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Staff and patient absorbed doses due to diagnostic nuclear medicine procedures

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ABSTRACT

Background: Annual patient effective dose equivalent can be considered as a quantitative physical parameter describing the activities performed in each nuclear medicine department. Annual staff dose equivalent could be also considered as a parameter describing the amount of radiation risk for performing the activities. We calculated the staff to patient dose equivalent ratio to be used as a physical parameter for quantification of ALARA law in nuclear medicine departments.

Materials and Methods: As a part of nationwide study, this paper reports the staff and patient absorbed dose equivalents from diagnostic nuclear medicine examinations performed in four nuclear medicine departments during 1999-2002. The type and frequency of examinations in each department were determined directly from hospital medical reports. Staff absorbed dose equivalents were calculated from regular personal dosimeter reports.

Results: The total number of examinations increased by 16.7% during these years. Annual patient collective dose equivalent (EDE) increased about 13.0% and the mean effective dose equivalent per exam was 3.61±0.07 mSv. Annual total staff absorbed dose equivalent (total of 24 radiation workers) in four departments increased from 40.45 mSv to 47.81 mSv during four years that indicates an increase of about 20.6%. The average of annual ratios of staff to patient effective dose equivalents in four departments were 1.83×10^{-3}, 1.04×10^{-3}, 3.28×10^{-3} and 3.24×10^{-3}, respectively, within a range of $0.9\times10^{-3} - 4.17\times10^{-3}$. The mean value of ratios in four years was about $2.24\times10^{-3} \pm 1.09\times10^{-3}$ that indicates the staff dose of about two 1000th of patient dose.

Conclusion: The mean value of ratios in four years was about $1.89\times10^{-3} \pm 0.95\times10^{-3}$ indicating the staff dose of about one 1000th of the patient dose. The staff to patient absorbed dose equivalent ratio could be used as a quantitative parameter for describing ALARA law in radiation protection and risk-benefit assessments. *Iran. J. Radiat. Res., 2004; 2 (2): 63-68*

Keywords: *Diagnostic nuclear medicine, staff and patient effective dose equivalent.*

INTRODUCTION

The risk of medical radiation exposure is often extrapolated to large population groups. Loss of life expectancy has been employed to assess risk and benefit of diagnostic nuclear medicine and radiology by some investigators (Reiners 1993, Shrimpton *et al.* 1999, Methler *et al.* 1983, Overbeek *et al.* 1997). Diagnostic medical radiation exposure, as well as nuclear medicine yields effective doses which commonly lie below or within the range of annual exposure from natural radiation (Reiners 1993, Shrimpton *et al.* 1999, Methler *et al.* 1983). In Nuclear medicine departments, there

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are two main categories of radiation exposures resulting from diagnostic examinations; staff and patients. Patient absorbed doses and the resulting collective effective dose equivalents in nuclear medicine departments have been reported by different investigators on the basis of type and frequency of examinations, and the amount of administered activities in several countries (Overbeek *et al.* 1994, Hausak *et al.* 2000, Li *et al.* 2001, Mohammadi and Tabeie 1995, Ftacnikova and Regan 1995, Reiners *et al.* 1994, Papadopoulos and Okkalides 1990, Bekhuis 1988, Poppitz 1982,1983, Roberstson 1982). In reality there are considerable differences among activities of nuclear medicine departments performed in predetermined period of time (annually) due to variations of examination type and frequency, and, hence the resultant staff and patient absorbed doses. So, by considering the well known ALARA law in radiation protection, what we concerned about is "reasonable" relationship between staff and patient absorbed doses in nuclear medicine departments. The main purpose of this study was the calculation of annual patient and staff absorbed doses resulting from diagnostic nuclear medicine examinations in Iran and introducing a new quantity called *staff to patient absorbed dose ratio* for each nuclear medicine department. This ratio represents the amount of annual staff absorbed dose (mSv) to achieve a unit for annual patient absorbed dose (1 Sv).

