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Establishment of National Diagnostic Reference Levels for Administered Activity in Diagnostic Nuclear Medicine in Thailand

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The diagnostic reference level (DRL) is a patient-exposure optimization tool used to evaluate radiation doses in medical imaging and provide guidance for protection from them. In Thailand, nuclear medicine DRLs have not been established yet. Therefore, this study surveyed dose levels in routine nuclear medicine procedures to provide national DRLs (NDRLs). **Methods:** NDRLs in Thailand were established by investigating the administered activity of radiopharmaceuticals in nuclear medicine examination studies. The NDRLs were determined on the basis of the 75th percentile (third quartile) of administered activity distribution as recommended by the International Commission on Radiological Protection. As part of a nationwide survey, datasets for the period between June 1, 2018, and August 31, 2019, were collected from 21 Thailand hospitals with nuclear medicine equipment. All hospitals were asked to report the nuclear medicine imaging devices in use, the standard protocol parameters for selected examinations, the injected activities, and the ages and weights of patients. All data were calculated to determine Thailand NDRLs, which were compared with international NDRLs. **Results:** The data reported by the 21 hospitals consisted of 4,641 examinations with SPECT or SPECT/CT for general nuclear medicine and 409 examinations with PET. The most widely performed examinations for SPECT were bone, thyroid, oncology, and cardiovascular imaging. The NDRLs for SPECT or SPECT/CT agreed well with published NDRLs for Europe, the United States, Japan, Korea, Kuwait, and Australia. In contrast, the NDRLs for ^{18}F-FDG PET in oncology studies were higher than for Japan, Korea, Kuwait, and Australia but lower than for the United States, the United Kingdom, and the European Union. **Conclusion:** This study presents NDRL results for adults in Thailand as a way to optimize radiation protection in nuclear medicine imaging. Moreover, the reported injected activity levels were comparable to those of other countries.

Key Word: diagnostic reference level; DRL; nuclear medicine; radiation protection

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Currently, the use of radiation in medical imaging continues to increase. Although exposure to radiation during diagnostic workup and treatment often offers patients the chance to overcome life-threatening illness, they are also at increased risk of adverse effects (*1*). To limit exposure of the general population to radiation and potential adverse effects to individual patients, diagnostic procedures that include ionizing radiation need to follow the as-low-as-reasonably-achievable principle. This principle includes justification of the procedure (radiation-based diagnosis and treatment are justified only when the benefit is clearly greater than the risk), optimization of the dose (the radiation dose must be kept as low as possible during justified radiologic diagnosis and treatment), and keeping within the legislated dose limits (applicable to staff but not to the patients being imaged) (*2–4*). Thus, exposure to radiation from medical imaging should be limited to the lowest level necessary to reliably answer the diagnostic question (*5*).

The motivation to minimize patients' radiation exposure while maintaining the quality of images is increasing worldwide (*6*,*7*). In Europe, the concept of a reference dose level was first established in the 1950s through dosimetry surveys of radiographic examinations in England (*8*,*9*). In the United States, the use of reference dose levels began in 1974–1981 with a nationwide trend survey on radiography use (*9*). Since then, the concept of diagnostic reference levels (DRLs) has been officially adopted by the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements to raise awareness of the potential risks associated with radiation (*10*,*11*).

DRLs for nuclear medicine examinations are defined as radiopharmaceutical activities to be administered to standard-sized adults. Deviation from the national DRLs (NDRLs) by more than 20% must be justified (*12*,*13*). Currently, there are more than 30 nuclear medicine departments in Thailand, but NDRLs have not yet been established. Therefore, the aim of this study was to establish such NDRLs for routine nuclear medicine procedures, allowing for optimization of radiation doses to patients and improvement of the radiation protection process.

MATERIALS AND METHODS

In 2021, the Nuclear Medicine Society of Thailand formed a committee to conduct a nationwide survey of all nuclear medicine departments, which were invited via email and telephone calls to provide information on the types of examinations commonly performed, the

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administered activities used, the types of imaging equipment available, and the standard procedures used to determine patient doses, as explained by publication 135 of the International Commission on Radiological Protection. Examinations of children were excluded.

The obtained data were analyzed using Microsoft Excel; median, third quartile, mean, SD, maximum, and minimum values were calculated for each examination type.

