Population exposure to ionising radiation from CT examinations in Aosta Valley between 2001 and 2008

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ABSTRACT. Recent and continuous advances in CT, such as the development of multislice CT, have promoted a rapid increase in its clinical application. Today, CT accounts for approximately 10% of the total number of medical radiographic procedures worldwide. However, the growing performance of the new CT generations have increased not only the diagnostic opportunities, but also the radiation dose to the patient. The relative contribution to the collective radiation dose is now estimated to be approximately 50%. Several papers have been published concerning the intensive use of CT and its contribution to the collective dose. However, most of the literature concerns the years 1997–2003 and the dosimetric evaluations are generally limited to the main standard protocols (chest, head and abdomen), deriving the effective dose by the simple application of the diagnostic reference levels. Only specific dosimetric analyses of single and innovative procedures have been published recently. Moreover, few data comes from Italian radiology departments. This paper aims to bridge these gaps. Firstly, it characterises in terms of measured CT dose index (CTDI) two last-generation scanners of the Radiological Department of Aosta Hospital. Secondly, it evaluates the effective dose from most of the CT examinations performed from 2001 to 2008 to compare protocols and technologies in line with the suggestions of the 2007 Recommendations of the International Commission on Radiological Protection, Publication 103. Finally, it estimates the collective dose to the population.

Received 26 May 2009
Revised 29 August 2009
Accepted 23 September 2009

DOI: 10.1259/bjr/66718758

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As reported by Brenner et al for the USA and the UK [1], and by Hansen et al for Denmark [2], the use of CT in the last decade has approximately doubled. Similar trends in CT practice have been observed in many other countries [3] and today CT accounts for approximately 10% of the total number of medical radiographic procedures worldwide. This study builds on previous research [4–10] but aims to bridge some of the gaps it leaves.

Methods and materials

The data used in this study were collected between 2001 and 2008 at the Radiological Department of Aosta Hospital. From 2000 to 2005 a General Electric (GE) LightSpeed 16 pro-8 slice and a single-slice CT GE HiSpeed DX/i were operating; the latter was used only for the head protocols and was replaced by a GE LightSpeed VCT 64-slice in 2005.

The mean effective dose to the standard adult man was evaluated by means of the software ImPACT CT Patient Dosimetry Calculator (ver. 0.99x), developed by the ImPACT (Imaging Performance Assessment of CT Scanners) group [11]. This tool uses the National

Radiological Protection Board (NRPB) Monte Carlo dose data sets produced in report SR250 [12], which provides normalised organ dose data for irradiation of mathematical phantoms (male, female and hermaphrodite average adult) by a range of CT scanners.

For better matching of the dose distribution for newer scanners, to scanners included in SR250, a standard CT dose index (CTDI) phantom, as defined by Bongartz et al [13], was used to measure values of the free-in-air CTDI_{air} (in mGy/100 mAs) and of the weighted CTDI_w.

Then, when mA, rotation time, mAs/rotation, collimation, slice width, pitch, start and end position are entered in the worksheet, the software evaluates the total effective dose, H , to the standard man using the tissue weighting factors, w_T , given in International Commission on Radiological Protection (ICRP) 60 [14]:

$$H = \sum w_T \times H_T$$

However, considering that the new w_T factors introduced by ICRP 103 [15] can significantly affect the effective dose values, especially for abdomen and chest procedures, effective dose calculations have also been performed by replacing the weighting factors from ICRP 60 [14] with the newest ones from ICRP 103 [15] (see Table 1) in the ImPACT software. The software's tissue database does not include the salivary glands and some remainder organs (extrathoracic

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Table 1. ICRP 60 and ICRP 103 weighting factors

Organ	w_T	
	ICRP 60	ICRP 103
Gonads	0.20	0.08
Bone marrow (red)	0.12	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Breast	0.05	0.12
Liver	0.05	0.04
Oesophagus	0.05	0.04
Thyroid	0.05	0.04
Skin	0.01	0.01
Bone surface	0.01	0.01
Brain		0.01
Salivary glands		0.01
Remainder	0.05	0.12

region, gall bladder, lymphatic nodes and oral mucosa); consequently, the doses to these organs were not calculated.