MATERIALS AND METHODS

As a part of nationwide survey, the data on annual diagnostic nuclear medicine procedures were extracted of hospital records from four nuclear medicine departments affiliated to Shahid Beheshti University of Medical Sciences & Health Services. The data, including type and frequency of examinations, type of radiopharmaceuticals used, and range of administered activity for each examination were obtained directly from hospital medical records for four years (1999-2002). To obtain mean administered activity, the actual administered activities were a period of registered for six months for every procedure. The mean effective dose equivalent per procedure was achieved by multiplying the mean dose used by the dose equivalent value (adopted from ICRP, 1988). The total patient effective dose equivalent (collective EDE) was obtained by multiplying the effective dose equivalent for particular procedure by corresponding number of patients. Annual staff absorbed dose equivalents were obtained from regular personal dosimetry records from Atomic Energy Organization of Iran (AEOI) and were summed annually for all radiation workers of departments, as staff collective dose equivalent.

RESULTS

Annual activities of each department, including examination type and frequency, radiopharmaceutical used and mean administered activity, effective EDE per administered activity and per examination, and finally collective EDE for each scan type are listed in tables 1 to 4 in a period of four years. Total number of procedures and collective EDE, total annual staff absorbed doses and the ratio of staff to patient absorbed doses are calculated at the bottom of tables. Contribution of renal, bone, cardiac, thyroid and lung examinations from total number of procedures and resulting collective EDE are given in figure 1. Renal (34-40%) and bone (13-22%) examinations has shown high frequencies during the four years, but renal examinations have had lower EDE per exam in comparison with bone and cardiac examinations; so, the contribution of renal examination from collective EDE (23-25%) is lower than that of the number of procedures (34-40%). Annual total numbers of procedures were 4930, 4909, 5959 and 5756; and the corresponding annual patient collective effective dose equivalents were 18555, 17670, 21249 and 20751, during four years period. The number of procedures increased about 16.7%, but the resulting collective EDE was increased about 13.0% during four years. The contribution of radionuclides used from total number of procedures and collective EDE is given in figure 2.

Table 1. Annual number of diagnostic nuclear medicine procedures performed in department 1 and resultant staff and population absorbed dose equivalents during 1999-2002.

Procedure	Radiopharmaceutical		Administered Activity (MBq)		EDE (mSv/ MBq)	EDE/ Exam (mSv)	Annual No. of procedures				Collective Patient EDE (Human-mSv)			
			Range	Mean			1999	2000	2001	2002	1999	2000	2001	2002
Thyroid	^{131}I	INa	0.74-3.7	2.26	24	24.86	0	0	0	0	0	0	0	0
	^{99m}Tc	TcO4	18-185	111	0.013	1.443	98	117	157	178	141.414	168.831	226.551	256.854
Bone	^{99m}Tc	MDP, PYP	296-925	740	0.006	4.44	336	447	505	470	1491.84	1984.68	2242.2	2086.8
Liver/ Spleen	^{99m}Tc	SC	37-222	185	0.009	1.665	12	13	12	9	19.98	21.645	19.98	14.985
Biliary	^{99m}Tc	IDA	37-296	185	0.017	3.145	30	18	27	26	94.35	56.61	84.915	81.77
Renal	^{99m}Tc	DTPA	370-555	481	0.005	2.405	365	350	382	381	877.825	841.75	918.71	916.305
	^{99m}Tc	DMSA	74-222	148	0.009	1.332	63	51	68	57	151.515	122.655	163.54	137.085
Lung perfusion	^{99m}Tc	MAA	37-222	185	0.001	0.185	89	117	96	84	16.465	21.645	17.76	15.54
Lung ventilation	^{133}Xe	^{81m}Kr	370-740	555	0.006	3.33	0	0	0	0	0	0	0	0
Cardiac	^{99m}Tc	MIBI	370-740	555	0.008	4.44	494	433	760	805	2193.36	1922.52	3374.4	3574.2
	^{201}TI	Ion	111-185	148	0.022	3.256	84	50	46	43	273.504	162.8	149.776	140.008
Brain	^{99m}Tc	TcO4	296-925	740	0.013	9.62	4	3	2	8	38.48	28.86	19.24	76.96
Whole body	^{131}I	INa	37-185	74	24	1776	3	2	3	2	28.86	19.24	28.86	19.24
MIBG	^{131}I	INa	37-74	37	0.014	0.518	0	0	0	0	0	0	0	0
Tumor	^{67}Ga	Citrate	74-370	222	0.1	22.2	2	8	10	16	44.4	177.6	222	355.2
Other	^{99m}Tc	TcO4	222-370	326	0.013	4.238	67	164	135	133	283.946	695.032	572.13	563.654
Total number of procedures							**1647**	**1773**	**2203**	**2212**				
Collective patient effective dose equivalent (Human-mSv)											**5655.939**	**6223.868**	**8040.062**	**8238.601**
Total staff absorbed dose equivalent (mSv)											**9.146**	**13.624**	**16.431**	**12.477**
Staff/Population absorbed dose equivalent ratio											**0.0016171**	**0.002189**	**0.002044**	**0.0015145**

