CHAPTER 5: DISCUSSION

5.1 Introduction

The aim of this research was to study the dose trends for standard abdominal CT examinations in Malaysia, including the relationship of dose to patient weight and the dose difference between spiral and non-spiral scanners. This chapter discusses the comparison of the risk dose descriptor (effective dose) to other studies carried out in other countries especially the UK and Europe. Following that two important CT dose indicators known as $CTDI_w$ and DLP_{exam} are also compared to those of other countries. Later a method of dose optimisation is recommended as a result of this current study. The weaknesses and limitation in the current study are indicated in several places where necessary. Finally, recommendations and suggestions for future areas of study are included to complement new knowledge in CT dosimetry.

5.2 Comparison of effective dose to other studies

From the year 2000 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000) it is seen that the Health Care Level (HCL) for a particular country, based on the number of physicians per unit population, has some effect on CT scanner density, and the patient CT dose values. The differences of dose value also occurred not only in different HCLs, but also for the countries within the same HCL. Several scanner densities for countries are listed in Table 5.1, where scanner density is the ratio of number of scanners to the population in millions. Thus it is assumed that the Malaysian dose value is comparable to other previous studies.

Table 5.1: Scanner density and typical dose between countries

Country	Number of CT scanners	Population (mil)	Scanner Density+	Effective dose of routine abdominal CT examination (mSv)	References
Germany	1,863	81.7	22.8	14.4 – 17.2	(Brix et al. 2003)
Australia	332	18.4	18	16.7	(Thompson & Tingey 1997)
Austria	NA	NA	NA	14.9	(Imhof et al. 2003)
Japan	11,050	125.8	87.8	12.9	(Nishizawa et al. 2004)
Norway	NA	NA	NA	12.8	(Olerud 1997)
Finland	NA	NA	NA	11.6	(Servomaa et al. 1994)
United Kingdom	370	59.7	6.2	10.0	(Shrimpton et al. 1999)
New Zealand	NA	NA	NA	9.7	(Poletti 1996)
Oman	NA	NA	NA	9.5	(Goddard & al-Farsi 1999)
Netherlands	22	16	1.4	6.0 – 24.0	(Van Unnik et al. 1997)
Malaysia	**101**	**23.3**	**4.3**	**13.0 (5 – 35)**	**Current research**

Note: NA – not available

+*CT scanners per million population*

According to the UNSCEAR report, Malaysia is one of the countries in the Health Care Level II (HCL II), with the physician to population ratio of 1:1406 in 2001 (Ministry of Health Malaysia 2001). In that report, only Oman, which is in the same HCL category as Malaysia, had a report on a CT dose study (Goddard & al-Farsi 1999). This study will contribute greatly to the knowledge in this level of healthcare category.

As mentioned previously, Malaysia has a population mean weight of about 60 kg (Lim et al. 2000). The dataset of patient weight ranged from 45 to 75 kg in this study with a mean value of 61±8 kg. This is in contrast to previous research from European Countries where the patient weight was about 70 kg. The calculated dose however using CT-EXPO, did not allow any adjustment for weight with doses given in comparison to the CTDI body phantom (PMMA, 32 cm in diameter) (Stamm & Nagel 2002).

The relevant quantity for risk assessment of a CT examination protocol is effective dose (see section 2.6.4). The effective dose from CT procedures depends on the CT scanner type, exposure parameters used and body regions as well as examination indications. As indicated from other studies, the patient effective dose from CT abdominal examinations are about 10 mSv, and have been estimated to increase the lifetime risk of a fatal cancer by 1 in 2000 (National Radiological Protection Board 1992). This current study had revealed that the mean effective dose for routine CT abdominal examination is 13±6 mSv in Malaysia. From figure 5.1 it is seen that the mean effective dose in Malaysia is 1.3 times that of the UK. In contrast, the global effective dose per examination was 13.7, ranging from 6.0 – 27.4 mSv (UNSCEAR

2000). It is impossible from the current study to calculate collective dose because the information of the number of patients examined annually was not collected. Thus, collective dose for the country cannot be estimated.