So, to better use the ImPACT software, we have measured the $CTDI_{air}$ and $CTDI_w$ in a phantom, varying the acquisition parameters as illustrated below:

- tube voltage from 80 kV to 140 kV;
- collimation equal to 1.25 mm, 5 mm, 10 mm, 15 mm and 20 mm for the 8-slice CT; 1.25 mm, 10 mm, 20 mm and 40 mm for the 64-slice CT;
- head and body field of view (FOV) definition for the 8-slice CT; small head, head, body and large body FOV definition for the 64-slice CT.

A calibrated pencil-type ionisation chamber (Model TM30009-0494; PTW, Freiburg) with 10 cm sensitive length and accuracy equal to $\pm 5\%$ with a digital exposure meter (Model Diadose E; PTW, Freiburg) was used to measure the CTDI values, given by:

$$CTDI = \frac{1}{T} \int_{-\infty}^{+\infty} D(z) dz = M \times F \times \frac{L}{T}$$

where M represents the electrometer reading in mGy, F is the calibration factor, L is the chamber sensitive length (cm) and T is the nominal slice thickness (cm).

Measurements were performed in standard head and body CT dosimetry phantoms made of cylindrical polymethylmethacrylate (PMMA) 16 cm and 32 cm in diameter and 15 cm in length.

The CTDI values were measured free-in-air along the central axis of the scanner gantry ($CTDI_{air}$) and along the central ($CTDI_c$) and peripheral ($CTDI_p$) axes of each dosimetry phantom. The weighted CTDI ($CTDI_w$) was then calculated:

$$CTDI_w = \frac{1}{3}CTDI_c + \frac{2}{3}CTDI_p$$

where $CTDI_p$ represents the average value of all eight peripheral CTDIs. The normalised $CTDI_w$ ($nCTDI_w$) in mGy/mAs is the $CTDI_w$ normalised to tube current-time product per axial rotation.

To take into account the CT output variation with X-ray collimated beam width, a collimation factor can be

Table 2. Parameter settings of the main acquisition protocols implemented on the GE LightSpeed 16 Pro 8-slice (GE-8) and on the GE LightSpeed VCT 64-slice (GE-64)

Protocol	CT	kV	mA	Noise index	Time (s)	Collimation (mm)	Slice thickness	Pitch
Cerebral	GE-8	140	200	–	1	10	2.5	1
		120	300	–	1	10	5	1
	GE-64	140	200	–	1	20	2.5	1
		120	300	–	1	20	5	1
Cervical spine	GE-8	120	400	–	1	10	2.5	0.875
	GE-64	120	250*	8	0.8	10	0.625	0.516
Chest, high resolution	GE-8	140	200	–	0.8	1.25	1.25	8
	GE-64	120	200	–	0.5	1.25	1.25	8
Chest	GE-8	120	255*	12	0.8	10	5	1.35
	GE-64	120	130*	15	0.5	40	5	0.984
Coccyx	GE-8	140	55*	15	1	10	2.5	0.625
	GE-64	140	200*	15	0.8	40	1.25	0.516
Hip	GE-8	140	120*	14	1	20	5	1.35
	GE-64	120	411*	14	0.8	40	1.25	0.984
Kidney	GE-8	120	100	–	0.7	10	5	0.875
		120	250	–	0.7	10	2.5	0.875
	GE-64	120	100	–	0.5	40	2.5	0.516
		120	395*	18	0.5	40	0.625	0.984
Lumbar spine	GE-8	140	55*	15	1	10	2.5	0.625
	GE-64	140	200*	15	0.8	40	1.25	0.516
Thoracic spine	GE-8	120	190*	12	1	10	2.5	0.875
	GE-64	120	101*	20	0.8	40	1.25	0.516
Total abdomen	GE-8	120	179*	11.6	0.8	20	5	1.35
	GE-64	120	170*	12	0.5	40	5	0.984

*Protocols that use automatic exposure control.

Table 3. $nCTDI_{air}$ and $nCTDI_w$ evaluated for GE LightSpeed 16 Pro

kV	Head (mGy/100 mAs)				Body (mGy/100 mAs)			
	$nCTDI_{air}$	$nCTDI_c$	$nCTDI_p$	$nCTDI_w$	$nCTDI_{air}$	$nCTDI_c$	$nCTDI_p$	$nCTDI_w$
80	10.9	6.2	6.6	6.5	8.1	1.4	3.5	2.8
100	18.5	11.7	12.0	11.9	14.9	4.4	6.8	6.0
120	27.8	18.4	18.7	18.6	23.1	5.2	10.3	8.6
140	40.1	27.2	27.3	27.2	34.5	8.1	16.2	13.5

$nCTDI_{air}$, normalised free-in-air CT dose index; $nCTDI_w$, normalised weighted CT dose index; $nCTDI_c$, normalised central CT dose index; $nCTDI_p$, normalised peripheral CT dose index.

evaluated using the $CTDI_{air}$ measurements with different collimations used in the clinical practice, as:

$$f_{coll} = \frac{CTDI_{air,coll}}{CTDI_{air,10mm}}$$

Then, the measured values of the $CTDI_{air}$, $CTDI_w$ and f_{coll} were added in the software database to improve the accuracy of the dose calculations.

