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Original Article

Occupational radiation exposure for various medical radiation workers, especially the dental radiation workers, in Taiwan from 2013 to 2020

Feng-Chou Cheng [a,b†], Ming-Chung Lee [a†], Mu-Hsiung Chen [c], Chien-Yi Ting [d,e], Chun-Ping Su [f], Shiang-Yao Liu [a,g], Chun-Pin Chiang [c,h,i*]**

[a] *School of Life Science, National Taiwan Normal University, Taipei, Taiwan*
[b] *Science Education Center, National Taiwan Normal University, Taipei, Taiwan*
[c] *Department of Dentistry, National Taiwan University Hospital, College of Medicine, National Taiwan University, Taipei, Taiwan*
[d] *Department of Medical Imaging and Radiological Sciences, College of Medical Science and Technology, Chung Shan Medical University, Taichung, Taiwan*
[e] *Chung Shan Medical University Hospital, Chung Shan Medical University, Taichung, Taiwan*
[f] *Department of Medical Imaging, National Taiwan University Hospital, College of Medicine, National Taiwan University, Taipei, Taiwan*
[g] *Graduate Institute of Science Education, College of Science, National Taiwan Normal University, Taipei, Taiwan*
[h] *Graduate Institute of Oral Biology, School of Dentistry, National Taiwan University, Taipei, Taiwan*
[i] *Department of Dentistry, Hualien Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, Hualien, Taiwan*

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KEYWORDS
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Abstract *Background/purpose:* The development of dental radiology in Taiwan has been over a century. This study explored mainly the profile of dental radiation workers and their occupational radiation exposure in Taiwan from 2013 to 2020.

* Corresponding author. Department of Dentistry, Hualien Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, No. 707, Section 3, Chung-Yang Road, Hualien, 970, Taiwan.
** Corresponding author. Graduate Institute of Science Education, College of Science, National Taiwan Normal University, No. 88, Sec. 4, Ting-Chou Road, Taipei, 11677, Taiwan. .
E-mail addresses: liusy@ntnu.edu.tw (S.-Y. Liu), cpchiang@ntu.edu.tw (C.-P. Chiang).
† These two authors contributed equally to this work.

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Dental radiation workers;
Measurably exposed dental radiation workers;
Dental radiation technologists;
Annual collective exposure dose

Materials and methods: This study used the secondary data analysis to survey mainly the changes of manpower of the dental radiation workers and their occupational radiation exposure in Taiwan from 2013 to 2020.
Results: The number of monitored dental radiation workers increased from 678 in 2013 to 770 in 2020. However, the proportion of monitored dental radiation workers to the total monitored medical radiation workers decreased from 4.29% in 2013 to 3.67% in 2020. Although the number of monitored dental radiation workers increased, the number of the measurably exposed dental radiation workers decreased from 2013 to 2020. The annual collective exposure dose fluctuated from 5.21 man-Sv to 15.47 man-Sv, but it showed a decreasing trend. Furthermore, the mean annual effective exposure dose of total monitored dental radiation workers (0.01—0.02 mSv) and that of the measurably exposed dental radiation workers (0.15—1.11 mSv) were relatively low among various medical radiation workers. In overall, the proportion of medical radiation technologists to dentists varied from 0.41 to 0.45.
Conclusion: Although the number of monitored dental radiation workers increase, the number of the measurably exposed dental radiation workers, the proportion of the measurably exposed dental radiation workers to the total monitored dental radiation workers, and the annual collective exposure dose for monitored dental radiation workers decrease from 2013 to 2020.

Introduction

At the end of 1895, Wilhelm Conrad Röntgen discovered X-ray. Moreover, two weeks after the publication of Röntgen's discovery, the German dentist Otto Walkhoff acquired a radiograph of his own teeth with the help of Fritz Giesel in 1896. This is the world's first X-ray film for human teeth. The use of X-ray for medical photography spread worldwide from 1896. Then, the first dental X-ray machines were manufactured in Germany by the company now known as Siemens in 1905. So far, dental radiology has a history of more than 120 years.[1—4]

In fact, the development of dental radiology in Taiwan is almost synchronized with the world. During the Japanese colonial period (1895—1945), the colonial government directly transplanted the western medical system to Taiwan, which also included the dental system.[5] According to Taiwan's dentist-related laws and regulations, as early as 1918 (Taisho 7), Enforcement Rules for Taiwan Dentist Order stipulated the names of the dental specialties. At that time, X-ray was already one of 11 dental specialties.[4] However, from 1906 when Taipei Hospital set up a dental treatment room in the Department of Surgery to 1918, Taipei Hospital had 13-year experience in performing dental treatments. In addition, Taiwan's dentist-related laws and regulations at that time also listed the dental radiology as one of the dental specialties, and dental X-ray machines have long been available in the world. A previous study concluded that the Department of Dentistry of Taipei Hospital in the 1920s probably already had dental X-ray machines, as well as the dentists of Taipei Hospital also had the professional ability to operate dental X-ray machines and to use the dental radiography for diagnosis of the jawbone diseases. Therefore, Taiwan's dental radiology also has a history of at least 100 years.[4—9]