This study, approved by the Institutional Review Board, Maharat Nakhon Ratchasima Hospital Ethics Committee, is in full compliance with the Declaration of Helsinki and the International Conference on Harmonization in Good Clinical Practice number 023/2019.

RESULTS

Data for the period between June 1, 2018, and August 31, 2019 were collected from 21 nuclear medicine departments and are shown in Table 1. The reported numbers of examinations were 4,641 for general nuclear medicine and 409 for PET. Because some protocols were used rarely, the NDRL for each protocol was calculated only if more than 4 departments used it. The radiopharmaceuticals that did not meet this condition included ^{99m}Tc-octreotide (used by 4 departments), ^{68}Ga-DOTATATE (2 departments), ^{99m}Tc-ethyl cysteinate dimer (4 departments), and ^{18}F-3,4-dihydroxyphenylalanine (2 departments). The condition was met by 32 protocols in 10 organ systems, with the 3 most commonly examined systems being the skeletal system, the endocrine system, and the cardiovascular system. The dose distributions for each protocol were generated in terms of 25th percentile, 50th percentile, 75th percentile, mean, minimum,

TABLE 1
National Survey Results for Thailand

Organ system and protocol	Radiopharmaceutical	Patients (*n*)	M/F (*n*)	Age (y)	Weight (kg)	Activity (MBq)	Modality
Skeletal/marrow	^{99m}Tc-MDP	2,284	882/1,402	59.29 ± 15.83	59.27 ± 13.51	720.39 ± 98.79	SPECT
Cardiovascular							
MUGA	^{99m}Tc-RBC	317	16/301	53.61 ± 10.87	58.62 ± 10.48	752.21 ± 90.65	SPECT, SPECT/CT
MPI MIBI							
Rest	^{99m}Tc-MIBI	205	97/108	66.33 ± 10.91	62.78 ± 15.75	421.06 ± 204.61	SPECT, SPECT/CT
Stress		211	97/114	65.92 ± 11.24	62.11 ± 14.0	719.28 ± 303.40	SPECT, SPECT/CT
MPI ^{201}Tl	^{201}Tl-chloride	40	30/10	68.28 ± 9.82	62.99 ± 15.56	97.68 ± 25.16	SPECT, SPECT/CT
Pulmonary							
Perfusion	^{99m}Tc-MAA	40	15/25	64.09 ± 14.02	59.41 ± 13.56	227.55 ± 74.00	SPECT, SPECT/CT
Ventilation	^{99m}Tc-DTPA aerosol	24	12/11	62.65 ± 11.05	66.65 ± 13.71	916.49 ± 190.18	SPECT, SPECT/CT
	^{99m}Tc-Technegas*					662.30 ± 139.49	SPECT, SPECT/CT