Table 2. Annual number of diagnostic nuclear medicine procedures performed in department 2 and resultant staff and population absorbed dose equivalents during 1999-2002.

Procedure	Radiopharmaceutical		Administered Activity (MBq)		EDE (mSv/ MBq)	EDE/ Exam (mSv)	Annual No. of procedures				Collective Patient EDE (Human-mSv)			
			Range	Mean			1999	2000	2001	2002	1999	2000	2001	2002
Thyroid	^{131}I	INa	0.74-3.7	2.26	24	24.86	13	17	14	25	323.18	422.62	348.04	621.5
	^{99m}Tc	TcO4	18-185	111	0.013	1.443	159	88	120	156	229.437	126.984	173.16	225.108
Bone	^{99m}Tc	MDP, PYP	296-925	740	0.006	4.44	469	119	365	440	2082.36	528.36	1620.6	1953.6
Liver/ Spleen	^{99m}Tc	SC	37-222	185	0.009	1.665	15	2	8	14	24.975	3.33	13.32	23.31
Biliary	^{99m}Tc	IDA	37-296	185	0.017	3.145	13	6	6	20	40.885	18.87	18.87	62.9
Renal	^{99m}Tc	DTPA	370-555	481	0.005	2.405	126	48	156	210	303.03	115.44	375.18	505.05
	^{99m}Tc	DMSA	74-222	148	0.009	1.332	21	19	32	43	50.505	45.695	76.96	103.415
Lung perfusion	^{99m}Tc	MAA	37-222	185	0.001	0.185	27	20	35	80	4.995	3.7	6.475	14.8
Lung ventilation	^{133}Xe	^{81m}Kr	370-740	555	0.006	3.33	0	0	0	0	0	0	0	0
Cardiac	^{99m}Tc	MIBI	370-740	555	0.008	4.44	12	7	2	23	53.28	31.08	8.88	102.12
	^{201}TI	Ion	111-185	148	0.022	3.256	0	0	0	0	0	0	0	0
Brain	^{99m}Tc	TcO4	296-925	740	0.013	9.62	3	4	2	1	28.86	38.48	19.24	9.62
Whole body	^{131}I	INa	37-185	74	24	1776	11	18	21	5	105.82	173.16	202.02	48.1
MIBG	^{131}I	INa	37-74	37	0.014	0.518	0	0	0	0	0	0	0	0
Tumor	^{67}Ga	Citrate	74-370	222	0.1	22.2	11	9	19	23	244.2	199.8	421.8	510.6
Other	^{99m}Tc	TcO4	222-370	326	0.013	4.238	53	8	66	156	224.614	33.904	279.708	661.128
Total number of procedures							**933**	**365**	**846**	**1196**				
Collective patient effective dose equivalent (Human-mSv)											**3716.141**	**1741.423**	**3564.253**	**4841.251**
Total staff absorbed dose equivalent (mSv)											**4.41**	**2.03**	**3.26**	**4.53**
Staff/Population absorbed dose equivalent ratio											**0.0011867**	**0.0011657**	**0.000915**	**0.0009357**