Today, Taiwan's dental radiology is governed and supervised by two official departments, the Atomic Energy Council and the Ministry of Health and Welfare. Except for dentists and medical radiation technologists who are under the management of the Ministry of Health and Welfare based on the Physicians Act and Medical Radiation Technologists Act, all related dental radiation workers are under the management of the Atomic Energy Council based on the Ionizing Radiation Protection Act. Therefore, according to the current laws and regulations, although only dentists and medical radiation technologists are qualified to operate dental equipment capable of producing ionizing radiation, dental radiation workers who engage in the practice of dental X-ray equipment, such as manufacturing, installation, use, maintenance, dismantling, or inspection, etc., in a radiation workplace with a certain level of radiation must be managed by radiation exposure dose monitoring.

2In this study, we extracted the public information about various medical radiation workers from the Taiwan occupational radiation exposure database to compare the differences in several parameters (including the number of the measurably exposed workers, the proportion of the measurably exposed workers to the total monitored workers, the annual collective exposure dose, and the mean annual effective exposure dose of the total monitored workers or the measurably exposed workers) between dental radiation workers and other medial radiation workers, and also analyzed the distributions of dental radiation workers, dentists, and medical radiation technologists. We hope that the results of this study can be used as a reference for the formulation of the dental radiation policy.

Materials and methods

This study adopted the methods of the secondary data analysis. The public information of the Taiwan occupational radiation exposure database was obtained from the website of the Atomic Energy Council. The occupational records included the categories of medical radiation workers, the number of total monitored workers and their gender, the number of the measurably exposed workers, the annual collective exposure dose (man-Sv), the mean annual effective exposure dose of the total monitored workers (mSv), and the mean annual effective exposure dose of the measurably exposed workers (mSv). This study investigated and analyzed the records of occupational radiation exposure claimed from 2013 to 2020. The medical radiation workers were divided into 5 categories, including the diagnostic radiology, dental radiation, nuclear medicine, radiotherapy, and all other applications. Excluding medical radiation workers in the category of all other applications, the occupational radiation exposure doses for medical radiation workers in the other 4 categories were analyzed for comparisons.

In addition, the numbers of registered dentists and medical radiation technologists were obtained from the website of the Ministry of Health and Welfare. The above data were also classified by the institution (hospital or clinic). This study further compared the profile of dental radiation workers, dentists, and medical radiation technologists, and their distributions and proportional relationship from 2013 to 2020.

Results

The numbers of total monitored medical radiation workers (including those in the categories of diagnostic radiology, dental radiation, nuclear medicine, and radiotherapy) and their gender, and the related parameters of occupational radiation exposure in Taiwan from 2013 to 2020 are obtained and shown in Tables 1–5. In addition, the number and distribution of registered dentists and medical radiation technologists in Taiwan from 2013 to 2020 are obtained and shown in Table 6. Therefore, the differences in the number of the measurably exposed workers, the annual collective exposure dose (man-S), the mean annual effective exposure dose of the total monitored workers (mSv), and the mean annual effective exposure dose of the measurably exposed workers (mSv) between dental radiation workers and other medical radiation workers could be compared, and the distributions of dental radiation workers, dentists, and medical radiation technologists could also be analyzed.

The changes in the number of monitored medical radiation workers and their occupational radiation exposure in Taiwan from 2013 to 2020.

In Taiwan, the total monitored medical radiation workers increased from 15,805 in 2013 to 20,970 in 2020 (Table 1). Thus, the total increased number of monitored medical radiation workers was 5165 with a mean annual increased number of 737.86 and a total increase rate of 32.68%. As the number of female medical radiation workers increased more than that of male medical radiation workers each year, the male-to-female ratio changed from 1:0.93 in 2013 to 1:0.99 in 2020. Because the total number of monitored medical radiation workers increased every year, the number of the measurably exposed medical radiation workers also increased from 1233 in 2013 to 1514 in 2020. Moreover, the total increased number of measurably exposed medical radiation workers was 281 with a mean annual increased number of 40.14 and a total increase rate of 22.79%. However, the proportion of the measurably exposed medical radiation workers to the total monitored medical radiation workers fluctuated from 6.87% to 8.72%, but the ratio showed a decreasing trend. Furthermore, the annual collective exposure dose fluctuated from 814.72 man-Sv to 1214.66 man-Sv, and it showed an increasing

Table 1 Occupational radiation exposure of monitored medical radiation workers in Taiwan from 2013 to 2020.