The effective dose from the current study is comparable to that carried out in Germany, Austria, New Zealand and the Netherlands (Table 5.1). The Brix et al (2003) study (Germany) was closely comparable to the current study in terms of the method of dose calculation but it was limited only to spiral CT examinations. The effective dose range (maximum over minimum) factor in Germany was only about 1.2 whereas the current study is 7 times. This larger range may be due to the current study's decision to include all the study areas in the abdomen as the whole abdomen while Brix et al (2003) limited their study to only the abdomen and pelvis. Van Unnik et al (1997) (Netherlands) used the same terms as this current study where all requested examinations for abdominal categories were included and thus a wider range of effective dose of about a factor of 4 was found. Imhof et al (2003) (Austria) again used the same method and found that the effective dose mean dose was 14.9 mSv. The Imhof et al study had a slightly higher effective dose that may be due to the larger average examination scan length which was about 66.1 cm (with scan length and series number was 38.9 cm and 1.7 respectively).

In general, the result of the current study reflected actual hospital practice for abdominal examinations in Malaysia, as do the studies of Van Unnik (1997) and in East Anglia, United Kingdom (Yates et al. 2004) and contrary to the study by Shrimpton et al (1991) where the calculated effective dose was derived from departmental typical routine abdominal examination protocols.

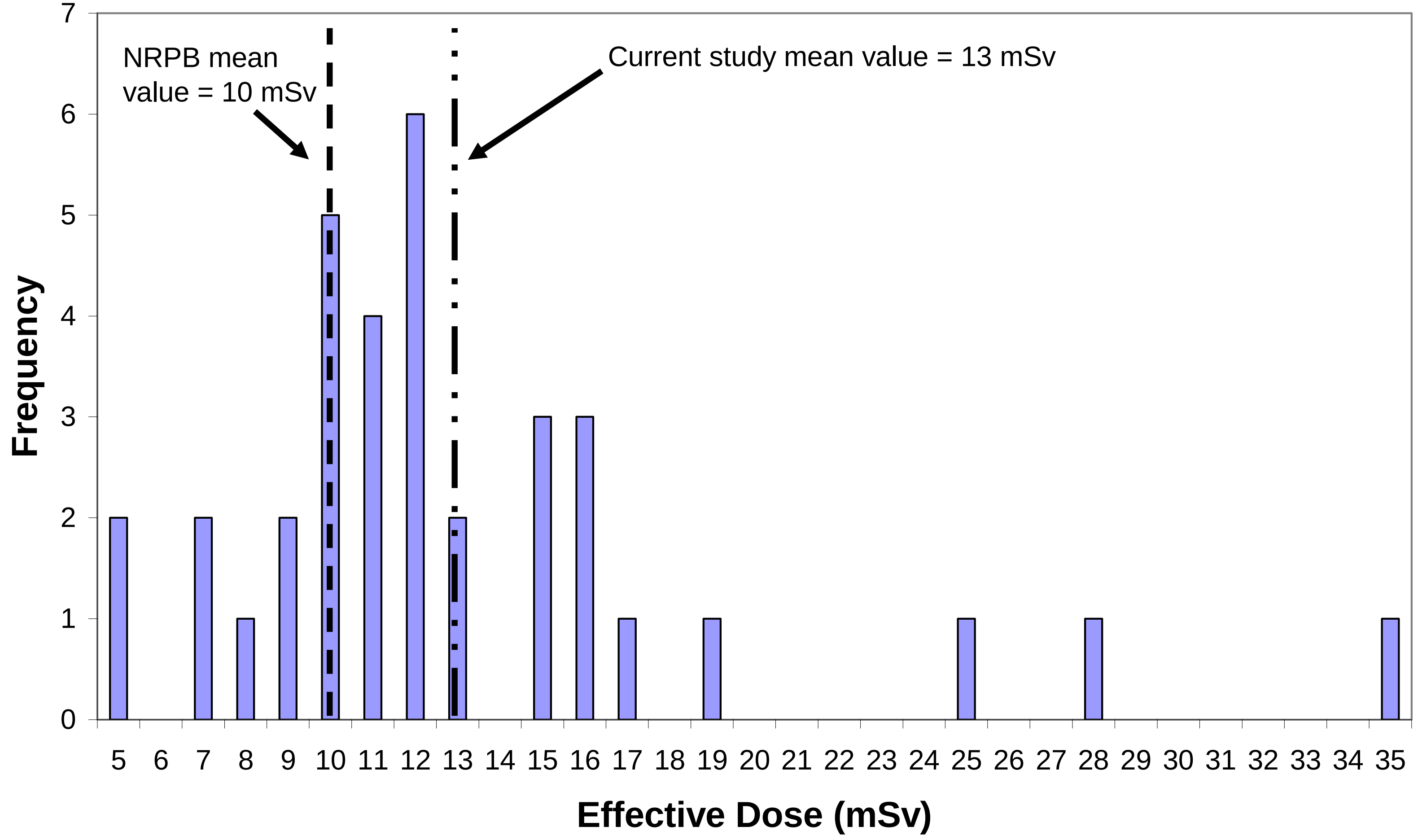

Figure 5.1: Effective dose from 35 scanners in the current study. Doted lines are mean value for comparison

In the latter study, scan length of pre and post contrast series were converted to a series factor in calculating effective dose.

Differences in the value of effective dose between countries may be due to the types of scanners surveyed being a combination of spiral, both single slice (SSCT) and multislice (MSCT), and non-spiral scanners. Analysis of dose from spiral and non-spiral scanners in this study indicates that the latter scanner type had a higher effective dose by a factor of 1.3 (Table 5.2). Similarly, Hidajat et al (2001), while not calculating effective dose, reported their values of the $CTDI_w$ and DLP showed that the conventional CT dose was higher than that of spiral CT by a factor of 1.8 and 2.3 respectively. Most of the conventional CT scanner centres in Malaysia carried out the examinations with both pre and post contrast series thus the dose factor comparing spiral and non-spiral scanners is much less than that reported by Hidajat et al (2001). No explanation can be found for this discrepancy.

