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Research Article

Estimation of the k-Value for Head CT Using ICRP-103 Tissue Weighting Factors

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Abstract

Multi-slice x-ray CT scanners are in highly use by physicians to assist them in diagnosing patients disease due to advances in their scanning speed, image processing and image quality. However, this trend results in patients being exposed to many fold higher doses compared to those for general x-ray radiography. This makes CT machines the major source of unwanted dose to the population from medical x-ray procedures. The $CTDI_{vol}$ and DLP parameters are quantities of concern in radiation protection measures. This study was aimed to examine the effective dose received by patients underwent head CT procedures In this paper we present our estimation of the k-value calculated from the DLP from the CT machine in the participating hospital using the ICRP 103 weighted tissue factor. Dose parameters were acquired from the machine and calculations were carried out using the ImPACT CTDosimetry software. We also compared the received doses by age and gender groups. We found that the doses are dissimilar between age groups and between male and female patients.

Keywords: *CT scanner; dose reference levels; effective dose; radiation protection; head procedures*

Estimasi Nilai k untuk CT Kepala Menggunakan Faktor Bobot Jaringan ICRP-103

Abstrak

CT-scanner sinar-X multi slice saat ini paling banyak dipergunakan oleh dokter untuk membantu menegakkan diagnosis penyakit pasien karena kecepatan pemindaian, pemrosesan citra, dan kualitas citranya. Namun hal ini membuat pasien mendapatkan dosis yang lebih tinggi bererapa kali lipat dibandingkan dengan radiografi sinar-X umum. Parameter CTDIvol dan DLP merupakan dua parameter yang diperhatikan dalam praktik proteksi radiasi. Tujuan penelitian adalah untuk menguji besaran dosis efektif dari tindakan pemeriksaan CT kepala. Dalam naskah ini kami menyajikan estimasi nilai-k yang dihitung dari DLP mesin CT rumah sakit responden untuk prosedur CT kepala dengan menggunakan factor bobot jaringan ICRP 103. Parameter-parameter dosis diperoleh dari mesin dan perhitungan dosis dilakukan dengan perangkat lunak ImPACT CTDosimetry. Kami membandingkan dosis yang diterima pasien berdasarkan usia dan gender. Kami mendapatkan bahwa dosis pasien berbeda-beda antar kelompok usia dan juga antara pasien pria dan wanita.

Kata Kunci: *CT scanner; dose reference levels; effective dose; radiation protection; head procedures*

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I. INTRODUCTION

Radiation protection in diagnostic imaging is aimed at ensuring that the benefits exceed the risks resulting from any radiation practices to individuals. Radiation protection work practices are optimized so that individual patient doses and the dose to the population are kept as low as reasonably achievable (ALARA) [1-3]. In 2014, the Indonesia Nuclear Energy Regulatory Agency (Badan Pengawas Tenaga Nukilir/BAPETEN) established a web-based database application for inputting dose data for CT Scan examinations called Si-INTAN (Sistem Informasi Data Dosis Pasien Nasional) or National Patient Dose Data Information System. Then, gradually for examinations of fluoroscopy and interventional in 2016, general radiography in 2017, diagnostic nuclear medicine in 2017, mammography and dental radiography in 2018, following the paper-based offline data collections in 2003-2013 [4]. Other countries, such as, Singapore [5], Turkey [6], Iran [7] and European Community [8] also have established their systems.

The use of x-ray CT scanners for diagnostic purposes is increasing since its first inception in the 1970s [9, 10]. It has become a popular modality of imaging due to continuous improvements in image quality, rapid operation, and its role in treatment planning. Development of image acquisition and processing techniques as well as the hardware systems and subsequent applications have been tremendous in the last decade. The introduction of multi-detector CT (MDCT) and its advanced techniques (e.g. helical, fluoroscopic, multi-slice and volume imaging) fulfil the demand for better image quality and faster image acquisition. These advances have increased the demand for CT imaging and have resulted in CT becoming a significant source of ionizing radiation dose to population from medical x-ray procedures [11, 12]. CT procedures can deliver doses to patients at level or order of magnitude higher compared to doses from conventional radiology [13]. When a patient undergoes multiple CT scans, the absorbed dose leads to a calculated increased risk of cancer [14-16] and possibly deterministic effects (e.g. skin injuries [17] and temporary bandage-shaped hair loss [18]). Consequently, more studies need to be performed to minimize patient dose without compromising minimum acceptable image quality through implementation of the ALARA principles.