	Number of total monitored medical radiation works			Related parameters of occupational radiation exposure				
	Male	Female	Total	A	B	C	D	E
2013	8203	7602	15,805	1233	7.80	814.72	0.05	0.66
2014	8413	7858	16,271	1354	8.32	789.11	0.05	0.58
2015	8833	8366	17,199	1499	8.72	920.39	0.05	0.61
2016	9229	8729	17,958	1233	6.87	1077.53	0.06	0.87
2017	9550	8972	18,522	1427	7.70	1164.07	0.06	0.82
2018	9825	9374	19,199	1532	7.98	1214.66	0.06	0.79
2019	10,190	10,101	20,291	1566	7.72	1186.37	0.06	0.76
2020	10,525	10,445	20,970	1514	7.22	1051.59	0.05	0.69
Total increased number	2322	2843	5165	281	−0.58	236.87	—	—
Mean annual increased number	331.71	406.14	737.86	40.14	−0.08	33.84	—	—
Total increase rate (%)	28.31	37.40	32.68	22.79	−7.44	29.07	—	—

A parameter: the number of the measurably exposed workers.
B parameter: the proportion of the measurably exposed workers to the total monitored workers (%).
C parameter: the annual collective exposure dose (man-Sv).
D parameter: the mean annual effective exposure dose of the total monitored workers (mSv).
E parameter: the mean annual effective exposure dose of the measurably exposed workers (mSv).

Table 2 Occupational radiation exposure of monitored diagnostic radiology workers in Taiwan from 2013 to 2020.

	Number of total monitored diagnostic radiology workers			Related parameters of occupational radiation exposure				
	Male	Female	Total	A	B	C	D	E
2013	6180	5542	11,722	683	5.83	311.04	0.03	0.45
2014	6273	5732	12,005	789	6.57	376.45	0.03	0.48
2015	6615	6080	12,695	826	6.51	364.84	0.03	0.44
2016	6821	6367	13,188	640	4.85	455.91	0.03	0.71
2017	7054	6472	13,521	685	5.07	388.61	0.03	0.57
2018	7208	6759	13,967	798	5.71	436.64	0.03	0.55
2019	7692	7239	14,931	910	6.09	510.89	0.03	0.56
2020	7896	7488	15,384	826	5.37	388.74	0.03	0.47
Total increased number	1716	1946	3662	143	−0.46	77.70	—	—
Mean annual increased number	245.14	278	523.14	20.43	−0.07	11.10	—	—
Total increase rate (%)	27.77	35.11	31.24	20.94	−7.89	24.98	—	—

A parameter: the number of the measurably exposed workers.
B parameter: the proportion of the measurably exposed workers to the total monitored workers (%).
C parameter: the annual collective exposure dose (man-Sv).
D parameter: the mean annual effective exposure dose of the total monitored workers (mSv).
E parameter: the mean annual effective exposure dose of the measurably exposed workers (mSv).

Table 3 Occupational radiation exposure of monitored dental radiation workers in Taiwan from 2013 to 2020.

	Number of monitored dental radiation workers			Related parameters of occupational radiation exposure				
	Male	Female	Total	A	B	C	D	E
2013	318	360	678	49	7.23	10.84	0.02	0.22
2014	300	352	652	47	7.21	9.44	0.01	0.20
2015	294	388	682	61	8.94	9.11	0.01	0.15
2016	308	403	711	11	1.55	7.23	0.01	0.66
2017	320	396	716	18	2.51	6.83	0.01	0.38
2018	313	396	709	16	2.26	13.00	0.02	0.81
2019	327	418	745	14	1.88	15.47	0.02	1.11
2020	334	436	770	11	1.43	5.21	0.01	0.47
Total increased number	16	76	92	−38	−5.80	−5.63	—	—
Mean annual increased number	2.29	10.86	13.14	−5.43	−0.83	−0.80	—	—
Total increase rate (%)	5.03	21.11	13.57	−77.55	−80.22	−51.94	—	—

A parameter: the number of the measurably exposed workers.
B parameter: the proportion of the measurably exposed workers to the total monitored workers (%).
C parameter: the annual collective exposure dose (man-Sv).
D parameter: the mean annual effective exposure dose of the total monitored workers (mSv).
E parameter: the mean annual effective exposure dose of the measurably exposed workers (mSv).

trend. In addition, the mean annual effective exposure dose of total monitored medical radiation workers and that of the measurably exposed medical radiation workers varied from 0.05 mSv to 0.06 mSv and from 0.58 mSv to 0.87 mSv, respectively.

The changes in the number of monitored diagnostic radiology workers and their occupational radiation exposure in Taiwan from 2013 to 2020.

