Investigation and analysis on level of medical exposure in radiodiagnosis and radiotherapy in Jiangsu Province in 2016

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Background: The aim of the present study is to investigate the frequency and the dose level of the medical exposure and estimate the distribution of the medical radiation in Jiangsu 2016, which can establish foundation to improve the protection of the medical irradiation.
Methods: All the medical institutions were covered in the fundamental information survey and 31 medical institutions were sampled to investigate the medical radiation frequency and the dose level. All the medical radiation information in 2016 were gathered in the sample hospital and a liner model were established to evaluate the medical radiation frequency in the whole province in 2016. The nuclear medicine diagnosis and therapy frequency were calculated by the inpatient number in sample hospitals and the whole province respectively. The exposure parameter, the dose information displayed in the equipment and the patient information of the digital radiography (DR) and CT in the sample hospitals were investigated and some dose level parameters were measured by a radio-dosimeter.
Results: By the end of the 2016, there were 9,248 medical radiation equipment in Jiangsu. The number of CT, linear accelerator and nuclear medicine (PET, SPECT) increased of 3.6, 5.2 and 5.0 times respectively, compared with the investigation results in 1999. The results showed that the frequency of radio-diagnostic, radio-therapy, nuclear medicine diagnostic, and nuclear medicine therapy was 710.85 (include CT 240.21), 2.80, 15.44, and 0.37 procedures per 1,000 persons. The results of the dose level indicated that the 75th percentile of the PA-chest, lumbar spine and the hip joint view were higher than the diagnostic reference level (DRL) in GB18871-2002. The 75th percentile value of the CT head and CT chest scan is 691 and 483 mGy·cm respectively, which is higher than the DRL in GBZ165. The 75th percentile values of the CTDI (computed tomography dose index) vol in all age groups of pediatric CT scans were higher than the DRL in which the 75th percentile value of the CTDI vol is 1.8 times higher than the DRL.
Conclusions: It is important to capture the frequency and the dose level of the medical radiation in Jiangsu Province and find out the vulnerable spot of the medical radiation protection. The results of the present investigation provided us the basic information to improve the distribution of the resources in radiation protection and enhance the protection of the patients.

Keywords: Radiodiagnosis and radiotherapy; medical exposure; frequencies of exposure; dose level; patient and examinee; radiological protection

Introduction

Ionizing radiation technology has been widely applied in the medical field and plays an increasingly important role in safeguarding public health. Meanwhile, the medical radiation protection involving the public health has become a public hot spot in modern society. The number of medical X-ray diagnosis increased from 330 to 488 per thousand population from 2000 to 2008, an increase of 1.48 times. The annual effective dose per capita caused by X-ray diagnosis increased from 0.40 to 0.62 mSv, an increase of 1.55 times. Medical radiation has gradually become the largest source of artificial ionizing radiation (1,2).

In the late 1990s, Jiangsu Province had participated in the investigation on the national medical radiation level during the "9th Five-Year" period, which organized by the former ministry of health, and grasped the frequency and dose distribution of medical irradiation in Jiangsu Province systematically (3). After 2000, due to the reform of health system, the adjustment of supervision and monitoring functions of radiological health, the survey of medical exposure levels in the province has not been carried out continuously, and only four districts were surveyed on the frequency of radiological diagnosis in 2015 (4). Meanwhile, the economic level and medical services in Jiangsu Province are developing rapidly, the per capita GDP has exceeded 10,000 dollars in 2016 and the overall economic, and social development has reached the level of medium developed countries. There are 204,687 active practicing (assistant) physicians, with 2.56 per 1,000 people, and have reached I level health care defined by the United Nations scientific committee on atomic radiation effects (UNSCRAR). According to the survey on the basic situation of radiological diagnosis and treatment in Jiangsu Province, there were 3,479 radiodiagnosis and radiotherapy institutions and 9,496 medical radiation equipment in 2016. Taking X-ray computed tomography equipment as an example, there are 1,110 in the whole province, 13.9 per million people, which is basically in line with Denmark, but has not reached the average of 14.7 in OECD countries. In order to adapt the developing economy and the application of radiodiagnosis and radiotherapy in our province and to grasp the basic situation of radiodiagnosis and radiotherapy and the application of medical radiation in our province, Jiangsu provincial center for disease control and prevention participated in the second unit "Survey of the frequency and dose level of the medical exposure in China" of the special topic "Medical radiation protection and quality control", which was undertaken by the Chinese center for disease control and prevention. With the cooperation of the provincial centers for disease control and prevention and medical institutions, the investigation and study on the medical radiation level of Jiangsu Province during the 13th Five-Year Plan period was carried out.