The dose values for SSCT and MSCT were found to differ but this current study did not attempt to differentiate the effective dose for those two types of scanners. Several authors have demonstrated that the mean effective dose value between SSCT and MSCT scanner types differ (Brix et al. 2003; Cohnen et al. 2003; Nagel 2004; Thornton et al. 2003). Brix et al (2003) for example, reported that the effective dose was changed from 7.4 mSv at single-slice CT to 5.5 mSv and 8.1 mSv at dual- and quad-slice CT respectively. In another study comparing the $CTDI_w$ and DLP_{exam} values between the two types of scanners (Nagel 2004) found that the MSCT had slightly lower dose indicators when compared to the SSCT scanner. However Quad-slice CT scanners had a higher DLP_{exam} while $CTDI_W$ was similar. For SSCT scanners with a solid-state detector, both the $CTDI_W$ and DLP_{exam} had lower dose indicators compared to all SSCT and MSCT scanners.

This is another reason why doses from the current study, lie in between those other studies, as they include all types of scanners in the one study. Maybe in future a conclusive dose comparison can be made between SSCT and MSCT type scanners thus allowing adaptation and implementation of reference dose recommendations.

5.3 Comparison of $CTDI_W$ and DLP to other studies

The mean $CTDI_w$ in this study was calculated as 18±7 mGy. This value is not significantly different from two studies which range between 15.6 to 17.5 mGy (Brix et al. 2004; Imhof et al. 2003). When comparing spiral and non-spital scanner types the mean $CTDI_w$ of this study is comparable to the studies by Hidajat et al and Shrimpton et al. The results of this current study indicate that the exposure factors used in Malaysia correspond to those used in other countries.

When comparing the current study to those of Hidajat et al and Brix et al for spiral CT scanners, the $CTDI_w$ is identical, however the DLP_{exam} values are different (Table 5.2). The identical $CTDI_w$ is believed to be because the distribution of spiral scanners in those countries is similar. In Malaysia, the transition from conventional to spiral type has just begun, with survey observations indicating that the recently installed scanners are spiral (Table 4.3). The DLP_{exam} of spiral CT scanners from the current study were about 70%, 79% and 280% relative to the studies of Brix et al, Imhof and Hidajat respectively (Table 5.3). The differences are believed to be related to the number of SSCT and MSCT scanner types in the studies, which is noted as another research area to be explored in Malaysia in the near future. Considering all types of scanners, the mean DLP_{exam} for this study was also higher than Hidajat et al by a factor of 1.2 and similar to that of Shrimpton et al (1.07).