The total monitored diagnostic radiology workers increased from 11,722 in 2013 to 15,384 in 2020 (Table 2). Thus, the total increased number of monitored diagnostic radiology workers was 3662 with a mean annual increased number of 523.14 and a total increase rate of 31.24%. As the number of female diagnostic radiology workers increased more than the number of male diagnostic radiology workers each year, the male-to-female ratio changed from 1:0.90 in 2013 to 1:0.95 in 2020. Because the number of total monitored diagnostic radiology workers increased, the number of the measurably exposed diagnostic radiology workers also increased from 683 in 2013 to 862 in 2020. Moreover, the total increased number of measurably exposed diagnostic radiology workers was 143 with a mean annual increased number of 20.43 and a total increase rate of 20.94%. However, the proportion of the measurably exposed diagnostic radiology workers to the total monitored diagnostic radiology workers fluctuated from 4.85% to 6.57%, but the ratio showed a decreasing trend. Furthermore, the annual collective exposure dose fluctuated from

Table 4 Occupational radiation exposure of monitored nuclear medicine workers in Taiwan from 2013 to 2020.

	Number of monitored nuclear medicine workers			Related parameters of occupational radiation exposure				
	Male	Female	Total	A	B	C	D	E
2013	422	610	1032	379	36.72	414.87	0.40	1.09
2014	417	613	1030	372	36.12	346.09	0.34	0.93
2015	442	620	1062	449	42.28	475.94	0.45	1.06
2016	449	627	1076	455	42.29	522.74	0.49	1.15
2017	464	647	1111	522	46.98	604.77	0.54	1.16
2018	470	653	1123	562	50.04	641.80	0.57	1.14
2019	462	651	1113	504	45.28	573.90	0.52	1.14
2020	484	633	1117	503	45.03	551.74	0.49	1.10
Total increased number	62	23	85	124	8.31	136.87	—	—
Mean annual increased number	8.86	3.29	12.14	17.71	1.19	19.55	—	—
Total increase rate (%)	14.69	3.77	8.24	32.72	22.63	32.99	—	—

A parameter: the number of the measurably exposed workers.
B parameter: the proportion of the measurably exposed workers to the total monitored workers (%).
C parameter: the annual collective exposure dose (man-Sv).
D parameter: the mean annual effective exposure dose of the total monitored workers (mSv).
E parameter: the mean annual effective exposure dose of the measurably exposed workers (mSv).

Table 5 Occupational radiation exposure of monitored radiotherapy workers in Taiwan from 2013 to 2020.

	Number of monitored radiotherapy workers			Related parameters of occupational radiation exposure				
	Male	Female	Total	A	B	C	D	E
2013	655	717	1372	76	5.54	40.62	0.03	0.53
2014	707	744	1451	80	5.51	25.33	0.02	0.32
2015	738	771	1509	89	5.90	30.91	0.02	0.35
2016	766	766	1532	37	2.42	29.08	0.02	0.79
2017	789	793	1582	67	4.24	62.19	0.04	0.93
2018	802	811	1613	72	4.46	42.87	0.03	0.60
2019	833	865	1698	59	3.47	31.67	0.02	0.54
2020	851	901	1752	75	4.28	37.32	0.02	0.50
Total increased number	196	184	380	−1	−1.26	−3.30	—	—
Mean annual increased number	28	26.29	54.29	−0.14	−0.18	−0.47	—	—
Total increase rate (%)	29.92	25.66	27.70	−1.32	−22.74	−8.12	—	—

A parameter: the number of the measurably exposed workers.
B parameter: the proportion of the measurably exposed workers to the total monitored workers (%).
C parameter: the annual collective exposure dose (man-Sv).
D parameter: the mean annual effective exposure dose of the total monitored workers (mSv).
E parameter: the mean annual effective exposure dose of the measurably exposed workers (mSv).

311.04 man-Sv to 510.89 man-Sv, and it showed an increasing trend. In addition, the mean annual effective exposure dose of total monitored diagnostic radiology workers was all at 0.03 mSv and that of the measurably exposed diagnostic radiology workers varied from 0.44 mSv to 0.71 mSv.

The changes in the number of monitored dental radiation workers and their occupational radiation exposure in Taiwan from 2013 to 2020.

The total monitored dental radiation workers increased from 678 in 2013 to 770 in 2020 (Table 3). Thus, the total increased number of monitored dental radiation workers was 92 with a mean annual increased number of 13.14 and a total increase rate of 13.57%. However, the proportion of monitored dental radiation workers to the total monitored medical radiation workers decreased from 4.29% in 2013 to 3.67% in 2020. As the number of female dental radiation workers increased more than the number of male dental radiation workers each year, the male-to-female ratio changed from 1:1.13 in 2013 to 1:1.31 in 2020. Although the number of monitored dental radiation workers increased, the number of the measurably exposed dental radiation workers decreased from 49 in 2013 to 11 in 2020. Moreover, the total decreased number of measurably exposed dental radiation workers was 38 with a mean annual decreased number of 5.43 and a total decrease rate of 77.55%. Furthermore, the proportion of the measurably exposed dental radiation workers to the total monitored dental

Table 6 The number and distribution of registered dentists and registered medical radiation technologists in Taiwan from 2013 to 2020.