Methods

Survey respondents

The basic information of the survey respondents were all radiological diagnosis and treatment institutions; Jiangsu Province has a total of 96 counties in 13 districts, 31 counties from 11 cities were randomly selected, every county select 1 hospital as the subjects (including 9 third-level hospitals, 12 second-level hospitals, and 10 others), including general hospitals and specialized hospitals (oral hospitals, women and children's hospitals, tumor hospitals, and Chinese medicine hospitals). All radiological activities in these institutions from January 1, 2016, to December 31, 2016 were investigated.

Survey content

The basic condition survey mainly aims at the basic situation of all medical institutions and the basic situation of radiological equipment of 31 medical radiation institutions. The organization information includes then hospital level, the quantity of equipment, the quantity of radiological workers, the equipment of radiological protection, the permit information of radiodiagnosis, and radiotherapy. The basic information of 31 medical exposure survey institutions includes the number of outpatients, inpatients, and various radiological workers, and the number, type, origin, and use of radiological equipment.

For the medical exposure frequency survey, we summarized the examination or treatment frequency in 2016 of all radiodiagnosis and radiotherapy equipment of medical exposure institutions, according to X-ray diagnosis (including chest photography, chest X-ray, limb and joint photography, cervical vertebra photography, thoracic vertebra photography, pelvic and hip photography, abdominal photography, gastrointestinal examination, dental photography, breast photography, gallbladder imaging, urography, oviduct imaging, extracorporeal lithotripsy and various CT examination), interventional radiology (including cardiovascular intervention, tumor intervention,

nerve intervention, peripheral vascular intervention, non-vascular intervention, diagnostic intervention and other interventions), radiotherapy (including head and neck tumor treatment, chest tumor treatment, digestive system tumor treatment, urogenital tumor treatment, bone and soft tissue tumor treatment, lymphoid and blood system tumor treatment, and other tumor treatment), and nuclear medicine application (the diagnoses included SPECT, PET, and others). The treatment use radionuclide I-131 to treat hyperthyroidism and thyroid cancer, use radioactive seed I-125 to treat tumors, and dress treatment with nuclear medicine and other treatments. The patients were divided into four groups according to gender and age, among which age were "0–15 years old", "16–40 years old", ">40 years old", and "undetermined age".

In the dose level survey of medical exposure, DR and CT of each surveyed medical radiation facilities were selected to register patient data. DR dose survey mainly collects the equipment information (including model number, high-voltage generator, half value layer, output volume) and the information of 5 patients at different examination sites (including age, gender, examination site, tube voltage, milliampere second, distance of focus to detector, and exposure field). The survey of CT dose collected equipment information (model and manufacturer) and 5 patients with different examination sites, including age, gender, examination site, tube voltage, milliampere second, collimation width, pitch factor, scanning length, weighted CT dose index (CTDIw) or volume CT dose index (CTDIvol), and dose length product (DLP). Five devices of different models were selected in 5 different hospitals to measure the dose. We select at least 20 patients with different examination sites of the chest, lumbar, cervical vertebra, pelvis and hip to measure the dose by thermoluminescence dosimeter.

