA} {\rm x} \, {\rm f} \tag{3}$$

Where f, is effective dose conversion factor

3. RESULTS AND DISCUSSION

In this study, a total of 33 pediatric CT examinations for brain and abdomen were performed (Tables 2& 3). Patient exposure factors were presented in (Table 1 & 2) for brain and abdomen, respectively. The tube current (mA) was automatic parameters, while the tube potential (kVP) was variable between 100 to 120 kVp, depend upon the patient size and the organ of interest. The radiation dose parameters were presented in terms of CTDIvol (mGy) and P_{KA} (mGy.cm). The mean CTDI_{vol} In this study 5.6±1.3 mGy and 34±14 for abdomen and pelvis, respectively. The mean P_{KA}) was 233.6±108mGy.c m and 665±300, at the same order. The effective dose per procedure were presented at the same Tables (2 & 3). The mean age for patients during brain scan was 3.5 years for abdomen group while the mean age for abdomen group was 4.6 years. The minimum age was 0.05 year and the maximum was 10 years. Significant variation was noticed between patient ages. However, this variation could increase the uncertainty of dose measurements and effective dose estimation since the patient weight may increase with age (Table 2). All scan parameters were presented in Tables 2 and 3. In general these variations of doses are due to differences in, tube voltages, number of scan, tube current and repeated scans. The scan parameters were comparable for all hospitals: exposure parameters, pitch, number of slices and slice thickness. The pitch for CT brain was lower compared to the pitch in CT abdomen. The effective doses in this study were higher in CT brain than abdomen. The structure of brain and abdomen is completely different. Therefore the variation may be due to the operator exposure protocol because the anatomical variation is not significant as the other organs. Variation

Parameter	Average ±sd	Minimum	Maximum	
Tube voltage (kVp)	116.6±7.7	100	120	
Tube current-time product	74.5±20	45	100	
(mAs)				
Slice thickness (mm)	2±0	2	2	
Pitch	1.01±0	1.01	1.01	
CTDIvol (mGy)	5.6±1.3	3.4	7	
P _{KA} (mGy.cm)	233.6±108	71	412	
Effective dose (mSv)	0.38±0.2	0.12	0.70	

TABLE 2 : CT Patient dose values for pediatric CT abdomen at king khaled Hospital

TABLE 3 : CT Patient dose values for pediatric CT brain at king khaled Hospital

Parameter	Average ±sd	Minimum	Maximum
Tube voltage (kVp)	120±0	120	120
Tube current-time product (mAs)	241.5±45	91	478
Slice thickness (mm)	1.8±1.4	1	5
Pitch	0.4±0	0.4	0.4
CTDIvol (mGy)	34±14	14	66
P _{KA} (mGy.cm)	665±300	366	1266
Effective dose (mSv)	1.1±0.5	0.62	2.2

in CT brain dose was previously describe by Ourashi et al [8] and many solutions was proposed to overcome this obstacle. Due to large discrepancies in pediatric weight, a very important technique are required for patient dose reduction based on patient's weight, clinical indication, and number of prior CT studies. In generalthese variations of doses are due to differences in, tube voltages, number of scan, tube current and repeated scans. There may be justifiable reasons for some variability in practice, of which the most important one is the difference in clinical indication [12]. Previous studies where systematic changes in scanning parameters were analyzed with respect to resulting image quality have reported dose reductions of up to 40% in CT scans of the head without loss of relevant information or diagnostic image quality. Muhogora 2010 [12] reported wide patient dose variation in CT procedures ranged up to factor of 55, suggesting that patients may exposed to unnecessary radiation and optimization is highly recommended The machine used in this study supplied with many tools to optimize patient radiation exposure during CT examinations such as tuning of exposure parameters during image acquisition such as automatic current selection and dynamic angular dose modulation. These techniques can reduce the dose up to 46%. However, many operators did not use the available techniques to reduce the dose. Awareness of variation and associated risks is needed to reduce radiation exposure. Consistent imaging protocols and adjustment of CT settings on the basis of clinical indication and the size of the child may reduce variation and radiation exposure from medical imaging. No correlation was found between patient age and dose, this means dose is dependent on exposure parameter and patient pathology.

CONCLUSIONS

The assessment of radiation dose to pediatric patient undergoing CT brain and abdomen was investigated. In this study variation in doses were observed. The radiation dose in Brain CT is higher compared to abdomen. The main contributor for this high dose was the use for adult protocol, which justify the important of use child protocol. The individual risk from the radiation associated with a CT scan is quite small compared to the benefits that accurate diagnosis and treatment can provide. Still, unnecessary radiation exposure during medical procedures should be avoided.

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ABSORBED DOSE RECEIVED BY PEDIATRIC PATIENTS WHO UNDERWENT FLUOROSCOPY GUIDED UPPER GASTROINTESTINAL SERIES AT ST. LUKE'S MEDICAL CENTER - QUEZON CITY

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Abstract

Fluoroscopic procedures, particularly upper gastrointestinal series, are essential to the practice of pediatric radiology. The radiation dose depends on the type of examination, the patient size and the equipment. The most convenient and widely used method for indirect monitoring patient dose is kerma air product (KAP). To determine mean absorbed dose received by pediatric patients who underwent fluoroscopy guided upper gastrointestinal series. The study is a retrospective descriptive study of 76 pediatric patients (0 to 10 years old) who underwent fluoroscopy guided upper gastrointestinal series at SLMC-QC. The age and sex of pediatric patients, KAP and total fluoroscopy time of the procedure were collected. The main outcome measure was kerma area product (KAP). Majority of the subjects were male (52.6%). The mean KAP for the age groups <1, 1-3, 3-10 years old were 54.2 ± 63 cGy.cm², 54.6 ± 50.1 cGy.cm² and 78.4 ± 90 cGy.cm². Out of 76 participants, 52 (68.4%) had abnormal findings.

1. INTRODUCTION

The study determined the mean kerma area product (KAP) of pediatric patients per age group who underwent upper gastrointestinal series (UGIS) at St. Luke's Medical Center – Quezon X-ray section. A similar published literature by Filipov et.al. was used as a reference for the study. The research determined the mean KAP by pediatric patients who underwent fluoroscopy upper gastrointestinal series in our institution with the same demographic profile.

For this research we included upper gastrointestinal series which included airway fluoroscopy and barium swallow studies. The study was done retrospectively by collecting kerma area product (in mGy-cm²) measurements over a period of 28 months from upper gastrointestinal series and airway fluoroscopy. The KAP measured in mGy.cm² was determined through generated values from Siemens Fluorospot X-rayimaging system Axiom Iconos R200 used in 3 procedure rooms. The data was then grouped according to age groups of 0-1, 1-3, 3-10 years old. Different institutions have different practices in performing UGIS and airway fluoroscopy, it is then important to be aware of the range of KAPs for these procedures.

2. METHODS

Design: The research design was a hospital based retrospective descriptive study.

Study setting: The study was conducted in St. Luke's Medical Center - Quezon City.

Sampling Method: All pediatric patients who underwent fluoroscopy guided upper gastrointestinal series at SLMC-QC

Inclusion criteria: All pediatric patients from 0 to 10 years old who underwent fluoroscopy guided upper gastrointestinal series at SLMC-QC from January 1, 2015 to April 30, 2017 was included in the study. *Exclusion criteria:*

- 1. UGIS of pediatric patients with no kerma area product
- 2. UGIS of pediatric patients combined with small intestinal series or barium enema

Procedural technique

The procedures were performed by pediatric radiologists with varying durations of professional experience (4–20 years), a pediatric radiologist fellow and one radiology resident at our academic institution, all of whom used methods to minimize radiation exposure to the pediatric patients in keeping with the ALARA principle.

The upper gastrointestinal series were done by oral administration of barium contrast material in standing anteroposterior (AP) and lateral positions under fluoroscopic guidance. The airways were evaluated under fluoroscopic guidance in lateral position. Barium or water soluble contrast material was admixed with the patient's milk and administered via a feeding bottle.

Radiation dose

Fluoroscopy equipment (Siemens Fluorospot X-ray imaging system Axiom Iconos R200) is licensed by Center for Device Regulation, Radiation Health and Research (CDRRHR). KAP was obtained from every procedure using a KAP meter installed in the fluoroscopy equipment. The dose information was logged by a radiologic technologist. KAP calibration is done annually by a medical physicist using radiation output test tools through obtaining the kV, the collimation / set area, and radiation output. Calibration factor was used in evaluation of radiation doses. KAP measurements were collected on a monthly basis by medical physicist and the annual analysis was compared to international reference levels which includes all fluoroscopic procedures that includes adults and pediatric patients in our institution.

The demographic information (age and gender) of pediatric patients who underwent upper gastrointestinal studies, from January 1, 2015 to April 30, 2017 on three fluoroscopic units (Siemens Fluorospot X-ray imaging system Axiom Iconos R200) at SLMC-QC were retrospectively collected.

KAP in mGy-cm² of the entire upper GI procedure was provided by the fluoroscopy equipment. The total fluoroscopy time of the procedure was also recorded for all the patients. The KAP provided by the fluoroscopy equipment were used as radiation exposure parameters of the patients for calculation in this study.

Data Analysis:

Data were encoded and tallied in SPSS version 10 for windows. Descriptive statistics were generated for all variables. For nominal data frequencies and percentages were computed. For numerical data, mean \pm SD were generated. Analysis of the different variables was done using the following test statistics: ANOVA – used to compare more than two groups with numerical data and T-test – used to compare two groups with numerical data.

3. RESULTS AND DISCUSSION

A total of 76 subjects were included in the study. Table 1 shows the distribution of subjects according to demographic characteristics. Their age ranged from 3 days to 10 years where almost 60% were <1 year.

	Frequency	Percentage
Age (in years)	(11-70)	
<1	43	56.6
1 – 3	17	22.4
3 - 10	16	21.1
Sex		
Male	40	52.6
Female	36	47.4
Procedure		
Barium Swallow	4	5.3
Esophagogram	2	2.6
Modified Esophagogram	2	2.6
UGIS	68	89.5
Findings		
Abnormal	52	68.4
Normal	24	31.6

TABLE 1. DEMOGRAPHIC CHARACTERISTICS OF SUBJECTS

Table 2 shows the comparison of mean KAP according to age and sex. There was no significant differences noted as shown by all p values >0.05.

	n	$\frac{\mathbf{KAP}}{(\text{Mean} \pm \text{SD})}$	p-value
Age (in years)			
<1	43	541.86 ± 625.01	
1 – 3	17	546.07 ± 500.73	0.44
3 - 10	16	783.84 ± 889.82	
Sex			
Male	40	566.50 ± 667.67	0.70
Female	36	624.02 ± 667.18	

TABLE 2. COMPARISON OF KAP ACCORDING TO AGE AND SEX

p>0.05- Not significant; $p \leq 0.05$ -Significant

Table 3 shows the comparison of time in minutes according to age and sex. There was no significant differences noted as shown by all p values >0.05.

	n	Time in Minutes (Mean ± SD)	p-value
Age (in years)			
<1	43	2.94 ± 3.05	
1 – 3	17	1.97 ± 1.90	0.52
3-10	16	2.73 ± 3.47	
Sex			
Male	40	2.51 ± 2.77	0.61
Female	36	2.86 ± 3.11	

p>0.05- Not significant; $p \leq 0.05$ -Significant

Table 4 shows the distribution of subjects according to procedure and findings. All subjects with esophagogram had abnormal findings while half of subjects with modified esophagogram had abnormal findings.

	Findings		Total
	Abnormal	Normal	
Procedure			
Barium Swallow	3 (75.0%)	1 (25.0%)	4
Esophagogram	2 (100%)	0	2
Modified Esophagogram	1 (50.0%)	1 (50.0%)	2
UGIS	46 (67.6%)	22 (32.4%)	68

TABLE 4. DISTRIBUTION OF SUBJECTS ACCORDING TO PROCEDURE AND FINDINGS

p=0.72 *Not significant*

4. DISCUSSION

A variety of diseases in the pediatric population is congenital in nature and can be evaluated by radiography. These include anomalies of the esophagus, stomach and the duodenum [1]. UGIS has also been used to evaluate gastroesophageal reflux disease (GERD) whether it is physiologic or pathologic [2]. Airway fluoroscopy is used in the evaluation of upper airway obstruction, manifested as narrow diameter of the airway in infants and children. Patients with upper airway obstruction typically present with stridor. Plain radiography and fluoroscopy are still the mainstays for the evaluation of stridor in children [3]. Fluoroscopy and UGIS is also used in assessing swallowing disorders and oropharyngeal aspiration [4]. UGIS and airway fluoroscopy indeed have a diagnostic value in the pediatric population.

The Kerma area product (KAP) is defined as the average the air kerma (in Gy) multiplied by the corresponding x-ray beam cross-sectional area (in cm^2), the product of which being expressed as Gy·cm². This represents the total amount of radiation incident on the patient and provides an indication of the total amount of radiation used in an examination [5]. The KAP can be used to estimate the effective dose. It represent the total energy incident on the patient and y distance [6].

The table 5 shows a comparison of mean KAP values from Filipov et.al. to our current study.

Age Range (years)	Mean KA	$AP (cGy.cm^2)$
	Filipov et al.	Current Study
0 - < 1	102+/- 19	54.2 ± 63
1 - < 3	142 +/- 25	54.6 ± 50.1
3-10	323+/-39	78.4±90

TABLE 5. COMPARISON BETWEEN MEAN KAP VALUES

The difference between the KAP values with their study compared to this study can be caused by difference of technique used in acquiring the KAP. They used dosimeters and the field size of the patient while our values where generated by the fluoroscopy machine. The operator in their study was not mentioned but in our institution, pediatric radiologists operate the fluoroscopy machine. This could lead to lower fluoroscopy time and radiation dose.

This study showed 68.4 percent of participants had abnormal findings. CT scan produces less radiation compared to fluoroscopy [7,8]. The low cost and the dynamic nature (real time assessment) of fluoroscopy makes it difficult to ignore the usefulness of UGIS and other similar fluoroscopy procedures. Many diseases such as gastroesophageal disease still employ the use of fluoroscopy as abovementioned. KAP values from this study can be used for reference for clinicians and fellow radiologists as baseline values. Furthermore, our values can be used to assure parents of the patients of the radiation dose received by their children in our local setting.

5. CONCLUSION

The mean KAP for the age groups <1, 1-3, 3-10 years old were $54.2 \pm 63 \text{ cGy.cm}^2$, $54.6 \pm 50.1 \text{ cGy.cm}^2$ and $78.4 \pm 90 \text{ cGy.cm}^2$. Out of 76 participants, 52 (68.4%) had abnormal findings. Majority of the subjects were male (52.6%). The absorbed dose and fluoroscopy time by the male and female patients when compared was not significant. This was also apparent in the different age groups. The subjects who underwent esophagogram all had abnormal findings while half of subjects with modified esophagogram had abnormal findings.

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CAMPAIGN AND EDUCATIONAL STRATEGIES THAT REDUCE CHILDREN'S EXCESSIVE EXPOSURE TO RADIOLOGICAL EXAMS.

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Abstract

The paper aims to describe the experience in rationalizing the use of radiological exams in children ensuring technical quality and in the implementation of the Radioprotection Campaign according to The Image Gently® protocols, that included training professional team and introducing the Radioprotection Wallet for children under 12 years old, as a tool for parents and doctors to control children's exposure to radiation. The project was held in a health care insurance system covering 140,000 people. To assess the effectiveness of these actions we compared the number of radiological exams performed at the pediatric emergency room in a period of one year preceding the campaign and in the next year. After the radioprotection strategies there was a 22% reduction of radiological exams performed at the pediatric emergency room. There was also a 29% reduction in the solicitation of two or more radiological exams for the same child or exams with two or more incidences. The campaign and the radioprotection project showed to have feasible strategies which were associated with reduction in radiological exams requested and performed at the pediatric emergency room. The survey was extended to a National Campaign and to an Academic Community in an University.

1. INTRODUCTION

The use of radiological exams had increased, probably due to the technological advance, the ease of performing radiological examinations, family insecurity and defensive medicine [1,2]. Although radiological exams, mainly Computed Tomography can aid in diagnosis, and offer security for physicians and parents, its excess use has caused concern, because of the cumulative effect of ionizing radiation [3-5].

The Image Gently® Campaign and the The Image Gently® Alliance together with Paediatric and Radiologic Society initialized an international committee and campaign to aware the use of ionizing radiation exams especially in children [6]. The implementation of radioprotection campaign and protocols has been developed all over the world [7-10].

Instead of awaring these principles involving patient and professional safety, a master thesis project was developed in a Private Hospital in Sao Paulo, Brazil, supported by a Post Graduation Course of a Medical Faculty University from 2011-2014[11]. From 2016 till now this project has continued stimulating other surveys to implement the campaign.

In South America, The Latin Safe organization was developed in 2015. Its mission was to promote though education a safe image diagnosis with emphasis on radioprotection, as well as following the Bonn Call for Action Platform [12,13].

The purpose of this paper is to describe this experience of implanting the campaign to rationalize the use of radiological exams in children ensuring technical quality and to implement the Radioprotection Campaign according to The Image Gently[®] protocols that included training professional team and introducing the

Radioprotection Wallet for children under 12 years as a tool for parents and doctors to control children's exposure to radiation. The used methodology aims to stimulate other hospitals and university centres to implement the program in Brazil.

2. METHODS

From 2011 to 2014 the project was held in a health care insurance system covering 140,000 people in a private Hospital in Sao Paulo. To assess the effectiveness of these actions we compared the number of radiological exams performed at the paediatric emergency room in a period of one year preceding the campaign and in the next year. An Education training performed for one year involving nurses, radiologists, paediatricians, radiological technicians and receptionists was done based on The Image Gently[®] protocols, with lectures and personal feedback by the researchers in the local job area, discussing the solicitation, radiation risks and safety execution of the exams in the paediatric emergency room. There were distributed 17,000 radioprotection children cards to report the kinds of radiological exams and their incidences.

This project was extended between 2016 and 2017 to a National Campaign to the units of the same Health Care, which represents 17,5 million of Brazilian Health Insurance Beneficiaries. It had with the approval of members from the Brazilian College of Radiology board of directors, disseminating the program. It stimulated the creation of Radioprotection Commissions to implement the campaign in other unit hospitals, giving references, new awareness instruments, a guideline implementation, lectures about radioprotection, medical protocols, technical criteria, dose indexes, and proposing a permanent Education Training to a multiprofessional team.

The survey was also extended to a university hospital, as a new project, approved by the Medical Faculty Ethics Committee, with the purpose to evaluate the radioprotection knowledge of the academic students, hospital physician members and employees. This new project was structured on the Kotter 8 steps process for leading change [14]. 1 Create the sense of urgency.; 2. Build a guiding coalition; 3 Form a strategic vision& initiatives; 4. Enlist a volunteer army; 5. Enable action by removing barriers; 6 Generate short-term wins; 7. Sustain acceleration; 8. Institute change. It will also includes the filling of questionnaires evaluation about the principle of Image Gently Campaign, resulting in indicators and orientation for a plan of action to the Training Education. We expect that 500 medical students, 100 doctors, and 200 Hospital employees answer the instrument. Also this Hospital University (Pontifical Catholic University of Sao Paulo) has created a radioprotection commission, who will initialize the pilot project analysing the procedures, check list workflow and dose index in the nursery and neonatal intensive care, with safety recommendation on executing the exams, institutional valid protocols of requesting the ionizing radiation exams; giving the children's card in the neonatal intensive care and nursery and making an explanation about the radiation risks to the parents. The Dose Index Register (DIR) [15], proposed by the American College of Radiology, as an indicator and consultancy monitoring system of the examinations is going to be applied in 2018.

3. RESULTS

The initial campaign was well accepted by all those involved. In the following year the radioprotection campaign we observed a 22% reduction of radiological exams performed at paediatric emergency room. There was also a 29% reduction in the solicitation of two or more radiological exams for the same child or exams with two or more incidences. The local hospital quality service took care of the program after its implementation.

The National project organized a guideline and stimulated the dissemination of a similar program to 42 units of the same Health Care. 16 have their own hospitals and radiological section, created a radioprotection commission.

The University Hospital in the same city created a Radioprotection Commission and started a similar campaign with engagement of radiologists, paediatricians, administrative staff, as well as members of the physicians and occupational safety professionals, and the pilot project has been initialized in the nursery and in the neonatal intensive care following Kotter Steps [14]. It also stimulated a scientific initiation student project from the Faculty of Medicine that will assess pre-evaluation and permanent education about radioprotection to undergraduation and graduation students, residents, and health professionals the training will be based on Image Gently® and Eurosafe Imaging® program, Local Health Surveillance [16], Interministerial Ordinance-Healthy

Ministry – Certification of Teaching Hospitals Program [17], and Brazilian College of Radiology [18] and American College of Radiology [19].

The data of the new project evaluation of the program for the National Campaign and the University Hospital will be available in 2018. This new project will also support to evaluate the impact of the campaign in 16 Healthy Unimed care system Units that have prepared a radioprotection commission, to improve patient safety and maintenance of the campaign. The Table 1 shows a summary of the strategies applied and the associated results.

Strategy	Result
Pilot radioprotection campaign for children	Disclosure for parents / guardians of patients, medical staff
	and technicians of The Image Gently® protocols
Distribution of radioprotection children card to record the	Control of radiological children examination
kinds of radiological exams and their incidences	
Education training (one year) on The Image Gently®	Professionals (nurses, radiologists, paediatricians,
protocols	radiological technicians and receptionists) prepared for
	radioprotection
Follow-up (after the campaign) of the radiological exam's	Reduction in the number of radiological exams compared to
number	the total number of exams (visits)
Follow up of radiological exam's solicitation	Reduction of the solicitation of two or more radiological
	exams for the same child or exams with two or more
	incidences
Creation of an effective radioprotection commission	Obtaining an institutional commitment to integrate
	radioprotection actions
Expand campaign at national level	Consolidation of strategies and results
Questionnaires on radioprotection for parents / guardians,	Evaluate each group's awareness for radioprotection
pediatricians, technicians and managers	
Permanent education about radioprotection to	Addressing radioprotection since the training of health
undergraduation and graduation students, residents, health	professionals
professionals based on The Image Gently® and Eurosafe	
Imaging® program, local health surveillance and teaching	
hospitals, and Brazilian College of Radiology's normatives	

TABLE 1. RADIOPROTECTION STRATEGIES

4. DISCUSSIONS

The radioprotection principles must be disseminated to private, public Health Care Units, as well as Academic Community, in order to change culture and aware health professionals and the population about radiation ionizing exams risks and benefits. We all know that radiographic and tomography exams improve diagnostic accuracy, and decreases hospitals inpatients days of hospitalization. However, it must be used with consensual protocols in all the procedures involving radiological exams, from the correct solicitation, proper maintenance of the radiological equipment through physical analyses doses, following Brazilian health surveillance standards, daily check list workflow, radiologist validated dose reduction exams done by the X Ray Technician, quality evaluation and permanent education to all the team. The dose index register (ACR), seems to be a good instrument to control dose tomography exams and to promote technical support. Unfortunately, there is no much available funds for additional costs in this moment in Brazil.

The children radioprotection card can be a tool to aware and guide parents and paediatricians, to control radiological children examination, to decrease repeated exams. Historical patients record information and accessible previous exams during the appointment allow for a more safety-conscious medicine.

The others alternative image children examinations should be available for complementary diagnostic like ultrasound and Magnetic Resonance.

5. CONCLUSIONS

The campaign and the radioprotection project for children under 12 years old showed to be feasible strategies and were associated with reduction in radiological exams requested and performed at the paediatric emergency room. It also contributed to be an example to disseminate the program and give instruments to other Heathy Care Units and Academic Communities.

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RADIATION EXPOSURE DURING PAEDIATRIC HEAD CT IN TUNISIA: CT DOSE, ORGAN AND EFFECTIVE DOSES

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Abstract

Worldwide, there is a remarkable increase in the number of pediatric CT examinations performed. Therefore, concerns have been raised about radiation exposure to pediatric patients during CT procedures due to their high radio sensitivity and longer life expectancy than adults. The purpose of the paper was to assess and analyze radiation's dose from head CT in children, in six Tunisian hospitals representing different geographic regions; in order to optimize the received dose, minimize the radiological risk for this category of patients and try to establish national diagnostic reference levels. Patient data and exposure parameters were collected. Clinical protocols and exposure settings were analyzed. Doses were collected in terms of CTDI_{vol} and DLP values. Effective and Organ doses to specific radiosensitive organs were estimated using the Monte Carlo simulation software "Impact CTDosimetry". CTDI _{vol} values were estimated to be 24.9, 31.7, 45.5 and 47.8 mGy for respectively age groups <1y, 1-5y, 5-10y, 10-15y. In term of DLP, median values were about 346, 528, 824,897 mGy.cm for the same age groups respectively. From the whole results, we can deduce that there is a wide variation of the CT doses between the regional hospitals within the country and the university hospitals located at the capital region. The dose values found were comparable with those reported in the literature. The study showed an evident need for continuous training of staff in radiation protection concepts, especially within the regional hospitals and for a protocol review, in order to adjust practices to international guidelines for performing optimized pediatric CT examinations.