An intensive quality assurance programme has been implemented since 2001 for the CT scanners by the physicists of the Medical Physics Department, which has maintained the deviations of the CTDI values from the baseline less than $\pm 5\%$ according to the Radiation Protection No. 91 [16]. Consequently, the CTDIs measured in this study can be considered representative for the last decade.

Moreover, considering that the CTDI values reported in the literature [17] for the cranial protocols differ by less than 10% between the HiSpeed DX/i and LightSpeed VCT scanners, the results of the CTDI measurements can be reasonably used for the examinations performed between 2000 and 2005 on the HiSpeed CT.

The parameters of the acquisition protocols (kV, mA, noise index, rotation time, collimation, slice width and pitch) of the 46 different examinations implemented on the CT scanners were entered into the ImPACT software, as defined during the commissioning procedure, adapting GE default protocols to the radiologists' requirements. In Table 2, the protocol parameter settings for the main body areas are reported for both the CT scanners.

If the automatic system of mA control was used, the protocol was reproduced on a RANDO® Phantom (175 cm tall and 75.3 kg male, The Phantom Laboratory, Salem, NY) in order to establish an average value of mA to use in the ImPACT software.

Then, the effective dose to a male and a female adult patient in any exam by both the available CTs was evaluated. Considering that the phantom used in the NRPB report SR250 [12] is based upon a mathematical representation of an average adult, the effective doses to paediatric patients were evaluated applying the corrective coefficients proposed by Khursheed et al [18] to the hermaphrodite adult's effective dose. Errors incurred in the calculation of effective dose by the use of geometrical phantoms, owing to the anatomically incorrect organ shapes and distributions, were minimised by determining the scan ranges and by matching the fractions of radiosensitive organs irradiated at the scan boundaries in the voxel phantom to the Cristy phantom, as described by Castellano et al [19]. Moreover, the anatomical extent of each scan was also determined, taking into account the helical over-scan, which was assumed to be equal to an extra half-rotation at each end of the imaged volume.

Adopting these strategies, it can be assumed that errors in estimating the effective dose to the standard adult patient with the ImPACT software remain within 20%.

Data provided by the RA2000 Siemens Radiological Information System (RIS) in use at the radiological department allowed us to obtain the number and type of CT examinations performed from 2001 to 2008 as a function of the patient's age and sex.

By multiplying the number of any CT procedures performed per year by the dose obtained by the ImPACT software for that exam, its contribution to the collective dose was evaluated.

Finally, the number of CT examinations for 100 000 inhabitants has been evaluated using the data provided by the Aosta Valley OREPS (Osservatorio Epidemiologico per le Politiche Sociali) of number, sex and age in any different year considered in our study.

Results

Measurements of $nCTDI_{air}$, $nCTDI_c$, $nCTDI_p$ at 10 mm collimation and the calculated $nCTDI_w$ are reported in Tables 3 and 4 for the GE LightSpeed 16 Pro and GE LightSpeed VCT 64-slice, respectively. The calculated collimation factors are shown in Table 5.

The effective dose calculated by the ImPACT software for male and female standard adult patients using the ICRP 103 [15] weighting factors is reported in Table 6 for both the CT scanners and each considered CT protocol. The comparison with the results obtained using the ICRP 60 [14] weighting factors is given in terms of percentage differences.

The total number of examinations and the number of examinations per 100 000 inhabitants subdivided for sex and age are reported in Table 7.

The percentage distribution of the CT procedures by patient age is reported in Figure 1. Data show that approximately 70% of the examinations are related to patients older than 50 years old.

The number of patients younger than 10 years old undergoing CT procedures is illustrated in Figure 2.

Figure 3 shows the number of the CT examinations for the main procedure types. The percentage increment between 2001 and 2008 is equal to 49%, 232%, 80%, 65%, 68% and 27% for vertebral spine, total body, abdomen, chest, neck and head, respectively.