Survey method

The basic information survey of the organization shall be conducted by filling in the form. On the basis of the pre-survey in 2016, the medical exposure level survey was conducted by compiling the medical digital imaging and reading communication (DICOM) file program, holding the launching meeting, training the investigator, issuing the investigation form, and assigning the investigation task.

Survey data will be obtained by running DICOM file program in the server of hospital information department or calling the inquiry function of hospital information system if the hospitals have image archiving and communication system (PACS) or information management system (RIS). If the hospitals don't have, survey data will be recorded by radiology logbook or computer registration interface, and we will take a picture of these to register survey information.

Statistical analysis method

Statistical analysis

Correlation analysis and regression model fitting were conducted by SPSS19.0 statistical analysis software according to the factors (independent variables) such as the number of inpatients and outpatients, and the investigation results of radiodiagnosis and radiotherapy in the hospitals (dependent variables). The overall test of the linear regression model should have significant significance ($P<0.05$) if be performed, and the influence of independent variables on dependent variables should also be significant ($P<0.05$).

Annual frequency estimation method

If the linear regression models applied in all kinds of radiological diagnosis and treatment have significant significance, then, it can be used to predict the annual frequency of medical radiation from 2012 to 2016. If the linear regression models have not significant significance, the total number of all types of radiodiagnosis and radiotherapy in Jiangsu Province is equal to the total frequency of medical radiation exposure obtained in the survey divided by the total number of hospital outpatients or total number of inpatients, and multiplied by the total number of outpatients or total number of inpatients in all medical institutions in Jiangsu Province. The annual frequency of various radiodiagnosis and radiotherapy applications in 2012–2016 was predicted based on the total population estimation in Yearbook of Public Health and Family Planning in Jiangsu (5-9).

Quality control measures

Provincial health and family planning commission issued documents to start projects, training investigators and carrying out interim supervision. The frequency survey data was verified by calling PACS or RIS system using query function, and by organizing collective filling and data audit,

Table 1 Distribution of equipment of radiodiagnosis and radiotherapy in medical institutions in Jiangsu Province

Hospital level	Number of radiology institutions	X-ray diagnosis				Interventional radiology equipment	Radiotherapy			Nuclear medicine	
		Diagnostic examination equipment	Mammographic equipment	CT	Dental equipment		Radionuclide teletherapy equipment	Linear accelerator	Gamma-ray afterloading brachy-therapy equipment	PET	SPECT
Grade III	163	1,240	108	334	229	448	6	102	27	17	49
Grade II	401	826	76	356	234	480	2	32	2	1	2
Grade I	1,596	1,987	13	320	124	424	3	1	0	1	0
Others	1,319	984	24	100	807	134	0	1	0	1	1
Total	3,479	5,037	221	1,110	1,394	1,486	11	136	29	20	52

Note: diagnostic examination equipment mainly includes general X-ray camera, CR, DR, fluoroscopy machine, shredder, gastrointestinal machine, and bone density meter, etc. Dental radiography equipment includes dental laminator, oral panoramic machine, and oral CT. Radionuclide distance therapy equipment mainly includes cobalt-60 treatment equipment and stereotactic radiotherapy equipment (gamma knife).

the data which was logical errors or omissions would be timely verified by contacting medical institutions.

In order to ensure the reliability of the measured dose results, the dose survey was carried out by making the dosimeter wearing diagram and instructions, training and instructing hospital physicians/technicians to complete the dosimeter laying and recycling, conducting the dosimeter calibration and radiation calibration curve, and laying the dosimeter with the background.

Results

Basic information

Distribution of radiological diagnosis and treatment equipment in all medical institutions in Jiangsu Province

The distribution of radiological diagnosis and treatment equipment in Jiangsu Province in 2016 is shown in *Table 1*.