Gastrointestinal							
Protein losing	^{99m}Tc-HSA	15	5/10	51.16 ± 13.91	55.48 ± 8.34	609.02 ± 186.48	SPECT, SPECT/CT
Hepatobiliary	^{99m}Tc-IDA	12	8/4	64.59 ± 21.65	67.32 ± 16.60	237.17 ± 66.97	SPECT, SPECT/CT
Esophagus	^{99m}Tc-phytate	20	3/17	51.5 ± 11.43	54.56 ± 8.94	31.45 ± 1.11	SPECT
Gastric emptying	^{99m}Tc-phytate (solid meal)	22	7/15	51.52 ± 19.79	58.28 ± 6.52	38.85 ± 5.92	SPECT
GI bleeding	^{99m}Tc-RBC	13	9/4	64.82 ± 14.91	56.64 ± 8.42	490.99 ± 199.06	SPECT, SPECT/CT
Hemangiomas	^{99m}Tc-pertechnetate	10	3/7	50.49 ± 20.64	57.79 ± 6.71	214.97 ± 91.02	SPECT, SPECT/CT
Genitourinary	^{99m}Tc-MAG3	99	58/42	47.76 ± 15.51	61.42 ± 13.41	134.31 ± 75.85	SPECT
	^{99m}Tc-DTPA	49	25/24	49.98 ± 16.06	63.98 ± 15.94	156.51 ± 136.53	SPECT
Oncology	^{131}I-sodium iodide	99	14/85	46.42 ± 13.68	63.83 ± 14.24	95.83 ± 33.67	SPECT, SPECT/CT
	^{131}I-MIBG	21	5/16	48.25 ± 15.98	61.29 ± 13.49	44.77 ± 9.25	SPECT, SPECT/CT
	^{67}Ga-citrate	35	4/2	28.98 ± 11.81	55.0 ± 10.31	158.73 ± 22.57	SPECT, SPECT/CT
	^{99m}Tc-MIBI	29	8/22	49.02 ± 16.54	62.62 ± 13.87	731.49 ± 78.07	SPECT, SPECT/CT
	^{18}F-FDG	196	92/104	59.63 ± 14.80	59.84 ± 11.98	324.12 ± 83.62	PET/CT
	^{18}F-PSMA	15	15/0	68.64 ± 5.14	62.74 ± 0.61	242.72 ± 22.57	PET/CT
	^{68}Ga-PSMA	17	17/0	70.62 ± 10.54	70.03 ± 10.58	187.96 ± 44.03	PET/CT
Lymphatic	^{99m}Tc-dextran	20	3/17	57.49 ± 12.09	76.62 ± 22.61	96.20 ± 24.79	SPECT
	^{99m}Tc-nanocolloid	31	0/31	58.07 ± 12.23	NA	16.65 ± 10.73	SPECT, SPECT/CT
Endocrine							
Thyroid	^{99m}Tc-pertechnetate	332	54/278	49.22 ± 15.33	60.77 ± 12.43	120.25 ± 39.22	SPECT
	^{131}I-sodium iodide	201	28/173	47.33 ± 14.66	61.32 ± 13.25	122.10 ± 82.88	SPECT
Parathyroid	^{99m}Tc-pertechnetate	72	29/43	51.46 ± 15.75	57.99 ± 13.81	155.03 ± 117.66	SPECT, SPECT/CT
	^{99m}Tc-MIBI	106	42/64	51.96 ± 15.60	58.33 ± 14.54	709.29 ± 121.73	SPECT, SPECT/CT
Nervous system	^{18}F-FDG	18	9/9	71.66 ± 10.72	56.58 ± 8.26	251.23 ± 35.52	PET/CT
Infection/ inflammation	^{67}Ga-citrate	8	5/3	46.87 ± 17.41	43.03 ± 8.39	186.85 ± 19.98	SPECT/CT
	^{99m}Tc-SC-WBC	9	5/4	67.55 ± 14.04	48.0	728.90 ± 71.78	SPECT