For the conventional CT, the mean DLP_{exam} for the current study is higher than both of that of Hidajat et al and Shrimpton et al by a factor of 1.5. One reason for conventional CT having a higher dose then spiral CT scanners may be due to pitch. Generally the pitch used in conventional scanning is equal to one. This research indicates about 100% of conventional scanners used a pitch equal to one. Sometimes a pitch is used that is less than one to improve image detail in the sagittal or coronal reconstruction. A low pitch can also avoid misregistration of structures due to patient respiration movement. Another reason for higher dose in conventional CT scanners is that the equipment is generally old and uses gas type detectors that are less efficient than those of newer spiral scanners.

This study has introduced the parameter RAL_{exam} which can be used as an indicator of scan length and the number of series relative to the standard body length (Table 5.3). For example from Table 5.3, the DLP_{exam} for the current study is 121% with an examination scan length (RAL_{exam}) of 51 cm giving a DLP_{exam} of about 735 mGy.cm. In Germany the examination scan lengths were 62.4 cm and 67.3 cm for MSCT and SSCT scanners respectively, giving RAL_{exam} values of 149% and 160%.

Table 5.2: Comparison of the mean CT Abdominal doses between countries

Country	Authors	Scanner type	$CTDI_W$ (mGy)	$CTDI_{vol}$ (mGy)	DLP_{ser} (mGy.cm)	E_{ser} (mSv)	DLP_{exm} (mGy.cm)	E_{exm} (mSv)
Malaysia	**Current study**	**All**	**18.0**	**16.0**	**454**	**8.0**	**735**	**13**
		Spiral	**16.8**	**13.4**	**403**	**7.2**	**695**	**12.4**
		Conventional	**23.8**	**23.8**	**657**	**11.7**	**896**	**16.1**
Germany	(Brix et al. 2003)	SSCT	18.5	13.9	585	10.3	981	17.2
		MSCT	15.6	12.6	529	9.7	790	14.4
Austria	(Imhof et al. 2003)	Spiral	17.5	na	na	na	880	14.89
Germany	(Hidajat et al. 2001)	Conventional	28.7	na	na	na	571	na
		Spiral	15.7	na	na	na	247	na
United Kingdom	(Shrimpton et al. 1991)	Conventional	25.6*	na	na	na	597*	10.0
Australia	(Thompson & Tingey 1997)	na	na	na	na	na	na	16.7
New Zealand	(Poletti 1996)	na	na	na	na	na	na	11.6
European Commission	(European Commission 1998)	na	25.6*				597*	
Netherlands	(Van Unnik et al. 1997)	na	na	na	na	na	na	6 – 24
Japan	(Nishizawa et al. 2004)	na	na	na	na	na	na	12.9
Switzerland	(Aroua et al. 2002)	na	na	na	na	na	576	10.3
Oman	(Goddard & al-Farsi 1999)	na	na	na	na	na	na	9.5

Note: na – not available

** the result were from the same study*

Table 5.3: Comparison of the mean exposure parameters between countries

Country	Authors	Note	kVp	mAs	ST (mm)	BC (mm)	TF (mm)	Pitch	L_{ser} (cm)	L_{exm} (cm)	N_{ser}	RAL_{ser} (%)	RAL_{exm} (%)
Malaysia	**Current study**	**All scanners**	**122**	**205**	**8**	**9**	**11**	**1.3**	**30**	**51**	**-**	**71**	**121**
		Spiral	**122**	**189**	**8**	**8.9**	**na**	**1.3**	**29**	**53**	**-**	**72**	**127**
		Conventional	**122**	**271**	**10**	**9.7**	**na**	**1.0**	**29**	**41**	**-**	**68**	**97**
Germany	(Brix et al. 2003)	SSCT	123	198	8.6	na	na	1.4	39.6	[a]67.3	1.7	94.2	160
		MSCT	121	200	na	na	na	1.3	41.9	[b]62.4	1.5	99.7	149
Austria	(Imhof et al. 2003)	Spiral	125	189.9	8.1	na	11.3	1.4	38.9	66.1	1.7	92.6	157

Note: na – not available

5.4 Radiation dose optimisation

One method to optimize the dose delivered to patients is by introducing diagnostic reference levels (DRL) (Shrimpton et al. 1998). The comparison of those values was made with the European Commission report as in Figures 5.2 and 5.3. As a result, the third quartile values of $CTDI_{w,}$ $CTDI_{vol}$ and DLP_{exam} can be proposed as DRL values for routine CT abdominal examination in Malaysia.