According to *Table 1*, 9,248 X-ray diagnostic and interventional radiology devices were installed in Jiangsu Province in 2016. Compared with the survey of 5,152 X-ray diagnostic devices in 1999, the number of X-ray increased with 0.8 times. Among them, CT increased from 241 to 1,110 with an increase of 3.6 times (3) CT has accounted for 12% of the total number of radiological diagnostic equipment. In 2016, there were 176 radiotherapy devices, compared with 101 devices in 1999, the total number of radiotherapy devices increased by 1.7 times. Although equipment annual growth rate of 10% in the total number, different types of radiation therapy equipment quantity changed a lot. Such as using the distance of radioactive isotope radioactive treatment unit (cobalt therapy apparatus, gamma knife) decreased by 74%, close after therapy unit quantity reduced by 10%, on the contrary, the number of linear accelerators has increased with 5.2 times (10), from 22 to 136 units. Moreover, recently nuclear medical diagnostic equipment PET and SPECT increased with 5.0 times from the 12 in 1999.

The radiology devices proportion of different levels hospitals was 4.7%, 11.5%, 45.9% and 37.9% respectively, among which other types of hospitals were mainly dental clinics and private hospitals, and nearly 58% of stomatological photography equipment was concentrated in those. The number of large medical equipment in tertiary hospitals including CT, radioisotope long-distance treatment equipment, linear accelerator, after-installation, PET, and SPECT, accounted for 30.0%, 54.5%, 75.0%,

Table 2 General medical reserves data of the 31 medical institutions and Jiangsu Province in 2016

Hospital level	Outpatient number	Inpatient number	Medical staff	Radiation workers	Radiation equipment	Radiodiagnosis and radiotherapy number
Grade III	10,401,361	428,369	15,521	1,089	206	1,915,871
Grade II	5,512,151	206,372	6,960	242	90	860,192
Grade I and others	563,731	12,578	588	19	15	50,645
Total	16,477,243	647,319	23,069	1,350	311	2,826,708
The whole province*	524,150,000	12,757,990	610,791	–	–	–

*, data from "Jiangsu Health and Family Planning Yearbook 2017".

93.1%, 85.0%, and 94.2% respectively.

The basic situation of medical services of the surveyed 31 medical institutions

Among the 31 medical institutions investigated, there were 31 medical institutions with radiological diagnosis, 10 with interventional radiology, 6 with radiotherapy, and 5 with clinical nuclear medicine. In 2016, there were 2,826,708 radiodiagnosis and radiotherapy cases, 16,477,243 outpatient, 647,319 inpatients, 23,069 medical staff, 1,350 radiation workers, and 311 radiation equipment in the 31 investigated medical institutions. As can be seen from *Table 2*, the number of outpatients of the surveyed samples accounted for 3.14% of the total number of hospital staff, inpatient accounted for 5.07%, and medical staff accounted for 3.78%.

Medical exposure frequency of the surveyed 31 medical institutions

There were 2,826,708 radiodiagnosis and radiotherapy cases in the 31 medical facilities in 2016, including 1,614,409 cases of general photography, 955,261 cases of CT examination, 25,762 cases of breast photography, 71,831 cases of dental photography, 15,727 cases of interventional radiology, 61,124 cases of chest fluoroscopy, 5,530 cases of radiotherapy, and 24,335 cases of nuclear medical examination and treatment. The composition ratio of various radiodiagnosis and radiotherapy applications is shown in *Figure 1*. As can be seen in *Figure 1*, radiological diagnosis accounted for 96.52%, including various types of radiography: CT examination, chest fluoroscopy, gastrointestinal examination, various types of contrast examination, breast and dental radiography and other applications; interventional radiology accounted for 0.56%, nuclear medicine application including diagnosis and treatment accounted for 0.86%, and radiotherapy accounted for 0.20%.

