Patient dose resulting from CT examinations in Yazd, Iran

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Background: With the introduction of computed tomography in diagnostic radiology a new and fundamentally different imaging modality has become available. Meanwhile, it is clear that the absorbed doses by the patients during CT were relatively high in comparison with those of other diagnostic radiology techniques. The aim of this survey was to determine the average absorbed dose in Yazd province by CT examinations, and to survey the potential risks per year by these examinations. **Materials and Methods:** This study was conducted in CT centers of Yazd during 2005-2006. The examination frequencies from 3 CT scanners were collected from all types of examinations. Effective dose were determined by CT Dose program (ImPACT CT patient dosimetry calculator). To use of this software, $CTDI_{air}$, mAs and the thickness and number of slices in each type of CT examinations should have been measured. $CTDI_{air}$ was measured by pencil diode detector. **Results:** It was estimated that the annual collective dose and caput dose were about 32.48 Person-Sv and 0.038 mSv, respectively for the Yazd population, which is lower than that reported for other countries. The numbers of examinations per 1000 people of Yazd was 18 which were equal to many other countries such as UK and New Zealand. The mean effective dose of each CT examinations was also lower than that of other countries. **Conclusion:** Using the ICRP risk factors, radiation dose from CT could be induced to about 1 fatal cancer per year in Yazd. Therefore choosing CT imaging must be completely justified. **Iran. J. Radiat. Res., 2007; 4 (3):**

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INTRODUCTION

Advances in medical technology make complex diagnostic procedures readily available to the clinical practice. The patient dose will highly depend on the diagnostic procedure used, and thus the population dose and dose distribution may change with improvement of technology [1]. It is well known that CT is related to high radiation dose to the patient. Many ways are found in the literature to describe and measure radiation dose in CT examinations [2-4]. Computed tomography has made dramatic advances, both in its breadth of application, and in its technological improvements. The advances are such that it is possible with the spiral technique to carry out an entire examination of the chest within a single breath hold as against a few minutes in earlier systems. Yet these advances have brought with them the potential for greatly increased doses of radiation to the patient [5].

The conditions of exposure during CT examinations are quite different from those in conventional x-ray procedures and specific techniques are necessary in order to allow detailed assessment of patient dose from CT. Surveys of CT practice using various methods of dosimetry have established the increasing importance of CT as a significant source of medical x-ray for populations in developed countries [5]. It has been recognized that dose to population from CT examinations represent a major fraction of the total exposure to ionizing radiation from medical practices [5]. In the UK concluded that in 1989 CT examinations represented 20% of the annual collective dose, while the percentage of the CT examinations was only 2% of the total of x-ray medical examinations. Because of the proliferation of CT scanners by 1997, the annual collective dose was raised to 40% and now this percentage certainly has risen [6, 7]. The raise of collective dose in CT is mainly due to the fact that with

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the exception of angiography and GI tract examinations, CT examinations deliver to the patient a radiation dose considerably higher than that of the conventional X-ray [8]. For example, it has been reported that in conventional radiology a chest examination results in a typical effective dose of 0.04 mSv compared with 8.3 mSv in CT, while in a head examination the effective dose are 0.1 mSv and 1.8 mSv respectively [7].

Although magnetic resonance imaging was expected to reduce the frequency of computed tomography, but this has not happened. Indeed, the use of computed tomography has grown. Wall reported a 30% reduction in doses of radiation from common radiological procedures compared with 10 years ago but an increase in radiation doses of about 35% for computed tomography examinations [9]. In view of the above considerations, it can be said that there exists a need to monitor CT examinations doses on a national basis. Several surveys have been carried out in various countries [10-14]. There wasn't any CT scanner fifteen years ago in Yazd, but now two conventional CT and one spiral scanner system are exist. In the present study, the values of CT doses, the examination frequencies, the collective effective dose and the per caput dose are reported.