The distribution of the number of CT procedures performed on the same patient in a year is reported in Figure 4 on a logarithmic scale. The distribution of procedure type, considering only patients who have more than six scans per year, is illustrated in Figure 5. The number of patients *vs* the effective dose is shown in Figure 6 on a logarithmic scale.

Table 4. $nCTDI_{air}$ and $nCTDI_w$ evaluated for GE LightSpeed VCT 64-slice

kV	Small head (mGy/100 mAs)				Head (mGy/100 mAs)				Body (mGy/100 mAs)				Large body (mGy/100 mAs)			
	$nCTDI_{air}$	$nCTDI_c$	$nCTDI_p$	$nCTDI_w$	$nCTDI_{air}$	$nCTDI_c$	$nCTDI_p$	$nCTDI_w$	$nCTDI_{air}$	$nCTDI_c$	$nCTDI_p$	$nCTDI_w$	$nCTDI_{air}$	$nCTDI_c$	$nCTDI_p$	$nCTDI_w$
80	12.9	7.0	7.6	7.4	13.1	7.4	8.9	8.4	13.1	1.7	4.4	3.5	9.5	1.5	4.0	3.2
100	21.1	13.0	13.4	13.3	21.5	13.7	15.6	15.0	21.6	3.5	7.8	6.4	16.7	3.3	7.5	6.1
120	30.6	20.0	20.7	20.5	31.2	21.1	23.6	22.8	31.3	5.8	11.7	9.7	25.3	5.6	11.6	9.6
140	41.4	28.0	28.2	28.1	42.2	29.5	32.3	31.4	42.2	8.6	16.6	13.9	35.4	8.4	16.8	14.0

$nCTDI_{air}$, normalised free-in-air CT dose index; $nCTDI_w$, normalised weighted CT dose index; $nCTDI_c$, normalised central CT dose index; $nCTDI_p$, normalised peripheral CT dose index.

Table 5. Collimation factors evaluated for GE LightSpeed 16 Pro and GE LightSpeed VCT 64-slice

GE LightSpeed 16 Pro		GE LightSpeed VCT 64-slice	
Collimation (mm)	Relative CTDI	Collimation (mm)	Relative CTDI
20	0.91	40	0.85
15	0.99	20	0.86
10	1.00	10	1.00
5	1.24	1.25	1.40
1.25	2.06	–	–

CTDI, CT dose index.

The annual per caput effective dose to different age-related groups of the Aosta Valley male and female population is illustrated in Table 8.

Finally, the contribution of the main clinical protocol to the per caput effective dose is reported in Figure 7.

Discussion

The values of $nCTDI_w$ measured in head and body phantoms are consistent with those reported in the literature [17]. The relative difference is within $\pm 5\%$.

The collimation factors show that both the CT scanners have well-matched collimation for larger beam width (f_{coll} close to 1), but worse collimation for the narrowest beam width. A dose evaluation that does not take into account the collimation factor for the narrowest beam could lead to an underestimation of more than two times. All collimation factors agree well with the ImPACT data.

The comparison between the effective dose obtained for the two available CT scanners shows significant differences in dose for head, chest and vertebral spine that can be correlated to changes in exposure factors such as slice widths and noise index. Moreover, with the advent of the GE LightSpeed VCT-64, new protocols have been introduced, such as “head–chest–abdomen”, involving a large body area or requiring more than one scan and consequently leading to high doses to the patient.

The comparison between the effective doses obtained using the ICRP 103 [15] and ICRP 60 [14] weighting factors shows that the former leads to a general decrease in the effective dose, with an average percentage difference of 14% and differences between male and female patients owing to the different fractions of radiosensitive organs that are irradiated directly. This trend is mainly due to the differences in the w_T values of the gonads and thyroid for the vertebral, total body, abdomen and neck protocols. The greatest deviation (up to 41%) observed in the head protocols can be related to the w_T values of the brain, which in ICRP 103 [15] is considered a radio-sensitive organ with a w_T equal to 0.01, while in the ICRP 60 [14], as the remainder organ, it is associated to a w_T of 0.025. Moreover, as reported above, the software does not take into account the salivary glands and oral mucosa, so in the head protocols calculations can lead to an underestimation of the effective dose.

The thoracic spine and chest are the only protocols that show a percentage increment in effective dose owing to the different w_T value of the breast, which increases from 0.05 in ICRP 60 [14] to 0.12 in ICRP 103 [15].