Results of frequency estimation of various radiodiagnosis and radiotherapy in Jiangsu Province

Through correlation analysis and linear regression equation fitting, the total number of hospital inpatients was significantly correlated with the total number of radiological diagnosis, the total number of CT examination and total number of radiotherapy (P<0.05), while the total number of hospital outpatients was significantly correlated with the number of radiological diagnosis and CT examination (P<0.05). Because the correlation coefficient of linear regression model of the total number of inpatients and diagnosis or treatment is superior to the correlation coefficient of linear regression model of the total number of outpatients and diagnosis or treatment, so the annual total number of inpatients of Jiangsu Province can be used to predict 2012–2016 medical exposure frequency of diagnostic radiology, CT examination, and radiotherapy. The frequency of clinical nuclear medical exposure was predicted by the proportion of the total number of inpatients in the sample hospital combined with the total number of inpatients in the province. The medical radiation frequency level of various radiodiagnosis and radiotherapy applications in Jiangsu Province is shown in *Table 3*.

The survey showed that the frequency of radiological diagnosis was 710.85 cases per thousand population which was predicted by the total number of inpatients and total population in Jiangsu Province in 2016, among which the CT examination frequency was 240.21, accounting for 1/3 of the total. The frequency of medical exposure for radiotherapy application was 2.80 cases per thousand people; clinical nuclear medicine diagnosis was 15.44 cases, while radionuclide therapy accounted for 0.37%. Compared
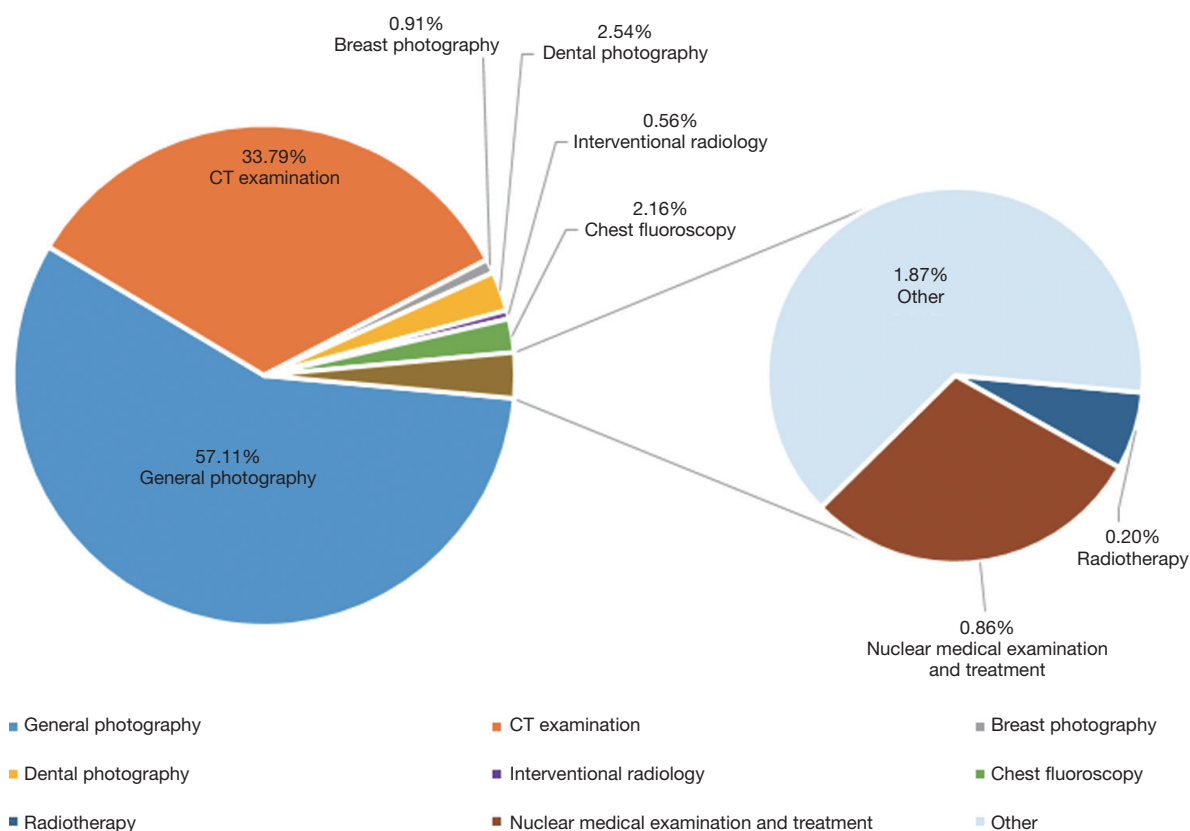
Figure 1 Contribution to the frequency of various types of medical exposure.