	Number of registered dentists			Number of registered medical radiation technologists			Proportion of medical radiation technologists to dentists		
	Hospital	Clinic	Overall	Hospital	Clinic	Overall	Hospital	Clinic	Overall
2013	1764	11,030	12,794	4863	379	5242	2.76	0.03	0.41
2014	1870	11,308	13,178	5121	398	5519	2.74	0.04	0.42
2015	1918	11,584	13,502	5284	431	5715	2.75	0.04	0.42
2016	1982	11,930	13,912	5493	447	5940	2.77	0.04	0.43
2017	2115	12,264	14,379	5730	466	6196	2.71	0.04	0.43
2018	2121	12,596	14,717	5911	500	6411	2.79	0.04	0.44
2019	2186	12,941	15,127	6126	507	6633	2.80	0.04	0.44
2020	2183	13,246	15,429	6339	534	6873	2.90	0.04	0.45
Total increased number	419	2216	2635	1476	155	1631	—	—	—
Mean annual increased number	59.86	316.57	376.43	210.86	22.14	233	—	—	—
Total increase rate (%)	23.75	20.09	20.60	30.35	40.90	31.11	—	—	—

radiation workers also showed a decreasing trend from 7.23% in 2013 to 1.43% in 2020. The annual collective exposure dose fluctuated from 5.21 man-Sv to 15.47 man-Sv, but it showed a decreasing trend. In addition, the mean annual effective exposure dose of total monitored dental radiation workers and that of the measurably exposed dental radiation workers varied from 0.01 mSv to 0.02 mSv and from 0.15 mSv to 1.11 mSv, respectively.

The changes in the number of monitored nuclear medicine workers and their occupational radiation exposure in Taiwan from 2013 to 2020.

The total monitored nuclear medicine works increased from 1032 in 2013 to 1117 in 2020 (Table 4). Thus, the total increased number of monitored nuclear medicine workers was 85 with a mean annual increased number of 12.14 and a total increase rate of 8.24%. As the number of male nuclear medicine workers increased more than the number of female nuclear medicine workers each year, the male-to-female ratio changed from 1:1.46 in 2013 to 1:1.31 in 2020. Because the number of monitored nuclear medicine workers increased, the number of the measurably exposed nuclear medicine workers also increased from 379 in 2013 to 503 in 2020. Moreover, the total increased number of measurably exposed nuclear medicine workers was 124 with a mean annual increased number of 17.71 and a total increase rate of 32.72%. Besides, the proportion of the measurably exposed nuclear medicine workers to the total monitored nuclear medicine workers also showed an increasing trend from 36.72% in 2013 to 45.03% in 2020. Furthermore, the annual collective exposure dose fluctuated from 346.09 man-Sv to 641.80 man-Sv, and it showed an increasing trend. In addition, the mean annual effective exposure dose of total monitored nuclear medicine workers and that of the measurably exposed nuclear medicine workers varied from 0.34 mSv to 0.57 mSv and from 0.93 mSv to 1.16 mSv, respectively.

The changes in the number of monitored radiotherapy workers and their occupational radiation exposure in Taiwan from 2013 to 2020.

The total monitored radiotherapy workers increased from 1372 in 2013 to 1752 in 2020 (Table 5). Thus, the total increased number of monitored radiotherapy workers was 380 with a mean annual increased number of 54.29 and a total increase rate of 27.70%. The male-to-female ratio of monitored radiotherapy workers fluctuated between 1:1 and 1:1.09. Although the number of monitored radiotherapy workers increased, the number of the measurably exposed radiotherapy workers fluctuated, and there were only minor changes between 2013 and 2020. However, the proportion of the measurably exposed radiotherapy workers to the total monitored radiotherapy workers showed a decreasing trend from 5.54% in 2013 to 4.28% in 2020. Furthermore, the annual collective exposure dose fluctuated from 25.33 man-Sv to 62.19 man-Sv, and it showed a decreasing trend. In addition, the mean annual effective exposure dose of total monitored radiotherapy workers and that the measurably exposed radiotherapy workers varied from 0.02 mSv to 0.04 mSv and from 0.32 mSv to 0.93 mSv, respectively.

The comparison of the situation of dental radiation workers with that of other medical radiation workers.