The quality of CT images and absorbed dose depends on several factors, such as patient size, equipment, technique and type of examination, the tube kV_p and mAs, scan time, collimation size, feed speed (table speed) and pitch. Inevitably, dose optimization involves modifying procedures to obtain lowest acceptable image quality for diagnostic purposes [19-24]. Many studies have been conducted to investigate the volume CT dose index ($CTDI_{vol}$), dose-length product (DLP) and diagnostic reference levels (DRLs) for local and national standards [25-37]. The establishment and use of DRLs to assist in dose optimization are of major public interest.

Effective dose (ED) was introduced by the ICRP in 1977 [38] and is defined as the weighted sum of doses to tissues that are known to be sensitive to radiation

$$H_E = \sum w_T \cdot H_T \qquad (1)$$

where w_T is the weighting coefficient of a specific tissue (T) or organ, and H_T is the dose equivalent to tissue T. The CTDosimetry calculation spread-sheet version 1.0.2 published by the imPACTscan group allows the calculation of ED for a wide range of application of CT [39]. The software calculates doses using Monte Carlo techniques developed by Shrimpton et al. [40-42].

In its publication No. 102, ICRP [43] gave an empirical estimate for ED using the relationship [44]:

$$\mathrm{ED} = k \cdot \mathrm{DLP} \qquad (2)$$

where k ($\mathrm{mSv.mGy^{-1}.cm^{-1}}$) is an empirical weighting factor, independent of scanner type and specific to a body region. The DLP is calculated according to

$$\text{DLP (mGy.cm)} = \text{CTDI}_{\text{vol}} \text{ (mGy)} \times \text{scan length (cm)} \qquad (3)$$

Therefore, in the area of radiation protection, in addition to knowing the DLP value of the machine, knowing the value of k-value is also important. Thus, in this study we aimed to determine the k-value for routine head CT examinations that comply with the ICRP 103 definition of effective dose, conducted using a multi-slice CT scanner.

Knowledge and information on all dosimetry parameters from CT examinations on individual CT scanners will benefit all stakeholders in CT; patients, physicians and institutions. These parameters may then be compared directly with other scanners, other institutions and with international norms. In turn, these comparisons will assist in limiting the population dose acquired from CT without eliminating its profound contribution to patient care.

II. METHOD

Patients

Routine head scans are the most frequently performed CT investigations in our hospital, where the state neurological and interventional imaging service is based. The data used in this study were from random patients having head CT procedures comprising 102 persons (50 males and 52 females) with a patient age range from 20 to 90 years in Radiology Department, Sir Charles Gairdner Hospital, Nedland, Perth, Western Australia.