Table 6. Effective dose evaluated for each examination performed using the two CT procedures at the Radiological Department of Aosta Hospital for male and female standard adult patients

Exam type	Exams (protocols) list	Female			Male		
		CT 8 slices	CT 64 slices	Variation from ICRP 60	CT 8 slices	CT 64 slices	Variation from ICRP 60
		(mSv)	(mSv)		(mSv)	(mSv)	
Vertebral spine	Lumbar spine*	8.7	27.0	−10%	7.7	23.0	−4%
	Lumbar spine (pre- and post-contrast scan)*	17.4	54.0	−10%	15.4	46.0	−4%
Total body	Thoracic spine*	14.0	10.0	2%	14.0	10.0	2%
	Thoracic spine (pre- and post-contrast scan)*	28.0	20.0	2%	28.0	20.0	2%
	Hip*	5.8	14.0	−18%	5.8	14.0	−22%
	Hip (pre- and post-contrast scan)*	11.6	28.0	−18%	11.6	28.0	−22%
	Cervical spine	5.6	5.9	−5%	5.6	5.8	−6%
	Cervical spine (pre- and post-contrast scan)	11.2	11.8	−5%	11.2	11.6	−6%
	Coccyx*	5.2	16.0	−24%	5.3	16.0	−24%
	Coccyx (with contrast)*	10.4	32.0	−24%	10.6	32.0	−24%
	Head–chest–abdomen*	40.0	19.1	−11%	40.0	19.0	−9%
	Head–chest–abdomen (post-contrast scan)*	41.0	20.3	−12%	41.0	20.2	−11%
Abdomen	Chest–abdomen*	12.4	12.0	−8%	12.5	12.0	−8%
	Chest–abdomen (post-contrast scan)*	12.4	12.0	−8%	12.5	12.0	−8%
	Total abdomen*	6.4	5.7	−15%	6.2	5.5	−14%
	Total abdomen (pre- and post-contrast scan)*	12.8	11.4	−15%	12.4	11.0	−14%
	Abdomen superior (pre- and post-contrast scan)*	7.8	7.6	−5%	7.2	6.8	−3%
	Abdomen superior*	3.9	3.8	−5%	3.6	3.4	−3%
	Abdomen inferior (pre- and post-contrast scan)*	16.2	7.0	−20%	16.6	7.4	−24%
	Abdomen inferior*	8.1	3.5	−20%	8.3	3.7	−24%
	Kidney (pre- and post-contrast scan)*	36.0	36.0	−14%	36.4	36.0	2%
	Virtual colonoscopy	3.0	3.0	−17%	2.8	2.8	0%
Chest	Chest high resolution	3.7	1.2	9%	3.7	1.2	9%
	Chest*	8.6	3.8	12%	8.6	3.8	12%
	Chest (pre- and post-contrast scan)*	17.2	7.6	12%	17.2	7.6	12%
Neck	Neck	5.8	4.3	−4%	5.8	4.3	−4%
	Larynx	5.8	4.3	−4%	5.8	4.3	−4%
	Larynx (post-contrast scan)*	5.8	4.3	−4%	5.8	4.3	−4%
	Oral cavity – pharynx	5.8	4.3	−4%	5.8	4.3	−4%
	Oral cavity – pharynx (post-contrast scan)*	5.8	4.3	−4%	5.8	4.3	−4%
Head	Ear	2.8	3.6	−38%	2.8	3.6	−38%
	Ear (post-contrast scan)*	2.8	3.6	−38%	2.8	3.6	−38%
	Skull	1.2	1.2	−29%	1.2	1.2	−29%
	Intracranial angiography	2.4	2.4	−8%	2.4	2.4	−4%
	Paranasal sinus	0.6	1.9	−27%	0.6	1.9	−27%
	Paranasal sinus (pre- and post-contrast scan)*	1.2	3.8	−27%	1.2	3.8	−27%
	Face bone	1.0	2.3	−21%	1.1	2.3	−21%
	Face bone (post-contrast scan)*	1.0	2.3	−21%	1.1	2.3	−21%
	Cerebral	1.2	1.2	−29%	1.2	1.2	−29%
	Cerebral (pre- and post-contrast scan)*	2.4	2.4	−29%	2.4	2.4	−29%
	Eye socket	0.4	1.0	−41%	0.4	1.0	−41%
	Eye socket (post-contrast scan)*	0.4	1.0	−41%	0.4	1.0	−41%

*Protocols that use automatic exposure control.