1. INTRODUCTION

Nowadays, computed tomography (CT) is becoming the major source of patient exposure. Children are at greater risk of radiation exposure than adults because the rapidly dividing cells of children tend to be more radiosensitive and they have a longer expected life time in which to develop potential radiation injury. The risk of radiation-induced cancer development should be a concern in pediatric patients because it can develop after a long-latency period [1,2].

Therefore, it is important to evaluate radiation exposure in children in order to ensure that pediatric doses are kept to a minimum whilst maintaining the clinical effectiveness in order to improve the optimization of this high-dose imaging modality for this especially vulnerable section of the population.

Currently, there is no documented evidence related to Tunisian pediatric CT practice with respect to protocols and how these are applied. This lack of information regarding CT dose values is an obvious deficit regarding the CT exposure-associated risks in Tunisian children especially in the regional hospitals within the country that have fewer human resources specifically trained in terms of patient radiation protection.

Head CT is the most frequent CT exam in pediatrics and most often in a traumatic context. An understanding of patient doses requires, likewise, the evaluation of organ and effective doses since they highlight the magnitude of risk in CT examination of children [3,4].

In this pilot study, CT Dose Index (CTDI_{vol}), Dose Length Product (DLP), effective doses as well as organ doses were assessed in different hospitals within the country, including regional and university hospitals that perform pediatric head CT examinations and the results were compared to those published from other countries.

2. METHODS AND MATERIALS

The study aimed firstly to gather the specifications of the CT equipment of the selected sites, Secondly, to collect CT review data for children of both genders after the hospital's management authorization and to classify them in four age groups: <1 y, 1-5 y, 5-10 y, 10-15y.Technical settings (kVp, mAs, pitch, slice thickness, rotation time, scan length...) and the displayed CTDI_{vol} and DLPs, were collected for each patient.

Dose measurements for the determination of CTDI_{vol} were performed using a CT reference PMMA 16 cm diameter phantom representing the head of a child placed at the isocentre of the CT scanner together with a calibrated pencil-type ionization chamber Model RaySafe Xi with 10 cm sensitive length.

CT organ doses and effective doses were obtained using the ImPACT CTDosimetry software package ver.1.0.4 (27/05/2011) [5].

3. RESULT

For all the audited CT installations, The CTDI_{vol} measurement results demonstrate a good agreement between the displayed and the measured dosimetric quantities.

Figure 1 and 2 present the dose indicators values of our study compared to those from international studies: Portugal [6], Germany [7], UK [8], Belgium [9] and Switzerland [10].

1200



FIG 1 .Comparison of CTDI_{vol} with previous studies



FIG 2. Comparison of DLP with previous studies

The Effective doses per hospital and per age group estimated using the Impact CT software with the ICRP103 definition are displayed in Table 2

TABLE 1.	MEDIAN	VALUES	OF PATIENT	EFFECTIVE	DOSE ((mSv) PER AGE	GROUP
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Age group	UH1	UH2	UH3	RH4	RH5	RH6
Scanner Model	SIEMENS Somatom Emotion	GE BrightSpeed Elite	SIEMENS Definition AS+	NEUSOFT	GE BrightSpeed Excel	NEUSOFT
<1 y	1,8	2,4	1,9		2,5	3,3
1-5 y	2,0	2,2	2,6	5,0	2,5	2,0
5-10 y 10-15 y	1,9 1,4	2,2 1,9	4,0 2,4	4,6 2,9	2,7 2,6	3,0 2,9

FIG. 3 presents the estimated organ doses for selected organs as eye lens, brain and thyroid in terms of median values per age groups for all participating hospitals



4. DISCUSSION

In this work, pediatric brain CT practices were evaluated in different Tunisian public regional and university hospitals dispersed in the whole regions. This is the first time pediatric CT dose assessment fully based on a nationwide pilot study. A large variation is observed among and within hospitals. The main contributor to these variations was the use of different techniques and protocols, for adults in some cases, which shows the importance of using only pediatric protocols for CT examinations in children.

As an overall trend, the CTDI and DLP values of the present study are comparable to the data reported from other studies [7,8,9,10] and clearly lower than those of the Portuguese study [6]. There may be reasonable reasonable reasons for some variability in doses, of which the most important one is the difference in pediatric CT practices and the clinical indications.

The results of effective dose estimations (E) using ICRP (103) presented in Table 1 show that the mean values per age group do not vary widely between hospitals except for to regional hospitals RH6 and RH4 which presented the highest effective doses for all age categories. These high values are due to the high DLP values since there is a strong correlation between the effective dose and DLP which takes into account CT scanning parameters.

The effective dose allows for a rough comparison between different CT scenarios but provides only an approximate estimate of the true risk. For risk estimation, the organ dose is the preferred quantity. The anatomical scan regions suggest radiation risk exposure to sensitive organs such as the eye lens and thyroid gland, which increases the probability of eye cataracts and cancer.

It is evident from fig.3 that large variations of organ dose (eye, brain and thyroid) exist within and among hospitals with outstanding values in the RH4 and lowest ones in UH1. The eye lens is an example of an organ with an attributed deterministic radiation effect: If the eye is exposed to a dose above a certain threshold, a cataract will be produced. Controlling radiation exposure to the eyes is, hence, important especially in patients who require multiple scans.

Furthermore, organs on the periphery of the scan volume can have a significant variation in absorbed dose across the organ due to partial irradiation. The highest thyroid absorbed dose is dependent on each individual scan and the selection of collimation as the thyroid may or may not be within the scan volume. It is also showed that brain received a high doses reaching 52mGy.Indeed, although the brain was once considered a comparatively radioresistant organ, more recent data suggest that it is significantly radiosensitive, particularly at very low doses, with the risk increasing with decreasing age [11]. Estimated cancer risks from pediatric CT examinations would, by definition, be larger, particularly for CT examinations of the head, because of the larger contribution of radiation- induced thyroid cancer [12].

The magnitude of exposure raises concerns about its potential adverse effects, particularly the risks of leukemia and some solid cancers that can be induced by exposure to ionizing radiation [13].

The most recent risk projections [14] suggest that, for children with normal life expectancy, the lifetime excess risk of any incident cancer for a head CT scan (with typical dose levels used in the USA) is about one cancer per 1000 head CT scans for young children (<5 years), decreasing to about one cancer per 2000 scans for exposure at age 15 years. Moreover, cumulative doses of about 50 mGy might almost triple the risk of leukemia and doses of about 60 mGy might triple the risk of brain cancer [15]

The benefits of properly performed and clinically justified CT examinations should always outweigh the risks for an individual child; unnecessary exposure is associated with unnecessary risk. Minimizing radiation exposure from pediatric CT, whenever possible, will reduce the projected number of CT-related cancers.

5. CONCLUSION

In this study, pediatric radiation dose was investigated for head CT procedures. The large variation in doses, notably organ doses, observed among and within hospitals suggests that pediatric patients are still exposed to a large amount of unnecessary radiation and optimization is not fulfilled yet. This emphasizes the potential radiation risks for this especially vulnerable section of the population and asserts that patient organ doses could be substantially minimized through careful selection of scanning parameters based on clinical indications. Our work take a picture of the local practice in pediatric CT examination at the different regions within the country and demonstrates the necessity of the training in patient protection involving all the stakeholders in the professional societies, universities, radiation protection regulatory body and the supplier of the CT installations, especially in the dose optimization and image quality by using the available tools and opened the way for the establishment of national DRLs.

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EVALUATION AND OPTIMIZATION OF ORGAN DOSES IN PAEDIATRIC CT EXAMINATIONS

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Abstract

An experimental approach to evaluate organ doses in pediatric anthropomorphic phantoms by using TLDs and OSLDs was employed in the present study. Several analyses were performed in order to stablish the best way to achieve the main results in this investigation and the methodology proved to be efficient. The characteristics of the OSLDs were analyzed to verify their applicability for evaluating doses from CT procedures, and presented homogeneity, linearity with the incident air kerma, reproducibility, reusability and an energy-dependent response to distinct effective energies. These dosimeters were applied along with TLDs in a pediatric anthropomorphic phantom to evaluate organ doses due to clinical CT protocols. These protocols were selected after analysis of patient data collected from the Institute of Radiology of the School of Medicine of the University of São Paulo. Organ doses measured with dosimeters were compared with Monte Carlo simulations and for organs within the scanned region, differences between measured and simulated absorbed organ doses were within ±20%. Moreover, these results showed that a misalignment and incorrect positioning of the patient in the couch can increase an organ dose by more than 100%.

1. INTRODUCTION

Since the development of the first Computed Tomography (CT) equipment in the early 1970s, this diagnostic imaging modality has gone through several improvements. Exclusively digital and high quality images production without superposition of anatomical structures, examinations as fast as five seconds and the capability of diagnosing important pathologies with no need of exploratory surgeries are some of the great advantages when using this technique. As a consequence, the role of this diagnostic procedure has been widely increasing worldwide. In the US, for instance, 2.2 million CT exams were performed in 1980, only 10 years after its implementation [1]. This number increased to 78.7 million in 2015 [2]. As a result, absorbed dose by patients due to this technique has become a concern among radiologists, researchers and manufacturers, leading to the development of different methodologies to evaluate it. Ionization chambers, thermoluminescence (TL) and, more recently, optically stimulated luminescence (OSL) dosimetry, for instance, have been widely applied in order to estimate organ doses in vivo, in post-mortem subjects and in phantoms [3]. Another approach that has been extensively used are the Monte Carlo simulations, which can be applied in comparison with experimental results. The present study aims to evaluate organ doses due to clinical CT protocols routinely applied at a partner hospital, by using Lithium Fluoride doped with Magnesium and Titanium (LiF:Mg, Ti) thermoluminescent dosimeters (TLDs) chips and Aluminum Oxide doped with Carbon (Al2O3:C) optically stimulated luminescent dosimeters (OSLDs) in a pediatric anthropomorphic phantom. To do so, OSLDs characteristics were extensively assessed to verify their applicability in measuring CT doses. Additionally, this study aims to evaluate protocols frequently applied to pediatric patients, looking for tools to optimize non-adequate practices. After this analysis, different clinical protocols were selected and adopted in experimental measurements. This work is part of the IAEA Coordinated Research Project E2.40.20 entitled "Evaluation and Optimization of Paediatric Imaging", and have taken into account international recommendations for patient dose optimization [4], [5].

2. METHODS

In the present work, a pediatric phantom, model 705, was used. It represents a 5-year old, 110 cm tall and 19 kg pediatric patient. CIRS uses a synthetic bone material based on the appropriate bone composition typical of each age. The physical density of the bone material used in this phantom is 1.52 g/cm3. The phantoms are

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constructed with CIRS proprietary tissue equivalent materials, used to represent soft tissue, bone, cartilage, spinal cord, spinal disks, lungs, and brain. The lung tissue is constructed with a low-density inhale formulation equivalent to 0.21 g/cm3 and effective atomic number (Zeff) of 7.38. The soft tissue has a density of 1.055 g/cm3 and effective atomic number of 7.15 [6]. In order to estimate the organ mass fractions of the CIRS ATOM 705 pediatric phantom, two approaches were adopted. Due to the soft-tissue nature of the organs as stated by Golikov & Nikitin [7], volume fractions were determined as the values of fi. The lung volume fractions were estimated based on the CT images of the phantom and a segmentation technique. The liver location and volume fractions per slice were estimated using a commercial software. The thyroid location was obtained from the study developed by Inkoom and collaborators [8].

The following characteristics of OSLDs were investigated in the present study: batch homogeneity, energy response, linearity of dose response, reproducibility, reusability and effect of uncertainties with the normalization of OSL signals per their response to beta radiation. The material used was the Al2O3:C OSLD Landauer LuxeITM tape (Landauer, Inc., Glenwood, USA) fractionated into disks measuring 3 mm in diameter, as previously described. A group LiF:Mg, Ti TLD-100 chips (Harshaw Chemical Company, OH, USA) was simultaneously irradiated in a set of control measurements for comparison of results. Irradiations were performed using a constant potential x-ray tube MCN 421 (Philips, Germany). RQR and RQT x-ray beam standard [9] were validated in this equipment and used during the procedures described in the present study. A clinical 64-slice CT scanner Brilliance 64 (Philips, Germany), from the Institute of Radiology of the College of Medicine of the University of São Paulo (InRad/FMUSP), was used in an additional set of measurements. Experimental setups are described below.

An automated Riso TL/OSL reader model DA-20 (DTU Nutech. Inc., Roskilde, Denmark) was used to read the information from the dosimeters after each exposure. This equipment operates with a sample carousel with 48 stainless steel cups, which rests on a motor driven turntable that enables the carousel to rotate. This rotation is computer controlled, so that each sample is individually read according to a pre-set configuration [6]. This reader works with detection and stimulation systems. The light detection system consists of a photomultiplier tube (PMT), which captures the light emitted by the dosimeters, along with filters, which keep the scattered light from reaching the PMT and define the detection spectral window. The luminescence stimulation system consists of both a heating element that is used for TL measurements and a light stimulation system that is used for OSL measurements [10].

3. RESULTS

An evaluation of the CT examinations was conducted at InRad in order to identify the most frequent CT studies performed at this Institution in the years 2014, 2015 and 2016. During 2015, for instance, more than 50 modalities of CT studies performed at the partner hospital in about 84,000 patients were identified. From this large number, only about 3,300 patients were pediatric patients in the age range 0-15 years old. FIG. 1 presents the ten most applied procedures in these patients, where one can notice that head CT examinations correspond to 42% of the total examinations and thorax CT is the 5th most applied procedure, corresponding to 5% of the total examinations. Similar trend was found for the years 2014 and 2016.



FIG. 1. Left: ten most applied CT examinations performed in pediatric patients at the Institute of Radiology of the College of Medicine of the University of São Paulo (InRad/FMUSP) in 2015. Head CT corresponds to 40% of the total examinations and Thorax CT is the 5th most applied protocol, corresponding to 6% of the total examinations. Right: Five most applied CT procedures during 2014-2016. These graphics were constructed with the software Origin®2016 (OriginLab Co., MA, USA).

The protocol studied was the Thorax for children protocol using the Philips Brilliance 64 CT scanner. Such protocol was commonly applied in children in the age range from 2 to 5 years old. CTDIvol and DLP displayed by the CT scanner in this protocol were 7 mGy and 196.3 mGy.cm for a scan length of 22 cm. The phantom was irradiated from the middle of slice 8 until the middle of its abdomen, so that thyroid and lungs were irradiated by the primary beam. As a result, doses obtained for both organs are comparable: for the thyroid, doses were estimated as 6.79 ± 0.08 mGy with the TLDs and 7.26 ± 0.19 mGy for the OSLDs. For the lungs, doses were estimated as 6.1 ± 0.3 with the TLDs and 6.0 ± 0.3 with the OSLDs. These results highlight the importance of choosing both the adequate scan length and the right position of the patient on the couch, otherwise the thyroid can receive as much radiation dose as the lungs.

Monte Carlo simulations were adopted to validate the experimental methodology proposed in the present study. Such approach has been proved to be a reliable tool to estimate organ doses, since a variety of voxelized phantoms and different CT scanners can be implemented [11]. In the present work, protocol parameters previously described were simulated in the software NCICT [12] and CalDose (www.caldose.org/)[13].

4. DISCUSSIONS AND CONCLUSIONS

Evaluation of organ absorbed doses due to clinical CT procedures in a clinical institution was the main objective of the present study. This study was performed by applying TL and OSL dosimeters in anthropomorphic phantoms and organ doses due to protocols routinely applied were assessed. TL dosimeters applicability for CT dose measurements was evaluated in a previous work [14], but OSL dosimeters were evaluated in the present study to verify their behavior when exposed to CT beams. Additionally, data from about 120 patients were collected and analyzed in terms of CT dose indexes so that pediatric patient data could also be compared with international DRLs. Protocol selection was performed after this analyses. Target organs were chosen in terms of their radiosensitivity and the protocols selected.

Experimental results are in good agreement with the simulations performed with the software NCICT (TABLE 1). The highest percent differences between experimental measurements and NCICT is 15%, between experimental measurements with OSLDs for the lungs. When comparing data with simulations performed by CalDose, percent differences are a little higher (23 and 24% for the lungs), but for the thyroid, this discrepancy is up to 171%, which did not happen with simulations performed with the NCICT software. This is a consequence of the choice of the scan length of irradiation, as previously described. With NCICT it is possible to choose the same scan length used in the experimental acquisition, while in CalDose_XCT this scan length is fixed. As a consequence, it was possible to simulate an irradiation starting in the neck of the phantom, the same as performed with the physical phantom and, therefore, percent difference between the measured and simulated thyroid doses is 10% for TLD and only 4% for OSLD. This protocol measurement performed with CalDose_XCT, however, started in the beginning of the lungs and, as a consequence, thyroid dose was only due to scattered radiation. A 171% increase in thyroid dose due to a direct irradiation highlights the importance of properly positioning and aligning patient in the couch.

TABLE 1. ABSORBED DOSES (MGY) CALCULATED FOR BOTH TLD AND OSLD, AND SIMULATED VALUES OBTAINED WITH NCICT AND CALDOSE FOR THE THORAX FOR CHILDREN PROTOCOL. PERCENT DEVIATION (Δ) BETWEEN EXPERIMENTAL AND SIMULATED VALUES FOR THE ATOM CIRS PHANTOM ARE ALSO PRESENTED.

Absorbed dose (mGy)				Δ (NCICT)		Δ (CalDose)		
Organ	TLD	OSLD	NCICT	CalDose	TLD	OSLD	TLD	OSLD
Lung	6.06 ± 0.08	5.94 ± 0.08	6.97	7.85	13%	15%	23%	24%
Thyroid	6.79 ± 0.08	7.26 ± 0.19	7.54	2.68	10%	4%	-154%	-171%

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THORACIC MDCT SCANS IN CHILDREN: SHOULD AUTOMATIC EXPOSURE CONTROL BE ABANDONED?

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Abstract

The aim of this study was to investigate thyroid organ, surface and effective dose between thorax MDCT scans performed with fixed tube current and automatic exposure control (AEC). Four paediatric anthropomorphic phantoms simulating newborn, 1-year-old, 5-year-old and 10-year-old child underwent routine thoracic scans using a 16-slice-CT. Scans were performed with and without AEC on each phantom. Dose measurements were performed with thermoluminescent dosimeters placed at locations in/on the phantoms. Location of thyroid organ within phantom slices was determined by anthropometric data from CT examinations of patients body size closely matching size of phantoms. Effective dose was estimated by dose length product per ICRP 103. For mean thyroid organ dose, AEC induced a significant increase by 55%:newborn, 70%:1-year-old), 62%:5-year-old) and 5%:10-year-old). Activation of AEC increased mean thyroid surface dose from 5%:10-year-old to 70%:newborn. The increase of effective dose as a result of application of AEC ranged from 7%:10-year-old to 54%:newborn. AEC should be abandoned as a dose optimization tool during thoracic MDCT, especially in neonates, infants and children younger than 10-year-old.

1. INTRODUCTION

The rapid technological growth in multi-detector computed tomography (MDCT) utilisation is well known, and with it has come an increase in the cumulative effective dose (ED) to the general population [1-6]. MDCT has led to significant improvements in both image quality and image acquisition time.

Paediatric and young adult populations have an increased risk for stochastic effects [7-13] as compared with older adults, for the same radiation exposure [5-6, 14-17]. This requires the utilisation of dose management strategies for CT especially in children and young adults.

The aim of automatic exposure control (AEC) is to improve the consistency of image quality between patients and to control the absorbed dose by modulating the tube current according to the patient's attenuation [18]. The thyroid gland and breasts, which are radiosensitive organs [10], are exposed by the primary and potentially by the secondary beam during thoracic CT scans in children. The aim of this study was to investigate the thyroid organ and surface dose, breast surface dose and effective dose between thorax MDCT scans performed with fixed tube current (FTC) and AEC.

2.0 METHODS

Four paediatric anthropomorphic phantoms (ATOM Phantoms, CIRS, Norfolk, VA) that represent the average individual as newborn, 1-year-old, 5-year-old and 10-year-old child were utilised in this study (Fig. 1).


FIG. 1. Paediatric anthropomorphic phantoms used in this study representing the average individual as newborn, 1-yearold, 5-year-old and 10-year-old, from left to right. Data on their weights (kg) and heights (cm) are displayed on each phantom.

CT scanning was done with a 16-slice CT scanner (Sensation 16, Siemens, Germany). The scanner is equipped with a 60 kW high voltage generator and a Dura Akron B X-ray tube. It is also equipped with a state of the art AEC system (CARE Dose 4D, software version syngo CT 2006G, Siemens, Erlangen, Germany).

Lithium fluoride thermoluminescent dosimeters (TLD-100) (Harshaw, Ohio, USA) chips, 3.0 x 3.0 x 0.9 mm³, were used to determine the dose imparted to the thyroid gland and breast of each of the four anthropomorphic phantoms. The TLDs were annealed for 1 h at 400 °C followed by 20 h at 80 °C before the measurements were taken. All TLDs were calibrated in air against a known dose delivered by a conventional X-ray tube tube with tube voltage equal to 120 kV. Dose measurements were performed using the Barracuda X-ray multimeter (RTI Electronics, Mo[°]Indal, Sweden).

Each phantom was loaded with TLDs to measure the thyroid surface and organ doses, and breast surface dose from standard thorax CT scans. The location of each radiosensitive organ within the phantom slices was determined using a novel approach which employed anthropometric data from CT examinations of patients with body size that closely matched the size of the phantoms [19]. Each scan was repeated 5 times to increase TLDs signal and reduce the statistical error of the measurement. The effective dose (E) was estimated by the dose-length product (DLP) method. The percentage E difference (%E) achieved upon AEC activation was calculated using the following equation:

where $E_{fixed mA}$ and E_{AEC} are the effective dose values estimated for fixed mA and AEC-activated scans, respectively.

3.0 RESULTS

A large variation on the percentage dose difference between fixed tube current and AEC-activated scans was found among the phantoms for the thyroid doses. AEC-activated scans increased the thyroid surface dose compared with FTC scanning from 6% (10-year-old) to 68% (newborn), whilst the thyroid organ dose increased from 5% (10-year-old) to 70% (1-year-old).

Measured CTDI_{vol} values (at 100 mAs_{QR} and 120 kV) ranged from 1.1/1.6 mGy (newborn and 1-year-old) to 1.9/2.0 mGy (10-year-old) for fixed mA/AEC respectively. The calculated E using the DLP method ranged from (0.7/1.1 mSv) for newborn, and (1.0/1.1 mSv) for 10-year-old for fixed mA/AEC respectively. A comparative evaluation of the percentage difference between $E_{fixed mA}$ versus E_{AEC} achieved in FTC and AEC activated scans is presented in Fig. 2.



FIG. 2. A comparative evaluation of the percentage difference between $E_{fixed mA}$ versus E_{AEC} achieved in FTC and AEC-activated scans.

 $E_{fixed mA}$ and E_{AEC} are the effective dose values estimated for fixed mA and AEC activated scans, respectively; AEC, automatic exposure control

4.0 DISCUSSION

The use of AEC induced a significant increase for the mean thyroid organ dose by 55% for newborn, 70% for 1-year-old, 62% for 5-year-old and 5% for 10-year-old in this study. Similarly, for the mean thyroid surface dose, activation of AEC increased by 70% for newborn, 55% for 1-year-old, 35% for 5-year-old and 5% for 10-year-old. The mean breast surface dose by increased by 69% for newborn, 32% for 1-year-old, 9% for 5-year-old, whilst a reduction of 13% was recorded for the 10-year-old.

In this study, the new DLP to effective dose conversion factors that were recently presented by Deak et al. [20] was used to calculate the E. These factors were derived based on ICRP publication 103 [10]. The effective dose also increased as a result of the application of AEC by 54% for newborn, 48% for 1-year-old, 41% for 5-year-old and 7% for 10-year-old. Three parameters affect the effective dose estimate namely; mAs, scan length and the effective dose per DLP conversion factors (k). The findings from this study is similar to another study by Papadakis et al. [21].

5.1 CONCLUSION

The use of AEC induced a significant increase in the thyroid organ dose by a maximum value of 70% for 1year-old for thorax CT scans. Similarly, activation of AEC increased the mean thyroid surface dose by 70% for newborn, and the mean breast surface dose by 69% for newborn. The increase of the effective dose as a result of application of AEC ranged from 7% for 10-year-old to 54% for newborn.