Imaging techniques

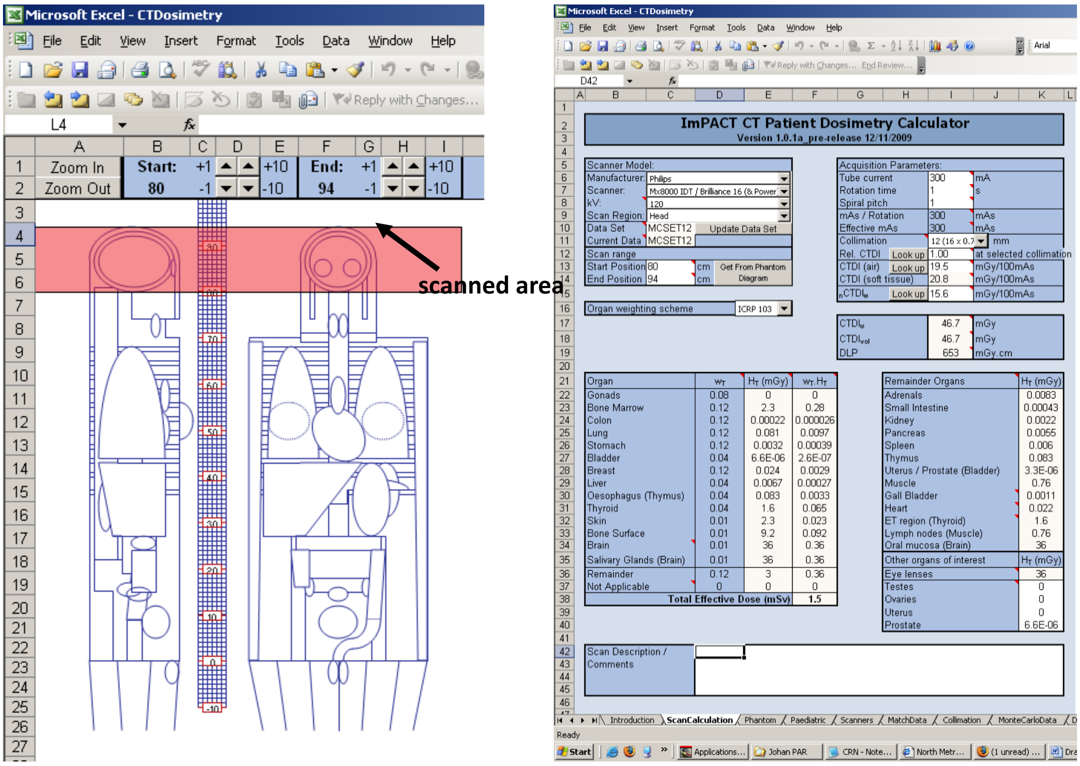
The CT examinations were performed with a multislice helical scanner (Philips Brilliance 64) using tube voltage 120 kV_p, tube current 300 mA, scan time 1 sec, 0.625 mm × 16 cm collimation, scan length 13.00 cm to 16.31 cm, pitch 1 and axial imaging. The Philips scanner does not offer dose modulation for head studies.

Dosimetry data

The images used in this study were acquired from the hospital PACS. The dosimetry data were extracted from image headers and dose pages of the image series using a MATLAB® program, written in-house. The information downloaded include acquisition date and time, manufacturer and model name, description of treatment, patient birth date and gender, kV_p, protocol name, series information, slice thickness (mm), tube current (mA), exposure time (s), scan length (cm), CTDI_{vol} (mGy), and DLP (mGy.cm).

CT organ doses were estimated using the ImPACT CTDosimetry software [39] licensed to the hospital that calculates dose for irradiation of a modelled head phantom as illustrated in Figure 1. The software employs

CT dosimetry data from the National Radiological Protection Board [40-42]. Head dose was calculated for an adult male, with scan lengths ranging from 13 cm to 18 cm. The adult head mass was set at 1.45 kg from the ICRP reference man in its publication No. 89 [45]. Organ doses were calculated using similar set parameters to those used on patients: an x-ray tube current of 300 mA and scan time of 1 s (i.e. to obtain 300 mAs), an x-ray tube voltage of 120 kV_p and a pitch of 1. In addition, we selected the 16-slice option for the machine although we use a 64-slice with patients, due to the unavailability of the corresponding equipment in the software selection.



(a) (b)

Figure 1. The ImPACTscan CTDosimetry software showing: (a) the computational phantom set up used in this study and (b) the corresponding scan calculation sheet. The scan (indicated by the shaded area) was performed to the head from 80 cm to 94 cm. The effective dose calculation may use the organ weighting scheme of ICRP-60 or ICRP-103. The figure shows ICRP-103 as the selected scheme.

III. RESULTS AND DISCUSSION

Figure 2 shows the patient population according to their age group and gender. Compliance tests conducted annually for our Philips Briliance64 scanner measured the $CTDI_{100}$ free in air as 21.3, 21.0 and 21.3 mGy/100mAs for the last three consecutive years. Meanwhile, the ImPACT software gives $CTDI_{100}$ free in air for the selected scanner as 19.5 mGy/100mAs. Therefore, we have adjusted the $CTDI_{air}$ free in air in the ImPACT calculations according to our measured values.

The range of DLP is 627–867 mGy.cm as presented in Table 1. The frequency distribution, expressed as percentage, is shown in Figure 3. The most frequent DLP obtained was in the range of 711-720 mGy.cm that corresponds to the scan length of a slightly below 15 cm.

Table 1. Summary of the results and its comparisons to ICRP [38, 45] and European [39] standards No. 16262. Calculations from the ImPACT [34] software are also presented. ImPACT and SCGH values were calculated using the ICRP-103 tissue weighting factor.