Table 7. Number of examinations per 100 000 inhabitants subdivided by year and sex

Age	Sex	Number of examinations per 100 000 inhabitants							
		2001	2002	2003	2004	2005	2006	2007	2008
Total exams		7850	8864	9825	10343	11263	11695	11940	12035
All	Female	3612	3879	4422	4667	5094	5329	5554	5446
	Male	4238	4986	5403	5676	6169	6366	6386	6588
Years <2	Female	4	7	10	8	11	3	2	3
	Male	32	21	14	12	13	8	7	5
2 ≤ years <10	Female	16	24	28	21	32	29	12	9
	Male	33	40	32	30	51	25	17	36
10 ≤ years <20	Female	89	109	102	87	103	103	146	116
	Male	138	193	172	161	193	161	157	179
20 ≤ years <30	Female	197	205	218	270	227	247	205	231
	Male	315	347	353	370	384	356	406	362
30 ≤ years <40	Female	319	341	382	412	423	408	427	383
	Male	427	503	604	532	574	575	623	566
40 ≤ years <50	Female	401	476	536	488	540	556	558	631
	Male	486	531	610	679	727	720	721	845
50 ≤ years <70	Female	1198	1227	1399	1413	1572	1655	1655	1649
	Male	1569	1752	1882	1880	2084	2446	2241	2355
Year ≥70	Female	1388	1490	1748	1966	2185	2328	2548	2425
	Male	1237	1598	1737	2012	2143	2075	2213	2241

The trend observed in the number of CT procedures per 1000 inhabitants reported in Figure 3 (from 78 examinations in 2001 to 120 in 2008) is consistent with that assessed for the USA (from 91 in 1991–1996 [3] to 220 in 2007 [1]), for France (from 33 in 1991–1996 [3] to 69–98 in 2002 [5]) and for Denmark (from 3 in 1979 to 55 in 2005 [2]). This may be correlated to the increased number of CT installations all over EU countries [20] (from 14.46 to 17.41 per million of population from 2000 to 2005) and

consequently to the increased use of CT procedures for level 1 countries [3].

The greatest contribution to the percentage increase in the CT examinations in the Aosta Valley is represented by vertebral spine, head, total body and abdomen examinations.

The decrease observed in the number of paediatric patient examinations (Figure 2) may be considered the outcome of the efforts made by the radiologists to make

Figure 1. Analysis by patient's age of the proportion of CT examinations performed between 2001 and 2008 at the Radiological Department of Aosta Hospital.

Figure 2. Number of CT examinations performed between 2001 and 2008 on paediatric patients (<10 years) at the Radiological Department of Aosta Hospital.

the paediatricians aware of radiation protection issues in paediatrics and the corresponding need to use, if possible, a diagnostic method other than radiography.

As far as the population collective dose is concerned, the results show an increment of approximately 100% from 2001 to 2008, which is almost twice that of the number of examinations. This is because most examinations registering the largest numerical increment (abdomen, spine, total body) also show the largest effective dose values. Consistent with the above, using the ICRP 103 [15] weighting factors to estimate effective doses leads to the collective dose decreasing by 11% and 5% for the female and male population, respectively, because of the different contribution of the dose to the gonads in the CT protocols registering a higher examination number and effective dose, such as lumbar spine and kidney.

As suggested by the ICRP 103 [15], the relationship between the effective dose and the probability of delayed radiation effects is critically dependent on the age and sex of the exposed population. Thus, the calculated effective dose values have not been used for assessing radiation risks to the population of patients by simple

application of the nominal probability coefficients for radiation-induced cancer given by ICRP, which have been derived for a general population.

The exponentially growing use of CT causes a marked increase in patients receiving multiple CT scans (Figure 4) and consequently high total effective doses (Figure 5). This emphasises the importance of identifying ways that the patient dose can be minimised without affecting the diagnostic information provided. With this aim, appropriate strategies of exposure justification and optimisation will help to contain the effective dose to the patient, as suggested by the ICRP guidances [14, 20] and EU Council Directive 97/43/Euratom [21]. These include selecting the optimum scanning parameters, reducing the number of scan phases, limiting the scan length and using the automated dose modulation. In some cases this could also approximate dose threshold for deterministic effects.