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REFERENCE DOSE FOR PEDIATRIC COMPUTED TOMOGRAPHY IN NORTHERN IRAN ARASH JANBABANEZHAD¹, MOHAMMAD REZA DEEVBAND², ALI SHABESTANI MONFARED¹, FATEMEH NIKSIRAT SUSTANI¹,

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Abstract

The major part of medical exposure comes from Computed Tomography (CT). pediatrics are more radiosensitive than adults, so optimization of CT procedures in pediatrics is suggested. The purpose of the study was to calculate dose to pediatric patients' undergoing CT scans and also propose local Diagnostic Reference Levels (DRLs). Questionnaires were send to seven public hospitals to collect information about patient, protocol and CT scan machines. Dose measurement was performed in four age categories: 0-1, 1-5, 5-10 and 10-15 years old and the recommended quantities that used in CT for dose expression including CTDIw and DLP were obtained. Values of 40, 48, 59.5, 59.5 mGy; 16.9, 16.9, 17.14, 17.14 mGy; 17, 17, 17, mGy; 17, 17, 19.2, 19.2 mGy in terms of CTDIw and 448, 538, 758, 758 mGy cm; 129, 129, 154, 167 mGy cm; 184, 225, 306, 315 mGy cm; 289, 408, 595, 670 mGy cm in terms of DLP as regional DRL for brain, sinus, chest, abdomen and pelvic procedures were obtained respectively. The variations in dose of some procedures were remarkable. As the application of CT technology progress, revision of protocols, for pediatric patients CT scan, following established reference levels is necessary.

1. INTRODUCTION

A study performed in United Kingdom have shown that pediatric CT examinations were increased about 63% [1]. Since the pediatric tissues have higher radiosensitivity, so their carcinogenetic risk can be more than adults [2]. In the last decade a number of researches were performed and indicated that optimization of paediatric radiation dose is required [3–9]. International Commission on Radiological Protection (ICRP) suggested Diagnostic reference level (DRL) in ICRP Publication 60 and 73 [10-11] as a tool for optimization. The third quartile of the dose distribution is defined as DRL [12]. This study aimed to evaluate pediatric CT dose values and propose regional DRL.

2. METHODS

Data were collected within a year for four pediatric CT procedures at Mazandaran public hospitals including: brain, sinus, chest and abdomen and pelvic scans. CT dose measurement was carried out using a calibrated pencil ionization chamber (DCT10 RS, Electronics, Molndal, Sweden) connected to X-ray multimeter (Barracuda, RTI Electronics, Molndal, Sweden) and 16cm diameter CT dosimetry phantom regardless of age or scan area. Recommended quantities that used in CT for dose expression were Weighted CT Dose Index (CTDIw), Dose Length Product (DLP) and Volumetric CT Dose Index (CTDIvol), which were measured in the study. Measurements were repeated three times.

The data were analysed to assess the number of examinations. The mean value, the third quartile, standard deviation and p-values of data were calculated.

3. RESULTS

The seven hospitals participated in this study using spiral CT systems were encoded alphabetically from A to G. For all procedures, significant differences were observed in the scan parameter among the hospitals. Hospital C used lower tube voltage (kVp) for the younger patients, but other hospitals used a constant kVp for all age groups. The variation in the mAs value was also remarkable. Hospitals A, C and G used higher mAs with increasing patient age, but in hospital B higher mAs was observed for two youngest age groups. Differences in

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the slice thickness (from 4 to 10 mm) were also observed among the hospitals. Variations in CT scan machines and their parameters were resulted in patient dose variations between different hospitals for the same type of CT procedures. The mean value, amplitude and standard deviation of measured values in paediatrics age group are shown in table 1.

Dro oo duroo	Age		CTDI	W			DLP		
Procedures	groups	Mean	Amplitude	75%	SD	Mean	Amplitude	75%	SD
	0-1	30.8	56-15	40	14	291	460-126	448	127
	1-2	30.8	56-15	40	14	352.5	461-157.2	461	133
Brain	2-5	37.5	59.5-15	56	17.6	439	722-168	616	206
	5-10	34.2	68-25.5	59.5	15.7	488	816-160	758	259
	10-15	41.8	70-25.5	59.5	20.4	518	840-197	758	257.4
	0-1	12	25.8-3.8	16.9	7.7	72	135.2-21	129	44
Sinus	1-2	12	25.8-3.8	16.9	7.7	75.8	135.2-25	129	43.6
	2-5	12	25.8-3.8	16.9	7.7	84.6	135.2-28	129	45
	5-10	12.3	23-1.8	17.14	7.9	100	174-34	541	52
	10-15	12.3	23-1.8	17.14	7.9	116.7	175.8-40	167	52.4
	0-1	7.8	23-1.8	17	8.5	86.6	184-27	184	80
	1-2	7.8	23-1.8	17	8.2	94	230-27	221	90
Chest	2-5	8.5	23-1.8	17	8.2	123	345-36	229	117.8
	5-10	9	23-1.8	17	8	157	368-55	306	128
	10-15	9.7	23-1.8	17	7.4	208	437-75	315	125
	0-1	9.6	32-2.6	17	11	141	384-47	289	137
	1-2	9.7	32-2.6	17	11	165	448-47	374	170
Pelvis and Abdomen	2-5	9.7	32-3	17	11	214	576-83	442	205
	5-10	10.7	32-3	19.2	10	287.7	640-96	595	229.5
	10-15	12.8	32-6	19.2	11	435.7	704-203	670	221.9

TABLE 1. The mean value, amplitude and standard deviation of measured values in paediatrics age group

Significant variation was seen in the dose of similar scan area, although there was a tendency between radiation dose and patient age. For brain scan, an increase in the DRL of $CTDI_v$ and DLP were observed by increasing paediatrics' age. A same increase in DRL of DLP was also observed in sinus, chest, abdomen and pelvic procedures. The standard deviations showed large variation in DLP of all procedures. The p-value of related results was calculated bellow 0.05. The differences were significant comparing the mean value of DLP between this study and United Kingdom, particularly in the 10-15 years old age group for brain and chest examinations.

4. DISSCUSSIONS AND CONCLUSIONS

This is the first study about measuring pediatric dose in CT scan procedures in north of Iran. The total frequency of procedures was near 32000 CT examinations during one year. Pediatric dose showed large variations for all procedures and each category. The CTDI_v and DLP of Brain CT scan had the highest values for all age groups in comparison with other procedures, which can be due to the thinner slice thickness and high level of mAs. Table 2 compares our DRL with proposed DRLs for Germany [14] and United Kingdom [13]. According to Table2, the obtained DRLs for brain CT scan of all age groups were higher than Germany and United Kingdom except the 10-15 years category that our DRLs were lower. In chest, abdomen and pelvic scans, the obtained DRLs were higher except the DLP value of 10-15 years category in chest CT scan, in which the obtained value was lower than United Kingdom result. This may be because of our lower scanning length in age group 10-15 years

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old compared to United Kingdom. In chest scans, all categories had same $CTDI_v$ values, but DLP was reduced by decreasing age, which was due to the shorter scan length in younger patients. In comparison with German results, our scan length was lower in all procedures except for the abdomen and pelvic procedures in age groups 5-10 years and 10-15 years. So, the dose can be decreased by reducing the scan length. Both $CTDI_v$ and DLP value of abdomen and pelvic procedures had the most inter center variation. The study indicated that in some hospitals, same protocol and radiation factor used for all age categories.

Duo oo duuroo	Age			CTDI			DLP			
Procedures	groups	This Survey	EC	United Kingdom	Germany	This Survey	EC	United Kingdom	Germany	
	0-1	40	40	30	33	448	300	270	390	
	1-2	40	40	45	40	461	750	470	520	
Brain	2-5	56	60	45	40	616	750	470	520	
-	5-10	59.5	70	50	50	758	750	620	710	
•	10-15	59.5	70	65	60	758	750	930	920	
	0-1	16.9	-	-	11	129	-	_	95	
Sinus -	1-2	16.9	-	-	13	129	-	-	125	
	2-5	16.9	-	-	13	129	-	-	125	
	5-10	17.14	-	-	17	154	-	-	180	
-	10-15	17.14	-	-	20	167	-	_	230	
	0-1	17	20	12	3.5	184	200	300	55	
	1-2	17	30	13	5.5	221	200	230	110	
Chest	2-5	17	30	13	5.5	229	200	230	110	
	5-10	17	30	20	8.5	306	200	370	210	
•	10-15	17	30	4	6.8	315	200	480	205	
	0-1	17	20	20	5	289	330	170	145	
-	1-2	17	25	20	8	374	360	250	255	
Pelvis and Abdomen	2-5	17	25	20	8	442	360	250	255	
Abdomen	5-10	19.2	30	30	13	595	800	500	475	
-	10-15	19.2	30	14	10	670	800	560	450	

TABLE 2. The details of Protocol which is used in different centers for brain examination

Using the same CT scan protocol for children and adults was resulted in radiation exposure higher than necessary in children, which can be due to the lack of awareness about radiation protection among staff at different hospitals. So, revision of CT protocols and reducing dose variation among different hospitals are crucially needed. The established DRLs would be suitable for the current situation of north region of Iran in CT procedures.

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JUSTIFICATION AND OPTIMIZATION IN PEDIATRIC RADIOGRAPHY

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Abstract

The system of radiation protection of children in radiography is based on principles of justification and optimization. To implement these principles into existing Russian radiation protection environment a set of methodological guidelines has been developed and implemented. X-ray examinations for children are justified through a radiation risk assessment based on effective dose estimation and age-specific coefficients. Optimization is performed through establishment of diagnostic reference levels for different age groups of children. Preliminary diagnostic referent levels have been developed and proposed in St-Petersburg for the following age groups: newborn, 1, 5, 10, 15 years. To complement the proposed justification methodology, diagnostic reference levels were established in effective dose.

1. INTRODUCTION

Questions of radiation protection of patients in medicine are currently the priority when using sources of ionizing radiation in connection with the expansion of methods and the increase in the volume of X-ray examinations, as well as the use of modern equipment and technologies [1]. The critical group of the population in radiology are children [2]. In these conditions care is needed for the health of children [3]. Therefore, the issues of radiation protection of children in medicine are particularly important and require practical improvement. This publication offers modern tools and methods for radiation protection of children in traditional diagnostic radiology.

Objectives of the study:

- To determine the doses irradiation of children with different X-ray procedures.
- To prepare guidelines and methodical documents containing methods of modern radiation protection for children.

2. MATERIALS AND METHODS

The studies were conducted in pediatric medical facilities in St. Petersburg during 2014-2016 years. A total of 29 organizations were surveyed. Investigations were carried out on 33 X-ray diagnostic units. Effective doses and the radiation risk of children at different ages (5 age categories with an average age of newborn, 1, 5, 10 and 15 years) and both sexes were determined for different X-ray examinations. The localizations of investigations were: the skull, lungs, spine, pelvis and abdomen.

The effectiveness of radiation protection was assessed by the criteria of justification and optimization. The justification of X-ray procedures was determined by the radiation risk of children, optimization - by establishment of preliminary DRL and the effectiveness of protective measures [4].

The risk was evaluated for certain age group on the basis of effective dose, using the nominal risk factors of ICRP [5], adjusted for age-related radiosensitivity [6].

The DRL was determined from the effective dose, obtained on the basis of direct measurements of the input dose or the dose area product (DAP) by the intrinsic technique described in [7]. The protective measures were evaluated by dose reduction in the form of an integrated approach, including taking into account the optimization of the parameters X-ray procedures.

3. RESULTS OF THE STUDY.

3.1. Determination of radiation doses of children's patients

Effective doses of children were determined for different types of examinations (tabl.1). It is shown that the doses of radiography, which constitute in an absolute majority of X-rays examinations, varied from 0.03 mSv for younger children to 0.55 mSv in adolescents. As a rule, with increasing age of children, the value of the effective dose per procedure is increased, except for lung studies. The largest doses are accompanied by studies of the spine (thoracic and lumbar regions - from 0.36 mSv, to 1.0 mSv) in a direct projection in adolescents; pelvis - 0,32 mSv and abdomen - 0,55 mSv (up to 1,8 mSv). Elevated doses are observed in newborns.

3.2. Justification for X-ray examinations of children

We used a multi-step approach to the justification process, which should take into account all the components of the diagnostic radiology: the specificity of the patient's illness, the requirements of clinical treatment standards, the competence of medical personnel, the available equipment, the cost of various diagnostic methods and the time required to conduct them.

The use of X-ray examinations was justified in each individual case for a specific procedure and for a specific patient. This was done, using the risk assessment of stochastic effects [6]. For this purpose, the risks for the examined types of X-rays examinations and the doses of irradiation of children were selected and identified (tabl.2). It is determined, that the risks of children vary from negligible in young children to low for different types of studies.

Radiation risk (relative units)	Risk level	Effective dose, mSv	Diagnostic radiology	Dental radiology
Negligible (< 10 ⁻⁶)	Less than 1 case per million people	< 0,01	X-ray of the extremities	Separate films, lateral craniogram, cephalostat
Minimum (10 ⁻⁶ - 10 ⁻⁵)	From 1 to 10 cases per million people From 1 to 10	From 1 to 10 Radiography: skull, chest, cases per 0,01–0,1 cervical spine million people Photofluorography (digital)		Panoramic X-ray
Very low (10 ⁻⁵ - 10 ⁻⁴)	cases per one hundred thousand people	0,1 – 1,0	<u>Radiography:</u> thoracic spine, lumbar spine, pelvis, abdomen <u>Photofluorography (</u> film)	СТ
Low (10 ⁻⁴ - 10 ⁻³)	From 1 to 10 cases per ten thousand people	1,0 - 10	<u>Fluoroscopy</u> : chest, stomach, intestinal	

TABLE 2. IRRADIATION LEVELS AND RADIATION RISK OF CHILDREN WITH DIFFERENT X-RAY EXAMINATIONS

The approach was emphasized, that the principle of justification primarily implies the use of alternative (nonradiative) methods.

3.3. Optimization of the level of exposure of children.

Optimization was aimed at two main elements of the diagnostic process: 1. X-ray imaging and radiological equipment (including parameters of its operation) and 2. Methods of work of the personnel of diagnostic radiology.

The main task of the optimizing implementation of the X-ray examinations was to adjust the work of the personnel of the diagnostic radiology and thus to achieve a minimum dose for a child patient with minimal exposure in obtaining the proper diagnostic information.

Procedure	Projection	Newbo	rn	1 year		5 years	5	10 year	S	15 year	S	Adults	3
Tiocedule	Tojection	Dose, mSv	DRL ⁴ , mSv	Dose, mSv	DRL, mSv	Dose, mSv	DRL, mSv	Dose, mSv	DRL, mSv	Dose, mSv	DRL, mSv	Dose, mSv	DRL, mSv
	Δ P ¹	0.04 ²	0.05	0.03	0.07	0.04	0.09	0.04	0.06	0.05	0.09	0,07	0.08
Skull	AI	$(0.01-0.17)^3$	0.05	(0.004-0.07)	0.07	(0.01-0.09)	0.09	(0.02-0.07)	0.00	(0.01-0.14)	0.09	(0,005-0,36)	0,08
Skull	Lat	0.03	0.05	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0,03	0,03
	Lut	(0.004-0.08)	0.05	(0.002-0.04)		(0.002-0.04)	0.05	(0.01-0.04)	0.05	(0.01-0.07)	0.05	(0,003-0,16)	
	PA/AP	0.03	0.05	0.04	0.05	0.03	0.03	0.03	0.04	0.03	0.04	0,08	0,09
Chest		(0.01-0.08)	0100	(0.01-0.13)	0102	(0.01-0.14)	0.00	(0.01-0.08)	0.01	(0.01-0.08)	0101	(0,008-0,57)	
chiest	Lat	0.04	0.05	0.04	0.05	0.04	0.03	0.04	0.04	0.06	0.08	0,13	0,17
	(0.01-0.14)	0.00	(0.01-0.15)	0102	(0.01-0.12)	0.00	(0.01-0.15)		(0.01-0.24)	0.00	(0,01-1,04)		
	AP	0.12	0.22	0.04	0.07	0.05	0.06	0.05	0.06	0.05	0.08	0,07	0,08
Cervical	ervical	(0.02-0.22)		(0.01-0.07)		(0.004-0.21)		(0.01-0.27)		(0.01-0.16)		(0,004-0,6)	
spine	Lat	0.03	0.02	0.03	0.05	0.03	0.02	0.04	0.02	0.05	0.03	0,05	0,06
	(0.01-0.1)		(0.01-0.09)		(0.002-0.2)		(0.004-0.39)		(0.003-0.44)		(0,005-0,3)		
	AP	0.17	0.30	0.24	0.35	0.17	0.26	0.24	0.32	0.36	0.58	0,41	0,40
Thoracic		(0.03-0.3)		(0.05-0.41)		(0.02-0.49)		(0.04-0.72)		(0.04-0.93)		(0,024-4.0)	
spine	Lat	0.14	0.26	0.15	0.23	0.14	0.18	0.18	0.22	0.27	0.32	0,28	0,34
		(0.02-0.26)		(0.04-0.31)		(0.01-0.41)		(0.03-0.51)		(0.02-0.72)		(0,015-1,32)	
	AP	0.14	0.28	0.21	0.24	0.29	0.36	0.33	0.45	0.36	0.50	0,7	0,93
Lumbar		(0.01-0.28)		(0.01-0.85)		(0.02-0.73)		(0.05-0.7)		(0.04-0.6)		(0,09-3,67)	
spine	Lat	0.16	0.29	0.16	0.35	0.16	0.25	0.20	0.30	0.40	0.58	0,7	0,87
		(0.02-0.29)		(0.01-0.48)		(0.02-0.35)		(0.04-0.35)		(0.04-1.02)		(0,06-6,71)	
Abdomen	AP	0.10	0.15	0.12	0.07	0.14	0.15	0.34	0.43	0.55	0.64	0,84	0,88
		(0.02-0.28)		(0.02-0.44)		(0.03-0.44)		(0.14-0.68)		(0.22-1.8)		(0,05-6,71)	
Pelvis	AP	0.06	0.08	0.06	0.11	0.13	0.21	0.25	0.33	0.32	0.50	0,7	0,81
		(0.02-0.2)		(0.01-0.19)	5.11	(0.01-0.51)		(0.06-0.63)		(0.03-0.96)		(0,05-5,19)	
Hip	AP	0.02	0.05	0.02	0.04	0.09	0.06	0.23	0.29	0.22	0.43		
пір АР		(0.01-0.05)	0.05	(0.01-0.04)		(0.01-0.46)		(0.03-0.47)		(0.02-0.44)			

TABLE 1. EFFECTIVE DOSES AND DIAGNOSTIC REFERENCE LEVELS (DRL) OF CHILDREN'S IRRADIATION FOR DIFFERENT AGES IN RADIOGRAPHY

¹Antero-posterior projection, ² middle value, ³ range, ⁴ 75%-quantile

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The personnel of the medical organization (medical physicists, engineers et al.) had to: have full information about operating modes and equipment protocols; have the ability to adjust protocols and change the settings of equipment in the absence of representatives of the supplier (developer); ensure the integration of software equipment into the hospital-wide information network (RIS/HIS); to achieve compliance of the characteristics of purchased equipment with regulatory requirements; to support diagnostic standard doses (DSD) for patients of different age and weight categories not higher than those established in a country/region DRL. Examples of DRL are given in table 1.

In particular, for radiography and fluoroscopy, dose reduction was provided by using modern highsensitivity X-ray receivers, dose restriction at the receiver, virtual collimation means, removable screening grid (rasters), the presence of pulsed fluoroscopy with variable transmission speed (frames per second) and the possibility of saving the last frame, as well as improving the algorithms pre- and post-processing images (spectral filters, digital subtraction etc.).

3.4. Development of methodological documents

With reference to general radiology and pediatric practice, a set of methodological documents (guidelines and recommendations) designed to provide the required conditions for radiation protection and radiation monitoring has been developed [6-9].

Guidelines have been developed in the development of the requirements of regulatory and regulatory documents, including specialized sanitary rules for ensuring radiation safety during X-ray examinations in diagnostic radiology [10, 11].

The instructions contain requirements for modern methods of radiation protection pediatric patients on the basis of the principles of the justification X-ray examinations and the optimization of the dose, in particular, the use of the criteria of the radiation risk of children on the one hand and the DRL, as an important tool of reducing doses for children.

The guidelines take into account the peculiarities of pediatric X-ray examinations, including high radiosensitivity, anthropometric characteristics and age dynamics. The guidelines apply to all major areas of diagnostic radiology in pediatry and consider radiation protection of patients in radiology, including radiography, fluoroscopy and fluorography; X-ray dentistry; computer tomography and interventional X-ray, as well as nuclear medicine.

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SECONDARY LUNG CANCER RISK IN PEDIATRIC PATIENTS TREATED FOR HODGKIN'S LYMPHOMA WITH 3D CONFORMATIONAL RADIOTHERAPY

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Abstract

For Hodgkin's lymphoma (HL) survivors, there is an increased risk of multiple secondary cancers compared to the general population; this includes lung cancer. This study aims to estimate the risk of secondary lung cancer in pediatric patients treated for Hodgkin's lymphoma with 3D conformational radiotherapy at some radiotherapy centers in Brazil. For this purpose, the competition model was applied, taking into account the fractional nature of the dose delivery and also the non-uniformity of the dose in the organ. The risk of secondary lung cancer was estimated using the LQ parameters α/β =3.07, α_1 =0.031 Gy⁻¹, β_1 =0.010 Gy⁻², obtained for lung damage after thoracic irradiation for Hodgkin's lymphoma. The estimated risk of secondary lung cancer ranges from 4.74 to 16.02%. The ability to predict radiation-induced cancer risks associated with radiotherapy protocols should allow the risks of a second cancer to be included in the treatment planning, potentially reducing secondary cancer incidence.

1. INTRODUCTION

The side effects that can be observed due to a cancer treatment are classified as early and late side effects, depending on whether they occur during the treatment, shortly after the end of the treatment, or months to years after completion of treatment. Side effects of Hodgkin's lymphoma treatment have been reported and include cardiovascular and lung diseases, endocrine abnormalities and secondary cancers [1]. Historically, relatively large irradiation fields were used in the treatment of HL. In order to reduce the risk of late side effects, there has been a big emphasis on the use of low radiation doses and smaller treatment fields, especially for young patients. For HL survivors, there is an increased risk of multiple secondary cancers compared to the general population; these include breast, lung, colorectal, thyroid, sarcomas, and stomach cancer [2]. The lung is among the most sensitive organs of late response, with acute pneumonitis and fibrosis identified as the major issue [3]. However, the emergence of secondary cancers after the treatment of HL has become very significant. Thus, this study aims to estimate the risk of secondary lung cancer in pediatric patients treated for Hodgkin's lymphoma with 3D conformational radiotherapy at some radiotherapy centers in Brazil.

2. METHODS

2.1. Hodgkin's lymphoma treatment data

3D conformational radiotherapy treatments were selected from pediatric patients who suffered Hodgkin's lymphoma treated at some radiotherapy centers in Brazil, with the intention of estimating the risk of secondary lung cancer. The planning target volume (PTV) consisted of the CTV (clinical target volume) with a 0.5 cm isotropic margin. A total of 9 patients were evaluated, for whom the prescribed dose (D_P) was 25.2; 23.4; 20.0

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and 19.8 Gy, delivered in 14, 13, 10 and 11 fractions (n), respectively. The most frequently used energy for the treatment was 6 MeV, and in some cases a combination of 6 and 15 MeV was used. The common characteristics to all treatments were the use of the Varian Millennium 120 MLC and the technique field-in-field. The linear accelerators used were Varian: Trilogy, Clinac 600C and CL2300C. Prescription doses and the fractionation scheme are shown in the Table 1.

Patient	Linac	Energy (MeV)	Beams	$D_P(Gy)$	n
1	Trilogy	6	6	25.2	14
2	Trilogy	6	6	23.4	13
3	Clinac 600C	6	4	25.2	14
4	CL2300	6 and 15	4	23.4	13
5	CL2300	6	4	25.2	14
6	CL2300	6 and 15	2	25.2	14
7	Trilogy	6	4	20	10
8	CL2300	6	3	19.8	11
9	Clinac 600C	6	8	25.2	14

TABLE 1	INFORMATION	REGARDING	TREATMENT	PARAMETERS
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From the Eclipse treatment planning system, the cumulative and differential HDVs were extracted for both the planning target volume (PTV) and the lung. This data served to perform a dosimetric study, taking into account the minimum dose (D_{min}), maximum dose (D_{max}), mean dose (D_{mean}), conformity index (CI) and dose homogeneity (HI), as well as dose-volume constraints for the lung.

2.2. Estimation of the secondary cancer risk

The risk was estimated using the competition model, considering the dose distribution in the organ of interest, for which the differential dose-volume histograms were used. The competition model takes into account the concurrent risks of genetic transformation of cells (initiation) and the increased likelihood of death of these cells at higher radiation doses (inactivation). These two mechanisms create the form of a dose response curve for secondary cancer that rapidly increases at low doses and drops abruptly at high doses [4]. When this model is used for the prediction of cancer risk after radiotherapy, it must be modified to take into account the fractional nature of the dose delivery. The role of fractionation in influencing cell survival has been extensively demonstrated over the years. More recently, it has been shown that similar fractionation effects also appear for the induction of DNA mutations [4]. Thus, it is assumed that both processes must be equally affected by fractionation. The risk of fractional irradiation can be given by Equation 1.

$$Ri \, \mathbf{\hat{\phi}} = (\mathbf{\hat{\phi}}_1 D + \frac{\beta_1 D^2}{n}) \exp\left[-\left(\mathbf{\hat{\phi}}_2 + \frac{\beta_2 D^2}{n}\right)\right] \tag{1}$$

Where D represents the total dose administered in n fractions, the first term in Equation 1 is the linearquadratic (LQ) estimate for initiation and the second term is the LQ estimate of cell survival. \blacklozenge_1 , \diamondsuit_1 and \diamondsuit_2 , \diamondsuit_2 are the linear and quadratic coefficients for the initiation and inactivation, respectively. In order to take into account the non-uniformity of the dose in the organ, the differential dose-volume histogram was used. The method for estimating the risk is applied calculating, at each dose range, from the differential dosevolume histogram and then integrate the result according to the dose distribution, as shown in Equation 2.

$$To \mathbf{a} \mathbf{a} Ri \mathbf{a} = \frac{\sum_{i} v_{ix} Risk(D_{i})}{\sum_{i} v_{i}}$$
(2)

Where v_i is the tissue volume receiving a dose D_i administered in *n* individual fractions, and $Risk(D_i)$ is the dose-response relationship of the competition model.

