Effect of Radiation Dose Reduction on Parameters in Pediatric Head CT Examination

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Abstract:
Radiation must be as low as can be reasonably achieved for CT examination, particularly in pediatric patients. This study was conducted by using two procedures (control and modified) prepared with 64-slice Siemens CT scan (SAMTOM Definition), calibrated in accordance with international protocols. A total of 60 pediatric patients underwent brain examination for a variety of clinical diseases. The effective dose (Eff.dose) was calculated and effective current-time products (in effective milliampere-seconds, Eff.mAs) were measured. Calculation of Eff.mAs and Eff.dose was performed for each CT examination; these were statistically analyzed by using one-way ANOVA and independent t-tests, in accordance with the (ICRP) report for estimating risk (K) factor.

Two procedures of standard (control) protocol and modified head CT scans were reviewed for the diagnosis of pediatric patients, 0-12 years of age. There were no gender-based differences between these two procedures with respect to either Eff.dose or Eff.mAs. However, there was a strong relationship between patient’s age and both (Eff.dose and, Eff.mAs), indicated by the significant P value (p<0.05). Notably, the correlations between Eff.dose and Eff.mAs were weakly negative (inversely proportional) in both control and modified groups. Despite, the reduction of Eff.dose and Eff.mAs, dose reduction could be achieved without compromising image quality during head CT scans for pediatric patients.

Keyword: Head CT scan; Effective dose ED; physics of CT; Radiation risk, Eff. dose
Introduction

Clinical advantages of computed tomography (CT) examination must be balanced against potential risks by radiation exposure, although brain CT scanning represents a useful and valuable diagnostic tool for pediatric population[1]. Notably, CT scans have been used in medicine for more than 40 years; however, radiation exposure is increasingly recognized as a public health issue, particularly because the rates of CT use have increased rapidly in the United States, with more than 60 million CT scans performed per year; similar usage is observed elsewhere[2].

Developments of CT technology have led to improved image quality and the ability to obtain additional diagnostic information. Nonetheless, the potentials for increased risks of radiation-induced cancer offset the diagnostic benefits associated with higher-dose techniques. As with all fields of medical physics and radiology, diagnostic imaging involves elements of risk that must be balanced against the advantage provided [3].

The advent of multi-detector CT (MDCT) was in the 1990s. The Radiological Society of North America meeting was a substantial step toward isotropic volume imaging[3]; this revolutionary development technology has contributed to extensive enhancements in its diagnostic applications and accuracy, even in young patients. However, a major drawback of MDCT is the use of ionizing radiation, which includes risks of radiation-induced side effects[4]. Thus, many studies have considered the significant correlation between radiation exposure and risk of cancer[5].

Furthermore, these side effects are particularly problematic for patients who are very sensitive to radiation-induced carcinogenesis and have many continuing years of lifetime for the development of cancer. A recent study in the UK found that “children who received an active bone marrow dose of ≥30 mGy from CT, or a brain dose of ≥50 mGy form CT, were at greater risk of leukemia, compared with those who did not” [6].

Many strategies are used to minimize the total dose of ionizing radiation received during CT. The first strategy involves reduction of the total number of CT scans performed by reduced use of CT studies
and greater reliance on clinical information to assist diagnosis. The second strategy involves replacement of CT with non-radiation imaging modalities studies, such as ultrasound, or fast-sequence MRI[7].

Another strategy to minimizing ionizing radiation dose is the modification of CT scanning techniques by changing parameters to achieve dose reduction. Important CT parameters affecting radiation dose include tube current, scanning time, tube potential, anatomical range of study, scan pitch, and number of axial slices. The modification of one or more imaging factors may reduce dose absorption [8]. Effective dose (Eff.dose) and effective milliampere-second (mAs, here abbreviated as Eff.mAs) serve as indicators of the dose absorbed by the human body.

Notably, (Eff.dose) is a measure of the possible risk from ionized radiation dose and potential genetic effects; “It enables a comparison of risk estimates associated with partial or whole-body ionizing radiation exposures, with respect to the radiation sensitivities of various organs in the body”[1,9,10].

