Sains Malaysiana 45(4)(2016): 567–573

Evaluating Organ Dose and Radiation Risk of Routine CT Examinations in Johor, Malaysia

(Penilaian Dos Organ dan Risiko Radiasi Pemeriksaan CT Rutin di Johor, Malaysia)

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ABSTRACT

In this study, radiation doses from CT scan procedures and its related risks to the patients from five hospitals in Johor State, Malaysia were analyzed. The survey was conducted in a two-month period encompassing data for 460 patients with the number for each hospital being set at 32, 30 and 30 samples for CT brain, CT thorax and CT abdomen, respectively. The results indicated that the $CTDI_w$, DLP and effective dose values ranged from 7.0±1.3 to 67.7±3.4 mGy, 300.2±135.4 to 1174.2±79.9 mGy.cm and 1.5±0.2 to 11.7±6.65 mSv, respectively. The organ doses were calculated using CT EXPO software (Ver. 2.3.1, Germany) and were found to vary within the hospitals and the type of the CT examinations. Effective cancer risks per procedure were calculated by multiplying organ dose with the nominal cancer risk that was adapted from International Commission on Radiological Protection (ICRP) Publication 103. The values ranged from 0 to 1449 cancer cases per one million procedures for these three routine examinations. This present work showed that the CT systems can impart high radiation doses and increase of radiation risk to patients if optimization protocols are ignored.

Keywords: CT scan; effective dose; organ equivalent dose; risk assessment

ABSTRAK

Dalam kajian ini, dos sinaran daripada prosedur imbasan CT dan risiko yang berkaitan dengan pesakit daripada lima hospital di Johor, Malaysia telah dianalisis. Kajian ini dijalankan dalam tempoh dua bulan meliputi data untuk 460 pesakit dengan bilangan untuk setiap hospital ditetapkan masing-masing dengan 32, 30 dan 30 sampel untuk CT otak, CT toraks dan CT abdomen. Keputusan menunjukkan bahawa CTDIw, DLP dan dos berkesan, masing-masing berjulat 7.0±1.3 hingga 67.7±3,4 mGy, 300.2±135.4 hingga 1174.2±79.9 mGy.cm dan 1.5±2 hingga 11.7±6.65 mSv. Dos pada organ telah diukur menggunakan perisian CT-EXPO (Versi 2.3.1, Jerman) dan didapati berbeza-beza antara hospital. Risiko kanser efektif bagi setiap prosedur dikira dengan mendarabkan dos organ dengan risiko kanser nominal yang telah disesuaikan daripada laporan Suruhanjaya Antarabangsa bagi Perlindungan Radiologi (ICRP) Terbitan 103. Nilainya adalah berjulat antara 0-1449 kes kanser bagi setiap satu juta prosedur bagi tiga pemeriksaan rutin ini. Kajian ini mendedahkan sistem CT boleh menyebabkan dos radiasi yang tinggi dan peningkatan risiko radiasi kepada pesakit jika protokol pengoptimuman diabaikan.

Kata kunci: Dos berkesan; dos setara organ; imbasan CT; penilaian risiko

Introduction

Radiological examination utilizing X-rays remains as the most commonly used ionizing radiation in the fieldof medicine, responsible as the most substantial man-made source of radiation exposure to the world population (Jessen et al. 1999; Rehani 2012). In diagnostic radiology, dose monitoring are carried out to reassure exposures are within the reference limits and the established optimization of the radiation protection of patients (O'Daniel et al. 2005; Shrimpton et al. 2006). Dose measurements are required in every hospital to ensure compliance with acceptable reference level as well as consideration to justification and appropriate optimization. International Commission on Radiological Protection (ICRP) had stated that the use of computed tomography (CT) had inclined significantly and the radiation dose from CT procedures may be too high (Rehani 2012). Since the past two decades, a number of CT dose survey shave been undertaken in many countries around the world. These efforts were vital in order to recognize significant variations in patient doses between different radiological departments for the same type of CT examination (Brix et al. 2003; Muhogora et al. 2006; Shrimpton et al. 2006; Suliman et al. 2011; Verdun 2008). These variations in dose within and among hospitals justify dose assessment in order to optimize CT practice (Muhogora et al. 2006).