3. RESULTS

In Fig. 1, on the left is shown the differential lung HDV and on the right the risk contribution per dose, are observed two peaks in both cases, at low and high dose, the main contributors to the risk.



FIG. 1. Differential HDVs (left) of lung and the risk contribution per dose (right) of patients undergoing secondary cancer risk analysis.

For the PTVs, the dosimetric parameters are shown in Table 2. The Homogeneity index and conformity index were defined as: HI = $(D_{2\%}-D_{98\%})/D_{50\%}$, CI = $V_{95\%}/V_{PTV}$. A higher HI value, ranging from 0 to 1, represents worse homogeneity. A higher CI value, ranging from 0 to 1, represents better conformity.

Patient	$V_{PTV}(cm^3)$	\mathbf{D}_{\min}	D _{max}	D _{mean}	V _{95%}	V _{107%}	CI	D _{2%}	D _{98%}	D _{50%}	HI
		(Gy)	(Gy)	(Gy)	(%)	(%)		(Gy)	(Gy)	(Gy)	
1	1085.5	19.82	28.23	26.61	96.85	50.91	0.97	27.91	23.67	26.98	0.16
2	1179.1	0.005	28.38	25.36	95.74	68.45	0.96	27.70	19.57	25.72	0.32
3	953.4	10.98	29.61	26.74	94.66	57.54	0.95	28.95	20.37	27.18	0.32
4	919.5	7.03	26.19	24.69	99.15	35.60	0.99	25.82	22.30	24.88	0.14
5	85.0	20.73	27.28	26.41	99.60	3.28	0.996	27.00	24.84	26.51	0.08
6	462.0	19.40	28.87	27.44	98.79	83.12	0.988	28.51	24.48	27.68	0.15
7	801.5	12.67	22.28	21.00	97.43	30.88	0.97	22.12	18.67	21.11	0.16
8	585.6	12.39	23.14	21.34	95.16	66.97	0.95	22.79	17.35	21.60	0.25
9	369.7	0.26	28.90	19.55	63.26	22.13	0.63	27.90	0.56	26.25	1.01

TABLE 2.PTV COVERAGE BASED ON DVH ANALYSIS.

In Table 3, are shown the dose-volume constraints of the lungs, $V(_{xGy})$ represents the percentage of an organ's volume receiving $\ge x$ Gy.

Patient	Volume	D _{min}	D _{max}	D _{mean}	V_{5Gy}	V_{10Gy}	V _{15Gy}	V_{20Gy}
	(cm ³)	(Gy)	(Gy)	(Gy)	(%)	(%)	(%)	(%)
1	2486	0.27	27.82	9.88	40.82	35.55	31.79	29.31
2	1404.5	0.44	27.31	11.21	49.23	41.84	37.66	33.98
3	1945.7	0.28	28.45	10.13	42.95	37.37	33.09	29.86
4	2003.3	0.28	26.22	10.07	45.47	39.41	35.45	31.55
5	981.1	0.14	27.11	4.35	17.79	15.85	14.09	12.68
6	2402.9	0.08	25.53	6.17	27.74	24.28	21.86	19.24
7	763.6	0.54	22.18	11.34	59.66	51.82	45.66	30.38
8	646.5	0.26	22.88	9.33	47.03	40.22	35.46	25.71
9	994.1	0.28	27.24	8.89	41.53	32.07	26.86	22.57

TABLE 3. LUNG DOSIMETRIC PARAMETERS.

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The optimal dose (D_{opt}) for the lung is equal to 15 Gy [5]. The LQ parameters were: $\alpha/\beta = 3.07$ Gy, $\alpha_1 = 0.031$ Gy⁻¹ and $\beta_1 = 0.010$ Gy⁻² [6]. In the Table 4, are shown the parameters of cellular survival (α_2, β_2) calculated using Equation 3 [7] and considering $(\alpha/\beta)_1 = (\alpha/\beta)_2$, and the estimated risk of secondary lung cancer.

$$\boldsymbol{\phi}_{2} = \frac{1 + \frac{2D}{2}\boldsymbol{\phi}_{1}}{\frac{2D^{2}}{\boldsymbol{\phi}_{1}} + \frac{D^{2}}{\boldsymbol{\phi}_{2}} + \frac{2D^{2}}{\boldsymbol{\phi}_{2}} + D_{\boldsymbol{\phi}\boldsymbol{\phi}_{1}}}{\boldsymbol{\phi}_{1}}$$
(3)

TABLE 4. CELL SURVIVAL PARAMETERS AND ESTIMATED LIFETIME ABSOLUTE RISK.

Patient	$\alpha_2(Gy^{-1})$	$\beta_2(\text{Gy}^{-2})$	n	Risk (%)
1	0.0494	0.0161	14	10.25
2	0.0485	0.0158	13	12.69
3	0.0494	0.0161	14	10.49
4	0.0485	0.0158	13	11.10
5	0.0494	0.0161	14	4.74
6	0.0494	0.0161	14	6.66
7	0.0448	0.0146	10	16.02
8	0.0462	0.0150	11	12.92
9	0.0494	0.0161	14	10.75

4. CONCLUSION

The assessment of the plans indicates that lower volumes of the lung receiving significant doses are related to a lower risk of inducing a secondary cancer in the lung, as expected. From the point of view of reducing the risk of secondary lung cancer, it may be beneficial to reduce the total volume of treatment in pediatric patients treated for Hodgkin's lymphoma with 3D conformational radiotherapy. Radiobiological models can be included in the treatment planning system in order to estimate and reduce the incidence of secondary cancer after radiotherapy, especially in the absence of epidemiological studies.

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TECHNETIUM-99m IN BREAST MILK AFTER A NUCLEAR MEDICINE EXAMINATION OF A BREASTFEEDING PATIENT – DOSIMETRY AND RECOMMENDATIONS

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Abstract

Activity in breast milk samples was measured after administration of ^{99m}Tc-labelled radiopharmaceuticals to three mothers who were referred for nuclear medicine procedures (^{99m}Tc-pertechnetate, ^{99m}Tc-MAA/^{99m}Tc-DTPA aerosols and ^{99m}Tc-MAG3). The activity concentration in the breast milk as a fraction of the activity given to the mother was calculated followed by determination of the effective dose to the infant who was assumed to ingest the breast milk. The total fraction of activity excreted in the breast milk varied, 16% of the activity administered to the mother for ^{99m}Tc-pertechnetate, 1.8% for ^{99m}Tc-MAA/^{99m}Tc-DTPA aerosols and 0.056% for ^{99m}Tc-MAG3. Based on an effective dose limit of 1 mSv to the infant, it is recommended that breastfeeding should be interrupted for 12 hours for ^{99m}Tc-pertechnetate and ^{99m}Tc-MAA/^{99m}Tc-DTPA aerosols. During these 12 hours breast milk should be expressed at the ordinary feeding time (three meals) and discarded. Following this period, breastfeeding may resume without restriction. For ^{99m}Tc-MAG3 no interruption is necessary, though a 4-hour interruption (one meal discarded) will assure that the infant is exposed to only low absorbed dose in the case of any potential free 99mTc-pertechnetate.

INTRODUCTION

Administration of radiopharmaceuticals to mothers who are breastfeeding is generally avoided because the activity is secreted into the breast milk, which may result in unnecessary irradiation of an infant who ingests the milk. When a nuclear medicine procedure of a breastfeeding mother is vital it may be necessary to temporarily interrupt breastfeeding. Breastfeeding is important for the infant as well as for the mother [1]. Unfortunately, breastfeeding is often terminated unnecessarily. On the other hand, in those situations when a necessary cessation of breastfeeding is ignored, serious harm to the child may appear. As nuclear medicine examinations in breastfeeding patients are avoided and thus not part of clinical routine, it is important to have access to proper, clear and easily accessible recommendations on the duration of a feasible interruption in breastfeeding in those cases when it is necessary to perform the examination. Systematically collected data on the excretion of radionuclides into breast milk are rare [2-4]. Data are often published in the form of case reports, e.g. [5, 6]. There are a few reviews published [7, 8] based mainly on compilations of data published previously. Recently the International Commission on Radiological Protection (ICRP) published extensive recommendations including 47 different radiopharmaceuticals [9]. However, many of the studies contributing to the recommendations are based on a small number of patients and measurements. It is therefore important to continue collection of biokinetic data and dosimetric analysis for the infant of the nuclear medicine patient who is breastfeeding. In the study, we supplement our previously published data-base [2-4] with additional biokinetic and dosimetric data based on measurement and analysis on breast milk samples from three breastfeeding patients referred for a nuclear medicine examination.

METHODS

Breast milk samples from three breastfeeding mothers were included in the study. The patients were referred to Skåne University Hospital in Malmö for various nuclear medicine procedures. One patient was referred for a renography procedure (^{99m}Tc-MAG3), one for a thyroid scintigraphy (^{99m}Tc-pertechnetate) and one patient for a combined lung perfusion/ventilation study (^{99m}Tc-MAA/^{99m}Tc-DTPA aerosols). (Table 1).

Immediately after the administration of the radiopharmaceutical, breastfeeding was interrupted and the mother was instructed to use a breast milk pump during the infant's regular feeding times. Informed consent was achieved from the patients. Samples of breast milk from at least four feedings were taken. The point of time when the breast milk was expressed and the volume of each breast milk sample were noted. The activity in the sample or in a fraction of it was measured using a background shielded NaI(Tl)-spectrometer. Standard samples with thoroughly determined activity of the same radionuclide and the same volume as the breast milk samples in identical test tubes, as well as background samples of the same volume, were measured immediately before and after the breast milk samples in the same spectrometer. The activity concentration (Bq/ml) in the samples was calculated and corrected for physical decay from the time of administration. The activity concentration as a fraction of the activity given to the mother was calculated and a time-activity concentration curve was produced for each patient. The effective half-times and fractions for the activity concentration in the breast milk were calculated for each of the patients from bi-exponential curves fitted to the time-activity concentration data using the least-square-method. The total activity ingested by an infant was calculated from the time-activity concentration curve, assuming that the infant was fed 133 ml every four hours, until a negligible activity concentration remained in the breast milk. The mean absorbed dose to various organs and tissues as well as the effective dose to a newborn infant (body weight 3.5 kg) per unit activity administered to the mother were calculated for the total fraction of administered activity excreted in the breast milk and the absorbed dose coefficients [mGy/MBq, oral ingestion] and the effective dose coefficient [mSv/MBq] for the infant. The dose coefficients were determined in the same way as described by Leide-Svegborn et al., [2] assuming that the activity excreted in the breast milk was in the form of ^{99m}Tc-pertechnetate (^{99m}TcO₄).

RESULTS

The excretion of activity into the breast milk was rapid, with the peak value of the activity concentration reached in the first breast milk samples for all the three patients, within 5 hours after administration (Fig 1). The initial activity concentration in the breast milk varied somewhat for the three mothers, from approximately 10^{-3} to 10^{-5} ml⁻¹ (MBq in 1 ml breast milk per MBq administered to the mother), which is in concordance with results previously reported by Leide-Svegborn *et al.*, [2]. The effective half-time for the three patients in the study, however, did not vary as much (Table 1). Also this is in agreement with results previously reported [2].

Radiopharmaceutical	Activity administered to the mother	Total fraction excreted in milk (% of MBq _{mother})	T _{eff} (h)	Effective dose to a newborn infant (mSvinfant/MBqmother)
^{99m} Tc-pertechnetate	145 MBq	16	3.9	2.9.10-2
^{99m} Tc-MAA/ ^{99m} Tc-DTPA aerosol	173 / 26 MBq	1.8	4.0	3.4.10-3
^{99m} Tc-MAG3	70 MBq	0.056	3.4	1.1.10-4

TABLE 1. The radiopharmaceuticals and the activity administer to the mothers, the effective half-time and total fraction excreted in the breast milk and the effective dose to the newborn infant.

The total fraction of activity excreted in the breast milk varied, from 16% of the activity administered to the mother for ^{99m}Tc-pertechnetate to 0.056% ^{99m}Tc-MAG3 (Table 1). With no interruption in breastfeeding, the effective dose to a newborn infant per unit activity administered to the mother was determined to be 2.9·10⁻² mSv_{infant}/MBq_{mother} for ^{99m}Tc-pertechnetate, 3.4·10⁻³ mSv_{infant}/MBq_{mother} for the ^{99m}Tc-MAG^{99m}Tc-DTPA aerosol and 1.1·10⁻⁴ mSv_{infant}/MBq_{mother} for ^{99m}Tc-MAG3 (Table 1). Without any interruption in breastfeeding the infant who ingests the milk would get an effective dose of 4.3 mSv, 0.67 mSv and 0.0073 mSv for ^{99m}Tc-pertechnetate ^{99m}Tc-MAG3, respectively.



Figure 1. Fraction of administered activity per ml breast milk at various times after the administration of $(-- \bigtriangleup --)^{99m}$ Tc-MAA/ 99m Tc-DTPA aerosols, $(--\bigstar --)^{99m}$ Tc-MAA [2], $(--\blacksquare --)^{99m}$ Tc MAG3 and $(--\blacksquare --)^{99m}$ Tc-MAG3 [2], $(--\bullet --)^{99m}$ Tc-pertechnetate and $(--\bullet --)^{99m}$ Tc-pertechnetate [2], for the mothers included in the study and results reported by Leide-Svegborn *et al.*, [2].

DISCUSSION

The results for the patient that underwent a lung perfusion/ventilation examination with ^{99m}Tc-MAA/^{99m}Tc-DTPA aerosols are in concordance with those reported by Mountford and Coakley [6]. The effective half-time for the activity concentration in breast milk was 4.0 hours. The individual variation in the initial ^{99m}Tc-concentration (Fig 1) and, likewise, in the total activity excreted in the breast milk are presumably caused by various amounts of ^{99m}Tc-pertechnetate in the initial ^{99m}Tc-MAA preparation, and by varied rates of breakdown of macro aggregates in the lungs [2]. For the patient who received ^{99m}Tc-MAG3, only a small fraction of the administered activity was excreted in the milk (0.056 %). This was in agreement with previously reported values for this substance, (range: 0.020%–0.10%) [2]. This low amount of activity excreted in the breast milk is probably due to rapid passage of the substance through the kidneys and urinary bladder of the mother. The fractions reported in the study and by Leide-Svegborn *et al.*, are less than those reported by Evans *et al.* [10] of 0.7% and 1.0% for two different patients. The effective half-time of 3.4 hours was, however, in agreement with their reported values of 3.2 hours and 4.0 hours [10].

The fraction of the administered activity of ^{99m}Tc-pertechnetate that was excreted in the milk, 16% was of the same magnitude as reported earlier, (range: 5.3%–19% [2]). The effective half-time of the activity concentration in breast milk was 3.9 hours which in agreement as reported by Leide Svegborn *et al.*, (range: 2.7–3.9 hours) [2]. Normally, the labelling efficiency is better than 95-98% for most ^{99m}Tc-substances and ^{99m}Tc-pertechnetate as

an impurity is not considered a problem. However, concern has been expressed about *in vivo* breakdown of the ^{99m}Tc-MAA with release of free ^{99m}Tc-pertechnetate within the body. Similarities in the patterns of the decrease in the activity in breast milk with time for ^{99m}Tc-labelled radiopharmaceuticals (Fig 1 and [2])

indicate that the activity in breast milk with time for of ^{99m}Tc-pertechnetate. Berke *et al.* [11] found by chromatography that after an injection of ^{99m}Tc-MAA to the mother, ^{99m}Tc in breast milk was present as free pertechnetate. Thus, the results and the recommendations on breastfeeding interruption are based on the assumption that it is free ^{99m}Tc-pertechnetate that is present in the breast milk.

Based on the results of the study and an effective dose limit of 1 mSv to the infant, our recommendations is that for ^{99m}Tc-pertechnetate and ^{99m}Tc-MAA/^{99m}Tc-DTPA aerosols, breastfeeding should be interrupted for 12 hours during which breast milk should be expressed at the ordinary feeding time (at least three meals) and

discarded. Following this period, breastfeeding may resume without restriction. For ^{99m}Tc-MAG3 no interruption is necessary, though a 4-hour interruption (one meal discarded) will assure that the infant is exposed to only a low absorbed dose in the case of any potential free ^{99m}Tc-pertechnetate in the radiopharmaceutical given to the mother.

CONCLUSION

Cessation of breastfeeding or avoiding the nuclear medicine procedure may not be necessary for some ^{99m}Tc-labelled radiopharmaceuticals. Special concern should, however, be given to ^{99m}Tc-pertechnetate and ^{99m}Tc-MAA/^{99m}Tc-DTPA aerosol, where a 12-hour interruption is recommended during which at least three feedings should be expressed and discarded. For ^{99m}Tc-MAG3 no interruption is necessary, though a 4-hour interruption (one meal discarded) will assure that the infant is exposed to only a low absorbed dose in the case of any potential free ^{99m}Tc-pertechnetate in the radiopharmaceutical given to the mother.

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COMPARISON OF DOSE-AREA PRODUCT IN INFANTS DURING BARIU MEAL PROCEDURES

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Abstract

Barium meal procedures are used in the diagnosis of gastro-intestinal disorders, and involve a series of fluoroscopic images. These types of diagnosis result in a higher patient dose than conventional x-ray imaging. Pediatric patients are more radiosensitive and more likely to develop mutations due to the radiation exposure during their lifetime. The goal of this work is to estimate the radiation exposure levels of pediatric patients that were submitted to the barium meal procedure and confront the results found in the literature. The acquisition of a modern equipment made it possible the modification of several technical parameters aiming the reduction of dose for the patients. The reduction observed was 64%, for patients between 0 and 1 year of age, and 68% for patients between 1 and 5 years old, when compared with the literature.

1. INTRODUCTION

The use of ionizing radiation for medical proposes is increasing the total dose received from artificial sources. Although computed tomography represents a large section of that dose, radiographic imaging and fluoroscopic procedures correspond approximately to 10% of the total artificial dose [1]. When infants are subjected to imaging radiation the exposure needs to be compatible with their body size and is challenging to achieve comparatively low doses. Many facilities don't have the appropriate equipment or trained personnel to perform a proper exam in children. That results in very large amounts of unnecessary radiation exposure [1][2].

In Brazil, only a few studies have been done with the purpose of evaluating the doses received by infants during fluoroscopic procedures. The literature is even more sparse for barium meal procedures, not to mention those which propose an optimization for the exam [3–5]. Brazil does not have a diagnostic reference level (DRL) for children and with so few studies performed, it is necessary to use international DRLs in order to compare the results and check if the procedures being performed in paediatric hospitals stay within the expected dose [5].

The present study aims to compare the doses recorded in a previous work [3] from the same hospital that used an outdated equipment with those from a recently acquired equipment. The previous work was done in 2014/2015 and an optimization for the barium meal procedure was proposed. The results from that work showed a significant reduction of dose after applying the optimization; but the reported doses were still higher when comparing with some more recent papers [6–8]. The equipment used in the previous work was limited to using a continuous fluoroscopy beam and did not have the option for a removable grid or additional filtration; as suggested in many optimization guidelines [1, 4, 9].

Recently, a new fluoroscopy equipment was acquired by the hospital for paediatric exams. The features are promising and include: pulsed fluoroscopy, removable anti-scatter grid and very low exposure times. The present study intends to compare the doses from an optimized work done a few years ago with the doses that are currently being measured in infants.

2. METHODS

The first study [3] performed in the hospital used a Philips Diagnost 93 over couch system. The old equipment had a total nominal filtration of 2.5 mm aluminium.

A FLEXAVISION F3 Package from Shimadzu is the new equipment that has been used to perform the fluoroscopic procedures. A dose-area (DAP) meter was installed in the equipment in order to estimate the air kerma-area product ($P_{k,a}$) during the exposures. Along with the $P_{k,a}$ the following values were also collected:

- From the patient: age and weight, in order to categorize the patients in age groups of 0-1, 1-5, 5-10 and 10+ years, as reported in 2002 by NRPB as standard age groups. The patient's weight is going to be used in cases where the dose seems to be much higher for that age group;
- Technical information: total fluoroscopy time, kV and mAs selected for radiographic images, kV and mAs used in fluoroscopy irradiation, number of images taken (in "last image hold" mode and radiographic images), use of anti-scatter grid and focus-table distance were also collected.

Data from 10 exams were collected for the new equipment.

3. RESULTS AND DISCUSSION

The new equipment brought new options for technical set ups that can be addressed for reduction of dose. Table 1 shows the changes that the new equipment allows the technicians/physicians to perform that were not available in the previous equipment. These technical parameters are suggested by the EC recommendations [9].

TABLE 1. TECHNICAL DIFFERENCES BETWEEN THE PREVIOUS EQUIPMENT USED (PHILIPS) [3]AND IN THE PRESENT STUDY (SHIMADZU)

Technical Parameters	Philips Diagnost 93	Shimadzu Flexavision F3
Additional filtration	NO	NO
Pulsed exposition	NO	YES
Last image hold mode	YES	YES
Removable grid	NO	YES
Nominal focal spot value between 0.6 and 1.3	YES	YES
Maximum air kerma rate of 0.6 mGy/s	YES	YES
Minimum of 70 kV	YES	YES

3.1. P_{k,a} values found and comparison with the literature

The results found in the present study and the comparison with other previous works are shown in Table 2. The $P_{k,a}$ values found were obtained changing the technical parameters suggested by the EC. It is important to mention that no extra training for the staff on how to further reduce the exposure was performed. A pulsed fluoroscopic beam was used in all of the new procedures. In the data collected, frames per second (fps) ranged from 5 to 10. The selection of frame rate in the exams was made by the operator and may have a direct impact in the patient dose, as shown in the age group "5-10". That particular exam was performed using 10 fps and varied substantially when compared with the others age groups that used 5fps. The grid was removed when the patient's weight surpassed 18 kg, according to in the literature [1].

TABLE 2. COMPARISONS BETWEEN THE MEAN DAP (µGy.m²) ESTIMATED IN THE PRESENT AND PREVIOUS WORK, ALONG WITH MEAN DATA FROM THE LITERATURE. [3, 7, 8, 10]

Studios	Age groups (in years)							
Studies	0-1	1-5	5-10	10+				
Present	17.88 ± 2.8	22.14 ± 3.7	115.87^{1}	_2				
Filipov, 2017	50 ± 10	70 ± 10	80 ± 10	140 ± 30				

¹The age group "5-10" contains only one preliminary result. Therefore is not possible to determine if that number is going to represent the whole category.

² No exams were collected for this age group.

Hiorns, 2006	6.4 ± 8.6	9.5 ± 11.4	25 ± 26	25 ± 26
Bibbo, 2016	35	61	108	231
NRPB, 2002	70	200	325	560

By using the new technical parameters it was possible to achieve up to 64% and 68% in dose reduction in two age groups – 0-1 and 1-5, respectively – when compared with prior optimized work [3]. In the age group "5-10" a higher dose was observed when compared with the doses reported in Filipov's paper and other from the literature [7, 8]. This result gives rise for reflection about the modifications that need to occur in order to achieve lower radiation exposure to age group "5-10".

The mean DAP estimated in the present work for age groups "0-1" and "1-5" were also lower when compared with the reported values in others studies [7, 10]; however, still greater than the DAPs values described by Hiorns' work [8].

3.2. Others factors to be considered

Along with the pulsed fluoroscopy and the anti-scatted grid, other factors should be considered in order to further minimize the dose. The use of "last image hold" (LIH) instead of taking new radiographic images can spare the patient from significant additional dose. Studies show that it is possible to reduce the radiation dose by a factor of 10 by using LIH [11]. It is known that LIH presents lower image quality than radiographic images. However, if the image produced by the fluoroscopic beam presents enough quality and all the diagnostic information can be found, there is no need to expose the patient with more ionizing radiation. Radiographic imaging should be saved for situations when very small details need to be seen [1]. The ALARA principle should always guide the choices made during any procedure.

Information about the images taken during barium meal procedures can be found in Table 3. None of the exams followed by the present study used LIH for record the images. The images reported in Table 3 are all radiographic images. The mean number of radiographic images taken during the procedures in the present work and in the previous study [3] are very similar in all age groups. These similarities indicate that the dose reduction seen in Table 2 were due to the use of pulsed fluoroscopic beam, as there were no important decrease in numbers the images recorded.