(Eff.mAs) is mAs per slice or true mAs divided by pitch; it has a direct influence on patient radiation dose. Thus, a reduction in mAs will be accompanied by similar reduction in radiation dose[11].

The purpose of this study was to measure the values of Eff.dose and Eff.mAs for two different (modified and control) protocols of pediatric head CT scan, depending on patients’ ages and gender. The measurements of Eff.dose and Eff.mAs were performed by setting CT parameters (tube current, tube potential, and scan pitch) for the modified protocol with respect to the control examination, for similar patients in related age groups.

Methods and Materials

This prospective study was performed at Al-Hussein Teaching Hospital in Samawah City, Al-Muthanna Governorate, Iraq, from October 2017 to May 2018. A total of 60 pediatric patients (31 male (51.6%) and 29 female (48.3%)) were included from inpatient units, in addition to pediatric and neurosurgery outpatient clinics; these patients underwent two separate brain CT scans during 1 and 6 month follow-up examinations, using both, control and modified sets of parameters. All patients were examined by 64- slice Siemens CT scan with consideration for specific organs, ages, and genders (Table 3).

Ethical approval was obtained from the parents of all patients’. Head CT scans were performed in children between the ages of 0 and 12 years who were referred for CT examination for variety of clinical indications. Inclusion criteria were as follows:

1. Trauma
2. V-P shunt
3. Delayed milestone
4. Brain atrophy

Patients were examined two times by different CT examination protocols (control and modified). The parameters adjusted between control and modified protocols were potential voltage, tube current, and pitch. Table 1 shows a set of CT parameters that were used for the control protocol.

**Table 1: Parameters of control protocol**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control Head CT scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube voltage(kVp)</td>
<td>120</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>350</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The modified protocol was applied with the adjusted parameters shown in Table 2, to determine the distinctions of adequacy and clinical efficacy.

**Table 2: Parameters of modified protocol**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Modified Head CT scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube voltage(kVp)</td>
<td>80</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>200</td>
</tr>
<tr>
<td>Pitch</td>
<td>1</td>
</tr>
</tbody>
</table>

A pitch factor has chosen to be 1 indicates overlap of x-ray beams form each rotation. Therefore, when a pitch value is less than 1 that indicates beams overlap and dose is highly absorbed[11][12]

Consequently, parameters of dose-length product (DLP) and current-time product, recorded by the MDCT scanner at the time of the scan, were collected from the CT dose report for each case. All data were collected from the records system of the hospital. Eff. dose was calculated from the corresponding DLP by using age and gender-adjusted risk factors (see Table 3).

**Table 3: Risk factor $K_{(age, gender)}$ values [13]**

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Risk Factor $K_{(age, gender)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 year</td>
<td>0.011</td>
</tr>
<tr>
<td>1-3 years</td>
<td>0.0067</td>
</tr>
<tr>
<td>4-7 years</td>
<td>0.004</td>
</tr>
<tr>
<td>8-12</td>
<td>0.0032</td>
</tr>
</tbody>
</table>
Two important quantities were considered for modifications of both Eff.dose and Eff.mAs: CT dose index (CTDIvol), which is dependent on exposure factors, scan field of view, and pitch factor selections; and DLP, which represents the total radiation dose delivered during a specific CT scan in (mGy.cm). CTDIvol and DLP were used because CTDIvol represents an essential dose indicator for a given CT scanner, and permits calculation of DLP as follows [8]:

$$\text{DLP} = \text{CTDI}_{\text{vol}} \times \text{scan length}$$

Similarly, Eff.dose quantified the total dose of radiation absorbed by the body and considered each organ’s sensitivity to radiation toxicity. Calculation of Eff.dose (in mSv) for each head CT scan comprised the product of DLP and the reported risk factor k (in mSv/[mGy-cm]), as follow:

$$\text{Eff.dose (mSv)} = k \times \text{DLP} \ [8]$$

Where $K_{(\text{age, gender})}$ coefficient is known as “Organ weighting factor” depending on age and body region irradiated by normalizing ED per DLP. It has been periodically reviewed by (ICRP) for effective dose calculations to account the difference in radio sensitivity of tissue.[4][12]

The measurement of Eff.mAs was provided by the software of the CT program at the end of scanning and was collected from the CT dose report for each case.