*Cyclomedica.

MDP = methylene diphosphonate; MUGA = multigated acquisition; RBC = red blood cells; MPI = myocardial perfusion imaging; MIBI = methoxyisobutylisonitrile; MAA = macroaggregated albumin; DTPA = diethylenetriaminepentaacetic acid; HSA = human serum albumin; IDA = iminodiacetic acid; GI = gastrointestinal; MAG3 = mercaptoacetyltriglycine; NA = not applicable; PSMA = prostate-specific membrane antigen; SC-WBC = sulfur colloid white blood cells.

Age, weight, and activity are expressed as mean ± SD.

TABLE 2
NDRLs for Most Common Procedures in Thailand

Organ system and protocol	Radiopharmaceutical	Mean activity ± SD (MBq)	Percentile of dose distribution			Mean	NDRL (MBq)
			25th	50th	75th		
Skeletal/marrow	^{99m}Tc-MDP	720.39 ± 98.79	680.80	747.03	773.30	720.39	773.3
Cardiovascular							
MUGA	^{99m}Tc-RBC	752.21 ± 90.65	715.58	740.00	795.50	752.21	795.5
MPI MIBI							
Rest	^{99m}Tc-MIBI	421.06 ± 204.61	273.80	310.80	658.60	421.06	658.6
Stress	^{99m}Tc-MIBI	719.28 ± 303.40	305.25	740.00	947.2	719.28	947.2
MPI ^{201}Tl	^{201}Tl-chloride	97.68 ± 25.16	92.50	99.90	115.81	97.68	115.81
Pulmonary							
Perfusion	^{99m}Tc-MAA	227.55 ± 74.00	185.00	214.60	240.5	227.55	240.5
Ventilation	^{99m}Tc-DTPA aerosol	916.49 ± 190.18	784.4	888.00	1110	916.49	1110
	^{99m}Tc-Technegas*	662.30 ± 139.49	545.38	678.58	752.95	662.30	752.95
Gastrointestinal							
Protein losing	^{99m}Tc-HSA	609.02 ± 186.48	408.48	632.70	723.35	609.02	723.35
Hepatobiliary	^{99m}Tc-IDA	237.17 ± 66.97	195.36	214.23	235.69	237.17	235.69
Esophagus	^{99m}Tc-phytate (esophagus)	31.45 ± 1.11	30.71	31.45	31.45	31.45	31.45
Gastric emptying	^{99m}Tc-phytate (solid meal)	38.85 ± 5.92	37.37	39.22	40.7	38.85	40.7
GI bleeding	^{99m}Tc-RBC	490.99 ± 199.06	307.84	451.77	677.1	488.40	677.1
Hemangiomas	^{99m}Tc-pertechnetate	214.97 ± 91.02	185.00	185.00	186.48	214.97	186.48
Genitourinary	^{99m}Tc-MAG3	134.31 ± 75.85	108.41	118.40	134.31	134.41	134.31
	^{99m}Tc-DTPA	156.51 ± 136.53	66.60	185.00	185	156.51	185
Oncology	^{131}I-sodium iodide	95.83 ± 33.67	74.00	74.00	111	95.83	111
	^{131}I-MIBG	44.77 ± 9.25	38.48	42.55	46.62	44.77	46.62
	^{67}Ga-citrate	158.73 ± 22.57	144.30	144.67	174.64	158.73	174.64
	^{99m}Tc-MIBI	731.49 ± 78.07	740.00	754.80	784.4	731.49	784.4
	^{18}F-FDG	324.12 ± 83.62	268.62	320.42	376.29	324.12	376.29
	^{18}F-PSMA	242.72 ± 22.57	223.48	237.91	263.81	242.72	263.81
	^{68}Ga-PSMA	187.96 ± 44.03	150.59	190.55	209.05	187.96	209.05
Lymphatic	^{99m}Tc-dextran	96.20 ± 24.79	79.18	90.65	103.6	96.20	103.6
	^{99m}Tc-nanocolloid	16.65 ± 10.73	14.80	14.80	14.8	16.65	14.8
Endocrine							
Thyroid	^{99m}Tc-pertechnetate	120.25 ± 39.22	91.02	109.52	140.6	120.25	140.6
	^{131}I-sodium iodide	122.1 ± 82.88	74.00	111.00	185	122.10	185
Parathyroid	^{99m}Tc-pertechnetate	155.03 ± 117.66	106.19	130.98	166.5	155.03	166.5
	^{99m}Tc-MIBI	709.29 ± 121.73	604.58	740.00	794.76	709.29	794.76
Nervous system	^{18}F-FDG	251.23 ± 35.52	223.48	251.23	268.25	251.23	268.25
Infection/inflammation	^{67}Ga-citrate	186.85 ± 19.98	49.58	186.11	192.4	186.85	192.4
	^{99m}Tc-SC-WBC	728.9 ± 71.78	736.3	740.00	765.9	728.9	765.9

*Cyclomedica.

MDP = methylene diphosphonate; MUGA = multigated acquisition; RBC = red blood cells; MPI = myocardial perfusion imaging; MIBI = methoxyisobutylisonitrile; MAA = macroaggregated albumin; DTPA = diethylenetriaminepentaacetic acid; HSA = human serum albumin; IDA = iminodiacetic acid; GI = gastrointestinal; MAG3 = mercaptoacetyltriglycine; PSMA = prostate-specific membrane antigen; SC-WBC = sulfur colloid white blood cells.