Table 3 Frequency distribution of various radiological diagnosis and treatment in Jiangsu Province

Year	Radiodiagnosis (including interventional radiology)		Radiotherapy	Clinical nuclear medicine	
	Total frequency	CT frequency		Nuclear medical diagnosis	Radionuclide therapy
2012	522.07	176.42	2.05	11.34	0.27
2013	576.90	194.95	2.27	12.53	0.30
2014	630.42	213.03	2.48	13.69	0.33
2015	664.08	224.40	2.61	14.42	0.34
2016	710.85	240.21	2.80	15.44	0.37
Increase	36.2%	36.2%	36.6%	36.2%	37.0%

with the predicted data in 2012, the medical exposure frequency of various radiotherapy applications increased by 36.2% to 37.0%.

Medical exposure dose

In this study, we investigated the exposure parameters of a total of 694 subjects in 5 image position (chest, cervical vertebra, lumbar vertebra, pelvis, limbs and hip) with 27 DR devices, and measured the surface-dose of 50 subjects in 5 devices. Exposure parameters and dose surveys were also conducted for a total of 2,159 patients with 20 CT scans, including the head, chest, abdomen, lumbar spine (for adults only), spine, limbs and coronary arteries.

Table 4 Summary of investigation on dose of examinee in CT in Jiangsu Province

Inspection area	75th percentile values of the CTDI vol (mGy)	75th percentile values of DLP (mGy·cm)
Head	57.6	691
Chest	17.6	483
Abdomen	17.9	646
Lumbar spine	33.3	523
Spine (no lumbar spine)	26.3	526
Limbs	20.2	375
Coronary	54.1	973

After summarizing the exposure parameters of radiological diagnostic DR subjects, it was shown that the imaging parameters of different parts were skewed. Using the median analyze the exposure parameters of each inspection site, it is found that the chest photography condition was the highest, with the median of 90 kV, 150 cm and 1,517 cm^2, while the lumbar spine photography condition was the highest, with the median of 32 mA. The differences in the values of relevant parameters (including tube voltage, milliampere second, focus to detector distance and radiation field) used in different shooting positions were statistically significant. According to the measured results of ESD dose at different photographic locations, 75% of ESD values of patients at the back and front of the chest, the side of the chest, the lumbar vertebra, the side of the lumbar vertebra, the side of the neck, the side of the neck, the pelvis and the hip were 0.45, 0.61, 11.36, 16.37, 1.17, 1.38, 4.21 and 10.75 mGy, respectively. Except for the three photographic sites of posterior anterior thoracic position, lumbar vertebra position and hip joint, the ESD 75% value was slightly higher than the guidance level of GB18871-2002, and the rest of the photographic sites were all lower than the guidance level.

The summary of the dose survey results of CT examinees is shown in *Table 4*. Among them, DLP 75% of the head and chest scans were all higher than the diagnostic reference level (DRL) obtained from the IAEA research data in GBZ165-2012 appendix A. The survey also showed that the CTDIvol75% values of the skull CT scan of children aged 0–1, 1–5, 5–10 and 10–15 years old were 51.3, 57.3, 50.3 and 55.4 mGy, respectively, all were higher than the DRL GBZ165-2012 appendix A , especially, the skull scan's

CTDIvol75% values of the aged 0–1 were 1.8 times of the DRL.