	Average number of images recorded					
Age group (in years)	Filipov, 2017	Present study				
0-1	5.5 ± 0.5	5.5±0.5				
1-5	6.4 ± 0.7	6.5±1				
5-10	6.3±1.3	51				
10+	5.7±0.9	_2				

TABLE 3. MEAN NUMBER OF RADIOGRAPHIC IMAGENS RECORDED IN THE PRESENT AND PREVIOUS STUDIES.

4. CONCLUSIONS

The present work aimed the comparison between the $P_{k,a}$ reported in Filipov's results [3] and the present study evaluation; both studies followed the EC recommendations for optimized pediatric fluoroscopy procedures. The new equipment allows the implementation of technical parameters that were not available in the previous equipment; the use of a pulsed fluoroscopic beam in conjunction with an anti-scatter removable grid were accountable for 68% and 64% of dose reduction in patients between 1 and 5 years of age and patients up to 1 year old, respectively. The $P_{k,a}$ estimated for two-thirds of the age groups studied were lower than the 3/4 of the results reported in the literature. The average dose for the age group "5-10" was only lower than 1/4 of the works compared. The result found for this last age group might be an indicator for the necessity of an

optimization, involving personnel training and utilization of all the new features provided by the new equipment.

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PEDIATRICRADIATION PROTECTIONTHROUGHDMSA ^{99m}Tc ADMINISTRATEDACTIVITYSTUDYATNUCLEARMEDICINE DEPARTMENT, CONSTANTINE, ALGERIA.

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Abstract

Introduction:

Pediatric Medical radiation protection passes by prescription of optimal activities allowing an adequate examination with minimal irradiation.

The aim of this work is to compare injected and recommended EANM dosimetry and pediatrics committees (EANM.DPC) activities for ^{99m}Tc-DMSA renal scintigraphy. Material and methods:

A retrospective study, conducted for 118 children, explored for renal nuclear medicine procedure using ^{99m}Tc-DMSA. Age, body-mass and ^{99m}Tc-DMSA activities (DMSAa) were reported and compared to the recommended activity (REa) calculated through the EANM.DPC.

The DMSAa were divided as:

-Equal activity (Ea): REa. -Lower activity (La): REa (<-0,1mCi). -Higher activity (Ha): REa (>+0,1mCi).

Results:

```
\frac{1}{52} (Ea) = (44.1%).

50 (La) = (42.4%) among whom: 26 (-0,1mCi).13(-0,2mCi).7(-0,3mCi).2(- 0,5mCi).

2(-0,6mCi).

16 (U2) = (12.5%) among whom 14 (-0.1mCi) 2 (+0.2mCi)
```

16(Ha) = (13.5 %) among whom: 14 (+0,1mCi). 2 (+0,2mCi).

Discussion:

Thus 86,5% have(Ea) or (La) compared to the EANM with optimal dosimetry. 3,4% (-0.5 and -0.6 mCi) were children with adults body-masses which can explain found gap.

13,5% have minor higher activities.

Conclusion:

Children radiation protection passes by appropriate prescription DMSAa strictly related to body-mass following EANM.DPC recommendations.

Topic: Radiation protection of children

1. INTRODUCTION

The administration of radioactive sources is governed by the three rules of radiological protection which are justification, optimization and dose limitation. These rules must be used with rigor, especially in young population. In this order we checked compatibility between administered and international recommended activities, especially EANM Dosimetry and Pediatrics Committees [2] (EANM.DPC) ⁽²⁾ during renal scintigraphy [1] using ^{99m}Tc–DMSA ⁽¹⁾ in newborn, children and teenagers.

The justifications of the pediatric population study choice are:

- 75% of renal scans were children⁽³⁾
- Radiation increased sensitivity of the children [5]
- Radiopharmaceutical agent high absorbed doses to the kidneys for obstructive pathologies. [6]

⁽¹⁾ Dimercaptosuccinic acid labeled ^{99m}technetium.

⁽²⁾ EANM.DPC (European Association of Nuclear Medicine Dosimetry Pediatrics Committees).

2. METHODS

Retrospective study on 118 children's files (46 girls and 74 boys) aged between 1month and 15 years old explored in Nuclear Medicine Department, University Hospital Dr Benbadis, Constantine, Algeria for renal scintigraphy using ^{99m}Tc–DMSA⁽¹⁾.

Scintigraphy protocol was:

- Required minimum hydration[2]
- Body mass measured.
- DMSA-99mTc preparation with quality control procedure⁽⁴⁾

— Dedicated dose prepared measured under gamma camera before and after direct intra venous injection with injection site count.

- 4 hours later, delay frames acquisitions: Anterior, Posterior, LPO and RPO
- Uptake quantification according available protocol on our Workstation (Extended Bright View) from Philips who offers a dedicated application (kidney absolute uptake).

— Depth kidney was calculated automatically by the application using age, weight and height. Activities were divided as:

- \Box Equal activity (EA) ⁽⁶⁾ = recommended activity (REa) ⁽⁷⁾ (+/- 0.1 mCi)
- \Box Low activity (La) ⁽⁸⁾ = (REa) ⁽⁷⁾ (<-0.1mCi)
- \Box High activity (HA)⁽⁹⁾ = (REa) ⁽⁶⁾ (>+0.1mCi):
- 3. RESULT

a. The demographic characteristics of the study population are summarized in Figure 1

FIG. 1. Patient population distribution 30 25 ■under1 Y 2-3 Y 20 POPULATION 🖬 4-5 Y 🖬 6-7 Y 15 10 🖬 10-11 Y 🖬 8-9 Y 5 🖬 12-13Y 🖬 14-15 Y 0 AGE (Year)

Patients under one year old were 21% (25/118), 79 % (90/118) had less than 7 years (majority of the population were newborns and very young patients), and children over 10 years 17%(20/118) were only a small proportion.

b. Checking medical indications of kidney nuclear medicine procedure using ^{99m}Tc-DMSA on this young patient group are resumed figure 2.



FIG. 2. ^{99m}Tc–DMSA imaging indication distribution.

Ureteropelvic junction syndrome Hydronephrosis Megaureter Vesicoureteral reflux Mute kidney Acute/chronic pyelonephritis valves of the ureter Abnormal duplex kidney Displastic kidney Ectopic kidney Renal lithiasis Under pyelic obstacle Urinary tuberculosis Horseshoe kidneys Multicystic kidney Acute kidnev failure

No information

- (3) Personnel experience 118 children file /157.
- (4) Manufacture procedure of quality control in our case IBA Molecular Renocis®.
- (5) Patient can have one or many medical indications.
- (6) Recommended activity $\pm 0.1 \text{ mCi}$.
- (7) Recommended activity by EANM.DPC.
- (8) Recommended activity by EANM.DPC <-0.1 mCi.

(9) Recommended activity by EANM.DPC>+0.1mCi.

The parenchymal consequences of urinary diseases described above (Fig 2) can be grouped and constitute the major of kidney scintigraphy indications ⁽⁵⁾. [1,7,8]

- Consequences of congenital urinary diseases.
- Ectopic kidney detection.
- Renal focal abnormalities detection.
- Acute or chronic pyelonephritis.
- Nonfunctional kidney confirmation.
- c. Checking the quality of prescriber's panel: 94% of the ^{99m}Tc-DMSA kidney scintigraphy prescribers presents a high degree of specialization giving to the examination all its value because they are in close relation with:
- Age of the patient: Pediatric specialist and Pediatric surgeon.
- Disease specialists: Pediatric surgeon, Urologist and Nephrologist.

TABLE 1. PRESCRIBER'S QUALITY PANEL.

Speciality	Number	Percent
Pediatric surgeon	86	73
Pediatric physician	20	17
Urologist	4	3
Nephrologist	1	1
Other	4	3
Unknown	3	3

d. The prescription of ^{99m}Tc–DMSA in this population of patients related to the weight by comparing administered and to calculated theoretical activities using the EANM. DPC guidelines.

The activities were classified as follows:

- Equal activity (EA) ⁽⁶⁾: 92 patients (78%)
 - $\Box 52 (Ea)^{(6)} = (REa)^{(7)}$
 - \Box 14 (Ea) ⁽⁶⁾ = (REa) (+0.1mCi).
 - \Box 26 (Ea) ⁽⁶⁾ = (REa) (-0.1mCi).
- Low activity (La) ⁽⁸⁾: 24 patients (20%)
 - 13 (La) $^{(8)}$ = (REa) (-0.2mCi).
 - \Box 7 (La) ⁽⁸⁾ = (REa) (-0.3mCi).
 - \Box 2 (La) ⁽⁸⁾ =(REa) (-0.5mCi).
 - \Box 2 (La) ⁽⁸⁾ =(REa) (-0.6mCi).
- High activity (HA) ⁽⁹⁾: 2 patients (2%)
 - \Box 2 (Ha) ⁽⁹⁾ = (REa) (+0.2mCi).
- 4. DISCUSSIOIN
- a. Majority of patients were under 7 years and the largest category had less one year.
- b. Medical indications were respected as well as found in the different publications (one or many indications can be associated in the same patient)
- c. High degree of prescribers' specialization gave to the exam all its importance in order to take care adequately this diseases in this particular population to avoid severe complications and definitive sequelae.

⁽⁶⁾ Recommended activity +/- 0.1mCi.

⁽⁷⁾ Recommended activity by EANM.DPC.

⁽⁸⁾ Recommended activity by EANM.DPC <-0.1 mCi.

⁽⁹⁾ Recommended activity by EANM.DPC>+0.1mCi.

d. Recommended activities variation to the children is generally 0.04mCi per body mass unit (1kg) except weight between 3-10kg which activity is stable.[1] In this order equal activity (Ea) was specified as REa +/- 0.1 mCi including small variations between (0.01-0.03 mCi).

98.3 (116/118) received equal or lower activities according EANM.DPC ⁽¹⁾ recommended activities with a favorable dosimetry [1,9].

Patients having lower activities 20.3% (20/118) were motivated by:

- Children with adult body-masses.
- Reduced activity in relation with urinary obstructive diseases in order to reduce urinary system received dose.

Dosimetry evaluation shows a slight increased effective dose compared to EANM.DPC in order of 0.0814milliSv for the first and 0.111milliSv for second [7].

In final as any retrospective study a minor part of information was lost.

3. CONCLUSION

- □ Local law guide the radiopharmaceutical prescriptions helped by the society's guideline.
- □ Required medical indication prescribed by a medical competence able to use it.
- Dosimetry study did not show dose who can reach the critical thresholds.
- $\hfill\square$ The implementation of an internal system is necessary and allows to:
 - □ Harmonize prescriptions.
 - Detect the possible abnormalities.
 - □ Take decisions (in case)
 - Obtain the total satisfaction of three rules of the radiation protection especially in pediatric population.

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PATIENT DOSES IN HEAD CT EXAMINATIONS IN MONTENEGRO: INITIAL RESULTS

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Abstract

Results on collecting data, concerning exposure of patients in pediatric computerized tomographic (CT) diagnostic in Montenegro, have been presented in this work. Institute for children diseases, Center for radiologic diagnostic as well as Emergency Center, all being the integral parts of Clinical Center of Montenegro, have been covered by this work. Data have been collected for typical CT head examination, including four age groups of patients younger than 15 (<1, 1 - 5, 5 - (10 and 10-15). Total number of examined pediatric patients is 118. For each patient, volumetric CT dose index (CTDI_{vol}) and product of dose and length (DLP), along with data for patients and technical parameters used for scanning, have been recorded. For CTDI_{vol} and DLP, mean value, standard deviation, minimal and maximal values, have been calculated, as well as their values of third quartile (Q3) and median, that the best presents of estimated patient dose in medical institutions with a small number of samples, like it was a case with this work. All examination results have been read on command consoles of CT devices. Results show significant variations concerning exposure of pediatric patients in various CT departments of the same institution, what implements the necessity of practice harmonization. Therefore, this shows that CT diagnostic needs urgent optimization of practice, meaning protocol.

1. INTRODUCTION

During previous two decades, computerized tomography (CT) has been characterized by enormous technological progress as well as by development of new applications, and those things have enabled the spreading of area of CT diagnostic application, and possibility of its use in various dynamic studies and medical fields [1]. Introduction of new technological possibilities of application, as it is multislice (MSCT) and spiral scanners, which provide the possibility of very fast acquisition of data and reconstruction of diagnostic pictures, makes the modern diagnostics become impossible to be applied without use of this weapon [1-2]. However, this expansion of CT technique has led to significant increase of patient radiation doses which haven't been completely estimated [3]. On global level, according to UNSCEAR report for years 2000 and 2008, contribution of CT examinations in total radiation examinations of population, is in constant increase, when dose for individual/patient is concerned, as well as the total number of examinations. Therefore, contribution of dose which generates from CT examinations, in comparison to total dose of medical exposures, has increased from 34% to 43% [5].

Many researches show that, all around the World, number of CT examinations is rapidly increased, specially with children [3, 6-7]. For instance, when clinic practice in Great Britain is concerned, number of KT examinations with children and adults significantly increases and it is on the level up to 10% [8]. Out of total number of CT frequencies, pediatric examinations cover 5% [9]. The children are more sensitive to ionizing radiation, and they are supposed to live longer, therefore the possibility for development of radiation cancer is higher with them is higher than with the adults. Radiation sensitivity is ten times higher with children at very early age in comparison to average adult person. [10]. On the basis of Brenner's researches published at the beginning of 2001, it has been found that the risk for appearance of fatal carcinoma with children, who has been subjected to CT scanning, is about 1 in 1000 [6]. It has also been determined that, in many institutions, when children are subjected to CT examination, same parameters of exposition are used as for adults, and this makes the doses for children become significantly higher [5]. These results initiated the collection of data concerning exposure of pediatric patients on national levels, as well as on international ones [12-14].

This all together has initiated the introduction of concept Diagnostic Reference Levels – DRL, which enables easier and constant monitoring of patient dose trends, as well as identification of medical institutions which carry on bad work practice, meaning practice with higher patient dose. Considering the trend of collective dose increase, due to medical exposures, awareness of introduction of DRL, especially on national level, and of process of protocol optimization, significantly increase as well [5].

In Montenegro there is the same trend of appearances in pediatric CT diagnostics: increase of examination frequency, high dose pediatric patients, protocol for adults are used with children CT examinations, increase of use of helical scanning mode, long time scanning, etc. There are no established national diagnostic reference levels (DRLs). Actually, these are the first data collected for CT examinations in pediatric practice through participation in IAEA (International Atomic Energy Agency) project RER/9/132 Strengthening Member State Technical Capabilities in Medical Radiation Protection.

2. METHODS

These investigations include Institute for Children's diseases in Montenegro, Center for radiological diagnostic and Emergency Department, all of them are integral parts of Montenegro Clinic Center. There is only one children Institute (polyclinic) in Montenegro which has X-ray diagnostic ward in its organization structure. It is custom with us, on tertiary level of health care, to send all children patients from Montenegro to this institution for CT and magnetic resonance (MR) examinations. This polyclinic is equipped with very old CT which is not adjusted for children examinations, with very poor technical possibilities, it gets warm very fast and it is very hard to be started. Because of that, very small number of CT examinations (patient/daily) is done in this institution on yearly level. The reason for such trend is availability of MR equipment in this institution. If CT diagnostic information is needed, certain number of patients is sent to Center for radiologic diagnostics.

Data concerning number of examinations on yearly level have been collected from Clinical Center Archives and they are not quite precise. Analyzing available data it has been found that the most frequently are done CT examinations of head (over 90 %), abdomen (one patient per week) and lungs (one patient per month), and all this has been done according to recommendation of IAEA.

Collecting data, concerning levels of exposure of pediatric patients, has been done according to IAEA project RER 9/132 [13-15]. Data have been collected for standard and CT head examination for four different age patient groups below the age of 15 (<1,1 - <5,5 -<10 and 10-15 years). For each age group, at least 5 patients of both sex, have been collected. Total number of analyzed pediatric patients is 118. Basic/technical characteristics of CT devices, as well as the number of performed CT examinations on yearly level, have been presented in Table 1. Mean values for technical parameters of examination, such as voltage, product of current and time and pitch, have been also collected.

epartment	nufacturer Model CT	lumber of detectors	Year of nufacturing	Available Automatic Dexposure Control	Scanning	Ahgle gantry (°)	lumber of paediatric aminations /p	Voltage ⁸⁸	ŀt** (mAs)	Pitch. P**
D	M5 //	Ζ -	ma	H	•1		H H S	ŗ		-
	II:41-:4-	1	2007	N.	A: - 1	(0, 10)	260	116±8	195±28	1±0.1
А	Hitachi pronto	ittachi pronto 1 2007	2007	INO	Axial	(0-18)	260	(100-120)	(115-300)	(0.85-1)
ъ	Siemens/Somation	~ 1	2010	3.7		0	4.40	118±6	321±93	0.86 ± 0.1
в	Sensation	ion 64 2010 Yes Helical 0 149	149	(100-120)	(150-3080)	(0.85-1)				
C	Siemens/Somatom		2000	T 7	** ** *	0	1.60	121±9	289±70	0.59 ± 0.1
C	Emotion 16	16	2009	Yes	Helical	0	162	(100-130)	(150-380)	(0.55-0.85)

Tabela I. Characteristics for CT units, number of paediatric examinations* and technical parameters**

*number of examintions for 2015; ** these values include all age groups

Data concerning patients: number of patient, sex, weight and height; have been recorded as well (Table 2). For each patient, volumetric KT dose index ($CTDI_{vol}$) and product of dose and length (DLP), have also been recorded. For $CTDI_{vol}$ and DLP, mean value with standard deviation, minimal and maximal values, have been calculated. Values of median and Q3 for all four age groups have also been calculated, for they are good indicators of radiologic practice. Data have been collected reading values which have appeared on command console.

3. DISCUSSION

Presented results show that values CTDI_{vol} and DLP significantly differ, when head examination is concerned, among different wards in the same institution. Values, which have been recorded in this research, for CTDI_{vol} are in intervals (35-69) mGy, and for DLP in intervals (402-1749) mGy, for head examination, considering all four age groups. Comparing range of values recorded for pediatric patients to already published values, it can be concluded that they are on the level of minimal values for adults, and that they are either on the very level or slightly above these results.

	De	partment A		De	partment B		Department C			
Age groups	patients	Weight	Height (cm)	, umber of patients	(Kg)	Height (cm)	patients	Weight	Height (cm)	
(year)	(male/female)	$\begin{array}{c} \text{mean value} \pm \text{sd} \\ (\text{min-max}) \end{array}$		(male/female)	$\begin{array}{c} \text{mean value} \pm \text{sd} \\ (\text{min-max}) \end{array}$		(male/female)	$\begin{array}{c} \text{mean value} \pm \text{sd} \\ \text{(min-max)} \end{array}$		
0 1	11	6±2	64±7	6	7±3	69±8	6			
0 - 1	(6/5)	(3-12)	(55-75)	(2/4)	(4-11)	(55-79)	(3/3)	-	-	
1 - 5	11	20±4	103±13	8	17±3	100 ± 11	10			
	(7/4)	(14-20)	(80-114	(2/6)	(13-21)	(80-114	(6/4)	-	-	
5 - 10	13	30±9	130±11	10	32±8	135±8	8			
	(7/6)	(20-51)	(110-150)	(6/4)	(19-45)	(121-150)	(5/3)	-	-	
10-15	14	54±12	162±13	9	47±13	157±10	12			
	(11/3)	(37-78)	(135-164)	(5/4)	(35-55)	(140-167)	(6/6)	-	-	

Table 2. Basic Patient Demographic Data

Table 3. Distributions of CTDI_{vol} for standard head examination for pediatric patients observed in three departments

					CTDL1	mGv)				
Age groups		А			B	moy)		С		
(years)	Mean ± sd (min-max)	median	Q ₃	Mean ± sd (min-max)	median	Q_3	Mean ± sd (min-max)	median	Q ₃	
0-1	35±16 (9-55)	27	49	38±17 (23-60)	29	52	39±21 (23-60)	29	48	
1-5	48±12 (27-55)	55	55	44±19 (17-60)	60	60	40±22 (17-72)	30	61	
5 - 10	48±15 (14-55)	55	55	46±19 (15-60)	60	60	57±20 (31-72)	72	72	
10 -1 5	45±12 (28-55)	55	55	56±10 (30-60)	60	60	69±6 (60-72)	72	72	

Table 4. Distributions of DLP for standard head examination for pediatric patients observed in three departments

	DLP (mGy· cm)									
Age groups	Age groups A				В			С		
(years)	Mean ± sd (min-max)	median	Q ₃	Mean ± sd (min-max)	median	Q ₃	Mean ± sd (min-max)	median	Q3	
0-1	402±196 (109-744)	356	556	606±457 (260-1459)	482	673	631±437 (260-1460)	517	673	
1-5	655±196 (352-910)	717	799	816±401 (327-1315)	925	1220	804±1417 (327-1430)	634	1178	
5 - 10	710±233 (178-999)	800	827	1020±485 (420-1784)	923	1377	1340±520 (756-2111)	1276	1786	
10-15	708±226 (342-1047)	794	846	1470±174 (1195-1745)	1372	1598	1749±386 (1360-2509)	1640	2027	

In the cases when distribution is reached on smaller number of patients, recommendation given by some authors, for determination of reference value, is that mean value should be used [16]. Since mean value and Q_3 , recorded for a small number of patients, significantly differ, we will show values of median, because it seems to be real indicator of practice [15]. It can be noticed that values of dose parameters in Department A are similar, especially for groups of elder patients and this is so, probably due to very poor technical possibilities of their CT device, as well as due to the fact that the same protocol has been applied for all ages patients.

In departments B and C, it is evident increase in doses, according to increase of various age groups, and due to this fact, when pediatric patients are to be scanned, selection of protocol is to be done according to age/dimensions of child. Value of voltage, most commonly used, is 120 kV, no matter what age or weight the patient is. Selection of voltage value depends on level of contrast in picture which is demanded by radiologist, and that is the reason that so high level of voltage is applied. Values of pitch factor and rotation time of X-ray tube also remain unchanged in all four age of patients. High values of mAs has been also recorded. For elder children (5-10 and 10-15 years age) higher value of voltage is usually applied in comparison to younger age groups (0-1 and 1-5 years age), and this generally has been followed by decrease of mAs value, not being practice onexamined CT devices.

Length of scanning area impacts the exposure of patients as well. There is recommendation for CT examinations to be done only in area which is of interest for diagnostics (Sts, and, when pediatric patients are concerned in only one stage per each examination [11]. Considering the fact that CT scanning protocols are usually created by CT devices producers, parameters can be very rarely modified by operators who, very rarely accept suggestions concerning optimization of their practices. As a first step in procedure to raise their awareness of this matter, we have distributed posters related to CT examinations, than we pointed their attention to free publications, as well as to the site IAEA dealing with education in radiation production field [17].

1. CONCLUSION

Results of collecting data concerning level of exposure in pediatric CT diagnostic in Montenegro. Scope of recorded values for CTDI_{vol} and DLP is so wide and that gives enough opportunities for optimization of CT protocol. Establishing of national DRL is the best means in the optimization process in many countries. Montenegro also needs the establishing of national DRL for standard procedures with CT scanning of pediatric patients. Results of this research have also shown that, in our country, head CT is the most frequent procedure in pediatric CT diagnostics, therefore the optimization process should start just with these examinations. The only possibility to decrease the exposure of patients, especially children, is to educate all people who are, directly or indirectly, involved in examinations procedure.

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REFERENCE DOSE FOR PEDIATRIC COMPUTED TOMOGRAPHY IN NORTHERN IRAN ARASH JANBABANEZHAD¹, MOHAMMAD REZA DEEVBAND², ALI SHABESTANI MONFARED¹, FATEMEH NIKSIRAT SUSTANI¹, RUHOLLAH ABDI³, MEHRDAD NABAHATI¹

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Abstract

The major part of medical exposure comes from Computed Tomography (CT). pediatrics are more radiosensitive than adults, so optimization of CT procedures in pediatrics is suggested. The purpose of the study was to calculate dose to pediatric patients' undergoing CT scans and also propose local Diagnostic Reference Levels (DRLs). Questionnaires were send to seven public hospitals to collect information about patient, protocol and CT scan machines. Dose measurement was performed in four age categories: 0-1, 1-5, 5-10 and 10-15 years old and the recommended quantities that used in CT for dose expression including CTDIw and DLP were obtained. Values of 40, 48, 59.5, 59.5 mGy; 16.9, 16.9, 17.14, 17.14 mGy; 17, 17, 17 mGy; 17, 17, 19.2, 19.2 mGy in terms of CTDIw and 448, 538, 758, 758 mGy cm; 129, 129, 154, 167 mGy cm; 184, 225, 306, 315 mGy cm; 289, 408, 595, 670 mGy cm in terms of DLP as regional DRL for brain, sinus, chest, abdomen and pelvic procedures were obtained respectively. The variations in dose of some procedures were remarkable. As the application of CT technology progress, revision of protocols, for pediatric patients CT scan, following established reference levels is necessary.