TABLE 3
NDRLs for Thailand Compared with Other Countries

Organ system and protocol	Radiopharmaceutical	Thailand	Japan	Korea	Australia	Kuwait	U.K.	United States	European Union
Skeletal/marrow	^{99m}Tc-MDP	773.3	950	925	920	944	600	848–1,185	500–1,110
Cardiovascular									
MUGA	^{99m}Tc-RBC	795.5	—	740	1,030	740	800	916–1,301	600–1,000
MPI MIBI									
Rest	^{99m}Tc-MIBI	658.6	900	555	620	976	800	519–1,153	560
Stress		947.2	1,200	1,110	1,520	976	800	945–1,402	1,100
MPI ^{201}Tl	^{201}Tl-chloride	115.81	180	111	120	—	80	—	75–150
Pulmonary (perfusion)	^{99m}Tc-MAA	240.5	260	222	240	217.5	100	147–226	100–296
Gastrointestinal									
Hepatobiliary	^{99m}Tc-IDA	235.69	—	370	210	—	150	—	—
Gastric emptying	^{99m}Tc-phytate (solid meal)	40.7	—	111	44	37	12	31–50	150–540
Genitourinary	^{99m}Tc-MAG3	134.31	400	500	305	370	100	283–379	100–370
	^{99m}Tc-DTPA	185	400	555	500	90	300	407–587	—
Oncology	^{131}I-sodium iodide	111	—	185	185	—	400	—	90–400
	^{18}F-FDG	376.29	240	370	310	230	400	461–710	200–400
Endocrine									
Thyroid	^{99m}Tc-pertechnetate	140.6	300	217	215	185	80	—	75–222
	^{131}I-sodium iodide	185	—	185	185	200	400	—	90–400
Parathyroid	^{99m}Tc-MIBI	794.76	800	740	900	900	900	—	400–900
Nervous system	^{18}F-FDG	268.25	240	370	250	231	250	—	—
Infection/inflammation	^{99m}Tc-SC-WBC	765.9	—	888	800	892.5	200	—	300–600

MDP = methylene diphosphonate; MUGA = multigated acquisition; RBC = red blood cells; MPI = myocardial perfusion imaging; MIBI = methoxyisobutylisonitrile; MAA = macroaggregated albumin; IDA = iminodiacetic acid; MAG3 = mercaptoacetyltriglycine; SC-WBC = sulfur colloid white blood cells.

Data are megabecquerels.

maximum, and SD. The third quartile (75th percentile) was used to establish NDRLs as shown in Table 2; these are compared with those of other countries in Table 3.

DISCUSSION

Thailand has about 30 nuclear medicine departments, including those in government hospitals and those in private hospitals. Some of these departments did not wish to participate in the survey, and some were newly established and not yet in service. Therefore, the study collected data from 21 departments.

The collected data, categorized by organ system, included protocols involving the skeletal system or bone marrow, cardiovascular system, pulmonary system, gastrointestinal system, genitourinary system, lymphatic system, endocrine system, and nervous system, as well as oncologic studies and studies of infection or inflammation.

The myocardial perfusion imaging ^{99m}Tc-methoxyisobutylisonitrile rest and stress protocols showed the largest SD for activity. This large SD is due to differences among departments, with some performing a 1-d protocol and others performing a 2-d protocol. In the 1-d protocol, regulations stipulate that the activity must be 3 times higher in the second study than in the first study (*14*). In contrast, in the 2-d protocol, the hospital prescribes the dose or uses a fixed dose of about 740 MBq in both the first study (on day 1) and the second study (on day 2). However, for no department did the injected activity exceed the NDRL.

A comparison of NDRLs between Thailand and other countries is shown in Table 3. For most protocols, the NDRLs agreed well with those of other countries (*5*,*15*–*17*). However, for oncologic protocols using ^{18}F-FDG, the NDRL in Thailand was higher than those in Asia (Japan, Korea, and Kuwait) and Australia but lower than those in the United States, the United Kingdom, and the European Union (*5*,*18*). The expected cause of this difference is that some departments reported fixed activity levels for a standard patient rather than general average doses (*5*).

CONCLUSION

This study established NDRLs for adults in Thailand through a survey of 21 nuclear medicine departments. NDRLs are effective at reducing patient exposure and optimizing radiation protection. Nevertheless, the NDRL should be regarded not as an index of good or bad medical practice but as supplemental data for optimization. Moreover, the NDRL is not considered a limit; the first priority for any diagnostic examination is to achieve sufficient image quality. NDRLs should be periodically reviewed and updated as the medical environment changes, such as when technologic advances in PET and SPECT cameras allow for administration of a decreased activity of radiopharmaceutical.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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KEY POINTS

QUESTION: Can NDRLs for Thailand be established via a survey of nuclear medicine departments?

PERTINENT FINDINGS: A survey of 21 nuclear medicine departments in Thailand allowed the establishment of NDRLs for adults and comparison of these NDRLs with those of other countries.

IMPLICATIONS FOR PATIENT CARE: NDRLs can be used to optimize radiation protection in patients but should not be regarded as an index of good or bad medical practice.

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