Table 3. Annual number of diagnostic nuclear medicine procedures performed in department 3 and resultant staff and population absorbed dose equivalents during 1999-2002.

Procedure	Radiopharmaceutical		Administered Activity (MBq)		EDE	EDE/ Exam	Annual No. of procedures				Collective Patient EDE (Human-mSv)			
			Range	Mean	(mSv/ MBq)	(mSv)	1999	2000	2001	2002	1999	2000	2001	2002
Thyroid	^{131}I	INa	0.74-3.7	2.26	24	24.86	60	61	31	22	1491.6	1516.46	770.66	546.62
	^{99m}Tc	TcO4	18-185	111	0.013	1.443	2	346	255	32	2.886	499.278	367.965	46.176
Bone	^{99m}Tc	MDP, PYP	296-925	740	0.006	4.44	284	111	114	152	1260.96	492.84	506.16	674.88
Liver/ Spleen	^{99m}Tc	SC	37-222	185	0.009	1.665	20	5	7	0	33.3	8.325	11.655	0
Biliary	^{99m}Tc	IDA	37-296	185	0.017	3.145	0	0	14	0	0	0	44.03	0
Renal	^{99m}Tc	DTPA	370-555	481	0.005	2.405	1334	1454	1297	1228	3208.27	3496.87	3119.285	2953.34
	^{99m}Tc	DMSA	74-222	148	0.009	1.332	32	43	52	39	76.96	103.415	125.06	93.795
Lung perfusion	^{99m}Tc	MAA	37-222	185	0.001	0.185	0	0	0	0	0	0	0	0
Lung ventilation	^{133}Xe	^{81m}Kr	370-740	555	0.006	3.33	0	0	0	0	0	0	0	0
Cardiac	^{99m}Tc	MIBI	370-740	555	0.008	4.44	13	11	2	15	51.72	48.84	8.88	66.6
	^{201}TI	Ion	111-185	148	0.022	3.256	0	3	0	0	0	9.768	0	0
Brain	^{99m}Tc	TcO4	296-925	740	0.013	9.62	0	2	0	0	0	19.24	0	0
Whole body	^{131}I	INa	37-185	74	24	1776	0	0	0	0	0	0	0	0
MIBG	^{131}I	INa	37-74	37	0.014	0.518	0	0	0	0	0	0	0	0
Tumor	^{67}Ga	Citrate	74-370	222	0.1	22.2	16	22	11	2	355.2	488.4	244.2	44.4
Other	^{99m}Tc	TcO4	222-370	326	0.013	4.238	589	713	504	334	2496.182	3021.694	2135.952	1415.492
Total number of procedures							**2350**	**2771**	**2287**	**1824**				
Collective patient effective dose equivalent (Human-mSv)											**8983.078**	**9705.13**	**7333.847**	**5841.603**
Total staff absorbed dose equivalent (mSv)											**26.99**	**29.53**	**22.98**	**23.24**
Staff/Population absorbed dose equivalent ratio											**0.0030045**	**0.0030427**	**0.003133**	**0.0039784**

Table 4. Annual number of diagnostic nuclear medicine procedures performed in department 4 and resultant staff and population absorbed dose equivalents during 1999-2002.