1. INTRODUCTION

A study performed in United Kingdom have shown that pediatric CT examinations were increased about 63% [1]. Since the pediatric tissues have higher radiosensitivity, so their carcinogenetic risk can be more than adults [2]. In the last decade a number of researches were performed and indicated that optimization of paediatric radiation dose is required [3–9]. International Commission on Radiological Protection (ICRP) suggested Diagnostic reference level (DRL) in ICRP Publication 60 and 73 [10-11] as a tool for optimization. The third quartile of the dose distribution is defined as DRL [12]. This study aimed to evaluate pediatric CT dose values and propose regional DRL.

2. METHODS

Data were collected within a year for four pediatric CT procedures at Mazandaran public hospitals including: brain, sinus, chest and abdomen and pelvic scans. CT dose measurement was carried out using a calibrated pencil ionization chamber (DCT10 RS, Electronics, Molndal, Sweden) connected to X-ray multimeter (Barracuda, RTI Electronics, Molndal, Sweden) and 16cm diameter CT dosimetry phantom regardless of age or scan area. Recommended quantities that used in CT for dose expression were Weighted CT Dose Index (CTDI_w), Dose Length Product (DLP) and Volumetric CT Dose Index (CTDIvol), which were measured in the study. Measurements were repeated three times.

The data were analysed to assess the number of examinations. The mean value, the third quartile, standard deviation and p-values of data were calculated.

3. RESULTS

The seven hospitals participated in this study using spiral CT systems were encoded alphabetically from A to G. For all procedures, significant differences were observed in the scan parameter among the hospitals. Hospital C used lower tube voltage (kVp) for the younger patients, but other hospitals used a constant kVp for all age groups. The variation in the mAs value was also remarkable. Hospitals A, C and G used higher mAs with

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increasing patient age, but in hospital B higher mAs was observed for two youngest age groups. Differences in the slice thickness (from 4 to 10 mm) were also observed among the hospitals. Variations in CT scan machines and their parameters were resulted in patient dose variations between different hospitals for the same type of CT procedures. The mean value, amplitude and standard deviation of measured values in paediatrics age group are shown in table 1.

Procedures	Age		CTDI	w			DLP		
Flocedules	groups	Mean	Amplitude	75%	SD	Mean	Amplitude	75%	SD
	0-1	30.8	56-15	40	14	291	460-126	448	127
•	1-2	30.8	56-15	40	14	352.5	461-157.2	461	133
Brain	2-5	37.5	59.5-15	56	17.6	439	722-168	616	206
•	5-10	34.2	68-25.5	59.5	15.7	488	816-160	758	259
•	10-15	41.8	70-25.5	59.5	20.4	518	840-197	758	257.4
	0-1	12	25.8-3.8	16.9	7.7	72	135.2-21	129	44
•	1-2	12	25.8-3.8	16.9	7.7	75.8	135.2-25	129	43.6
Sinus	2-5	12	25.8-3.8	16.9	7.7	84.6	135.2-28	129	45
	5-10	12.3	23-1.8	17.14	7.9	100	174-34	541	52
	10-15	12.3	23-1.8	17.14	7.9	116.7	175.8-40	167	52.4
	0-1	7.8	23-1.8	17	8.5	86.6	184-27	184	80
	1-2	7.8	23-1.8	17	8.2	94	230-27	221	90
Chest	2-5	8.5	23-1.8	17	8.2	123	345-36	229	117.8
	5-10	9	23-1.8	17	8	157	368-55	306	128
•	10-15	9.7	23-1.8	17	7.4	208	437-75	315	125
	0-1	9.6	32-2.6	17	11	141	384-47	289	137
•	1-2	9.7	32-2.6	17	11	165	448-47	374	170
Pelvis and Abdomen	2-5	9.7	32-3	17	11	214	576-83	442	205
	5-10	10.7	32-3	19.2	10	287.7	640-96	595	229.5
	10-15	12.8	32-6	19.2	11	435.7	704-203	670	221.9

TABLE 1. The mean value, amplitude and standard deviation of measured values in paediatrics age group

Significant variation was seen in the dose of similar scan area, although there was a tendency between radiation dose and patient age. For brain scan, an increase in the DRL of $CTDI_v$ and DLP were observed by increasing paediatrics' age. A same increase in DRL of DLP was also observed in sinus, chest, abdomen and pelvic procedures. The standard deviations showed large variation in DLP of all procedures. The p-value of related results was calculated bellow 0.05. The differences were significant comparing the mean value of DLP between this study and United Kingdom, particularly in the 10-15 years old age group for brain and chest examinations.

4. DISSCUSSIONS AND CONCLUSIONS

This is the first study about measuring pediatric dose in CT scan procedures in north of Iran. The total frequency of procedures was near 32000 CT examinations during one year. Pediatric dose showed large variations for all procedures and each category. The CTDI_{v} and DLP of Brain CT scan had the highest values for all age groups in comparison with other procedures, which can be due to the thinner slice thickness and high level of mAs. Table 2 compares our DRL with proposed DRLs for Germany [14] and United Kingdom [13]. According to Table2, the obtained DRLs for brain CT scan of all age groups were higher than Germany and United Kingdom except the 10-15 years category that our DRLs were lower. In chest, abdomen and pelvic

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scans, the obtained DRLs were higher except the DLP value of 10-15 years category in chest CT scan, in which the obtained value was lower than United Kingdom result. This may be because of our lower scanning length in age group 10-15 years old compared to United Kingdom. In chest scans, all categories had same CTDI_v values, but DLP was reduced by decreasing age, which was due to the shorter scan length in younger patients. In comparison with German results, our scan length was lower in all procedures except for the abdomen and pelvic procedures in age groups 5-10 years and 10-15 years. So, the dose can be decreased by reducing the scan length. Both CTDI_v and DLP value of abdomen and pelvic procedures had the most inter center variation. The study indicated that in some hospitals, same protocol and radiation factor used for all age categories.

Procedures	Age			CTDI]	DLP	
Procedures	groups	This Survey	EC	United Kingdom	Germany	This Survey	EC	United Kingdom	Germany
	0-1	40	40	30	33	448	300	270	390
	1-2	40	40	45	40	461	750	470	520
Brain	2-5	56	60	45	40	616	750	470	520
	5-10	59.5	70	50	50	758	750	620	710
Sinus	10-15	59.5	70	65	60	758	750	930	920
	0-1	16.9	-	-	11	129	-	-	95
•	1-2	16.9	-	-	13	129	-	-	125
Sinus	2-5	16.9	-	-	13	129	-	-	125
	5-10	17.14	-	-	17	154	-	-	180
	10-15	17.14	-	-	20	167	-	-	230
	0-1	17	20	12	3.5	184	200	300	55
	1-2	17	30	13	5.5	221	200	230	110
Chest	2-5	17	30	13	5.5	229	200	230	110
•	5-10	17	30	20	8.5	306	200	370	210
	10-15	17	30	4	6.8	315	DLP EC United Kingdom G 300 270 G 750 470 G 750 470 G 750 470 G 750 930 G 7 - G - - G - - G 200 300 G 200 230 G 200 230 G 200 370 G 200 480 G 330 170 G 360 250 G 800 500 G <t< td=""><td>205</td></t<>	205	
	0-1	17	20	20	5	289	330	170	145
•	1-2	17	25	20	8	374	360	250	255
Pelvis and Abdomen	2-5	17	25	20	8	442	360	250	255
	5-10	19.2	30	30	13	595	800	500	475
	10-15	19.2	30	14	10	670	800	560	450

TABLE 2. The details of Protocol which is used in different centers for brain examination

Using the same CT scan protocol for children and adults was resulted in radiation exposure higher than necessary in children, which can be due to the lack of awareness about radiation protection among staff at different hospitals. So, revision of CT protocols and reducing dose variation among different hospitals are crucially needed. The established DRLs would be suitable for the current situation of north region of Iran in CT procedures.

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REDUCING THE RADIATION DOSE FROM DIAGNOSTIC IMAGING IN CHILDREN: WHAT CAN ONE DEPARTMENT DO?

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Abstract

Staff in our department and our pediatricians are generally aware of the increased risks of radiation in children and seek to minimize them. However recent initiatives such as Image Gently and the Bonn Call for Action have stimulated us to look for additional ways that we can reduce radiation risk for the children in our diagnostic imaging department.

<u>Methods</u>: Two radiologists (MR, HM) are collaborating with two imaging physicists (IE, HI) and with clinical colleagues, to undertake a number of projects related to radiation dosage in the children we image. We examine our practice patterns to identify ways to reduce dose without impacting clinical outcomes.

<u>Results</u>: Our collaboration resulted in several projects assessing the effects of coning, magnification and grids on radiation dosage and image quality. We have undertaken several projects relating to dose assessment and reduction in NICU radiography. We also explored several clinical applications for digital tomosynthesis as a lower-dose alternative to CT.

<u>Conclusion</u>: Collaboration between radiologists and imaging physicists facilitates the undertaking of projects which have clinical impact in assessing and reducing radiation dose in children.

1. INTRODUCTION

Radiation protection in children is one of the tracks of this meeting. Staff in our department and our pediatricians have always been aware of the risks of radiation in children. However recent initiatives, such as Image Gently and the Bonn Call-for-Action, have stimulated us to look for ways that we can reduce the radiation risk for the children in our department.

2. METHODS

Two radiologists [MH, HM] have been collaborating with two imaging physicists [IE, HI] and some of our clinical colleagues to undertake projects to assess and reduce the radiation dose for the children who are imaged in the pediatric department. Our group looks at clinical practices in our department to identify potential radiation dose
savings. The fact that our group consists of radiologists and physicists ensures that our dose-reduction efforts do not compromise diagnostic quality.

3. RESULTS

Our investigations have focused primarily on three topics: radiation dose of infants who are treated in the neonatal intensive care unit (NICU), the tools available in imaging equipment which affect radiation dosage, and the potential role of digital tomosynthesis (DT) as an alternative to computed tomography (CT) in children.

2.1 ALARA in the NICU

Premature infants who are treated in NICUs are particularly susceptible to the risks of radiation because of their age and the frequent imaging required for their care. Our department and the neonatologists we work with have always been concerned about limiting the radiation that patients in our NICU receive [1]. We have carried out a number of studies to estimate organ and effective doses from NICU radiography [2], and developed a simple technique to estimate the effective dose from readily available parameters [3,4]. Using these methods we have studied the effective dose that our neonates actually receive [5,6]. As a result of these studies we implemented a high KV technique for NICU radiography which reduces dose significantly without impacting diagnostic quality. [7]. We have also worked on developing a method of automatically transmitting dose area product readings from the portable equipment used in our NICU to our PACS.

We are now undertaking studies to estimate the cumulative radiation dose that infants receive in the NICU. To determine comparative data we are undertaking a systematic review of the literature on the imaging examinations and radiation dose in the NICU. We are also carrying out a retrospective study over the last 30 years to determine if there is a correlation between the number of diagnostic imaging studies a neonate receives and the length of stay in the NICU. Recently infants as young as the gestational age of 23 weeks are being resuscitated. We are collaborating with a fellow in neonatology to determine whether the gestational age of 29 weeks or less correlates with the number of imaging studies that babies receive during their stay in the nursery.

2.2 Tools for dose reduction in pediatric imaging

In fluoroscopy, there are a number of system features which can affect radiation dose and image quality. In an initial investigation, we assessed the effects of magnification, image receptor to patient distance, coning, and the use pulsed fluoroscopy on the effective dose to children undergoing fluoroscopy. This study showed that increasing magnification increased the effective dose to patients up to 165% and increasing the image receptor to patient distance increased the effective dose up to 142%. Increasing collimation could reduce the effective dose by as much as 57% and using pulsed fluoroscopy could reduce it by as much as 62% [8]. This project has made radiologists, trainees and technologists in our department much more aware of the importance of managing these tools to limit radiation dose to children during fluoroscopy. Anti-scatter grids are a standard feature in radiographic and fluoroscopic imaging, but their use comes with a dose penalty. Since scatter increases with patient size, grid use maybe unnecessary when imaging smaller children. We investigated the use of grids in tomosynthesis [9]. We are currently conducting a clinical evaluation of the use of grids in chest radiography to determine the appropriate size and age of patients for using them. We are also investigating the use of grids in pediatric fluoroscopy. We recently completed a scoping review of the literature on the use of grids in fluoroscopy [10]. Only 14 papers have been published on the subject in the last 25 years, most of them on cardiac angiography and interventional procedures. Only six of them specifically examined the use of grids in pediatric fluoroscopy. We are currently undertaking a study of the use of grids in low-contrast pediatric fluoroscopy, particularly voiding cystourethrograms.

2.3 Digital tomosynthesis

In 2009 we acquired a DT-capable digital radiographic system and embarked on exploring pediatric applications of DT imaging, in collaboration with GE Healthcare. We initially studied the radiation dose resulting from DT imaging in children and the quality of the images [11,12]. Our results showed that DT dose was significantly less than that of CT, and the image quality was promising. We subsequently evaluated the potential use of DT in a number of specific clinical situations, including imaging of the sacroiliac joints (because of concerns for the uterus of female patients), renal calculi, and the evaluation of trauma to facial bones [13,14]. In these cases, the images were not considered clinically satisfactory by radiologists in our department. When we investigated the use of DT in imaging the paranasal sinuses, our results showed that using DT to exam sinuses in children was limited by movement artifact, particularly in children under the age of 10 years, positioning artifacts and artifacts produced by **unerupted teeth [15]**. We have also assessed the use of DT in the diagnosis of spondylolysis and in the assessment of bony abnormalities of the temporomandibular joints. Our investigations have shown that tomosynthesis is very effective for both these clinical indications and we now use it routinely in our department for these cases.

4. DISCUSSION

In collaboration with the Manitoba Centre for Health Policy, which has access to long-term administrative data, we plan to use the information acquired from our studies in the NICU to determine if NICU patients have an increased risk of leukemia which may be the result of their exposure to frequent x-ray imaging at an early age.

We intend to continue our studies of the appropriate use of grids in imaging children. The next planned project is an evaluation of the appropriate use of grids in high contrast fluoroscopic examinations in children.

We have recently installed a new low-dose CT scanner and we will be evaluating the radiation doses from this equipment to determine if there is still a significant radiation dose saving from using DT.

Most of our projects have involved students, and we have thus been able to expose radiology fellows (2), radiology residents (1), medical students (5), research assistants (2) and undergraduate students in various faculties (6) to the principals of radiation dose, image quality and radiation risk which we believe is an important side benefit of our work.

5. CONCLUSIONS

Close collaboration between imaging physicists and radiologists in our department has allowed us to undertake a number of projects to assess and potentially reduce radiation dose for the children whom we image.

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DISSEMINATION OF THE RADIATION PROTECTION PROGRAM FOR CHILDREN TO A BRAZILIAN SYSTEM OF HEALTHCARE COOPERATIVES

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Abstract

Introduction: In line with global actions for radioprotection, guided by the Image Gently campaign, supported by the Brazilian College of Radiology, a nationwide campaign was launched to disseminate and implement the Radiation Protection Program for Children throughout the "Unimed System," gathering cooperatives that represent 17.5 million of Brazilian health insurance beneficiaries. Objective: To promote the implementation of a structured, nationwide Radiation Protection Program, in accordance with national and international radioprotection guidelines. Method: Support materials were created for local dissemination and sensitization of multi-professional teams, with an Implementation Guide containing step-by-step actions to be carried out by the cooperatives, all based on the current literature, international campaigns and the Brazilian legislation. Participating cooperatives sign a membership agreement and receive support throughout the implementation process. Results: In the first year, 43 cooperatives (representing 2,7 million beneficiaries) joined the Program. Out of these, 16 have already prepared and enforced a Radioprotection Commission according to the Brazilian legislation, and began their activities following a structured schedule in tune with their local realities. Conclusion: Their adhesion to the campaign led to the revision and creation of protocols aimed at preventing the risks associated with ionizing radiation in the institutions involved.

1. INTRODUCTION

Diagnostic imaging currently plays an essential role in health care. Through it, physicians are guided for a better management of their patients' clinical picture, with more effective analyzes on each case and the possibility of optimizing the treatment offered.

With the increasing use of technology and improved access to imaging examinations, there has been a significant increase in exposure to ionizing radiation in the past decades, mainly associated with the use of computed tomography (CT) [1].

Several studies indicate that early exposure to ionizing radiation, even at low doses, in the long run, may increase the risk of leukemia, brain tumor and thyroid cancer, especially for children, due to their life expectancy [2-4]. It is also known that children are more sensitive to radiation, as their tissues are still developing [5,6], which makes radiation exposure monitoring even more important in this age group.

International campaigns emphasize the importance of the radiation protection program for children [7] and adults [8] to raise health professionals and patients' awareness about the risks related to excessive exposure to ionizing radiation. In addition to occupational risk issues, Brazilian law provides guidelines for population protection against possible inherent risks related to ionizing radiation use, and establishes a national policy for radiation protection in radiodiagnosis [9].

Unimed is a medical work cooperativist system that serves 37% of all Brazilian health insurance beneficiaries (17.5 million people) [10], thus having a great impact potential for the implementation of a radioprotection awareness program.

A pilot project was developed at one of the Unimed System hospitals in Sao Paulo, Brazil, based on a masters thesis submitted in 2013 by a radiologist physician and Unimed System cooperative member [11 - 12].

Based on the pilot project, taking the ImageGently [7] campaign as a reference and with the Brazilian College of Radiology [13] support, a national campaign for dissemination and implementation of Radiation Protection Program for Children was launched for the entire Unimed System.

2. OBJECTIVE

Promoting the national implementation of a Radiation Protection Program, in a structured manner and in accordance with national and international radioprotection guidelines.

3. METHODS

In May 2016, with support from the corporate marketing team, the national campaign "Radiation Protection Program for Children" was launched. The campaign was promoted throughout the entire Unimed System in internal communication channels and in major national events with cooperatives directors.

Aiming to standardize the campaign's flow of information from the cooperatives to the public, multiple support materials were created for local dissemination and awareness of the multidisciplinary team members. They were all based on scientific evidence, international campaigns and the Brazilian law. The following materials are available for download via web:

- Orientation booklet for physicians and radiology professionals;
- Orientation booklet for parents or guardians;
- A website with basic information on radioprotection for the lay public;
- An examination record card;
- A corporate campaign video;
- Campaign folders;
- Posters for corporate promotion; and
- Ads for newspapers and magazines.

As part of the promotion's supporting material, a step-by-step guide for program implementation was written, which includes the responsibilities of the radioprotection committee members and the process of communicating information to the public.

A data control sheet was also created for the participating institutions to report the monthly number of radiological examinations (chest and facial x-ray) and CT scans performed at the urgency/emergency care units and generated by elective appointments, separated into the following age groups: 0 to 4 years old; 5 to 8 years old; 9 to 12 years old. Like the number of examinations, the number of visits performed in the same period and place is also reported, subdivided in the same age groups.

After showing interest in joining the program, cooperatives signed a membership agreement and started being followed up, receiving support for any doubts raised during the implementation process. As this is a voluntary membership program which allows new participants to join at any time, actions proposed by the implementation guide were summarized in four phases to facilitate their monitoring (Fig 1).



FIG. 1. Program Implementation Phases

The analysis of the data and information sent by cooperatives is carried out by the national confederation of medical cooperatives - Unimed do Brasil. Where there is a department responsible for monitoring, clarifying doubts and promoting periodic meetings to disseminate results and exchange information among participants.

4. RESULTS

By the second half of 2017, 43 cooperatives (representing 2,7 million beneficiaries) have joined the program; 16 of them structured the radioprotection committee and started activities following the implementation guide, according to a structured schedule based on their local conditions.

Data regarding the number of examinations (chest and face x-ray; CT scans) were analyzed in relation to the number of elective appointments and emergency room visits. Age groups considered were 0 to 4 years old; 5 to 8 years old; 9 to 12 years old.

In the first year, i.e., the period from May 2016 to May 2017, collected data showed that the number of consultations was higher for the 0 to 4 age group, representing on average 62% of all consultations performed at the ER and 56% of elective appointments. Therefore, the demand for care was higher among children up to 4 years of age in relation to the other age groups considered.

In the same period, the percentage of examinations performed per consultation was higher for ER consultations in relation to elective appointments, that is, there was a greater number of requests for examinations per consultation in the emergency room than in the elective appointments.

5. DISCUSSIONS

Due to the differences between the services analyzed, such as the complexity of care and the influence of seasonality, it is not possible to establish a standardized, applicable to all structures range for the percentage of examinations demanded per consultation. On the other hand, results show that the demand for medical care is higher for the lower age groups; as a consequence, this group has a higher risk of being exposed to radiological examinations, especially in urgency and emergency care.

The incorporation of the new concepts to avoid unnecessary radiological examinations, the awareness of all those involved in patient care, including managers, radiologists, pediatricians, technical staff and the community, started a process of change. It involved promoting risk awareness to family members and preparing the care team for creating work instructions focused on radioprotection and equipment calibration planning, radiation exposure control for clients and instructions for the medical team on the new protocols for requesting diagnostic imaging.

The exchange of experiences with cooperative members in the more advanced stages of the program stimulates new participants and facilitates the processes of program implementation and follow-up, creating new solutions and clarifying any doubts on issues of each service.

6. CONCLUSIONS

Adherence to the program led to revision and creation of protocols to prevent the risks associated with ionizing radiation in the involved institutions. Dissemination of evidence-based knowledge, following the guidelines of relevant medical societies, strengthens professional support and promotes the development of a culture of safety.

The involvement of family and guardians, through the dissemination of information, directly affects the perception of risks associated with ionizing radiation and the sense of responsibility, patients being the main beneficiaries of this initiative.

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COMPARISON OF ASSESSMENTS OF RADIATION RISKS FOR RADIOGRAPHIC X-RAY EXAMINATION OF CHILDREN

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Abstract

The use of the effective dose and the nominal risk coefficients, averaged by sex and age, to assess the radiation risks of medical exposure has some significant limitations. A more accurate assessment of lifetime risk of long term stochastic health effects of patients is achieved by using the organ doses and age- and sex-specific risk factors. The lifetime risks of long-term stochastic health effects for different sex and age groups of children for 12 most common radiographic examinations (skull, chest, cervical spine, thoracic spine, lumbar spine, abdomen and pelvis), based on organ doses and age and sex risk factors calculated for the Russian population, were assessed and compared to the radiation risks based on both the effective dose and organ doses and the risk factors for the composite population. Assessment of risks based on the effective dose underestimates radiogenic risk for the Russian population up to a factor of 6 for girls and overestimates risk by a factor of 1.6 for boys. Risks assessed using risk factors for the Russian population were significantly lower compared to the risks based on the risk based on the risk factors for the Russian population were significantly lower compared to the risks based on the risk based on the risk factors for the Russian population were significantly lower compared to the risks based on the risk based on the risk factors for the Russian population were significantly lower compared to the risks based on the risk factors for the composite population.

1. INTRODUCTION

Protection of the patients from medical exposure based on the principle of justification requires weighing the clinical benefit and possible radiation harm (risk) from the X-ray examination. ICRP does not provide any specific recommendations for the evaluation of the radiation risks from medical exposure. It has become common practice to use effective doses for X-ray examinations and nominal risk factors averaged by age and sex for this purpose.

There are several limitations in using this approach to evaluate the risks from medical exposure [1, 2, 3, 4]. The age and sex distributions of personnel and entire population for whom the effective dose concept was developed is different from the age and sex distributions of patients [5, 6]. Estimates of lifetime risk of incidence of stochastic effects for children are higher up to a factor of 2-3 compared to the nominal risk values; for elderly (patients with age ≥ 60 years at the time of irradiation) they are, on the contrary, lower by a factor of 4-5 [7]. A more correct estimate of radiation risk is achieved with the use of organ doses and sex-age risk factors. The aim of the study was to compare different methods for assessing the risks of children in Russia: using organ doses and sex-age risk factors and effective doses and nominal risk factors

2. MATERIALS AND METHODS

Examinations of the skull, chest, cervical spine, thoracic spine, lumbar spine include the radiography of the corresponding area in two projections: antero-posterior and lateral, and the studies of the abdomen and pelvis consist only of radiographs in a antero-posterior projection. Thus, the work considers 12 radiographic procedures. 33 x-ray units were surveyed in 29 dedicated paediatric hospitals. Five age groups of children were considered:

newborns (<0.5 y), 0.5-2, 3-7, 8-12 and 13-17 years old - with an average age of 0, 1, 5, 10 and 15 years,

respectively. The anthropometric data for each age group corresponded to mathematical anthropomorphic phantoms [8] and was accepted as a characteristic of the typical patient for each age group. Patient doses and parameters of the examinations were collected for at least 10 typical patients from each age group for each X-ray unit.

The following data for the calculation of organ and effective doses of the patients was collected: radiation output of the x-ray unit (mGr·m²/mA·min), total filtration thickness and material of the filter, tube voltage (kV), tube current-time product (mAs), focal-image distance (cm), size of the irradiation field (cm·cm), and irradiation geometry (projection and location of the irradiation field) [9], dose-area product (DAP, cGy·cm²).