In recent years, dose to patient has become a major issue because of the increasing awareness and greater realization of the effects of ionizing radiation (Kalender 2014). Moreover, X-ray users are also interested in dose information and call for dose reduction. Therefore, there is an increasing demand for individual dose assessment of imaging diagnostic radiation exposures, for instance with the introduction of clinically applicable methodology for specific patient-organ dose determination (POSDE) (Chen et al. 2012; Kalender 2014)which limits the possibility of usage in real-time applications. The aim of this study was to develop fast on-site computed tomography (CT. The use of CT has shown a tremendous increase following the technical advances in equipment that have enabled much faster image acquisition and greater processing capabilities (Lee & Chhem 2010).

CT is an invaluable diagnostic tool for many clinical applications. These applications range from cancer diagnosis to trauma and to osteoporosis screening. A CT can reduce the need for invasive procedure to diagnose problems of the human body such as for blood vessel study. CT was the first imaging modality that has made possible to probe into inner depths of the body slice-by-slice. However, many researchers revealed that the exposure to CT scans were likely to increase the risk of getting cancer (Berrington de Gonzalez et al. 2009; Brenner & Hall 2007). The present study was conducted in order to assess the radiation doses and its related risk to the organ doses of patients under-going routine CT examinations in five public hospitals in Johor, Malaysia.

MATERIALS AND METHODS

DOSE SURVEY

The study was performed at five hospitals conducting CT procedures located in Johor, Malaysia. Specifically, the five centers were: Diagnostic Imaging Department, Hospital Sultanah Aminah Johor Bahru (H1); Diagnostic Imaging Department, Hospital Sultan Ismail Johor Bahru (H2); Diagnostic Imaging Department, Permai Psychiatric Hospital (H3); Diagnostic Imaging Department, Sultanah Fatimah Hospital Muar (H4) and Diagnostic Imaging Department, Segamat Hospital (H5). Details of the facilities of different CT scanners found in each hospital are shown in Table 1.

In accordance with the previous works reported elsewhere (Brix et al. 2003; Kharuzhyk et al. 2010; Muhogora et al. 2006; Shrimpton et al. 2006; Suliman et al. 2011) the questionnaires were prepared and filled up by the radiographer in-charge of the CT facility. All relevant information associated with the CT unit are required including the name and the type of scanner, the type of examination, the patient characteristics, the CT parameters and the radiation dose information. All CT scanners were optimally performed and passed the annual QA and PPM tests. A total of 460 patients with various CT examinations which includes the brain, thorax and abdomen were obtained in this study corresponding to 32, 30 and 30 samples for each CT examination procedure, respectively.

ORGAN DOSE AND RISK ASSESSMENT

Radiation doses from the patients were calculated using the format implemented in the program CT-EXPO (Version 2.3.1, Germany) as described in details elsewhere (Brix et al. 2003). This software offers automatic output calculation of effective dose to the organs based on the specific scanner model, manufacturer and scanning parameters as input data. There are several widely available do simetric tools in the market using similar method to quantify radiation doses in CT systems which varies based on the location and the type of scanners such as CT-EXPO and ImpaCT (Brix et al. 2003; Muhogora et al. 2006). From the calculation, three main dose descriptors were obtained: weighted Computed Tomography Dose Index ($CTDI_w$), Dose Length Product (DLP) and effective dose (E).

Conventional CT consoles were restricted to show $CTDI_w$ while current CT units provide for more detailed descriptors such as volume CTDI ($CTDI_{vol}$) and DLP. All scanning parameters, including patient characteristics and calculated results were collected and registered in Microsoft Excel for further analysis. The mean of $CTDI_w$, $CTDI_{vol}$, DLP and E from the calculations were characterized according to the region and protocols used.

The risk of cancer incidence (*R*) in a particular organ (*T*) following routine examination of CT was estimated by using the following equation:

$$R = \sum_T r_T \cdot H_T,$$

where r_T is the risk coefficients attained from the International Commission on Radiation Protection (ICRP) Publication 103(2007) (ICRP 2007) and the H_T is the organ-specific equivalent dose in organ *T*. The lifetime mortality risk (R) per procedure resulting from cancer was estimated by multiplying the effective dose (E) with the risk factor (r).