Procedure	Radiopharmaceutical		Administered Activity (MBq)		EDE	EDE/ Exam	Annual No. of procedures				Collective Patient EDE (Human-mSv)			
			Range	Mean	(mSv/ MBq)	(mSv)	1999	2000	2001	2002	1999	2000	2001	2002
Thyroid	^{131}I	INa	0.74-3.7	2.26	24	24.86	0	0	0	0	0	0	0	0
	^{99m}Tc	TcO4	18-185	111	0.013	1.443	0	0	51	57	0	0	73.593	82.251
Bone	^{99m}Tc	MDP, PYP	296-925	740	0.006	4.44	0	0	377	254	0	0	1673.88	1127.76
Liver/ Spleen	^{99m}Tc	SC	37-222	185	0.009	1.665	0	0	1	1	0	0	1.665	1.665
Biliary	^{99m}Tc	IDA	37-296	185	0.017	3.145	0	0	1	1	0	0	3.145	3.145
Renal	^{99m}Tc	DTPA	370-555	481	0.005	2.405	0	0	86	66	0	0	206.83	158.73
	^{99m}Tc	DMSA	74-222	148	0.009	1.332	0	0	0	0	0	0	0	0
Lung perfusion	^{99m}Tc	MAA	37-222	185	0.001	0.185	0	0	25	39	0	0	4.625	7.215
Lung ventilation	^{133}Xe	^{81m}Kr	370-740	555	0.006	3.33	0	0	0	0	0	0	0	0
Cardiac	^{99m}Tc	MIBI	370-740	555	0.008	4.44	0	0	1	0	0	0	4.44	0
	^{201}TI	Ion	111-185	148	0.022	3.256	0	0	0	0	0	0	0	0
Brain	^{99m}Tc	TcO4	296-925	740	0.013	9.62	0	0	0	0	0	0	0	0
Whole body	^{131}I	INa	37-185	74	24	1776	0	0	0	0	0	0	0	0
MIBG	^{131}I	INa	37-74	37	0.014	0.518	0	0	0	0	0	0	0	0
Tumor	^{67}Ga	Citrate	74-370	222	0.1	22.2	0	0	0	0	0	0	0	0
Other	^{99m}Tc	TcO4	222-370	326	0.013	4.238	0	0	81	106	0	0	343.278	449.228
Total number of procedures							**0**	**0**	**623**	**524**				
Collective patient effective dose equivalent (Human-mSv)											**0**	**0**	**2311.456**	**1829.994**
Total staff absorbed dose equivalent (mSv)													**5.36**	**7.64**
Staff/Population absorbed dose equivalent ratio													**0.002319**	**0.0041749**

