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A STUDY ON RADIATION DOSE IN DENTAL RADIOGRAPHY MEASURED ON HUMAN BODY AND PHANTOM

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Dental radiography is a very important diagnostic tool in modern dentistry. It also provides additional information for setting the procedure for the patient's future treatment. Dental radiography belongs to the low radiation dose class. The magnitude of the risk remains uncertain. This study provides for an informed selection in terms of the risk of these procedures. The thermoluminescent dosimeter (TLD) and a Rando phantom were used to detect the radiation dose on various organs including the optic lens, thyroid gland, gonad and spinal cord. The TLD was also placed on the skin surface of the volunteers corresponding to that of the phantom. The dose to the organs in their real position was calculated mathematically. We found that the dose on the lens was greatly affected by both the direction of the main beam of radiation and the distance between the exposed site and the organ. But the dose on the thyroid gland was mainly related to the direction of the ray and the exposure time. Gonadal dose may be related to the angulation of the central beam and the distance between the central beam and gonadal organ. In addition. the time factor may also be related. For the spinal dose, it may be mainly attributed to the target-organ distance and the angulation of the beam. In view of the angulation of the central ray and distance between the exposed site and the organ, the results showed that all the radiation doses were lower than those of previous reports. Possible reasons for these results including the improvement of collimator, beam filtration, increased kilovoltage, sensitivity of the film, increased focal-film distance and other related factors have been discussed.

Key words: thermoluminescent dosimeter (TLD), phantom, radiation dose

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Dental radiography is a very important tool in making a diagnosis and examining the process during treatment. The use of x-ray has increased greatly in recent years. According to the report of the United Nations Scientific Committee on the effects of atomic radiations, 145,000 dental x-ray machine had been used in United States up to 1980(1).

Recently, more public concern has been directed to the levels of medical and dental diagnostic exposure to ionizing radiation. Evidence has revealed that there may be some risk to patients from diagnostic exposure to radiation. White has reported that the major risk from dental radiography is believed to be the potential induction of leukemia(2). The principal risk associated with low doses of x-rays are cancers, mutation and congenital abnormalities(3). Because there may be a slight risk from dental radiography, dental practitioners are obliged to weigh the risk of exposure against the expected diagnostic benefit. Because of incomplete knowledge to the risks of low level exposure, decisions frequently must be made on the basis of practical comparative data, such as, which techniques result in the least absorbed dose and what is the relative diagnostic value of

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the films. An understanding of the extent of the relative risk depends on knowledge of the amount of radiation that is absorbed in various radiographic examinations.

There are many reports concerned with the radiation dose in different radiographic examinations. They usually use phantom and full mouth periapical films to detect the radiation dose during various kinds of radiography. The dose to various organs has not been systematically measured in either periapical or occlusal radiography.

This study was designed to measure the dose absorbed in various organs, such as the eye, thyroid gland, gonad and spinal cord, as a result of the most common radiography used in our dental clinic. This information should help us to make an informed selection in terms of these procedures. It was also our goal to express this data in a form that would help the dentist to discuss this topic with patients.

MATERIALS AND METHODS

A conventional dental radiographic unit (GE Company, 1000 model) in our dental clinic at Kaohsiung Medical College has been used. Its half value layer is 2.7 mm of aluminum, diameter of cone tip is 7.5 cm and focus cone tip distance is 8 inches. In our study, the exposure condition was fixed in 75 kVp, 15 mA, exposure time was set at 0.2 seconds per periapical film and 75 kVp, 15 mA, 0.35 seconds for intraoral occlusal film.

The thermoluminescent dosimeter (TLD) is an instrument which has been used to detect and measure the radiation dose. Each TLD is composed of 80 mg dehydrated powder of $CaSO_4$, that has been encapsulated in a black polyethylene capsule with a 3 mm internal diameter, 1 mm wall thickness and 20 mm length. For each reading, it took 17.25 ± 0.4 mg $CaSO_4$: Dy. The powder was measured with the Harshaw 2000 B & C TLD reader. One mm wall thickness is sufficient to establish electronic equilibrium for the 0.142 MeV γ-ray emitted from ^{99m}Tc[4]. The reader stability is ± 0.8%. The total error of the reader system in 0.1 μGy is within ± 0.5%. The calibration factors for TLDs include reader stability, fading and energy dependence of TLDs.

In our study, we used a Rando phantom to collect the corresponding organ dose first. Then, a mathematical method was applied to calculate the real dose to organs in the human body. Its composition and density were relatively equivalent to the human body. This phantom was composed of 35 slices. Each slice was 2.5 cm in thickness and had many holes of 0.5 cm in diameter.

The exposure condition of dental radiography empolyed with the phantom is shown in table 1. The x-ray cone was directed to the right side of the phantom and its occlusal plane is parallel to the horizontal plane. TLDs were placed in the phantom as shown in Fig. 1. It included the positions of eye, thyroid gland, gonad and spinal cord. Each location of the TLD received ten exposures. Then, the mean value of these ten exposures was expressed in μGy/examination.