TABLE 1. Details of facilities, manufacturer, brands, configurations of detector and installation year used in the five hospitals

Hospital	CT Scanner*				
	Manufacturer	Brand	Detector configuration	Year of installation	Covering district
H1	Siemens	Definition AS	64-slice	2010	Johor Bahru
H2	Siemens	Somatom Emotion Duo	2-slice	2004	Johor Bahru
H3	Siemens	Somatom Emotion 16	16-slice	2010	Johor Bahru
H4	Toshiba	Activion 16	16-slice	2010	Muar
H5	Siemens	Somatom Emotion 16	16-slice	2014	Segamat

*It should be noted that all of the CT scanners included in this study were subjected to Planned and Preventive Maintenance (PPM)

RESULTS AND DISCUSSION

The information obtained from the five hospitals was used to describe the patient characteristics and other scan parameters. The CT parameters presented in Table 2 are required to assess the radiation risks associated with the scanning examinations for patients in the Johor State, Malaysia. As indicated in Table 2, the effective tube current values of CT abdomen in H1 and H2 were 241.1±147.9 mAs and 80±0.0 mAs respectively with distinct variation in scan distance values of 36.9±18.4 cm and 39.6±12.1 cm, respectively. It is observed that such wide variation of three times could be attributed to the different types of scanners. Patient characteristics could contribute random variations where the scan distance may have impact on dose whilst age has nothing or less influence to do with scan conditions.

Radiation dose to the patients at the five hospitals expressed in terms of $CTDI_w$, DLP and effective dose are presented in Table 3. From this data we can see that CT examinations in H2 indicates the lowest mean values of $CTDI_w$, DLP and E for CT Brain (55.5 ± 2.0 mGy), CT Thorax (165.8±40.9 mGy.cm) and CT Brain (1.5±0.2 mSv), respectively. The highest value of $CTDI_w$ and DLP was noted at H5 and H4 in CT brain examination with a value of 67.7±3.4 mGy and 1174.2±79.9 mGy.cm respectively. The mean effective dose of 11.7±6.7mSv was noted to be highest for CT abdomen at H4.

Comparing the results of $CTDI_w$, DLP and effective dose with the facilities in Table 1, almost of the high values were obtained from scanner with 16 slice detector configurations except the one used at H3. It was observed that there was significant variation in the measured scan parameters in the five hospitals which attributed to difference in the size of the patients, scanned area, scan mode and effective mAs. This variation and its attribution could agree with research findings reported in previous literatures (Brix et al. 2003; Muhogora et al. 2006; Origgi et al. 2006). Furthermore, the variation of the type of CT equipment to the hospital specification for mean $CTDI_w$ and DLPled to higher dose of CT brain than other CT examination.

The highest effective dose values reported in this study for CT brain, CT abdomen and CT thorax, with respective values of 4.0±1.5, 11.7±6.7 and 6.4±2.7 mSv were compared with Muhogora et al. (2006) survey in Tanzania. The effective dose values obtained for CT brain, CT abdomen and CT thorax with respective values of 7.9±2.1, 13.2±6.8 and 2.6±2.1 mSvin Tanzania were higher than the present findings by factors of 2.0 and 1.1, respectively, except for the value of CT thorax of present findings which is higher by a factor of 2.4.

As indicated in Table 4, mean values of $CTDI_w$ and DLP were compared with the Diagnostic Reference Level (DRL) of European Commissioner (EC) (European Commission 1997) and Malaysian regulation (Ministry of Health Malaysia 2013). From the observation, the mean $CTDI_w$ of CT Brain exceeded DRL of EC and Malaysian regulation by a factors of 1.1 and 1.3, respectively while mean $CTDI_w$ values of CT thorax and CT abdomen were under the reference level of EC and Malaysian DRL. Obviously,