Number of patients		102 (F:52; M:50)
Patient age (y.o.)		20 – 90
Standard protocol used		Routine Axial Head
Tube voltage (kV_p)		120
Tube current (mA)		300
Scan time (s)		1
DLP (mGy.cm)	Range (SCGH)	626.5 – 867.0
	Average (SCGH)	730.7
	ImPACT	653
k ($mSv.mGy^{-1}.cm^{-1}$)	ICRP-60	0.0021
	EUR-16262	0.0023
	ImPACT [ICRP-103]	0.0023
	SCGH [ICRP-103]	0.0025
Effective Dose (mSv)	ICRP-60	1.51
	EUR-16262	1.66
	ImPACT [ICRP-103]	1.54
	SCGH [ICRP-103]	1.80

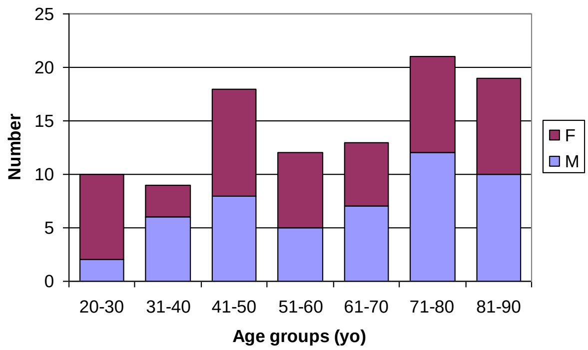


Figure 2. Distribution of patient ages grouped by decades (except for the range 20-30) and gender. Total number of patients = 102 (50 M, 52 F).

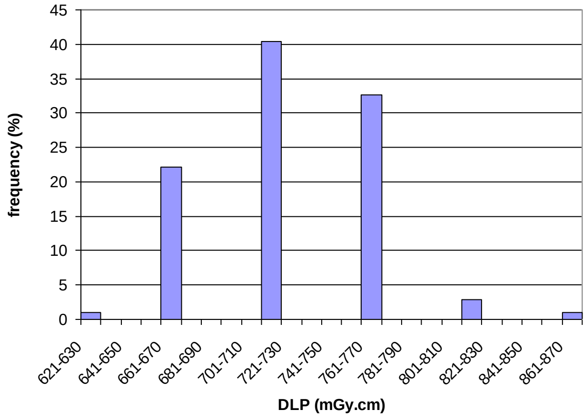


Figure 3. The bar chart of the occurrence frequency of DLP shows a normal distribution.

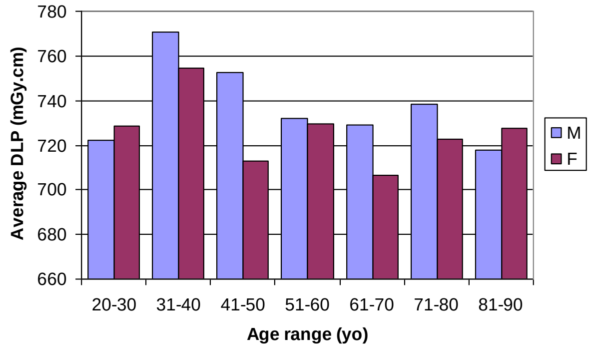


Figure 4. The DLP values of male and female patients over the range of their age. DLP values of male are higher than those of female, except that the most-left and most right groups show the other way.

The distribution of DLP values was independent of age (data not shown). The DLP ranges between 700-800 mGy.cm. While when we look at the difference between the male and female DLP (see Figure 4), the male DLPs are higher than those of female patients except for the extreme groups (i.e. 20-30 y.o. and 81-90 y.o.) that show the other way. Most interestingly is that the middle group (i.e. 51-60 y.o.) shows insignificant difference. The values are 732 mGy.cm for male and 729 mGy.cm for female.