Patients were grouped according to their gender, and divided into four groups according to their ages (<1 year, 1-3 years, 4-7 years, and 8-12 years),

All CT images of examined patients were reviewed in a blinded manner by three radiologists (B.A, M.S, and A.M) with 8, 15, and 12 years of experience in pediatric neuroradiology, respectively. Brain CT images were investigated for ventricular system diameters, locations of proximal ventricular shunt, size of any atrophic changes, injury to skull and brain tissue, and any significant structural changes.

A measurements of Eff.dose and Eff.mAs for control and modified protocols head CT scan were compared by using descriptive statistics. For each CT examination, Eff.dose and Eff.mAs were calculated among all scans and performed with sufficient dosing information to determine distinctions among the results. Furthermore, the absolute and percent reductions in ED and EM were calculated for each complementary pair of control and modified protocols. These calculations facilitated investigation of the dose reduction afforded by using the modified CT technique, compared with the control technique. Additionally, the number of head CT scans was recorded for each patient, according to gender and age groups, with considerations of risk factors.

This study used a completely randomized design (CRD) in the analysis of variance (ANOVA) for ED and EM data by using one-way ANOVA and independent t-tests at a 5% level of significance.
Moreover, correlations between Eff.dose and Eff.mAs values of control and modified groups were statistically analyzed by Pearson correlation coefficient. Data were processed and analyzed with the Statistical Program for the Social Sciences (SPSS 22); the results were expressed as Mean ± SD [14].

**Results**

Head CT scans performed with the control and modified protocols were reviewed for the diagnosis of pediatric patients <1-12 years of age; Eff.dose and Eff.mAs were measured. There was no significant difference between the two techniques in either Eff.dose or Eff.mAs (Table 4). Regarding Eff.dose, there were no marked variations in distribution on the basis of gender (p = 0.158 (control), p = 0.757 (modified)). Similarly, there were no marked variations in Eff.mAs on the basis of gender (p = 0.474 (control), p = 0.567 (modified)).

<table>
<thead>
<tr>
<th>Gender</th>
<th>Eff.dose (mSv)</th>
<th>Eff.mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean±SD</td>
<td>Modification Mean±SD</td>
</tr>
<tr>
<td>Female</td>
<td>3±1.3</td>
<td>1.97±0.7</td>
</tr>
<tr>
<td>Male</td>
<td>2.4±1</td>
<td>2±1.0</td>
</tr>
</tbody>
</table>

Table 4: Distribution of Eff.dose and Eff.mAs according to gender

* Represents a significant difference at p < 0.05

For analysis of age, both protocols were subdivided on the basis of four age groups. There was a strong relationship between patient’s age and both Eff.dose and Eff.mAs (p < 0.05). The variation in mean values of Eff.dose for patients < 1 year of age was higher than that of other age groups as shown in figure 1; the p value of Eff.mAs for the control protocol was 0.001, while the p-value of Eff.mAs for the modified protocol was 0.009, which indicated statistically significant difference between control and modified parameters specially for patient 8-12 years old was higher than other age groups as shown in Figure 2.
Figure 1: Distributions of Eff.dose values according to age groups.
Figure 2: Distributions of Eff.mAs values according to age groups.

Comparisons of Eff.dose and Eff.mAs values between control and modified protocols showed significant differences in both: Eff.dose means ± SD for the control was 2.6±1.2, while it was 2±0.84 for the Modified protocol. 2 ± 0.84 for the modified protocol (p < 0.05) Eff.mAs values also revealed a significant difference (p < 0.05) (Table 5).