TABLE 2. Selected CT parameters for organ dose measurements

Hospital / Examination	n*	Patient characteristics		Scan parameters		
		Age (years)	BMI** ($kg.m^{-2}$)	Tube output (kV)	Effective mAs	Scan range (cm)
H1						
Brain	32	46.7 ± 2.9		120	420	14.5 ± 1.8
Thorax	30	63.3 ± 8.2	20.2 ± 3.1	120	142.3 ± 15.3	45.6 ± 8.3
Abdomen	30	43.1 ± 8.8	23.2 ± 3.6	120	241.1 ± 147.9	36.9 ± 18.4
H2						
Brain	32	53.0 ± 2.5		130	260	12.2 ± 1.9
Thorax	30	50.2 ± 1.4	23.5 ± 3.7	110	90	39.8 ± 13.9
Abdomen	30	43.0 ± 8.2	21.2 ± 2.5	130	80	39.6 ± 12.1
H3						
Brain	32	51.4 ± 8.3		130	270	14.9 ± 2.4
Thorax	30	54.2 ± 8.7	23.1 ± 3.4	130	121.8 ± 71.3	40.3 ± 9.8
Abdomen	30	55.7 ± 11.2	23.6 ± 2.2	130	72.6 ± 20.4	31.3 ± 8.3
H4						
Brain	32	46.7 ± 2.9		120	375	16.2 ± 2.9
Thorax	30	63.3 ± 8.2	20.2 ± 3.1	120	166.5 ± 77.0	38.9 ± 18.3
Abdomen	30	43.1 ± 5.8	23.2 ± 3.6	120	81.6 ± 11.4	36.5 ± 8.9
H5						
Brain	32	51.4 ± 1.3		130	270	15.6 ± 0.7
Thorax	30	54.2 ± 1.7	23.1 ± 3.4	130	97.0 ± 19.8	38.2 ± 3.8
Abdomen	30	55.7 ± 2.2	23.6 ± 2.2	130	98.9 ± 28.1	44.5 ± 11.5

*Number of sample, **Body-mass index

TABLE 3. Measured $CTDI_w$, DLP and E from five hospitals in Johor State, Malaysia

Hospital	Region	$CTDI_w$ (mGy)		DLP (mGy.cm)		E (mSv)	
		Mean	SD	Mean	SD	Mean	SD
H1	Brain	60.5	1.9	838.3	87.4	1.9	0.5
	Thorax	8.7	2.6	374.8	133.6	6.9	2.9
	Abdomen	13.1	3.6	558.1	166.5	8.9	2.8
H2	Brain	55.5	2.0	756.0	62.2	1.5	0.2
	Thorax	5.6	0.7	165.8	40.9	3.1	1.1
	Abdomen	7.0	1.8	263.5	104.5	4.4	1.4
H3	Brain	65.2	9.8	943.3	202.3	2.1	1.0
	Thorax	12.6	7.9	535.9	304.1	10.1	6.6
	Abdomen	8.7	3.0	300.2	135.4	4.8	2.2
H4	Brain	65.4	0.6	1174.2	79.9	4	1.5
	Thorax	26.4	10.0	1077.9	479.7	4.6	3.5
	Abdomen	12.9	5.5	547.1	252.4	11.7	6.7
H5	Brain	67.7	3.4	975.7	262.6	2.4	0.6
	Thorax	11.1	2.4	479.0	187.5	6.4	2.7
	Abdomen	12.4	3.2	499.5	235.9	6.9	3.0

TABLE 4. Comparison of themean $CTDI_w$, DLP and E values with thecurrent reference levels from European Commission (EC) and Malaysia

Region	This study Min – Max (Mean±SD)		EC (1999) (European Commission 1997)		Malaysia (2009) (Ministry of Health Malaysia 2013)	
	$CTDI_w$	DLP	$CTDI_w$	DLP	$CTDI_w$	DLP
Brain	55.5 – 67.7 (62.9±4.9)	756.0 – 1174.2 (937.5±158.3)	60	1050	46.8	1050
Thorax	5.6 – 26.4 (12.9±8.0)	165.8 – 1077.9 (526.7±338.9)	30	650	19.9	600
Abdomen	7.0 – 13.1 (10.8±2.8)	263.5 – 558.1 (433.7±140.9)	35	780	12.8	450

the scan parameters and the protocols used were the main contributors to this higher output particularly, tube current and tube potential.

DLP is one of the ultimate dose descriptors which are important to determine the effective dose for CT examination. Interestingly, the mean DLP values of selected examinations in this study were below the level of the DRL. The mean DLP of CT brain, CT thorax and CT abdomen compared to DRLs were lower by a factor of 1.1, 1.2 and 1.8, respectively, when compared to the EC reference level.