Among all monitored medical radiation workers, the dental radiation group had the smallest number of workers, followed in an ascending order by the nuclear medicine group, the radiotherapy group, and the diagnostic radiology group. For the dental radiation group, there are more female workers than male workers, and the female workers had a larger mean annual increased number than the male workers, resulting in a gradually enlarged gap between the numbers of male and female dental radiation workers. This situation was not found in other medical radiation workers. The number of measurably exposed dental radiation workers decreased year by year and had the largest proportion of reduction, followed in a descending order by the radiotherapy workers and the diagnostic radiology workers, while the nuclear medicine workers had the greatest proportion of increase in the number of measurably exposed workers. The annual collective exposure dose of dental radiation workers decreased year by year, and had the largest proportion of reduction, followed by the radiotherapy workers, while the nuclear medicine workers had the largest proportion of increase in the annual collective

exposure dose, followed by the diagnostic radiology workers. For the mean annual effective exposure dose of the total monitored workers and that of the measurably exposed workers, the dental radiation workers usually received a smaller mean annual effective exposure dose and the nuclear medicine workers often received a larger mean annual effective exposure dose.

The number and distribution of registered dentists and registered medical radiation technologists in Taiwan from 2013 to 2020.

The total registered dentists increased from 12,794 in 2013 to 15,429 in 2020 (Table 6). Thus, the total increased number of registered dentists was 2635 with a mean annual increased number of 376.43 and a total increase rate of 20.60%. In hospitals, the total registered dentists increased from 1764 in 2013 to 2183 in 2020. Thus, the total increased number of registered dentists was 419 with a mean annual increased number of 59.86 and a total increase rate of 23.75%. In dental clinics, the total registered dentists increased from 11,030 in 2013 to 13,246 in 2020. Thus, the total increased number of registered dentists was 2216 with a mean annual increased number of 316.57 and a total increase rate of 20.09%.

Furthermore, the total registered medical radiation technologists increased from 5242 in 2013 to 6873 in 2020 (Table 6). Thus, the total increased number of registered medical radiation technologists was 1631 with a mean annual increased number of 233 and a total increase rate of 31.11%. In hospitals, the total registered medical radiation technologists increased from 4863 in 2013 to 6339 in 2020. Thus, the total increased number of registered medical radiation technologists was 1476 with a mean annual increased number of 210.86 and a total increase rate of 30.35%. In clinics or local medical institutions such as medical care radiological clinics, the total registered medical radiation technologists increased from 379 in 2013 to 534 in 2020. Thus, the total increased number of registered medical radiation technologists was 155 with a mean annual increased number of 22.14 and a total increase rate of 40.90%. In overall, the proportion of medical radiation technologists to dentists increased from 0.41 in 2013 to 0.45 in 2020 (Table 6). However, in hospitals, this corresponding value fluctuated from 2.71 to 2.90. In clinics, this corresponding value varied from 0.03 to 0.04.

Discussion

Dental radiography is the most useful and powerful diagnostic tool available for dentists. The use of X-rays as a standard diagnostic procedure is well established in dentistry.[10,11] This use of X-rays creates an obligation for dentists, dental radiation facility operator, and radiation competent authority who must weigh the benefits of additional diagnostic information against the risks of radiation exposure for patients and dental radiation workers.[12] According to current radiation protection concepts, exposure to all people should be kept at the level as low as reasonably achievable (ALARA). Therefore, radiographic procedures must be optimized to provide dentists with acceptable diagnostic information, while minimizing radiation exposure for all dental patients and dental staff.

Taiwan's Ionizing Radiation Protection Act also stipulates that radiation workers' occupational exposure should be below limits and kept ALARA, the employer should monitor each radiation worker's exposure dose. However, when a radiation worker's estimated annual cumulative exposure is unlikely to exceed a specific proportion of the exposure dose limit, the employer may instead monitor the operation environment or personal exposure doses through sampling. In addition, radiation practice must also comply with the following principle: any human activity that introduces new radiation sources or exposure pathways, enlarges the scope of worker's exposure, and changes the exposure pathways of existing radiation sources, thereby leading to either exposure of people or an increase in the number of people to exposure, for the purpose of obtaining a net benefit should be prohibited. Therefore, any medical radiation workplace and staff in Taiwan need to accept the management and supervision of the radiation competent authority. This also includes the workplace and the staff of dental radiation.

According to the information provided by the International Atomic Energy Agency on its website, employees performing dental radiography should generally not receive significant radiation doses if normal radiation protection measures such as distancing and shielding are used.[13] A UK report estimates a mean level of less than 0.1 mSv per year under the prevailing practice conditions. In the United States, the mean exposure dose received by dental workers is reported to be 0.2 mSv. If the radiation exposure doses received by the staff involved in dental radiography is very low, the routine staff monitoring is generally considered to be desirable, but is not required. Different national regulations should be considered. The UK guideline recommends that monitoring is generally not required unless the risk assessment indicates that individual exposure doses may exceed 1 mSv per year. However, the national guideline in some countries recommends the personal monitoring for all dental practices of using X-ray equipment. To monitor the dental practice through monitoring one or more individuals from time to time may be valuable in the situation that the formal regulation does not require monitoring of individuals.[13]

In this study, similar results were obtained and in line with the description of dental radiology from the International Atomic Energy Agency. In Taiwan, the proportion of the measurably exposed dental radiation workers to the total monitored dental radiation workers was only 1.43%—8.94% from 2013 to 2020. This indicates that more than 90% of the monitored dental radiation workers do not have measurable radiation exposure. In addition, the mean annual effective exposure dose of the total monitored dental radiation workers was only 0.01 mSv—0.02 mSv, and the mean annual effective exposure dose of the measurably exposed dental radiation workers was 0.15 mSv—1.11 mSv, suggesting that the majority of dental radiation workers in Taiwan follow the regulations set by the International Atomic Energy Agency when practicing.