Table 5: Comparison of ED and EM means between control and modified protocols.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control Mean ± SD</th>
<th>Modified Mean ± SD</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED</td>
<td>2.6±1.2</td>
<td>2±0.84</td>
<td>0.015*</td>
</tr>
<tr>
<td>EM</td>
<td>294.5±56.2</td>
<td>232.7±41.3</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

* Represents a significant difference at p < 0.05

In this study, correlation coefficients between Eff.dose and Eff.mAs values were assessed for both control and modified controls (Table 6). Regarding the control protocol, there was a weak correlation of Eff.dose with Eff.mAs (inverse relationship) as shown in Figure 1, where r = –0.133 (notably, the statistical evidence was also weak, p > 0.05).

Table 6: Correlation between ED and EM values of control and modified protocols.

<table>
<thead>
<tr>
<th>Study Groups</th>
<th>Parameters</th>
<th>Mean ± SD</th>
<th>r</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>ED</td>
<td>2.6±1.2</td>
<td>-0.133</td>
<td>0.329</td>
</tr>
<tr>
<td></td>
<td>EM</td>
<td>294.5±56.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited</td>
<td>ED</td>
<td>2±0.84</td>
<td>-0.033</td>
<td>0.885</td>
</tr>
<tr>
<td></td>
<td>EM</td>
<td>232.7±41.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Represents a significant difference at p < 0.05

Effective dose is inversely proportional to effective mAs as shown in Figure 3.
Although, Eff.dose parameters were reduced in modified protocol, with respect to Eff.mAs, the correlation of Eff.dose with Eff.mAs was weakly negative (inverse relationship), as shown in Figure 4, where $r = -0.033$ (notably, the statistical evidence was also weak, $p > 0.05$); this was comparable with that of the control protocol in Figure 3.

**Figure 3: Correlation between Eff.dose (ED) and Eff.mAs(EM) values of control protocol**

**Figure 4: Correlation between Eff.dose(ED) and Eff.mAs (EM) values of modified protocol**
Moreover, all CT images were interpreted by the aforementioned radiologists, who confirmed that there was no difference in the quality of CT images between groups by modifying the protocols that could alter the clinical management of patients included in this study (Figure 5 and Figure 6).

Figure 5: A 2 year old female with mental retardation and bloody skin lesion at right side of the face. Upper row images are control native CT images showing right parietal cortical calcifications (white stars), Eff.dose=3.996mSv, Eff.mAs=243mA/s and lower row of modified CT images showing cortical calcifications (white arrows) (Sturge-Weber syndrome), Eff.dose=2.597 and Eff.mAs=158mA/s.
Figure 6: Upper row CT images are for 11 year old female with delayed milestone. CT modified parameters are used and CT finding is normal, Eff.dose=5.056mSv and Eff.mAs = 289mA/s. lower row follow up CT images are for 11 years old female with chronic headache, CT control parameters are used and CT finding is normal, Eff.dose=6.823mSvEff.mAs= 483mA/s.

In this study, Eff.dose calculations and Eff.mAs measurements were compared between two techniques (control and modified) for head CT scan. There were remarkable distinctions, depending on parameters.

Discussion:

Ionizing radiations is generally harmful and potentially dangerous, but may exhibit health benefits [15]. High doses can cause visually dramatic radiation burns or rapid fatality; conversely, controlled doses can be used for medical imaging and radiotherapy[6].

CT examinations in pediatric patients have greatly contributed to the diagnosis of many clinical diseases. Radiation risks due to CT procedures are regarded as essential for diagnosis of pediatric patients. Tables 1 and 2 represents the CT scan parameters for control and modified CT examination protocols; the modified protocol represents the minimal standards that can be used for CT examination. In addition, pitch was set at 1 because it has been shown to provide the most uniform X-ray beams and contiguous of adjacent helical rotations, where parameters were adjusted according to scanned anatomy, to assess procedure justification with respect to benefit versus expected risk.