PATIENT ORGAN DOSE

Radiation risks using patient-specific organ doses calculated from $CTDI_w$ and DLP values independent from routine examinations will continuously interest many researchers (Cheung et al. 2007; Ngaile & Msaki 2006; Osei & Barnett 2009). Huda (2012) and Huda et al. (2010) for example, had published several articles regarding radiation risk based on the measurement of organ doses for CT exams. In their method, the ImPACT (2010) (www.impactscan.org) dosimetry calculator was used to generate organ doses for a variety of simulated adult body such as scanning techniques, patient ages and sex. Subsequently, to infer organ risks in each of the examinations studied, BEIR-VII risk factors were used. Although the method of calculation has been questioned by others (Balonov & Shrimpton 2012), the results are still usable in comparing the dose values within the radiological modalities and procedures (UNSCEAR 2010).

As indicated in Figure 1, the distribution of the organ equivalent dose values varies for the same examination and scanners, due to various CT parameters used during examination. The organ equivalent dose values of CT brain examination ranged from 5.8±1.1 to 61.0±3.1 mSv. The highest value was noted at the eyes lens with a value of 61.0±3.1 mSv where, as the lowest value of 5.8±1.1 mSv was found in the thyroid (Figure 1). This is in line with the study by Andrade et al. (2012) where the dose received by eyes lens during CT head procedure was also the highest at 36±23 mGy. These variations may be contributed by the different imaging protocols even when using similar brand of scanners. Doses from CT thorax reported in this study were moderately lower than previous study by Andrade et al. (2012) where the values ranged from 7.5 ± 2.2 to 15.8 ± 2.2mSv with the highest value noted in the thyroid and the lowest value noted in the salivary gland (Figure 1). Although the dose is significantly lower ,the possibility to induce stochastic effects has been established to be fall even at smaller thresholds (Hall & Brenner 2008).

In the case of CT abdomen in the hospitals studied presented in Figure 1, the values are closer to that of CT thorax. The CT exams for abdomen doses ranged from 10.7±0.8 to 13.8±1.1 mSv with the highest value of 13.8±1.1 mSv observed in the kidney and the lowest value of 10.7±0.8 mSv was reported in the adrenal with a value of 10.7±0.8 mGy. The highest value of 13.8 ± 1.1 mSvin the study for abdomen is far below the threshold dose for malformation but of concern for stochastic effect (UNSCEAR 2010).

CANCER RISK ASSESSMENT

Table 5 presents the probability of radiation risk induced by routine CT examinations, which was extrapolated by multiplying the organ equivalent dose with the appropriate nominal risk factor obtained from ICRP (ICRP 2007). In this situation, the organ equivalent dose is applied in the calculation in order to estimate the detrimental effects on patients that are exposed to various intensities of radiation. Our observation noted that lungs had the highest cancer risk during CT thorax examinations (1450 per 1 million examinations) while for CT abdomen examination, however, cancer risk for stomach was the highest with estimated 1147.9 per one million examinations. Generally, the largest organ dose is measured when the organ is in the primary beam. The cancer risk estimation, however, is difficult to be compared with other reference as the methodologies used to infer cancer and dose estimation are totally diverse.

CONCLUSION

In this study, the patient dose from most frequent CT examinations (CT Brain, CT Thorax and CT abdomen) at five public hospitals in Johor, Malaysia were presented in terms of $CTDI_w$, DLP and effective dose. These presented data were lower than the values conveyed in most literature. However, despite of its low dose exposure, the radiation