Discussions

The 1999's medical exposure level survey of Jiangsu Province revealed that, the annual total frequency of radiological diagnosis is 215 person-time per thousand population (3), and the frequency of the CT examination is 14.9 person-time per thousand population (11). Compared with the 2016's survey showing, the annual total frequency of diagnostic radiology (including interventional radiology) is 710.85 person-time per thousand population, increased 2.3 times, and the frequency of CT examination is 240.21 person-time per thousand population, increased 15.1 times.

At the same time, the 2016's survey suggested that, nowadays the number of doctors (including assistant physician) per thousand population and the total frequency of diagnostic radiology in Jiangsu both have a similar level to the Shanghai's data ten years ago (11). In addition, the predicted medical exposure frequency of radiotherapy and nuclear medicine diagnosis is more than twice as high as the survey data of Shanghai ten years ago, which may be related to the rapid development of medical accelerator, PET and SPECT equipment in Jiangsu Province in the past decade.

The total frequency of radiological diagnosis of Jiangsu Province is 1.5 times than the global average frequency which is 488 person-time per thousand population, and the frequency of Jiangsu is close to the Class I care level national data with UNSCEAR2008 report, such as Czech (800.39 person-time per thousand population), Britain's (697.48 person-time per thousand population), and other European developed countries (1).

The investigation also exposed the weak points of medical radiation protection for patients (examinees) working in radiological diagnosis and treatment. In CT examination, especially the DLP level of children aged 1–5, the CTDIVOL level of children aged 0–1 and 1–5 was much higher than the reference level. It is necessary to pay attention to the use of adult scan conditions on children in non-children hospitals. According to a British study, it has been greatly decreased that the irradiated dose of CT examination of children aged 0–4 years from 1990, with reducing the CT cube current by an average of 47% and the average absorbed dose of head dropped from 62 to 30 mGy (12). Therefore, it should be also used to control the quality work of CT examination to reduce the scanning conditions and effectively reduce the dose of patients.

Based on the sample survey of some medical institutions, this study analyzed the correlation between various kinds of open information including the population data, number of outpatients, number of inpatients and the total number of doctors in the Jiangsu's Health Yearbook. By establishing the frequency prediction model of radiological diagnosis and treatment application, the provincial medical radiation level data could be obtained quickly and conveniently, and the administrative department of provincial health commission can reasonably allocate resources to strengthen medical radiation protection.

This survey of medical radiation level shows that some of the domestic PACS systems in medical institutions have a good query function, which plays an important role in the smooth completion of the investigation. However, the informatization work of medical institutions is uneven. The information registration of radiotherapy and nuclear medicine patients in some hospitals were not included in the PACS or RIS system, and manual registration is still adopted. At the same time, the information of oral photography patients was not included in the PACS or RIS system in many medical institutions, and the conventional manual registration resulting in the lack of information such as age and gender of patients with oral photography.

There are also problems in the selection of sample medical institutions in this study. The number of tertiary comprehensive and specialized hospitals is relatively large, accounting for almost 1/3 of the 31 sample hospitals, which is far from the proportion of all levels of hospitals in Jiangsu Province, so that the prediction results of medical exposure frequency maybe relatively high. In the future, relevant hospitals should be reasonably selected according to the proportion of all levels of medical institutions in the province to make the survey results more representative. In addition, the next study should be to strengthen the in-depth research on the frequency and dose of medical radiation, so as to evaluate the dose contribution and risk assessment of medical radiation to the total population of the province, laying a good foundation for the transformation of radiological health work in the future.

Acknowledgments

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jphe.2019.04.01). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The surveyed data is obtained by running DICOM file program in the server of hospitals' information department and the files are encrypted by the hospitals. The patient's privacy could be protected.

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