We compared the differences in several parameters (including the number of the measurably exposed workers, the proportion of the measurably exposed workers to the total monitored workers, the annual collective exposure dose, and the mean annual effective exposure dose of the

total monitored workers or the measurably exposed workers) in four categories of medical radiation workers. For the proportion of the measurably exposed workers to the total monitored workers, the proportion for the dental radiation was generally low (1.43%–8.94%), while that for the nuclear medicine was generally high (36.12%–50.04%). For the mean annual effective exposure dose of the total monitored workers, the radiation exposure to dental radiation workers was generally low (0.01–0.02 mSv), while that to nuclear medicine workers was generally high (0.34–0.57 mSv). For the mean annual effective exposure dose of the measurably exposed workers, the radiation exposure to diagnostic radiology workers and to dental radiation workers was also low (0.44–0.71 mSv and 0.15–1.11 mSv, respectively), and that to nuclear medicine workers was also generally high (0.93–1.16 mSv). It was worth noting that the radiation exposure to both the measurably exposed diagnostic radiology and radiotherapy workers did not exceed 1 mSv, while the radiation exposure to the measurably exposed dental radiation workers exceeded 1 mSv in 2019. This also means that we cannot assume that the radiation exposure to the monitored dental radiation workers is generally low, therefore radiation monitoring measures are not necessary to be taken for the dental radiation workers. Thus, it may be acceptable to monitor the radiation exposure to dental radiation workers through sampling monitoring or through monitoring the staff working in high-intensity and high-density dental radiation workplaces, such as dental radiology departments in large hospitals or teaching hospitals.

It was also worth noting that the numbers of medical radiation workers in four different categories increased year by year, and the annual collective exposure dose (man-Sv) of the diagnostic radiology and nuclear medicine workers also showed an increasing trend. In contrast, that of dental radiation workers exhibited a decreasing trend. These results reflect that in recent years, the digitization of dental radiography and the advancement of dental radiation equipment have resulted in a marked reduction of radiation exposure dose to the dental radiation workers. However, the mean annual effective exposure dose of the measurably exposed dental radiation workers actually increased in recent years. We speculate that this may be related to the high popularity of using cone-beam computed tomography (CBCT) for diagnosis of jawbone lesions in Taiwan's dental institutions.[14] Overall, although dental radiography is still a safe and effective diagnostic method with low radiation exposure doses, the dental radiation workers should be very careful when performing dental radiography.

Currently, the public information of the Taiwan occupational radiation exposure database does not disclose the occupational categories of medical radiation workers involved in radiation exposure monitoring. A 2010 survey of medical radiation workers mentioned that these medical radiation workers include physicians (20%), medical radiation technologists (44%), physicists (10%), nuclear pharmacists (1%), nursing personnel (14%), medical technologists (3%), administrators (6%), and radiation protection personnel (2%), while their workplaces are medical centers (16%), regional hospitals (46%), district hospitals (25%), and local clinics (13%).[15] To the best of our knowledge, the majority of dentists and dental clinics are not involved in radiation exposure monitoring. Therefore, the dental radiation workers involved in radiation exposure monitoring may be dental radiation technologists, physicists, nursing personnel, administrators, and radiation protection personnel in the dental radiology departments of large hospitals or teaching hospitals. Moreover, there may also be employees in the industries of dental radiation equipment and dental radiation protection. However, the actual occupational distribution of dental radiation workers remains to be further studied.

In 2020, the proportion of the dental radiation workers to the total medical radiation technologists was 11.20% (770/6873), while the proportion of the diagnostic radiology workers to the total medical radiation technologists was 223.83% (15,384/6873). This means that medical radiation technologists are mostly engaged in diagnostic radiology, and are rarely engaged in dental radiology. The medical radiation technologists who engage in dental radiation work are so-called dental radiation technologists. In the field of dentistry or medical radiation, in fact, there are no such personnel as dental radiographers in Taiwan's dental system. In addition, there is no relevant system for training dental radiation technologists in the education of radiological technology, and there is almost no course of dental radiology in the schools of radiological technology. The way to become a dental radiation technologist is usually through the completion of the following processes. The graduates of schools of radiological technology get a medical radiation technologist license through examination. Then, they enter the dental radiology department of a hospital, receive some dental radiation training, and engage in dental radiation work. In Taiwan, dentists mainly practiced in dental clinics (85.85%, 13,246/15,429), while medical radiation technologists mainly practice in hospitals (92.23%, 6339/6873) (Table 6). The proportion of the clinic medical radiation technologists to the clinic dentists was only 4.03% (534/13,246) (Table 6). This means that the majority of dentists in the local clinics do not rely on dental radiation technologists to assist in the work of dental radiography.