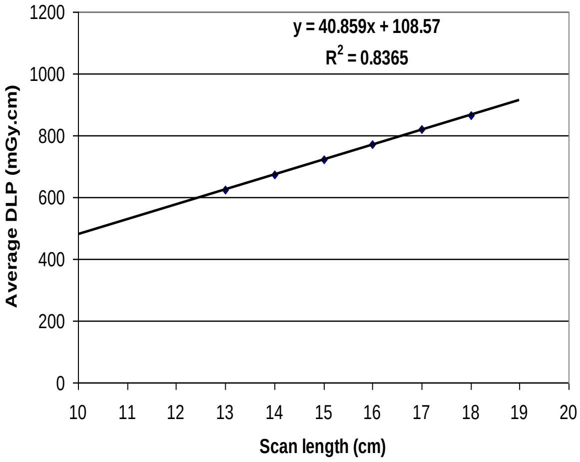


Figure 5. The linearity of the DLP as a function of the scan length. The curve uses data from images that gives CTDI$_{vol}$ of 40.859 mGy (the slope of the curve is the CTDI$_{vol}$).

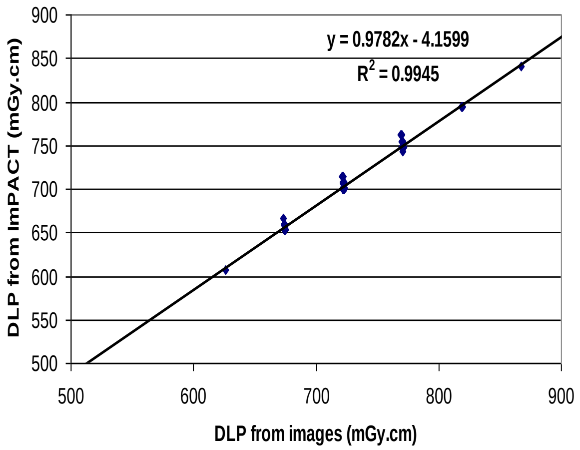


Figure 6. The correlation between the DLP obtained from images (image dose page) and the value calculated from ImPACT.

Figure 5 shows the linear relationship between measured DLP values and the scan length for all patients. The scan length is quantized and some DLP value is obtained for each scan length. The slope of the curve gives the CTDI$_{vol}$ value as 40.86 mGy, while the average of the individual images and the ImPACT calculation gave 48.1 and 47.2 mGy, respectively.

All results show a good correlation between the ImPACTscan values of DLP and the corresponding patient values as shown in Figure 6 (i.e. R^2 = 0.99) and agree to the results of other studies [46-49].

Table 1 summarizes the results from our Philips Brilliance 64 scanner calculations of the effective dose and the *k*-value. The calculations from ImPACTscan for Phillips Briliance16, using similar operational parameters and scan length of 14 cm, gives a DLP of 653 mGy.cm and the effective dose of 1.54 mSv (for ICRP-103). It can be seen that the *k*-value of our machine is 0.0025 mSv.mGy^{-1}.cm^{-1}. This finding is comparable to ICRP-60 (0.0021 mSv.mGy^{-1}.cm^{-1}) [43], European Community EUR-16262 (0.0023 mSv.mGy^{-1}.cm^{-1}) [44] and ICRP-103 (0.0023 mSv.mGy^{-1}.cm^{-1}) [39].

Figure 3 depicts the frequency (in percentage) of the DLP values. The most likely DLP encountered in the head procedure was 721 – 730 mGy.cm which correspond to a scan length ~15 cm. Figure 5 shows that for scanners without dose modulation, e.g. Philips Brilliance 64, the DLP and estimated ED is linear with scan length.

It is of interest, however, that the dose received by the patients is gender dependent, where male patients received more dose than their female counterparts. Figure 4 shows that the DLPs for men are in average larger than those for women. Therefore, men have longer scan length and, thus, the DLPs. More study should be carried out to verify the finding for the age groups of <30 y.o. and >80 y.o. that indicates otherwise.

The CTDosimetry software of ImPACTscan® was used to calculate the dose to the phantom for different scan length. Effective doses and DLPs were calculated for individual patients.

In this study we did not put in consideration the body weight of the patients that were not measured during the examinations. However, as we found that the dose is dependent on the organ mass, the future examinations should include this parameter. We are suggesting the inclusion of patients' body weight measurement in the examination protocol.

This study and the consecutive researches would enrich the Si-INTAN database with such data from domestic as well as oversea hospital.

IV. CONCLUSION

The calculation of the k-value using DLP data and dose estimates for the Philips scanner falls between the values recommended by two international bodies, the ICRP and the European Community. DLP delivered to the patients is age independent. Yet, it is dependent of the size of the organ.

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