As shown in chapter 4, the evaluation of dose variables for Malaysian CT scanners, especially $CTDI_{vol}$, showed statistical variation based on the calculations utilising the different protocols used by centres (Section 4.5.4). Hierarchical multiple regression statistical tests indicated that 90% of $CTDI_{vol}$ was dependent on scanner centres but not on patient weight. Similar findings have also been reported by a number of studies (Olerud 1997; Shrimpton et al. 1991; Van Unnik et al. 1997). This result shows that patient weight was not taken into consideration in manipulating the exposure factors, especially kVp, mAs and pitch in abdominal CT examinations. The $CTDI_{vol}$ for those scanners was found to differ but not for DLP_{exam} and E_{exam} . The difference of $CTDI_{vol}$ is believed to be due to the different parameter settings used between spiral and non-spiral scanners.

The optimum pitch used in CT abdominal examinations with a spiral scanner can vary from 1.0 to 2.0 (Hopper et al. 1997; Power et al. 2002; Silverman & Brink 1998; Slone 2000). Additionally, spiral CT can be used to do more series for any particular examination such as with multi-contrast phases series, and thus more scan volume is irradiated (Hidajat et al. 2001; Hopper et al. 1998). It was found that two scanners consistently used a pitch of 0.9 which made the doses from those centres high.

Statistical analysis also revealed that 9 scanners had a constant $CTDI_{vol}$ indicating that radiographer only manipulated exposure parameters for patients during CT abdominal examinations. This result is consistent with another study in the USA (Logan et al. 2003) that reported 69% of radiographers carried out the examination mostly from the preset protocol.

The balance between image resolution and image noise is important in producing a quality image. Thus optimum exposure parameters should be selected (section 2.4.3 and 2.8). The selection of automatic tube current modulation (Kalender et al. 1999) has been practiced by four centres in the current study. The use of this method can only reduce the dose by up to 20 to 45% from the original setting (Kalra et al. 2002; Tack et al. 2003). The use of an exposure chart based on patient equivalent diameter or abdominal circumference that has been discussed (Boone et al. 2003) and reported to save up to 58% in the patient dose. These should be considered in Malaysia.

Variation of $CTDI_w$ between different types of scanners is typically not more than 20% (Brix et al. 2004). As can be seen in Table 4.18, the mean of ${}_nCTDI_w$ for 15 types of scanners was 0.096±0.030 $mGy.mAs^{-1}$ with a range from 0.057 – 0.150 $mGy.mAs^{-1}$. In one study of the same type of CT scanner model over 12 hospitals in the UK, it was shown that the $CTDI_w$ for abdominal examinations was almost identical except for one hospital that had a 32% lower index than the others (Koller et al. 2003). This latter study shows that the dose can be optimised with selection of exposure factors such as choosing slice thickness and tube current (Koller et al. 2003).

Although patient weight differs in this study compared to European studies, the patient's lateral abdominal diameter is not very different. This may be the reason why $CTDI_{Vol}$ does not differ much between the current, Brix et al (2003) and Imhof et al (2003) studies (Table 5.2). A method to balance the exposure factors and maintain image quality should be followed in practicing CT abdomen examinations so that the dose to the patient can be optimised (European Commission 1998).

5.5 Weaknesses and limitations

Significant limitations in the collection of survey data have been identified from this study. A longer period of time and more skilled staff would have allowed a more substantial collection of data. A number of CT scanners that contributed data were later eliminated due to limitations of the dose calculator CT EXPO. This could be avoided to some extent by calculating the dose from those scanners using measured CTDI and normalised effective dose as suggested by the European Commission (European Commission 1998) and so increase the number of samples in the study.