MATERIALS AND METHODS

At the time of survey, three CT scanners in Yazd province were active (Ge CTCO 4000, Shimadzu SCT-7800 and Shimadzu SCT-3000TX) that correspond to 3.4 CT scanner per million populations. This ratio in various countries for example Japan, Greece and the UK during the last 8 years has been 68.5, 14.9 and 6, respectively [7]. This survey lasted about 1 year. The questionnaire to be answered by three general hospitals consisted of the number of patients examined, and the frequency of examinations for each category. It also requested information on the kV_p, mAs, number of slice, slices width, couch increment and pitch factor for each type of examination. In this survey the effective dose values were calculated from $CTDI_{air}$ (computed tomography dose index in air) measurement undertaken for each of examination in three scanners.

CTDI defined as:

$$\mathbf{CTDI} = \frac{1}{\mathbf{T}} \int_{-\infty}^{+\infty} \mathbf{D(z)dz}$$

that is the integral along an axis parallel to the axis of rotation z, of the dose profile D(z) for a single slice, divided by the nominal slice thickness T.

In practice, $CTDI_{100}$ is measured base on the below equation:

$$\mathbf{CTDI}_{100} = \frac{\mathbf{C.E(mGy)}}{\mathbf{N.T}}$$

Where E is the value which pencil dosimeter shows in mGy, C is Calibration factor, N is number of slices per rotation in conventional scanner (N=1 in our study) and T is thickness of slice.

DLP is the dose-length product which defined by the following equations:

For axial scanning:

$$\mathbf{DLP} = \sum_{\mathbf{i}} {}_{\mathrm{n}}\mathbf{CTDI}_{\mathbf{W}}\mathbf{.T.N.C}$$

For helical scanning:

$$\mathbf{DLP} = \sum_{\mathbf{i}} {}_{\mathrm{n}}\mathbf{CTDI}_{\mathbf{W}}\mathbf{.T.A.t}$$

where i represents each scan sequence forming part of an examination, N is the number of slice with thickness T, C is mAs, A is the tube current (mA), t is total acquisition time, and $CTDI_w$ is the weighted CTDI, which can be measured in cylindrical phantom by a calibrated pencil diode detector (Unfors multi-o-meter, Sweden). The most important scanning parameters have been tube voltage (kV_p), tube current exposure time product (mAs), and slice thickness, for each examination type in CTDI measurement. In order to estimate the radiation risk associated with CT examination, it was necessary to estimate Effective Dose (ED) which was the sum of the products of organ doses and corresponding weighting factors [15]. Shrimpton *et al.* calculated ED from $CTDI_{air}$ measurements by using Monte Carlo Conversion Coefficients [16, 17]. Another way for measuring ED is the use of an anthropomorphic physical phantom, which is measured in the location of organ or tissue of interest usually by using thermo luminescent (TLD_S), and then ED can be calculated. As a practical alternative, EC (European Commissioning) give region-specific normalized coefficients (E_{DLP}) to estimate the risk of CT examination protocol [18, 19]. Effective dose is derived from values of DLP with following equation [20]:

$$\mathbf{E} = \mathbf{E_{DLP}.DLP} \quad \text{(mSv)}$$

That E_{DLP} and DLP are in $mSv.mGy^{-1}cm^{-1}$ and mGy.cm, respectively. General levels for different regions in patient (Brain, Neck, Chest, Abdomen and Pelvis) are given in table 1. However, these dose values have been based on the result of previous survey information at 1980s [21]. The technical improvement in CT, and the use of the spiral technique in particular, has offered new possibilities in both diagnosis and dose reduction [21]. The purpose of our previous study was to evaluate routine CT examination protocols utilized in Yazd hospitals, and to compare the results with European Commission Reference Dose Levels (EC, RDL_S), but in the present survey it was to estimate the annual effective dose for the population, so the effective dose was determined by CT Dose program (ImPACT CT patient dosimetry calculator version 0.99X-2006). This software can calculate the effective dose or organelles dose resulting from CT examinations base on Monte Carlo simulation of x-ray which was achieved by Jones and Shirimton [19]. In order to use this software, $CTDI_{air}$ must be measured and added to mAs, thickness and number of slice in each type of CT examination [19]. $CTDI_{air}$ was also measured by a pencil diode detector (Unfors, Molti-O-Meter, Sweden).