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Organ and effective doses for the selected examinations were calculated using the PCXMC 2.0 software [10] based on DAP, for all X-ray units for five age groups using tissue weighting coefficients from ICRP Publication 103. Median values of organ and effective doses for each examination for five age groups for the whole patient sample were calculated and used for the subsequent risk assessment.

The calculation of lifetime attributive risks using a model from ICRP Publication 103 was performed according with the methodology provided by Ivanov et al. [11]. Median values of the organ doses for each examination and the sex-age cancer risk factors calculated for the Russian population (mortality and morbidity data for 2008 [12]) were used for the risk assessment. Organ and effective doses for children from different age groups were interpolated into 5-year intervals considering the dependence of radiation risk factors on age according to the equations 1-3:

 $DD_{vv}(0-4) = (DD_{vv}(0-0.5) + 2DD_{vv}(0.5-2) + 2DD_{vv}(3-7)/5; (1)$

 $DD_{pp}(5-9) = (3DD_{pp}(3-7) + 2DD_{pp}(8-12)/5;$ (2)

 $DD_{pp}(10-14) = (3DD_{pp}(8-12) + 2DD_{pp}(13-17)/5;$

(3) where: Dp is the organ dose from examination P, mGy;

For the 15-19 years age group, organ and effective doses were calculated for a mathematical phantom of 15 years.

Lifetime radiation risk for a patient of sex G and age A (years at the time of irradiation) from examination P was calculated according to Equation 4:

 $RR_{pp}(AA, GG) = \sum_{00} DD_{pp}(AA, 00) \cdot rr(AA, GG, 00)$ (4)

where: Rp (A, G) is the lifetime radiation risk for a patient of sex G at the age of A (years) due to the X-ray examination P, rel. units;

Dp (A, O) is the organ dose in the organ O of a patient of any sex at the age of A (years) from examination P, mGy;

R (A, G, O) is the nominal coefficient of radiation risk for irradiation of the organ O of a patient of sex G at the age of A (years), 10^{-4} mGy⁻¹.

For examinations performed in two projections, risk values were calculated as a sum of risk values for the corresponding projections.

3. RESULTS AND DISCUSSION.

Individual radiation risk Rp (A, G) for the patients of different sex and age for the selected X-ray examinations was calculated based on the organ doses and the age-sex risk factors. The results of risk calculations are presented in Table. 1.

TABLE 1.	LIFETIME RADIAT	ION RISK R _P (A, G)	FOR THE PAT	FIENTS BAS	ED ON	ORGAN DOSES
$D_P(A, O), DE$	EPENDING ON THE A	AGE AND SEX FOR	R DIFFERENT	X-RAY EXA	MINATI	ONS, 10 ⁻⁶

		Risks	, male		Risks, female			
X-ray exam				Age,	years			
	0-4	5-9	10-14	15-19	0-4	5-9	10-14	15-19
Skull	1,69	1,39	1,23	0,98	10,29	6,76	3,28	1,05
Chest	2,22	2,11	2,08	2,00	17,85	17,38	16,45	13,79
Cervical Spine	2,13	1,88	1,62	1,36	18,28	14,67	12,87	10,33
Thoracic Spine	7,70	10,46	13,22	12,86	57,07	58,25	57,01	48,57
Lumbar Spine	12,74	24,42	27,14	22,93	21,65	35,13	38,91	33,09
Abdomen	4,06	11,22	15,96	11,46	8,04	18,41	21,65	12,16
Pelvis	2,61	5,40	8,40	8,36	3,08	6,39	9,86	9,72

Radiation risk has a pronounced age and sex dependence for all selected X-ray examinations. The risk is higher for adolescents for some X-ray examinations: for radiography of lumbar spine and abdomen radiation risk for children of 10-14 years old is higher up to a factor of 2-4 compared to children of 0-5 years old. For the radiography of skull, cervical spine, thoracic spine and chest the radiation risk for women is significantly higher

compared to men (up to a factor of 7-8 for different age groups). That can be explained by the exposure of lungs, which are more radiosensitive for women, and mammary glands. The radiation risk for other X-ray examinations (lumbar spine, abdomen, pelvis) is comparable for women and men.

For comparison, the R(A) risk was calculated for the same age groups using the effective dose and the nominal risk factor of 0.057 Sv⁻¹ averaged over the sex and age. The results are comparable or higher (see Table 2) for all age groups for all X-ray examinations for men up to a factor of 3 (factor of 1.5 in average). On the contrary, the risk values for women of almost all age groups are lower up to a factor of 6. Only for the X-ray examinations of skull, abdomen and pelvis of the older age group, risks based on effective dose are comparable or slightly exceed risks estimated based on organ doses. For all X-ray examinations, the ratio of risk values obtained by different methods varies with age. The difference between the risk values estimated by different methods increases for men and decreases for women with increasing age.

TABLE 2. RATIO OF THE VALUES OF LIFETIME RADIATION RISK R(A), BASED ON EFFECTIVE DOSE, TO THE VALUES OF LIFETIME RADIATION RISK $R_P(A, G)$, BASED ON ORGAN DOSES, DEPENDING ON THE AGE AND SEX FOR DIFFERENT X-RAY EXAMINATIONS, 10^{-6}

		Risks ra	tio, male		Risks ratio, female			
X-ray exam	Age, years							
	0-4	5-9	10-14	15-19	0-4	5-9	10-14	15-19
Skull	1,17	1,77	2,43	2,71	0,19	0,36	0,91	2,53
Chest	1,59	2,07	2,62	2,99	0,20	0,25	0,33	0,43
Cervical Spine	1,38	1,61	2,01	2,72	0,16	0,21	0,25	0,36
Thoracic Spine	1,49	1,64	1,87	2,11	0,20	0,29	0,43	0,56
Lumbar Spine	0,95	1,03	1,18	1,34	0,56	0,71	0,82	0,93
Abdomen	0,96	0,99	1,26	1,75	0,49	0,60	0,93	1,65
Pelvis	1,08	1,04	1,11	1,22	0,92	0,88	0,95	1,05

Additionally, risks were calculated according to the method by Ivanov et al. [11] based on the organ doses using age and age risk factors for averaged European-American and Asian populations ("composite population") [11, 13]. Comparison of the results obtained for the "composite population" and the Russian population is presented in Table 3. Risk values for the Russian population are lower compared to the "composite population" for all ages of both sexes: for men by 45% in average, for women by 20% in average - except for X-ray examinations of the skull and cervical spine for women, for which the values for the Russian population are higher by 15% in average. The difference between the risks obtained for the presented populations does not significantly change with age.

TABLE 3. RATIO OF THE VALUES OF LIFETIME RADIATION RISK $R_P(A, G)$, BASED ON ORGAN DOSES, DEPENDING ON THE AGE AND SEX FOR DIFFERENT X-RAY EXAMINATIONS USING RISK COEFFICIENTS FOR THE COMPOSED POPULATION AND RUSSIAN POPULATION, 10⁻⁶

		Risks ra	tio, male		Risks ratio, female			
X-ray exam	Age, years							
	0-4	5-9	10-14	15-19	0-4	5-9	10-14	15-19
Skull	1,55	1,62	1,74	1,84	0,82	0,85	0,99	1,45
Chest	1,74	1,77	1,76	1,74	1,11	1,17	1,18	1,17
Cervical Spine	1,53	1,50	1,49	1,52	0,89	0,82	0,80	0,79
Thoracic Spine	1,76	1,77	1,79	1,80	1,12	1,16	1,22	1,25
Lumbar Spine	1,96	1,97	1,98	1,98	1,27	1,29	1,29	1,28
Abdomen	1,99	1,99	2,05	2,18	1,28	1,30	1,34	1,38
Pelvis	2,07	2,09	2,11	2,13	1,31	1,31	1,34	1,37

4. CONCLUSIONS

Detailed estimates of the lifetime radiation risk of long-term stochastic health effects due to radiography of children for seven most common X-ray examinations in Russia were obtained. The assessment of radiation risk was performed on the calculated organ doses and age-sex lifetime radiation risk factors for four age groups of children. The results indicated a significant (variability up to a factor of 4) dependence of risk on the sex and age of a child in the range from a newborn to 17 years.

For the Russian population, the risk assessment based on the effective dose and a nominal risk coefficient of 0.057 Sv^{-1} , proposed in ICRP Publication 103, underestimates radiation risk up to a factor of 6 (in average of 2.7) for girls, except for the skull, abdomen and pelvis examinations for the older age group. On the contrary, the use of the effective dose for boys overestimates the risk, by a factor of 1.6 in average.

The risk estimates obtained with use of risk factors calculated for the Russian population are lower than the similar values for the composite population for all ages of both sexes: for men by 45% in average, for women by 20% in average - except for X-ray examinations of the skull and cervical spine for women.

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Accidental Exposure of Foetus during Imaging of Pregnant Patient at the Gynaeco Obstetric and Paediatric Hospital of Douala, Cameroon

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Abstract

The use of X-Ray in medical radiology is always risky. In particular, when it comes to imaging pregnant women, the majority of foetus cells can be damaged. Despite all the requirements from international renowned organizations relating to imaging of pregnant women and new-borns, the unintentional irradiations of the foetus are still common in radiological procedures. A case that occurred at the Gynaeco Obstetric and Paediatric Hospital of Douala (Cameroon) in September 2015, is instructive. A 46-year-old woman about six months pregnant was subject to an X-Ray of the pelvis requested by a medical doctor following a suspicion "of osteonecrosis ». Investigations conducted by the National Radiation Protection Agency (NRPA) revealed that the patient was irradiated with parameters of 20 mAs and 90kV which lead to a dose to foetus of about 213 μ Gy. The lead apron that was used to protect the pelvis reduced the absorbed dose by a factor of 6. The hospital officials were advised to do more collaboration between referral medical doctors and radiologists as soon as the use of X-Ray on pregnant women is deemed necessary, to inform patients about the dangers of ionizing radiation on foetus, and to request for information on their pregnancy status as well.

1 Introduction

One of the most frequently asked questions in relation to the use of ionizing radiation in medicine concerns the management of pregnant patient. Instinctively, one may want to avoid use of ionizing radiation with a pregnant patient. However, there are a number of situations in which the use of ionizing radiation for diagnosis or therapy is appropriate. In addition, there are many female physicians and technicians who are employed in medical practices using ionizing radiation. Thousands of pregnant women and radiation workers are exposed to ionizing radiation each year (ICRP 84, 2000). According to Annex D of UNSCEAR 2000, X rays have also been used for more than 50 years to assess the dimensions of the maternal pelvis in pregnancy. For occupationally exposed pregnant women, the equivalent dose to the surface of the abdomen shall not exceed 2 mSv per year and the effective dose resulting from exposure shall not exceed 1 mSv from the time which the pregnancy is known until its term (ICRP 60 1991; Arête N° 1152/A/MINSANTE of 2013). According to presidential decree N° 2002/250, issued on 31st October 2002 (Cameroon Official gazette 2003), National Radiation Protection Agency (NRPA) is the competent authority for radiation protection and waste management issues. In this regard, NRPA authorizes and inspects the use of ionizing radiation sources to protect people and the environment against the harmful effects of ionizing radiation.

Since the Decree N° 2002/250 states in its article 4 (5) that NRPA is responsible to respond to radiological accident/incident, that is why it was notified of the radiological incident related to the irradiation of the foetus with X-ray machine that occurred at the Gynaeco Obstetric and Paediatric Hospital of Douala, Cameroon. Following to this notification, NRPA team carried out an investigative mission to estimate the foetus dose of the pregnant patient.

2 Material and method

2.1 Management of a pregnant patient

Ministry of Public Health Order Number 1152/A/MINSANTE of 2013 prescribes that measures should be taken to manage pregnant patients in diagnostic radiology. All X-ray examinations shall be justified whether the patient is pregnant or not. In addition, posters and radiation trefoil should be posted at surveyed and controlled areas within diagnostic X-ray departments and areas where diagnostic X-ray equipment is used to avoid unintentional radiation exposures of the embryo and foetus. When a patient has been determined to be pregnant or possibly pregnant, the radiologist usually begins by determining whether the foetus is going to be in the primary X-ray beam. If not, then the risk to the foetus is extremely low and the most important thing is to keep the number and type of exposures to a minimum while still getting the correct diagnosis.

When an examination is indicated in which the X-ray beam irradiates the foetus directly, and this cannot be delayed until after pregnancy, the most common ways to tailor examinations and reduce foetal exposure are to collimate the beam to a very specific region of interest. When a high-dose procedure is performed and when the foetus is known to be in the primary X-ray beam, the technical factors should be recorded to allow subsequent foetal dose estimation.

2.2 Experimental Foetal dose estimation

NRPA investigation protocol has been used to measure entrance skin dose (ESD) of the pregnant woman. According to Mahadevappa in 2011, Foetal dose be conservatively estimated as 0.15 times the entrance skin dose (ESD) for conventional radiography and fluoroscopy techniques.



Figure1: DIAVOLT kVp-meter

DIAVOLT kVp-meter (figure 1) which is non-invasive kVp, Peak Potential Voltage (PPV), dose and time meter for acceptance tests and quality control (QC) of diagnostic X-ray equipment was used for this measurement. According to the NRPA Guidance N°0050 (2016) on quality control of X-ray machine in diagnostic radiology, the given steps below were followed:

- Mode RAD/FLU was chosen;
- kVp ranged from 40 to 150 kV was set up;
- filtration of 2.5 mmAl as indicated on the tube was selected;
- DIAVOLT kVp meter was positioned on the top of the table at 100 cm of X-raytube;
- Laser light field was collimated within a standard size of the DIAVOLT;
- 20mAs and 90 kV were chosen for the tests;
- three measurements of ESD were recorded.

The DIAVOLT kVp meter was covered by a lead apron of 0.25 mmPb to simulate a similar condition of the examination for which the following physical parameters were used:

- Source to image receptor distance of 1meter;
- Tube potential setting is 90 kV;
- Tube current setting 200 mA;
- Exposure time 0.1 second;
- Beam size: 43 cm x 35.5 cm;
- Patient AP thickness is 26 cm;
- Total filtration 2.5 mmAl.

Table 1: Machine Characteristics

Generat						r		
WDM Radiology Equipment	Supplier	SN	Model	Filtr	ation	homologati on Number	Year fabrica	of ntion
	China Ressourc esWando ng Medical Equipme nt Co.Ltd	10320- 91	GFS50 2-8		/	/	2	2012
				r	Гube			
	Supplier	SN	Model	mA Ma x	kV- Ma x	Filtration (mmAl)	homolo gation Numbe r	Year of fabricati on
	China Ressourc esWando ng Medical Equipme ntCo.Ltd	120514 1	DX52- 30.50/1 25H- T2F	/	125	2,5mmAL	/	2012

3 Results and discussion

Table 2 shows measured doses by Diavolt kVp meter covered with lead apron. The mean value of about 1420 μ Gy was obtained.

Effectiveness of the shielding enclosed in lead apron was appreciated through a ratio between measured doses by Diavolt without a covered lead apron. Therefore, the shielding used to cover the pelvic attenuated the direct beam by a factor of about 6. The mean dose of 1420 μ Gy measured by Diavolt with a lead apron on it was used to estimate the foetus absorbed dose according to Mahadevappa in 2011. The obtained value which is 213 μ Gy is less than 100 mGy above which malformations may be suspected. This dose is relatively low and cannot be responsible for malformation effects. However, it presents a minor risk of cancer and leukemias for children aged from 0 to 15 years whose mothers have undergone irradiation during pregnancy.

I able	Table 2. Dose measurements by Diavoit covered with teau apron								
Parameters	Essay N°	Measured Entrance Skin dose (µGy)	Fetus dose estimated (ESD*0.15) (µGy)						
	1	1420	-						

Table 2: Dose Measurements by Diavolt covered with lead apron

20mAs,	2	1421	_
90kV	3	1419	-
	Mean	1420	213

According to the responsibilities of practices, the risk of cancer in teenagers must be taken into account in the follow-up of the pregnant woman by emergency physician and the radiologist. The need to justify any X-ray examination in this case and possibly to use nonirradiating imaging with equal diagnostic performance is advised. If the proposed radiological examination is the only way to establish the necessary diagnosis for the appropriate examination management, emergency physician and the radiologist are required to inform the patient of the risks of malformations and cancers that can occur.

The radiologist and radiation protection officer are responsible for recording the estimated dose of irradiation on the examination report. The medico-legal responsibility of the interveners imposes in addition to the justification, taking into account prenatal and postnatal risks.

4 Conclusions

In general, the medical follow-up of pregnant women is delicate and requires the collaboration of all the stakeholders. The ignorance of the effects of ionizing radiation on the foetus by some medical staff and the insufficient collaboration between them can be considered as the main causes of the incident. At the same time, the irradiation of a pregnant woman must be the subject of a documented consensus between medical staff. A report specifying the dose received in the abdomen must be recorded by the radiologist and radiation protection officer. The patient's information on the risks that can occur during the irradiation is prior to the X-ray exam is archived.

According to this incident, it was recommended to diagnostic radiology in medical sector in Cameroon to:

- justify any X-ray examination required for a pregnant woman when non-irradiating imaging cannot be used ;
- establish mechanisms for collaboration between medical personnel involved in the follow-up of pregnant women in order to take into account effects of ionizing radiation on the foetus and / or teenage year;
- put in place mechanisms for informing pregnant women about the risks to the foetus and / or teenagers when it is undergoing irradiation;
- put in place mechanisms for early notification of incidents;
- carry out training on radiation protection of personnel involved inradiology.

These measures are now shared during implementation of NRPA inspection program in the whole medical sector in Cameroon.

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PATIENT DOSE MONITORING AND DRLS FOR PEDIATRIC FLUOROSCOPIC PROCEDURES AT LATIFA WOMEN AND CHILDREN HOSPITAL / DUBAI HEALTH AUTHORITY/ UNITED ARAB EMIRATES

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TOPIC: Radiation Protection of Children

Abstract

The study demonstrates the ongoing actions of radiation safety programs on pediatric dosimetry and Diagnostic Reference Levels (DRLs) in medical applications in UAE, which is one of the safety requirements set by Federal Authority for Nuclear Regulation (FANR). Children are at higher risk from ionizing radiation than adults. Therefore, international organizations have given special attention to pediatric patient dosimetry of different age groups. The purpose of the paper is to present the ongoing actions at Latifa Women and Children Hospital (LWCH)/ Dubai Health Authority (DHA) on dose monitoring and DRLs for pediatric fluoroscopy procedures. The most common Fluoroscopic investigations for pediatric patients in LWCH-DHA are Micturating Cysto Urethrography (MCUG), Contrast (barium or water-soluble) Swallow, Contrast Meal and Contrast Enema. The LWCH-DHA aims to establish local diagnostic reference levels for pediatric fluoroscopy examinations in order to promote good practice by producing optimum range of radiation dose values for fluoroscopy examinations. A retrospective data collection done from PACS, IMPAX business intelligence system, RIS and fluoroscopy machine for all pediatric patients of age group from 0-13 years over a period of two years included in this study. The results benchmarked with the published international DRL values and the previous UAE data.

1. INTRODUCTION

Medical exposures are increasing with medical imaging growth. Increasing use of diagnostic medical imaging, performed worldwide each year, is exposing the populations to increase doses of ionising radiation. Dose monitoring and the implementation of Diagnostic Reference Levels are essential tools for the optimization of medical exposures. The paper presenting the dosimetry data and Diagnostic Reference Levels (DRLs) for pediatric fluoroscopy procedures of age group from 0-13years in Latifa Women and Children Hospital/DHA/UAE.

United Arab Emirates (UAE) has participated in many technical co-operation projects (National & Regional) with the International Atomic Energy Agency (IAEA) on patient dosimetry and local radiation protection education programs [1-7]. In these projects, the major contributors are professionals from Radiology, Medical Education and Medical Physics departments in DHA. The aim of this current study is to evaluate the pediatric radiation doses at DHA and move towards the establishment of local DRLs for pediatric fluoroscopy examinations in order to promote good practice by producing optimum range of radiation dose values.

2. METHODS

LWCH started fluoroscopy dose monitoring in 2009 with external DAP meter and diameter dose reading devices, which required the operators' input, such as patient weight, height and age. The installation of new digital fluoroscopy system (Siemens dRF Luminos) having an inbuilt DAP meter and equipped with flat panel detector

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records each patient doses automatically and provide the doses in a single capture record. The radiographers receive immediate and direct feedback related to the patient's exposure. The fluoroscopy system send each patient's exam protocol along with the fluoroscopy images to PACS which contains dose details and exposure parameters. In addition, radiographers fill the radiation dose in RIS (Radiology Information System) from the fluoroscopy system that can be retrieved from the IMPAX business intelligence system.

The most common Fluoroscopic radiological investigations for pediatric patients in LWCH are Micturating Cysto Urethrography (MCUG), Contrast (barium or water-soluble) Swallow, Contrast Meal and Contrast Enema of age group from 0-13 years. In LWCH, a child is a person of age from 0–13 years. While ICRP & other International standard used pediatric age, up to 15 years for dosimetry. [8-12].

A retrospective data analysis for all pediatric patient of age group from 0-13 years over a period of two years included in this study. Population size is categorized according to the published international standard age as 0-1m (new born), >1m-<1yr, 1 year, >1-5yrs, >5-10yrs and >10-13yrs [8 -12]. Retrospective data collected for 650 pediatric cases as mentioned in TABLE 1 from the IMPAX business intelligence, RIS and from the Fluoroscopy system. Minimum data collected for ten pediatric patients from each group and their 3rd quartile DAP value is considered to establish local DRLs [8, 9].

TABLE 1. DATA ANALYSIS FOR EACH FLUOROSCOPY EXAMINATION (DAP, Gycm	TABLE 1.	. DATA ANA	LYSIS FOR EAG	CH FLUOROSCOP	Y EXAMINATION	(DAP, G	ycm ²)
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Examination	Age Group	Sample	Min (Gycm ²)	1 st Quartile (Gycm2)	Mean (Gycm ²)	3rd Quartile (Gycm2)	Max (Gycm ²)
	0-1m (New born)	57	0.01	0.04	0.13	0.10	0.64
MCUG	>1m- <1yr	121	0.01	0.05	0.13	0.12	1.02
(278 patients)	1 yr	25	0.03	0.05	0.23	0.34	1.20
	>1-5yrs	43	0.01	0.06	0.30	0.35	1.67
	>5-10yrs	18	0.03	0.09	0.30	0.42	3.63
	>10-13yrs	14	0.01	0.21	0.86	1.01	3.60
Contrast	0-1m (New born)	15	0.06	0.09	0.17	0.19	0.55
Swallow	>1m- <1yr	17	0.01	0.10	0.19	0.22	0.57
(127patients)	1 yr	26	0.02	0.07	0.24	0.32	0.72
	>1-5yrs	45	0.01	0.09	0.30	0.40	0.94
	>5-10yrs	12	0.13	0.16	0.42	0.49	1.30
	>10-13yrs	12	0.08	0.29	0.57	1.02	1.35
Contrast Meal	0-1m (New born)	21	0.01	0.04	0.14	0.16	0.95
(146 patients)	>1m- <1yr	37	0.01	0.07	0.22	0.30	0.88
	1 yr	23	0.04	0.11	0.21	0.30	0.88
	>1-5yrs	39	0.03	0.10	0.27	0.36	0.86
	>5-10yrs	16	0.10	0.41	0.52	0.62	1.12
	>10-13yrs	10	0.63	0.63	1.00	1.34	1.48
Contrast	0-1m (New born)	20	0.01	0.03	0.13	0.13	0.57
Enema	>1m- <1yr	28	0.01	0.03	0.14	0.13	1.80
(99 patients)	1 yr	20	0.01	0.04	0.10	0.14	0.28
	>1-5yrs	16	0.01	0.12	0.33	0.37	1.04
	>5-10yrs	11	0.09	0.18	0.39	0.50	0.90
	>10-13yrs	4		In	sufficient da	ta	

3. RESULTS

LWCH/DHA radiation dose levels were benchmarked with the previous work done in DHA and favorable with those published in the literature. The DAP doses are almost equal with those published as NDRLs in UK (published in 2016) [11] and lesser than the previous LWCH dose result, NRDLs Australia (updated publication 2013) [9] and some literatures [10] as shown in TABLE 2.

- The authors have not been able to obtain sufficient data for the 10–15 years age group because the pediatric age group defined in LWCH/DHA is up to 13 years. While ICRP & other International standard uses pediatric age up to 15 years for pediatric dosimetry study.
- This is the age groups 0-1m, >1m-<1yr, 1 yr, >1-5yrs, >5-10yrs and >10-13yrs we followed, but in most literatures it is quoted as 0yr, 1yr, 5yr, 10yr and 15yr [9-12].

- Comparing the six age groups, including the newborn babies' similar dose levels were observed for the first two age groups. The dose difference between these two groups were not significant because the exposure parameters were similar.
- Age group1yr and <1-5yrs similar dose levels are observed.
- The dose levels are increasing with patient's age.
- The sample collection for contrast enema for pediatric age group 10-13 years is insufficient because of less practice in LWCH. These fluoroscopic procedures are justified with sonography guided procedures.
- The authors could not find Published DRLs values for new born babies 0-1 month age group and contrast enema for pediatric patient.