The other part of this study was to place the TLD on the skin surface of the volunteers corresponding to that on the phantom. All the volunteers were dental students and the average age was 22.85 years. The sample group for each different radiographic location

Table 1. The Exposure Condition of Dental Radiographic Examination with 75 kVp and 15 mA

Exposure area	Exposure time (second)	Vertical Angulation* (degree)
Maxillary		
Incisor	0.2	+40
Canine	0.2	+45
Premolar	0.2	+30
Molar	0.2	+20
Mandibular		
Incisor	0.2	−15
Canine	0.2	−20
Premolar	0.2	−10
Molar	0.2	− 5
Occlusal		
Maxillary	0.35	+65
Mandibular	0.35	−55

* The angle between the x-ray cone and the occlusal plane of the exposurer (phantom and volunteer).

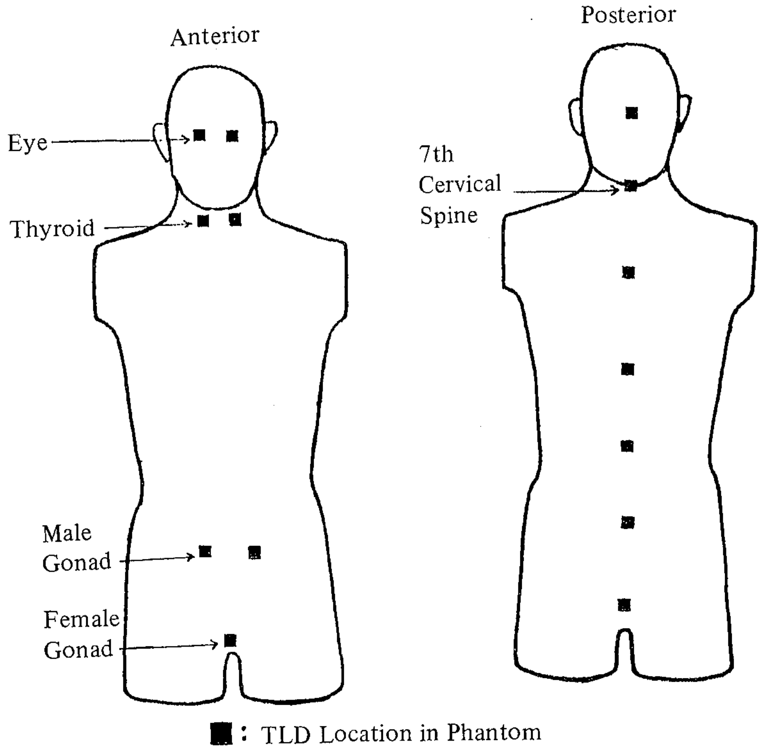

Fig. 1. Anterior view indicates the locations of the organs of eye, thyroid, gonad of female and male. In posterior view, the 2nd black square belongs to the position of 7th cervical spine; others represent the different segments of spine.

was at least twenty in number. The ratio of male to female was three to one.

The selected locations of the dosimeter were described as follow:

Nasion: capsule placed horizontally over the nasion on the same horizontal plane as the pupils of the eyes.

Thyroid: capsule placed horizontally over the middle third of the thyroid cartilage, just inferior to the thyroid notch. The mid-sagittal plane bisected the capsule.

Gonad: capsule placed directly ten cm below the umblicus of the mid-sagittal plane in both the male and female.

Spine: capsule placed on the protuberance of the seventh cervical spine which was easily located by palpation.

The TLD was also placed on the skin position corresponding to the organs of the phantom and was measured by the TLD reader. Then the doses to organs in their real position per each exposure of the volunteers could be calculated mathematically. All radiographs were taken by a well-trained dental assistant so that operative variability was minimized as much as possible. Also, all the volunteers were exposed according to the conditions as stated before.

RESULTS

Doses to the lens of the eye (Table 2) obtained from each periapical film of the phantom were from 0.09 to 12.37 μGy, and from the eye of the volunteers (Table 3) were 0.15 to 9.06 μGy. The maximum dose of both the phantom and volunteers was obtained from the right upper premolar area.

The location of maximum thyroid dose obtained from the phantom was measured at the upper incisor (2.3 μGy) and canine (2.08 μGy) areas respectively. But in volunteers, the maximum dose was absorbed during upper occlusal radiography (0.19 μGy)

Table 2. Doses of Affected Organs during Intraoral Periapical Radiography of Phantom (μGy).