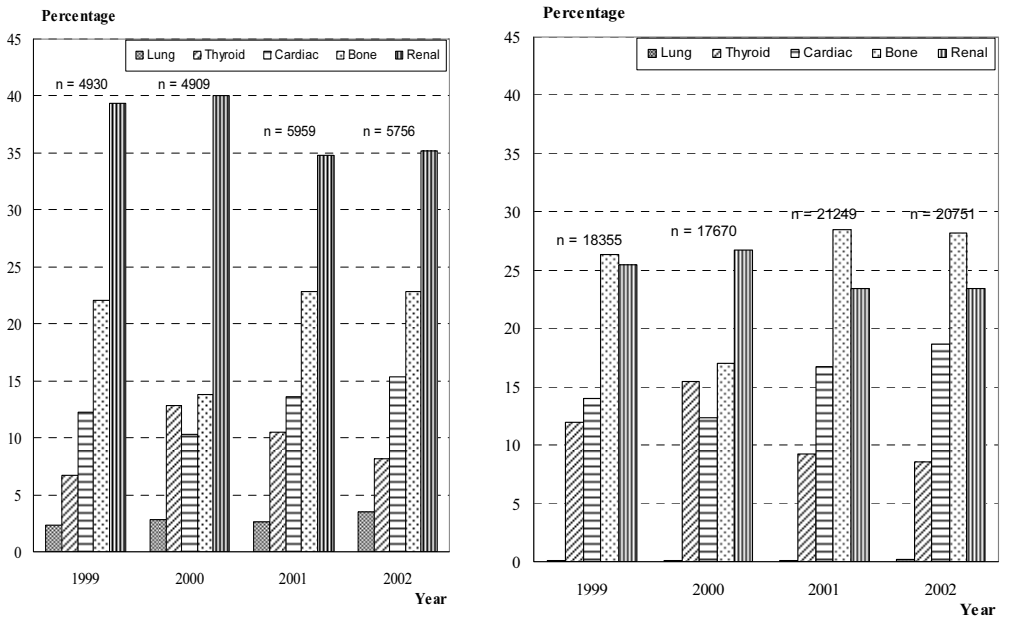

Figure 1. Percent of five procedures performed annually (left) and resulting effective dose equivalents (right) in four nuclear medicine departments (1999-2002).

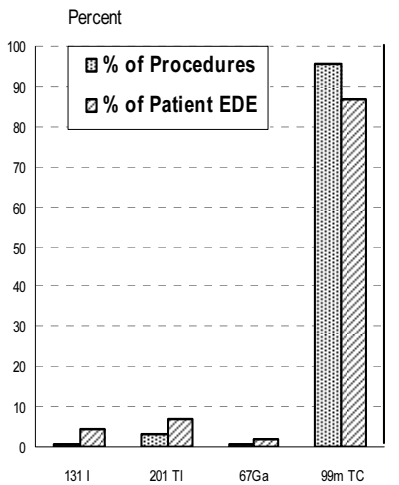

Figure 2. Contribution of radionuclides used from total number of procedures and collective EDE.

Ninety one percent of all nuclear medicine investigations were performed with ^{99m}Tc, and the remainder 9% with ^{201}Tl , ^{131}I and ^{67}Ga in four years. ^{99m}Tc with 91% use of the total radionuclide administered, delivered the patient effective dose equivalent of 87%. The mean effective dose equivalent (EDE) among four departments and during four years was found to be 3.72, 3.59, 3.56 and 3.60 mSv per examination. The annual staff collective dose equivalents of four departments were 40.45, 45.17, 48.08 and 47.81, respectively. That showed an increase of about 20.6% during four years. The average of annual ratios of staff to patient effective dose equivalents in four departments were 1.83×10^{-3}, 1.04×10^{-3}, 3.28×10^{-3}, and 3.24×10^{-3}, respectively, within a range of $0.9\times10^{-3} - 4.17\times10^{-3}$. The mean value of ratios in four years was about $2.24\times10^{-3} \pm 1.09\times10^{-3}$ that indicates the staff dose of about one 1000th of patient dose.

DISCUSSION

In comparison with our previous study in 1995 (Mohammadi and Tabeie 1995) there are considerable changes in trends of nuclear medicine examinations in Iran and these changes are also verified in larger groups of departments under study (about 30). First, thyroid examinations with relative frequency of more than 80% in 1995, has decreased to lower than 10%. Considerable decrease in relative frequency of thyroid examinations could have some reasons: change of referral

discipline (mainly by specialists), decreased incidence of goiter due to implementation of programs for iodine enrichment of diets, introduction of FNA and sonography techniques for diagnosis of thyroid disease.

Second, the ^{131}I with relative percent of administration of about 13.73% caused about 59% of collective EDE in 1995, but now, this radionuclide with relative percent of administration of about 0.82% has a contribution of about 4.38% to the collective EDE. This study clearly demonstrated that the use of ^{131}I with very high patient dose is reduced by a factor of 16, but it must be recommended that the ^{131}I is substituted with other radioisotopes of iodine such as ^{123}I for diagnostic purposes.

The values of the staff to patient dose equivalent ratios have a range of 0.9×10^{-3}-4.17×10^{-3} among four departments during four years, but the lower values correspond to departments with a reasonable number of staff and higher education. For better evaluation of the ratio, further studies on larger groups of nuclear medicine departments all over the country (study under investigation) and other countries is suggested.

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