Based on the results of this study, we found that the radiation exposure risk of dental radiation workers is much lower than that of other medical radiation workers, and dental radiation work is a kind of very safe medical radiation work. However, routine personnel radiation exposure monitoring for dental radiation workers is desirable, but is not required. No matter from the perspective of dentistry or radiological technology, the planning of future dental radiation education should consider not only the design of advanced courses for dental students, but also the introduction of innovative courses for students of radiological technology, which in turn can provide a new practice direction for medical radiation technologists, and expand their potential participation in the field of dental radiation work. In addition, a large number of clinic dentists have long lacked staff to assist in dental radiography. Therefore, it is also an important issue whether we shall introduce the role of dental radiographers for the dental system in Taiwan.

We conclude that although the number of monitored dental radiation workers increase, the number of the measurably exposed dental radiation workers, the proportion of the measurably exposed dental radiation workers to

the total monitored dental radiation workers, and the annual collective exposure dose for monitored dental radiation workers decrease from 2013 to 2020.

Declaration of competing interest

A conflict of interest occurs when an individual's objectivity is potentially compromised by a desire for financial gain, prominence, professional advancement or a successful outcome. *JDS* Editors strive to ensure that what is published in the Journal is as balanced, objective and evidence-based as possible. Since it can be difficult to distinguish between an actual conflict of interest and a perceived conflict of interest, the Journal requires authors to disclose all and any potential conflicts of interest.

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References

1. Ambika D, Narender S, Rishabh K, Rajan R. History of X-rays in dentistry. *Ann Dent Res* 2012;2:21—5.
2. Riaud X. First dental radiograph (1896). *J Dent Health Oral Disord Ther* 2018;9:33—4.
3. Pauwels R. History of dental radiography: evolution of 2D and 3D imaging modalities. *Med Phys Int J* 2020;3:235—77.
4. Cheng FC, Wang LH, Ozawa N, Wang CY, Chang JYF, Chiang CP. Dental technology of Taiwan during the Japanese colonial period. *J Dent Sci* 2022;17:882—90.
5. Cheng FC, Chiang CP, Chang YT. The influences of dental education in Japanese colonial period on the development of dentistry in post-war Taiwan. *J Fam Dent* 2012;6:27—31.
6. Cheng FC, Wang LH, Lin TC, Chang JYF, Chiang CP. Distributions of dentists and physicians in Taiwan during the Japanese colonial period from 1923 to 1924. *J Dent Sci* 2022;17:135—44.
7. Cheng FC, Wang LH, Ozawa N, Wang CY, Chang JYF, Chiang CP. Dental manpower and treated dental diseases in department of dentistry, Taipei Hospital (the predecessor of National Taiwan University Hospital) in 1923. *J Dent Sci* 2022;17:170—5.
8. Cheng FC, Wang LH, Ozawa N, Chang JYF, Liu SY, Chiang CP. Development of dental education for medical students in Taiwan during the Japanese colonial period. *J Dent Sci* 2022;17:903—12.
9. Cheng FC, Wang LH, Ozawa N, Chang JYF, Liu SY, Chiang CP. Dental education and special dental practitioner-cultivating system in Taiwan during the Japanese colonial period. *J Dent Sci* 2022;17:920—7.
10. Han GS, Cheng JG, Li G, Ma XC. Shielding effect of thyroid collar for digital panoramic radiography. *Dentomaxillofacial Radiol* 2013;42:20130265.
11. Toossi MTB, Akbari F, Roodi SB. Radiation exposure to critical organs in panoramic dental examination. *Acta Med Iran* 2012;50:809—13.
12. Horner K. Review article: radiation protection in dental radiology. *Br J Radiol* 1994;67:1041—9.
13. International Atomic Energy Agency. *Radiation protection of staff in dental radiology*. Available from, https://www.iaea.org/resources/rpop/health-professionals/dentistry/staff. [Accessed 1 May 2022].
14. Wang TY, Kuo PJ, Fu E, et al. Risks of angled implant placement on posterior mandible buccal/lingual plated perforation: a virtual immediate implant placement study using CBCT. *J Dent Sci* 2019;14:234—40.
15. Energy Council Atomic. *The 2010 survey on radiation cognition of medical radiation practitioners*. New Taipei City, Taiwan: Atomic Energy Council, 2011 [In Chinese].