Table 1. Proposed European Commission Reference Levels and region specific normalized effective doses for some routine CT examination [15].

Examination	$CTDI_W$ (mGy)	DLP (mGy.cm)	E_{DLP} ($mSv.mGy^{-1}cm^{-1}$)	ED (mGy)
Brain	60	1024	0.0023	2.35
Neck [a]	60	1024	0.0054	5.53
Chest	30	650	0.0170	11.05
Abdomen	35	780	0.0150	11.7
Pelvis	35	570	0.0190	10.83

$CTDI_W$: weighted CT Dose index; DLP: dose-length product; E_{DLP}: region specific normalized effective dose.
a: no specific reference value for neck is yet available, but for comparison brain values are used.

RESULTS AND DISSCUSION

Table 2 shows the number of CT units, and the number of units per million people in Yazd and various countries. Yazd has only three CT scanners and the CT units per million populations are fewer than those for other countries such as Japan, and Australia.

The annual numbers of CT examinations together with the number of CT examinations per 1000 people are given in table 3. The frequency of examinations per year, per scanner in different countries, and caput dose are also shown in this table. Based on the report, 5218 annual exams per scanner were achieved in Yazd hospitals which are more than the similar cases in other countries except Greece. On the other hand the frequency of exams in Yazd province has been lower than other countries except Denmark. This work load on each of CT units with limited operators could have decreased image quality. Table 4 gives the percent of each type of exam including with and without contrast for adults and pediatrics. Effective whole body dose was determined by CT Dose software.

Table 4 also shows mean effective dose and collective dose of each type of CT exams in Yazd. The effective doses resulting of each examination type were used for calculation of collective effective dose from the 3 scanners. The head examinations, which made up

Table 2. Number of CT scanner per million populations in various countries [7].

Country	Year	Number of CT scanners	CT scanners per million population
Yazd	2005	3	3.4
Greece	1999	152	15
Italy	1991	741	13
Australia	1994	332	18.7
UK	2001	340	6
Norway	1993	70	16.1
New Zealand	1992	21	7
Japan	1995	8500	68.5
USA	1999	4600	18

65.8% of all exams, were the most common examination with average effective dose of .845 mSv. Although it was the most common examinations, its contribution was 29% to the overall effective dose. The next most common CT examination was abdomen and pelvis which made up to 6.2% of all examinations. These exams with the largest average effective dose (6.2 and 8.45 mSv) were contributed to nearly 39% of the overall CT effective dose.

Table 5 shows the average effective doses of this survey which are compared with the surveys conducted in Norway[14], UK (NRPB)[16], New Zealand[10] and Australia [22].

The overall CT exams doses in the present study are lower than other studies, except in that of pelvis. It is suspected that the reason to this case lies in the large number of scanners or the greater number of scans per exam performed in those countries, which the range of effective dose are very wide.

The mean effective dose per CT examination was determined by summing the product of the effective dose in the number of examinations for each type of examination in each center and divided by total number of examinations recorded in our survey. The per caput effective dose were determined from dividing the collective dose by the Yazd population (860,000 person). Table 6 shows the mean effective dose per examination, collective dose and dose per caput of Yazd and the other countries. The mean effective dose of 3.43 for Yazd is almost similar to that found by studies in other countries, except Australia. This could be explained by the large number of scans per examination in Australia [22].

The ICRP 60 gives a risk coefficient of 4% per Sv for radiation induced fatal cancers for working age population[15]. The use of this coefficient and effective dose from the present survey, the estimation of fatal cancers and the number cancer per examination have been determined and are given in table 7. It was estimated that CT examination in Yazd could be induced to about 1.3 fatal cancers

Table 3. Number of examinations per year per scanner in various countries.