In future, training in data collection in the clinical setting is necessary. The limited number of patient cases in a small centre requires a longer period for data collection. Further, problems with erroneous data and unknown patient weight could be avoided if radiographers collecting the data were more familiar with the needs of this study. This situation also occurred in Germany when 70% of returned questionnaires contained severe discrepancies (Nagel 2004). This indicates that the education on the new CT technology should be established as a general priority, and particularly in Malaysia. Such action is expected to lead to low dose from CT scanning.

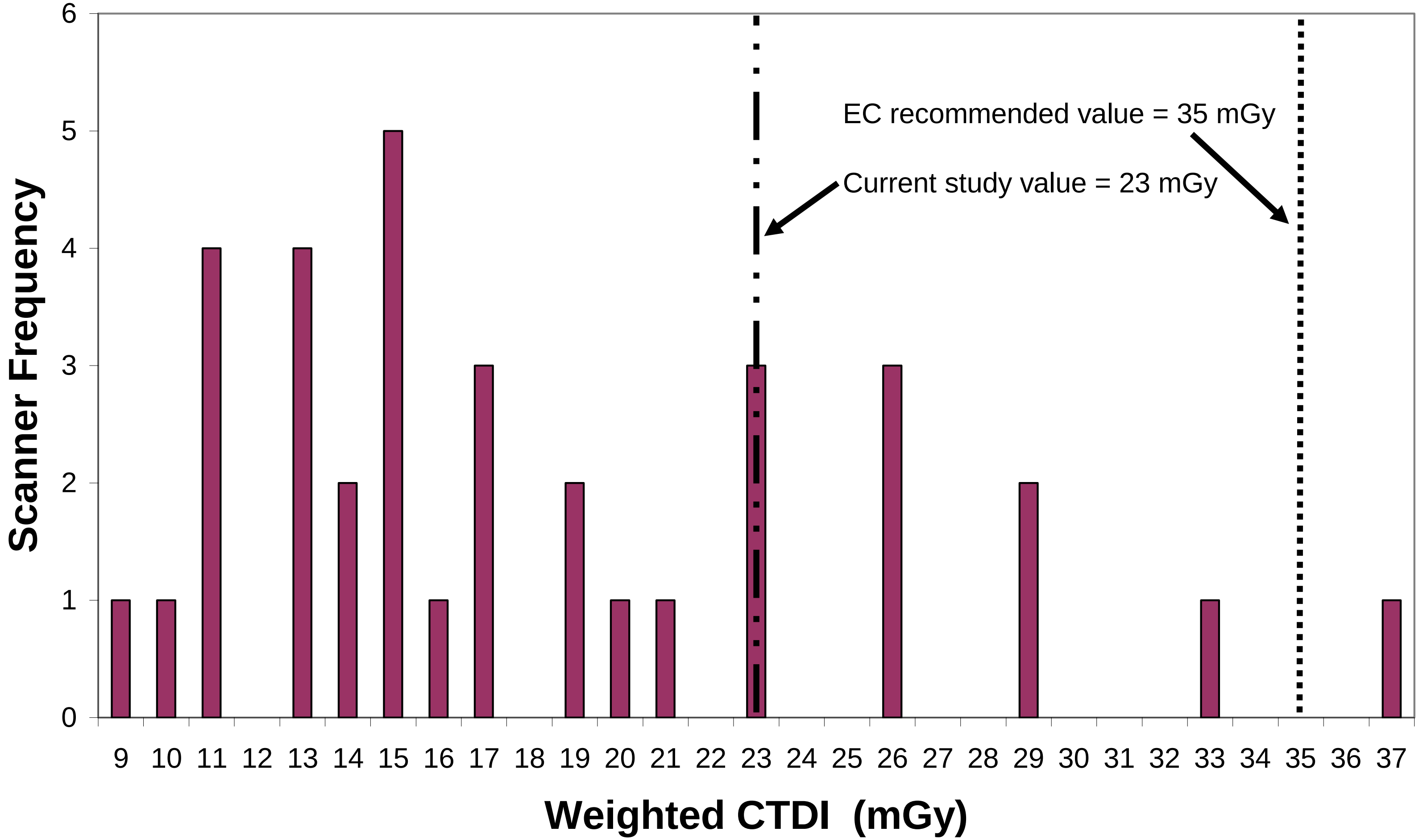

Figure 5.2: The Weighted CTDI ($CTDI_W$) per series for 35 scanners in the current study. Dotted lines are third quartile value for comparison