Because brain CT procedures require direct irradiation, control and modified protocol head CT scans were reviewed to calculate Eff.dose and Eff.mAs. Means and SD for each procedure according to gender Table 3 showed no significant differences between control and modified groups (p > 0.05) when its calculated by using Social Sciences (SPSS 22) ; this finding is consistent with that of Pearce et al.[9].

Nevertheless, the values of Eff.dose and Eff.mAs were strongly dependent on patient’s age; this finding is consistent with that of Brenner et al.[2], who showed robust difference according to age. For example, patients < 1 year of age showed a greater difference in Eff.dose mean value, primarily due to the
reduction of parameters in the modified protocol, which reflected a higher risk coefficient. However, a greater difference in Eff.mAs mean values was noted in the 8-12 age group, which might be attributed to scan length discrepancies. Moreover, there were no cases of insufficient imaging among all patients who were imaged by using the modified protocol, compared with the standard protocol.

Distributions of Eff.dose and Eff.mAs values for both protocols according to age (Figure 1 and Figure 2), indicated reductions when using the modified protocol, compared with the control protocol, for different age groups. For Eff.dose, these differences were as follows: < 1 year, 24%; 1-3 years, 22%; 4-7 years, 27%; and 8-12 years 23.5%. For Eff.mAs, these differences were 18%, 17%, 20%, and 23%, respectively; overall differences for Eff.dose and Eff.mAs were 24% and 22%, respectively, and were statistically significant (p < 0.05). These findings are approximately in agreement with those of King et al., who showed 15-20% savings in radiation dose [1].

Furthermore, the relationship between Eff.dose and Eff.mAs for both control (Figure 3) and modified CT protocols (Figure 4) may represent the effects of absorbing dose per individual brain scanners and show limited variation in organ exposure because of very weak negative correlation (inverse relationship) between Eff.dose and Eff.mAs (Table 6); this is consistent with the results of report by Alkhorayef [16]. This weak negative correlation (inverse relationship) is detected although Eff.dose with respect to Eff.mAs has been reduced. The negative correlation between eff.dose and eff.mAs is attributed to “when pitch is varied, the milliampere-seconds value is varied in a corresponding fashion to keep the effective milliampere-seconds value constant” that is according to Michael F. McNitt-Gray[11] whereas, Eff.dose predicted by DLP, where DLP is the total energy absorbed and it is strongly pitch dependent. When pitch increased, radiation dose deceased. The other reasons take account of patient’s size, time of scanning, energy of exposure, and procedures dose reduction [16]. Therefore, variation of Eff.dose values may have resulted from reduction of parameters (current tube, voltage, and pitch factor) because it was not significantly affected by changing eff.mAs.

Additionally, it is essential to justify the use of each procedure by consideration of benefit versus expected risk; thus, all CT images of examined patients in this study were reviewed by three radiologists. Notably, CT images from both protocols showed no reduction in image quality. Although this study was carefully prepared, there were some unavoidable limitations. This research was conducted on a relatively small group and included patients demonstrated a small subset of the possible clinical indications.
Therefore, to generalize the results for larger groups, an increased number of included patients and greater diversity of clinical indications is recommended.

**Conclusion:**

In summary, pediatric patients underwent head CT examination by two sets of CT parameters, and showed differences among four age groups. In the control head CT scan protocol, standard parameters were used; in the modified protocol, minimum settings were used. This study has shown that dose reduction could be achieved without compromising image quality in head CT scanning of head for pediatric patients.

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**Disclosure Statement**

Authors report no conflict of interest is declared; they are responsible for the content and writing of this article.

**Ethical statements**

The Ethics Committee of the College of Pharmacy at Al-Muthanna University approved this research in accordance with the Declaration of Helsinki and guidelines of the Iraqi Ministry of Education and Scientific Research.

**Statement of human rights**

The studies have been agreed by the appropriate Institutional Review Board (IRB) and have been performed in accordance with the ethical standards and declaration of Helsinki 1964 and its later amendments or comparable ethical standards.

**Statement of animal rights:** This article does not contain any studies with animals performed.

**Informed consent:** Informed consent was obtained from all individual participants included in the study.

**References**