Finally, the role and the importance of the radiological information systems have to be pointed out: the evaluation of the patient's lifetime cumulative dose from medical sources, of the collective dose to the population and an acceptable benefit/risk analysis. This would not be possible without the availability of comprehensive

Figure 3. Analysis by examination type of the number of CT examinations per 1000 population between 2001 and 2008 at the Radiological Department of Aosta Hospital.

Figure 4. Histogram of the number of CT examinations per patient between 2001 and 2008 at the Radiological Department of Aosta Hospital.

radiological data that only a radiology information system integrated with the hospital information system can provide.

Conclusions

This study presents detailed information about the number and the distributions of CT examinations performed at the Radiological Department of the Aosta Hospital from 2001 to 2008 and an accurate evaluation of the effective dose correlated to the main CT protocols

implemented on two last-generation scanners. Combining these data, we obtained an acceptable estimation of the dose to the population by CT procedures.

We have considered 47 different clinical protocols and two different scanners.

The results concerning the distribution of CT examinations by patient's age and sex, the number of examinations and the effective per caput dose are in agreement with previous studies performed in other European countries. This confirms the assumption that the Valle d'Aosta region can be considered as representative of level 1 countries (with at least 1 physician per 1000 population, as

Figure 5. Histogram of CT examination type performed on the same patient in a year at the Radiological Department of Aosta Hospital, considering only patients that have more than six scans per year.

Figure 6. Histogram of effective dose distribution for all CT examinations performed between 2001 and 2008 at the Radiological Department of Aosta Hospital.

defined by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3]).

Our study confirms that CT represents one of the largest contributors to the radiation exposure of the population from diagnostic medical sources. Consequently, appropriate strategies of dose evaluation and optimisation must be integrated into the quality assurance and diagnostic reference levels measurement programmes, which the radiological institutions have generally already implemented. In order that these strategies can achieve this goal, it is essential that

efficient and integrated radiological information systems support the clinical activities of the radiological department.

Acknowledgments

The authors express their gratitude to Dr Elisa Richetta for helping in the published database search and for participating in the first revision process of the manuscript. Gratitude is also expressed to Dr P Vittori of the

Table 8. Per caput effective dose (mSv) to different age-related groups of the Aosta Valley male and Female population between 2001 and 2008

Age	Sex	2001	2002	2003	2004	2005	2006	2007	2008
Total population		0.45	0.55	0.67	0.78	0.85	0.94	0.94	1.02
All	Female	0.39	0.44	0.56	0.66	0.74	0.83	0.83	0.89
	Male	0.51	0.67	0.78	0.91	0.96	1.06	1.06	1.16
Years <2	Female	0.01	0.02	0.07	0.05	0.08	0.01	0.02	0.01
	Male	0.22	0.12	0.10	0.11	0.05	0.02	0.02	0.01
2 ≤ years <10	Female	0.02	0.02	0.03	0.05	0.06	0.06	0.01	0.01
	Male	0.02	0.05	0.06	0.04	0.08	0.02	0.01	0.08
10 ≤ years <20	Female	0.08	0.08	0.07	0.10	0.10	0.12	0.18	0.18
	Male	0.08	0.16	0.17	0.16	0.19	0.17	0.17	0.19
20 ≤ years <30	Female	0.11	0.13	0.16	0.27	0.25	0.31	0.36	0.41
	Male	0.16	0.22	0.27	0.30	0.35	0.38	0.47	0.48
30 ≤ years <40	Female	0.20	0.22	0.27	0.31	0.38	0.39	0.47	0.49
	Male	0.23	0.29	0.42	0.39	0.42	0.46	0.67	0.59
40 ≤ years <50	Female	0.38	0.47	0.54	0.54	0.66	0.70	0.72	0.92
	Male	0.38	0.44	0.52	0.63	0.70	0.71	0.90	1.21
50 ≤ years <70	Female	0.60	0.65	0.82	0.94	1.12	1.24	1.14	1.23
	Male	0.86	1.04	1.21	1.35	1.47	1.76	1.56	1.81
Years ≥70	Female	0.91	0.98	1.34	1.61	1.68	1.96	1.93	1.93
	Male	1.78	2.55	2.75	3.47	3.40	3.55	3.27	3.24

Figure 7. Analysis by examination type of the effective per caput dose between 2001 and 2008 in Aosta Valley.

Aosta Valley OREPS (Osservatorio Epidemiologico per le Politiche Sociali) for providing the cancer mortality data.

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