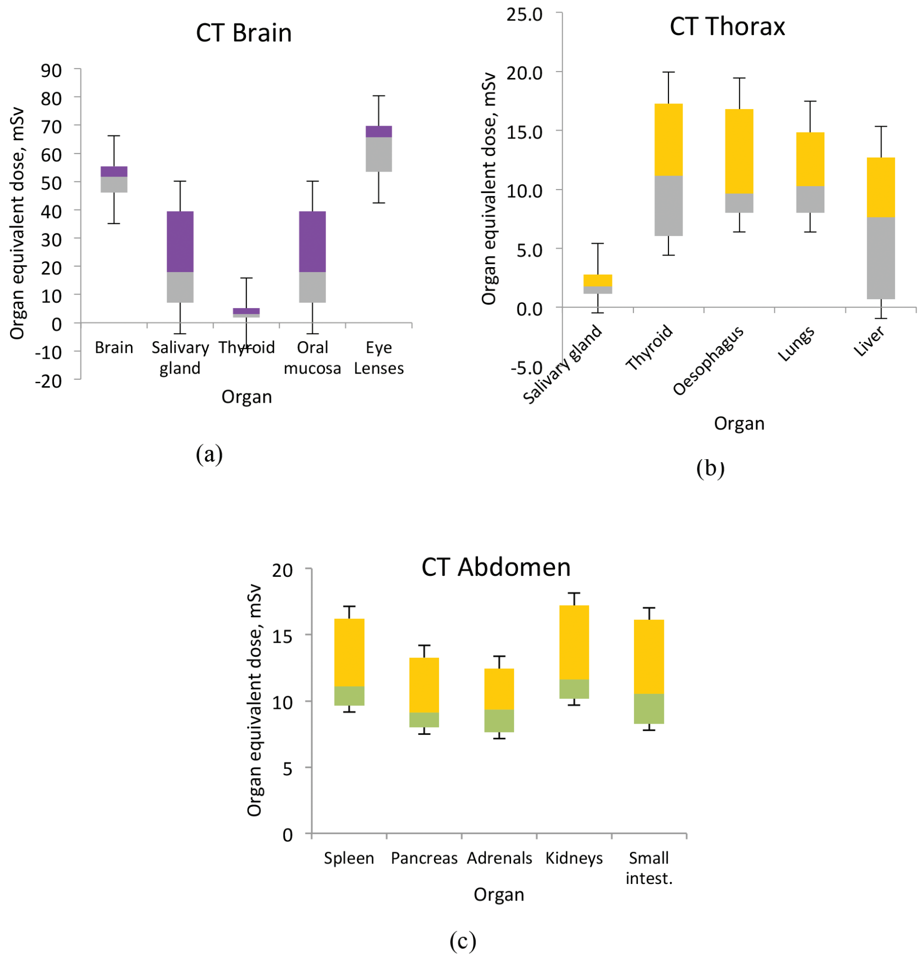

FIGURE 1. The distributions of the equivalent dose to the relevant organs for each examination: (a) CT Brain, (b) CT Thorax and (c) CT abdomen are presented in box-plots. The boxes represent the interquartile range between 25 to 75% and the whiskers represent the 10 to 90% of distribution. The bars inside the boxes represent the medians of the dose distribution

TABLE 5. Estimation of organ cancer risk according to thetype of examination

Type of examination		Organ						
		Thyroid	Esophagus	Lungs	Liver	Stomach	Colon	Ovaries
Nominal risk factor ($10^{-4}Sv^{-1}$)**		32.5	15.1	114.2	30.3	79.1	65.4	10.6
Brain	Mean H_t(mSv)	3.5	0.2	0.2	0.0	0.0	0.0	0.0
	Cancer probability (10^{-6})	113.4	3.0	22.8	0.0	0.0	0.0	0.0
Thorax	Mean H_t(mSv)	17.8	13.9	12.7	8.6	8.2	2.1	0.0
	Cancer probability (10^{-6})	578.5	209.9	1450.3	260.6	648.6	137.3	0.0
Abdomen	Mean H_t(mSv)	0.1	0.6	3.5	13.1	14.5	12.9	9.4
	Cancer probability (10^{-6})	3.3	9.1	399.7	396.9	1147.0	843.7	99.6

**Nominal risk factor values were obtained from Table A.4.2 of ICRP Publication 103(2007) report

risks from CT still exist due to its increase in usage every year. With patient characteristics random variations, and scan parameters specifically the scan range, it may be concluded that size of the patients plays a significant role in this study. Hence, it is important to create awareness among radiologist/radiographers/physicists to continuously monitor CT equipment performance through appropriate quality control programs. Finally, it is expected that future studies will examine the progress attained towards CT optimization techniques among radiology personnel.

ACKNOWLEDGEMENTS

The authors wish to thank the Ministry of Education (MOE), Malaysia for providing the financial assistance through the Research University Grant Scheme (RUGS), project number (Q.J130000.2526.06H10) and also to Dr Khatijah Abu Bakar, Head of the Diagnostic Imaging Department in Hospital Sultanah Aminah Johor for her valuable suggestions.

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Received: 14 August 2015
Accepted: 1 October 2015