TABLE 2. COMPARISON OF LWCH/DHA DRLs WITH OTHER PUBLISHED DRLs (GyCm2)

Examination	Age	LWCH (DHA)	(NDRLs) England -2016	(NDRLs) Australia-2013	(NDRLs) UK- 2009
	New born(0-1m)	0.1	-	-	-
	>1m- <1yr (0yr)	0.12	0.1	0.4	0.3
MCUG	1yr	0.34	0.3	1	0.8
MCUU	>1-5yrs	0.35	0.3	1	0.8
	>5-10yrs	0.42	0.4	2.1	1.5
	>10-13yrs	1.01	0.9	4.7	2.5
	0-1m (New born)	0.19	-	-	-
	>1m- <1yr (0yr)	0.22	0.2	0.8	0.4
Contrast	1yr	0.32	0.4	1.5	1.2
Swallow	>1-5yrs	0.4	0.5	1.5	1.3
	>5-10yrs	0.492	1.8	2.7	2.9
	>10-13yrs	1.02	3	4.6	3.5
	0-1m (New born)	0.16	-	-	-
	>1m- <1yr (0yr)	0.3	0.1	0.7	0.4
Contrast	1 yr	0.3	0.2	2	1.1
Meal	>1-5yrs	0.375	0.2	2	1.3
	>5-10yrs	0.6195	0.7	4.5	2.4
	>10-13yrs	1.34	2	7.2	6.4
	0-1m (New born)	0.125	-	-	-
	>1m- <1yr (0yr)	0.1325	-	-	-
Contrast	1yr	0.1375	-	-	-
Enema	>1-5yrs	0.37	-	-	-
	>5-10yrs	0.5	-	-	-
	>10-13yrs		Insuffic	ient data	

4. DISCUSSIONS

DRL values expected to change overtime due to the technological advances and developments in optimization. The data collection for some fluoroscopic examination is small in comparison with UK study. LWCH justified fluoroscopic procedures for contrast enema; contrast meal and contrast swallow with sonography guided procedures. The result of this study will contribute great importance in patient radiation safety at DHA / Latifa Women and Children Hospital by:

- Establishing local diagnostic reference levels in radiology department of LWCH which is one of the radiation safety requirements set by Federal Authority for Nuclear Regulation (FANR).
- Supporting the educational programs in Latifa Women & Children Hospital/DHA.
- Support for patient dose evaluation and dose recording in their medical files.
- Support and instruct the radiology team to avoid over exposure and dose creep in digital fluoroscopy practices.
- Contribute to set DHA Diagnostic Reference Levels (DRLs) and UAE DRLs (National DRLs).

5. CONCLUSIONS

In conclusion, the authors believe that the result of the study can be used as a bench mark and stimulus for future dose monitoring & dose recording efforts enabling the implication of Local and National DRLs. This study will also contribute great importance in patient radiation safety at DHA - Latifa Women and Children Hospital with the educational programs and giving education and instruction to the radiology team to promote good practice by producing optimum range of radiation dose values for pediatric fluoroscopy examinations.

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ESTIMATION OF RADIATION DOSE FROM 18F-FDG PET-CT USED IN STAGING AND FOLLOW-UP OF LYMPHOMA IN PEADIATRIC AND YOUNG ADULT PATIENTS

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Abstract

The combination of positron emission tomographic (PET) scanners and computed tomographic (CT) scanners, or PET-CT scanners, provides coregistered images of anatomic and functional information in a single study. The clinical applications of PET-CT have been expanding, mainly in oncologic diagnosis and management, as well as for other clinical indications, such as the investigation of fever of unknown origin, leading to the increasing demand for PET-CT studies. However, PET-CT examinations, especially those that include diagnostic CT, result in increased patient radiation exposure compared with stand-alone CT or PET examinations, as the effective dose is a combination of the dose from PET and the dose from CT. The increasing use of serial PET-CT scans in the management of pediatric malignancies raises the important consideration of radiation exposure in children and young adult patients. The present study was undertaken to estimate effective doses from the 18F-FDG PET-CT in pediatric and young adult patients with Hodgkin disease and non-Hodgkin lymphoma and to compare with the data in literature.

1. INTRODUCTION

PET with18 F-FDG has been accepted as a valuable tool in oncology practice. CT images are commonly acquired togetherwith PET images in a single imaging session with an integrated PET-CT scanner and are used for diagnosis on CT images themselves, localization of lesions delineated by PET, and attenuationcorrection of PET images [1].Recently, F18-FDG PET-CT has been advocated for diagnosis, staging, monitoring of response to therapy, and surveillance of lymphomas. The sensitivity of FDG PET is likely superior to that of conventional staging techniques. Furthermore, combined PET-CT has better diagnostic accuracy and is increasingly being implemented as the primary staging investigation [2].

As the availability of these dual-modality systems increases, PET/CT is of growing importance in pediatric imaging particularly for cancer detection, staging, therapeutic response monitoring, and outcome prediction [3–6]. However, both PET and CT are high-dose investigations, and impart a substantial dose of ionizing radiation, especially given the need for repeat imaging during patient treatment. Therefore, the

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increasing use of serial PET-CT scans in staging and follow-up of lymphoma in pediatric and young adult patientsraises the important consideration of patient dose assessment.

In pediatric nuclear medicine, imaging protocols are generally extrapolated from adult imaging guidelines. Several works have published recommendations on pediatric PET/CT protocols in an effort to provide guidance on recommended optimal imaging protocols [4,7,8]. The purpose of this study was to estimate the cumulative radiation dose from serial PET-CTstudies in pediatric and young adult patients with lymphoma, at Hôpital Chahids Mahmoudi, Tizi Ouzou Algeria.

2. METHODS

2.1. Patients

This retrospective study involved 42 pediatric and young adult patients, who received whole-body18 F-FDG PET-CT examinations for detection, staging and treatment follow-up of lymphoma between Mars 2016 and July 2017. The patients age involved in this study were in the range from 5 -18 years (mean age, 11.7 years; SD, 3.8 years) with histologically proved lymphoma. This review included collecting patient data including age (at the time of scan), gender, weight (kg), height (cm), dose length product (DLP) (mGy.cm) as reported by the scanner and the net injected FDG activity (MBq).

All the patients fasted for at least 6 hours before the scanning session and only oral hydration with glucose-free water was allowed. The fasting blood glucose level was recorded for all patients. Oral diazepam solution was given to patients before the intravenous (IV) administration of a radiopharmaceutical. All the patients were put to rest in a special uptake room for an average of 60 min and emptied their bladder before undergoing the PET/CT examination. All patients were scanned using weight-based PET/CT protocols (10).

2.2. Imaging procedures

All data were acquired on the GE Discovery IQ PET-CT (GE Healthcare, Milwaukee, WI, USA) scanner with standard axial field of view using 3D Q.Clear algorithm reconstruction. The scanner has three rings of BGO block detectors giving a 17.5 cm axial field of view, a 70 cm patient aperture, and is integrated with a 16 detector CT scanner with a 0.5 s rotation speed. FDG doses were given approximately 1 h before scanning commenced, with whole-body images acquired at 2-3 min per bed position. Whole-body protocol consisted of 6–8 bed positions (depending on patient height) from the base of skull to the mid-thigh.

For CT scan, standard scanning parameters for whole-body were selected, and same protocol was used with tube voltage of 120 kVp, collimation of 16×1.5 mm, a rotation time of 0.5 s and pitch factor of 0.75. The tube current-time was varying by using the automatic exposure control (AEC) technique. The acquisition time for the whole-body PET/CT scan was 30 min per patient. The image was reconstructed using Q.Clear algorithm in the axial view and reformatted to coronal and sagittal planes.

For each imaging study, image data was reviewed to determine the body region that was being examined; the start and stop location of each series was recorded for later use in estimating effective dose (ED). This was repeated for each CT and each PET performed. As part of this review, the technical parameters for each series were also recorded.

2.3. Estimation of effective dose

The calculation of PET-CT effective dose includes both internal and external exposure as provided in ICRP publication 103 and 106 [9,10]. The internal radiation exposure referred to the exposure emitted from radiopharmaceuticals 18F-FDG.

The effective dose associated with the CT exam (EDCT) was calculated from the reported DLP using a whole body effective dose per unit dose-length product conversion factor $k = 18 \ mSv/mGy.cm$ [11]:

 $\mathbf{A} = \mathbf{A} \mathbf{A} \mathbf{P} \mathbf{m} \mathbf{G} \mathbf{y} \mathbf{c} \mathbf{m} \times \mathbf{A} \mathbf{m} \mathbf{S} \mathbf{y} \mathbf{m} \mathbf{G} \mathbf{y} \mathbf{c} \mathbf{m}$ (1)

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Whilst this conversion factor is based on the ICRP 60 weighting factors, further investigation by Huda et al. [12] using the revised weighting factors of the ICRP 103 publication found a ratio of approximately one between the whole-body exam conversion factors, with a reported range of 14–20 mSv/mGy.cm.

The effective dose associated with the PET exam (EDPT) as a result of the injected FDG activity A was calculated based on the reported ICRP dose coefficient values G of 0.019 mSv/MBq for a young adult (15 -18 y), 0.024mSv/MBq for a 10-15 year child, 0.037mSv/MBq for a 5-10 year child and 0.056mSv/MBq for a 5 year child, where each was applied as necessary to patients who fell in the age range category (These data correspond to phantoms whose weights are respectively 73.7, 56.8, 33.2, 19.8, 9.72 and 3.6 kg) [10]:

 $f(Sv) = A M B(q \times \Gamma) m Sv / M B q \qquad) \quad (2)$

This value was then modified on a patient-by-patient basis to calculate the weight-scaled effective dose (EDPT-WS) [13], taking into account individual patient weights as opposed to the standard ICRP model sizes:

 $(mSV) = (mSV) \times (mSV$

The total effective dose associated with the combined PET-CT exam was considered as the sum of the PET and CT effective dose values:

$$\mathbf{OO}_{!''\#\$\%}(\mathbf{mSv}) = \mathbf{OO}_{!'}(\mathbf{mSv}) + \mathbf{OO}_{!'}(\mathbf{mSv})$$
(4)

3. RESULTS AND DISCUSSION

A summary of patient's information data and standard clinical whole-body 18F-FDG PET-CT scan parameters used at Hôpital Chahids Mahmoudi, Tizi Ouzou Algeria was presented in Table 1. TABLE 1. Patient and scan parameters

Nbre of patients	42
Age (years)	11.7±3.8 (5-18)
Weight (kg)	39.9±15.6 (15-73)
Height (cm)	147±17.2 (110-179)
Injected activity (MBq)	136±52.1 (50-262)
DLP (mGy.cm)	412±99.0 (251-592)

Table 2 represents the total effective dose from the combined PET and CT studies across each of the weight and age range categories with the PET dose component calculated by the ICRP model and scaled to patient weight.

TABLE 2. Effective dose for different patient categories

Category	ED _{CT} (mSv)	ED _{PT} (mSv)	ED _{PT-WS} (mSv)	$ED_{T}(mSv)$	ED _{T-WS} (mSv)
All patients	7.41±0.90	3.62±0.91	4.54±0.41	11.04±2.31	11.95±2.42
1-5 years	7.29 ± 0.09	3.44 ± 0.88	3.87±0.23	10.73 ± 0.91	11.16 ± 1.10
5-10 years	5.98 ± 0.84	3.36±0.72	4.37±0.42	9.34±0.94	10.35 ± 1.12
10-15 years	7.71±1.73	3.87±1.13	4.68 ± 0.45	11.57 ± 2.53	12.39 ± 2.62
15-18 years	9.86±0.49	3.52±0.44	4.68 ± 0.20	13.38 ± 0.70	14.54 ± 0.82
< 20 kg	$6.60{\pm}1.01$	2.56±0.30	4.11±0.60	9.16±1.30	10.71±0.83
20-29 kg	6.17 ± 0.90	3.13±0.60	4.46 ± 0.44	9.31±1.11	10.60 ± 1.20
30-39 kg	6.78 ± 1.81	3.32±0.62	4.57±0.33	10.11 ± 1.80	11.35 ± 1.90
40-49 kg	7.12±1.73	3.68 ± 0.80	4.60 ± 0.71	10.81±1.72	11.72 ± 2.10
50-59 kg	8.67±1.33	3.98 ± 0.93	4.60 ± 0.30	11.04 ± 0.52	13.27 ± 1.20
> 50 keg	10.08 ± 0.51	5.12±1.00	4.70±0.54	15.21±1.10	14.78 ± 1.42

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In this particular study, the average injected FDG activity was $(136\pm52.1 (50 -262))$ MBq. This resulted in a mean estimated effective dose of (3.62 ± 0.91) mSv from the PET component of the exam when using the ICRP assumptions of a standard model for dose calculation and (4.54 ± 0.41) mSv when taking into account patient specific weight. The total mean effective dose for the entire diagnostic investigation was found to be (11.04 ± 2.31) mSv when using the ICRP model and (15.58 ± 2.42) mSv when scaling to specific patient weight. The results from this study demonstrate that CT examination took the major role in contributing to the total effective dose of PET/CT imaging, corresponding to approximately 80.43%. This finding is in agreement with a study by Huang et al. [14], in which up to 81% of the total PET/CT effective dose was attributable to the CT doses. These studies all involved "full-body" CT scans, which ranged from mid-brain to mid-thigh and thus irradiated essentially all of the radiosensitive organs. The techniques for these scans were usually adjusted for patient size with kVp and/or mAs being reduced for smaller/younger patients. The effective dose estimates of effective dose associated with the CT scan could be made by taking into account the recommended size specific dose estimates (SSDE) presented in the recently released American Association of Physicists in Medicine (AAPM) Report No. 204. Future research will make such calculations.

The average total effective dose for each weight range category represented demonstrates a small increase with increasing patient weight. The CT component of the total effective dose can be seen to increase steadily with patient weight due to automatic increases in the beam current to account for increased patient width. Alternatively, despite an increase in injected FDG activity to account for larger patients, a steady decrease in the PET component of the effective dose can be seen with increasing patient weight, which results in a lower estimated dose. The two effects appear to more or less balance each other out over the entire range of patient weights seen in the study, with the effects of increased CT dose becoming more dominant at larger patient weights.

Patient-specific scanning protocols play an important role in diagnostic imaging, and this study suggests that both reduced injected FDG activities and AEC with CT can reduce effective dose to patients.

4. CONCLUSIONS

The low-dose protocols employed by the clinic have resulted in average effective dose values that are generally lower than previously reported in the literature. Using modern PET/CT scanner technology (hardware and soft- ware) that allows image quality to be maintained at lower activities and adjustable beam currents, the average total effective dose from a whole-body PET/CT exam is approximately 15.58 mSv, with 4.54 and 7.41 mSv resulting from the PET and CT components respectively. The use of iterative CT reconstruction algorithms in conjunction with low-dose FDG protocols may allow for future total effective doses from PET/CT whole body studies to be < 10 mSv.

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ESTIMATING PATIENT THICKNESS FROM A SINGLE RADIOGRAPH – A PROOF OF PRINCIPLE

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Abstract

Paediatric patient dose audit for radiographic examinations requires a measurement of patient size that is often not made at the time of the examination. This results in a lack of reliable data for national dose audit, and without up to date comparative data it is difficult for sites to optimise their local practice. An automated model for determining patient thickness from a linearly processed digital x-ray, the exposure factors used to acquire the image and simple measurements made on the x-ray equipment during quality assurance testing is presented. During validation, the estimates of the automated model was found to have an absolute deviation from the known thickness that ranged from 0.5-10.8mm (0.3-8.8%), with an average of 3.8mm (3%). This level of accuracy is acceptable for the intended application. An ethics application for a clinical trial is underway.

1. INTRODUCTION

The proposed methods for paediatric patient dose audit for radiographic examinations involve some measurement or estimation of patient size, be this a direct measurement of patient thickness in the examination orientation, a measurement of patient circumference, an estimate of patient diameter from height and weight measurements or simply a measurement of patient weight [1-2].

Across Europe, these measurements are not being routinely made however [3], meaning that there is not enough patient dose data submitted to national audits with an indicator of patient size to allow the preferred methodology to be used. As a result, no updated national reference levels can be proposed.

Existing reference values are largely based on dose audits undertaken when film was used [1]. These are no longer relevant to exposures made using Computed Radiography (CR) and direct Digital Radiography (DR).

Given the higher risk from ionising radiation to paediatric patients due to their increased radiosensitivity and longer life expectancy [4], the International Commission on Radiological Protection (ICRP) have recommended that specific consideration be given to the optimisation of paediatric exposures and this is present in most countries' national legislation.

Optimisation efforts are made more complicated by a lack of up to date dosimetry information against which to compare local practice. Many sites, particularly those with a low paediatric patient throughput, may simply not know how their practice compares with others at a national level.

The paper presents a computational model for automating the estimation of patient thickness in the examination projection that has been developed and describes the proof of principle achieved. It is hoped that with further development and a successful clinical trial, this model could automate the estimate of patient size required for paediatric patient dose audit of radiographic examinations. With more data, national reference levels can be updated which will benefit the optimisation efforts of all sites undertaking paediatric examinations.

2. METHODS

2.1. The computational model

The computational model uses a linearly processed digital radiograph, the exposure factors with which it was acquired, a priori knowledge of the characteristics of the x-ray unit and detector used for the exposure and measurements on the x-ray equipment that are similar to those routinely undertaken by Medical Physics departments during routine Quality Assurance (QA) testing.

Patient thickness is estimated using the rearranged form of the Beer-Lambert law;

$$x = -\frac{Ln(\frac{K_{d}}{K_{0}})}{\mu_{e}}$$
, where;

- x is the distance the x-ray beam travels through the attenuating medium (i.e. the patient thickness);
- k_d is the kerma at the detector;
- k_0 is the unattenuated kerma of the x-ray beam;
- μ_e is the effective linear attenuation coefficient of the attenuating medium. The estimation of each of these variables is now discussed in turn.

2.1.1. Detector kerma, k_d

For a linearly processed radiograph, pixel values (PV) are assigned in relation to the signal received across the detector. The average PV can be calculated for any sized area and at any location within the image. Whilst detectors have an energy dependence [5], it has been demonstrated that the quality of an x-ray beam at the exit surface of an attenuator is very similar above a certain attenuator thickness, found to be equivalent to 10cm of solid water high equivalence (Sun Nuclear Corporation). This is because in larger attenuators, much of the scattered radiation that is created is also attenuated. Therefore, where a PV to detector kerma calibration is measured using an attenuator in excess of 10cm of solid water at varying kV_p , a single calibration at each kV_p can be used to accurately estimate a detector kerma from a measurement of PV on the image.

2.1.2. Unattenuated kerma, k_0

 k_0 can be estimated using the examination kV_p , mAs, Focus to Detector Distance (FDD) and field size. For an x-ray machine, the output in terms of μ Gy/mAs at 100cm FDD for varying kV_p at the centre of the x-ray field is a commonly undertaken measurement during QA testing.

2.1.3. Effective linear attenuation coefficient, μ_e

A linear attenuation coefficient is unique to a single energy and a single material. In clinical exposures, the x-ray beam is composed of multiple energies, characterised by a kV_p and a defined half value layer (HVL).

As there are multiple x-ray energies, an effective linear attenuation coefficient can be used [1]. This can be defined as: $\mu_e = Ln \left(\frac{1}{Entrance kerma}\right)$.

Multiple μ_e can be calculated or simulated for varying tissue thicknesses and for varying combinations of kV_p and pre-attenuation HVLs. These can be applied as appropriate during the calculation.

Although physical measurements of entrance and exit kerma are the most desirable method for obtaining a value of μ_e to use in the automated model, it is clearly impractical to produce enough combinations of attenuator and x-ray beam quality to examine the changes in μ_e across the full range of clinically relevant scenarios.

Monte Carlo simulations offer the potential for the user to specify all aspects of an exposure, including xray beam quality, attenuator composition and size and exposure geometry. Multiple simulations were run in BEAMnrc [6] to examine the variation in μ_e with increasing attenuator thickness and changing attenuator composition. This allowed for the selection of an average value that could be used in the model for each kV_p. As with the detector kerma, this value was found to be consistent for an attenuator of an equivalent thickness greater than 10cm of solid water.

2.2. Validation of the model

The model described within this paper was used to estimate the thickness of the attenuator for eleven images acquired at 60, 70 or $81kV_p$ with a 100cm FDD using a dedicated CR cassette. Each image varied the thickness of solid water attenuator, the mAs and the field size.

For each of the eleven images, a manually calculated estimate of attenuator thickness was made using values for k_d and k_0 that were directly measured using a Raysafe R/F detector, and a value of μ_e that was calculated from measurements of entrance and exit kerma made using the Raysafe R/F detector. This was intended to investigate the uncertainty associated with the estimate of each variable; the values for each variable used by the model were directly compared to the measured values for each of the eleven images.

3. RESULTS

The estimates of attenuator thickness made using the automated model are presented in table 1; column 4 (headed 'Automated'). The estimates of attenuator thickness that were manually calculated using the measured values of k_d and k_0 and the calculated values of μ_e are presented in table 1; column 5 (headed 'Manual').

TABLE 1. ESTIMATES OF ATTENUATOR THICKNESS USING THE AUTOMATED MODEL AND ENTIRELY MEASURED DATA

Image	kVp	Known attenuator	Predicted thickness (mm) using;	
		thickness (mm)	Automated	Manual
1	60	110	110.7	110.0
2	60	130	131.1	132.0
3	70	115	122.4	117.4
4	70	140	144.6	142.1
5	70	170	169.5	171.5
6	81	100	109.6	102.5
7	81	120	130.8	125.2
8	81	140	143.9	143.9
9	81	165	164.3	166.8
10	81	170	180.3	181.6
11	81	190	185.0	192.6

The estimates made using the automated model have an absolute deviation from the known thickness that ranges from 0.5 - 10.8mm (0.3 - 8.8%), with an average of 3.8mm (3%). The estimates made using the manual calculation resulted in a deviation from the known thickness that ranges from 0.02 - 11.6mm (0 - 6.4%) with an average of 3.2mm (2.2%). The results of the automated model compare well with this standard.

The absolute error in the model's predicted values of k_d are generally low. They range from 0.01 – 0.25 μ Gy (0.4 – 16.1%) with an average deviation of 0.07 μ Gy (3.5%). The greatest uncertainty in the model is associated with the estimation of k_0 from look up tables of pre-measured data. The deviation between estimated and measured values ranges from 0.8 – 6.2 μ Gy (0.9 – 6.6%) with an average of 1.96 μ Gy (3.8%). The presence of a significant outlier (6.2 μ Gy) demonstrates that the model is affected by the occasional higher than expected variation in x-ray tube output for one exposure compared to another using the same exposure factors. The accuracy of the estimation of μ_e ranges from 0.0001 – 0.0011mm⁻¹ (0.6 – 5.1%) with an average deviation of 0.0005mm⁻¹ (2.5%).

4. DISCUSSIONS

A proof of principle has been achieved that demonstrates it is possible to accurately estimate the thickness of an attenuator from a linearly processed digital radiograph, the exposure factors with which it was acquired and the results of simple measurements made on the x-ray equipment beforehand.

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In considering whether this proof of principle has achieved results sufficient to merit continuation of the work, the maximum inaccuracy that can be tolerated by the end user should be considered. The aim of this work is to derive the thickness of a paediatric patient in the examination orientation and along the central axis of the x-ray beam. The current gold standard method for obtaining this measurement is a direct measurement using callipers [1].

Whereas the deviation of any measurement made using callipers will be minimal -1 - 2mm at most – the more significant source of inaccuracy for the calliper method is associated with a reproducible measurement position. A single operator could vary their measurement position from patient to patient by many centimetres superior or inferior to where they would centre the x-ray beam. As the patient will not be of uniform thickness, this adds to the inaccuracy of the thickness measurement. Accurate quantification of this would be very patient dependent, however a 10mm deviation would not seem unreasonable.

Therefore the model presented in the paper does not have any greater uncertainty than that of the existing gold standard measurement. The next step is for a clinical trial; sponsorship has been granted by the University of Dundee and NHS Tayside for a clinical trial to test the accuracy of the patient thickness estimation using the automated model described within the paper for patients undergoing anterior-posterior abdomen x-ray examinations. A formal ethics application is in preparation.

5. CONCLUSIONS

A model has been presented for estimating the thickness of a uniform attenuator using a single linearly processed digital x-ray image and pre-measured data pertaining to the unique characteristics of the x-ray system and detector. The results are promising, with absolute deviations between estimated and known thicknesses of solid water of 0.5 - 10.8mm recorded. The estimates of thickness made using the model compare well against an approach involving manual calculation using data measured at the time of the exposure, for which the deviations between estimated and known thicknesses ranged between 0.02 - 11.6mm. It is thought that uncertainties of this magnitude are acceptable for the intended clinical application of paediatric patient thickness estimation for the purposes of radiographic patient dose audit and an ethics application is in preparation for a clinical trial of the model.

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