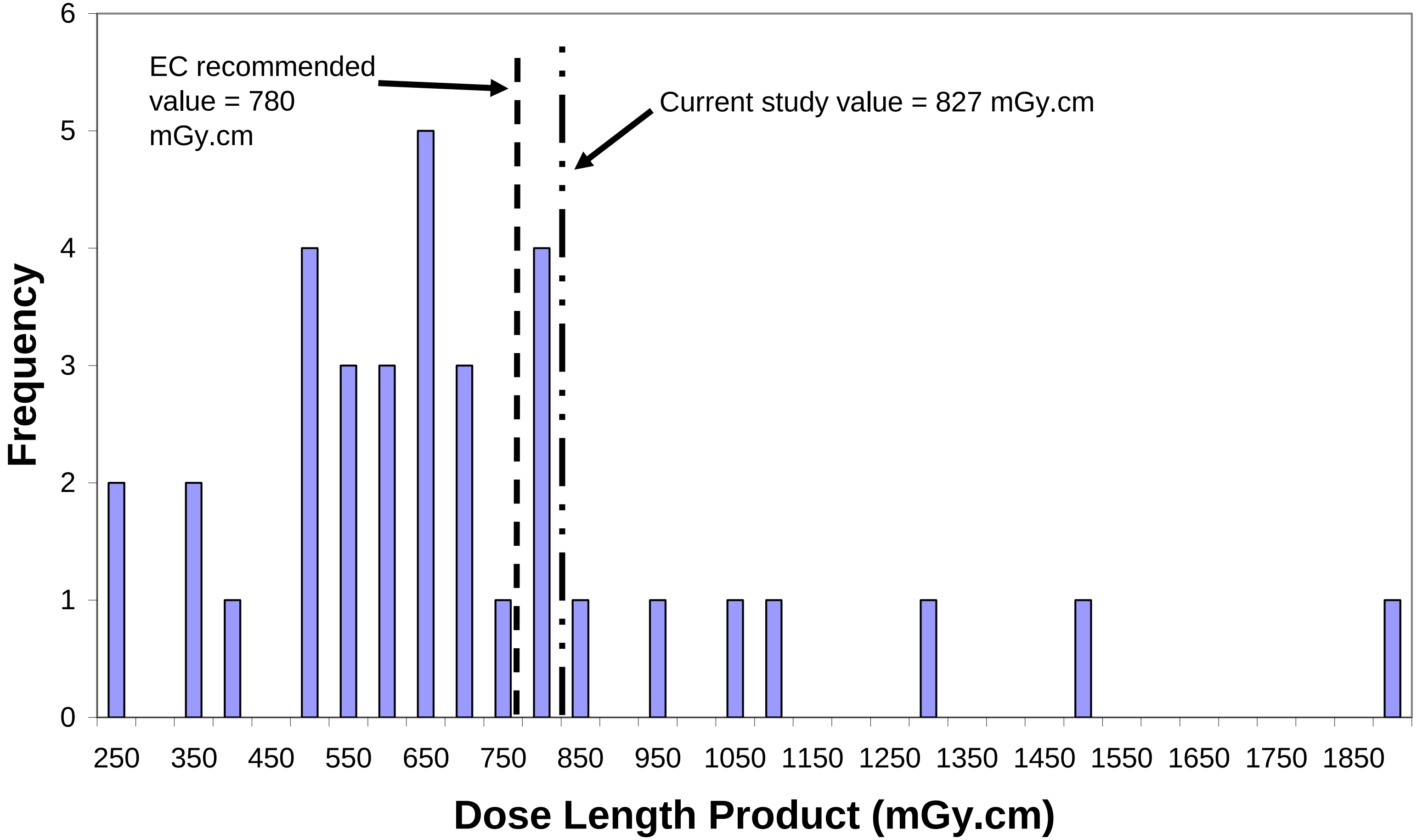

Figure 5.3: Dose Length Product per examination (DLP_{exam}) for 35 scanners in the current study. Dotted lines are third quartile value for comparison