Country	Exams per year (× 1000)	Exams per year per scanner	Caput Dose (mSv)	Exams per 1000 people
Yazd (2005)	17	5,218	0.038	18
Greece (1999)	920	5,693	0.5	86
UK (1991)	1270	3,678	0.059	22
Denmark (1989)	77	3,019	0.05	14
Sweden (1991)	216	2,222	0.1	24
New Zealand (1992)	62	2,950	0.08	21
USA (1990)	13000	2820	--	52
Australia (1994)	1060	3192	0.39	60
Japan (1995)	12000	1400	0.45	97

Table 4. Frequency of examinations type and mean effective and collective dose in separately.

Examination type	% of all Exams	Examinations per year	Mean effective dose (mSv)	Collective effective dose (person-Sv)
Brain	65.8	11421	0.845	9.46
Neck	1.3	232	1.36	.411
Chest	3.8	670	5.43	5.11
Abdomen	2.9	517	6.2	5.03
Pelvis	3.3	574	8.45	7.61
Sinus	6.9	1203	0.21	.304
HRCT	2.9	504	0.90	0.453
Lumbar Spine	3.1	535	2.4	1.33
Brain (pediatric)	9.3	1628	1.37	2.23
Abdomen(pediatric)	0.003	58	9.05	.525
Neck (pediatric)	0.0008	15	1.57	0.023
Total	100	17357		32.48

per year and that is about one fetal cancer induced for every 14000 examinations. There are also some mitigating factors which reduce the estimate of the number of induced cancer made here. This can partly be due to a shorter life expectancy than the general population that in CT patients.

Table 5. Comparison of mean effective dose with those from survey in Norway, UK, NZ and Australia.

Exam	This work	UK	NZ	Norway	Australia
Brain	.845	1.8	2.2	2	2.6
Chest	5.43	8.3	9.9	11.5	10.4
Abdomen	6.2	7.2	11.6	12.8	16.7
Pelvis	8.45	7.2	7.2	9.8	11
Lumbar Spine	2.4	3.6	5	4.5	5.2

CONCLUSION

Computed tomography (CT) is an extremely valuable diagnostic tool. Recent advances, particularly in multi detector technology, have provided increased and more diverse applications. However, there is also the potential for inappropriate use and unnecessary radiation dose. Some data indicate that low-dose radiation (such as that

Table 6. Mean and collective population dose.

Exam	Yazd	UK	NZ	Japan	Australia
Number of exams in 1000	17	850	62	12000	1060
Mean dose per exam (mSv)	3.43	3.9	4.4	4.7	6.6
Collective dose (person-Sv)	32.48	3300	273	56000	7000
Mean dose per caput (mSv)	.038	.059	.08	.45	.39

Table 7. Risk resulting from CT examinations in Yazd.

Exam	Yazd	Japan	NZ	UK	Australia
ICRP risk of fatal cancers	0.04	.04	.04	.04	.04
Collective dose (person-Sv)	32.48	56000	273	3300	7000
Induced fatal cancers/year	1.3	2240	10.9	132	280
Risk per exam.	0.00007	0.0002	0.0001	0.0001	.0003

in CT) may have a significant risk of cancer, especially in young children [23]. The main conclusion to be drawn from this survey's results is that CT has become a major, if not the main, contributor to the dose from diagnostic radiology. There is a potential risk of induction between 1 and 2 fatal cancer per years from CT exams in Yazd. In view of this potential risk, effort needs to be put into dose reduction techniques and strategies. It is important to limit CT radiation by following the ALARA (As Low As Reasonably Achievable) principle. There is a variety of strategies to limit radiation dose, including performing only necessary examinations, limiting the region of coverage, and adjusting individual CT settings based on indication, region imaged, and size of the patient. Referring physicians should be aware of the potential risks from CT and choose this modality only if the likely benefit to the patient is greater.

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