Exposure area	Organ					
	Eye		Thyroid	Gonad*		7 th cervical spine
	Left	Right		Male	Female	
Maxillary						
Incisor	0.388	0.394	2.334	0.0006	0.0004	0.056
Canine	0.263	10.824	2.080	0.0006	0.0005	0.030
Premolar	0.186	12.374	0.498	0.0004	0.0002	0.031
Molar	0.098	2.194	0.255	0.0005	0.0007	0.041
Mandibular						
Incisor	0.200	0.231	0.239	0.0002	0.0002	0.022
Canine	0.089	0.138	0.363	0.0002	0.0003	0.039
Premolar	0.093	0.154	0.365	0.0004	0.0002	0.004
Molar	0.086	0.110	0.266	0.0004	0.0004	0.088

* The average gonad dose of male and female was approximately 0.0004 μGy, respectively.

(Table 4). Both the thyroid doses and eye doses obtained from the phantom were higher than those from the volunteers.

For the gonadal doses, no matter whether obtained from male or female, the readings from the phantom were below the magnitude of 0.001 μGy. But the dose absorbed from the volunteers was more than the phantom. The maximum dose was obtained from the female who received the upper occlusal film projection (0.0023 μGy).

All the seventh cervical spine doses obtained from the phantom and the volunteers were below 0.1 μGy. The maximum dose to the volunteers (0.052 μGy) was obtained from the maxillary incisor projection. But the maximum dose to the phantom (0.088 μGy) was obtained from the mandibular molar projection. The spinal doses obtained from the phantom were also higher than the volunteers.

DISCUSSION

Because of tissue radiosensitivity, certain anatomic structures of the human body associated with dental radiographic procedures are of particular interest, especially, the exposure to the lens of the eye. This is due to the possible relationship between radiation and cataract formation. The dose that can possibly induce cataracts is between 200–2000 R[5]. But there is no report that the diagnostic dose can induce cataracts of the eye.

From the report of Antoku *et al*[6] during examination of upper premolar area of the phantom, the maximum dose to the lens was 29.7 μGy. In our study, the location of the maximum dose to the lens was found at upper premolar area which was similar to his report, but the dose (12.3 μGy) obtained from our study is only half of that in his report. The dose obtained from the right side was higher than the left side. This may be due to the fact that the cone was angulated and directed to the right side. On left side, the distance was further from the cone tip and the central beam did not pass through the lens directly. All the absorbed doses of the volunteers were lower than those of the phantom. During occlusal examination, the lens dose of Antoku's report (21.1 μGy) was much higher than that of our report in phantom (1.4 μGy).

The highest thyroid dose obtained from the results of the phantom study was in the areas of the upper incisor (2.33 μGy) and canine (2.08 μGy) portion which are much lower than the Antoku's report in which lower molars exposure incurred greater doses to the thyroid gland (34.3 μGy). Such a

Table 3. Doses of Affected Organs during Intraoral Periapical Radiography of Volunteers (μGy) (Mean ± SD)

Exposure area	N	Organ					
		Eye		Thyroid	Gonad*		7th cervical spine
		Left	Right		Male@	Female#	
Maxillary							
Incisor	26	0.186±0.089	0.251±0.097	0.067±0.029	0.0013±0.0005	0.0013±0.0003	0.052±0.025
Canine	25	0.133±0.036	5.424±1.447	0.256±0.147	0.0013±0.0006	0.0017±0.0007	0.012±0.006
Premolar	30	0.136±0.063	9.060±2.116	0.092±0.049	0.0011±0.0006	0.0013±0.0006	0.015±0.005
Molar	33	0.117±0.066	4.026±1.486	0.049±0.025	0.0010±0.0004	0.0013±0.0006	0.020±0.007
Mandibular							
Incisor	20	0.230±0.040	0.406±0.021	0.077±0.037	0.0012±0.0006	0.0014±0.0004	0.0250±0.031
Canine	21	0.137±0.049	0.233±0.115	0.033±0.014	0.0008±0.0003	0.0013±0.0007	0.0105±0.003
Premolar	20	0.088±0.048	0.148±0.081	0.089±0.032	0.0010±0.0004	0.0012±0.0006	0.0180±0.006
Molar	23	0.137±0.079	0.251±0.143	0.087±0.028	0.0012±0.0006	0.0017±0.0002	0.0300±0.005

N: Number of volunteers.
*: The average gonad dose was 0.0013 μGy.
@: The average male gonad dose was 0.0011 μGy.
#: The average female gonad dose was 0.0014 μGy.

Table 4. Doses of Affected Organs during Intraoral Occlusal Radiography of Phantom and Volunteers (μGy) (Mean ± SD)

Exposure area	P	Organ					
		Eye		Thyroid	Gonad		7th cervical spine
		Left	Right		Male	Female	
Maxilla		1.036	1.399	1.467	0.0009	0.0012	0.0427
Mandible		0.240	0.269	0.581	0.0005	0.0004	0.0464
	N	Left	Right		Male	Female	
Maxilla	33	0.392±0.203	0.413±0.090	0.190±0.813	0.0020±0.0008	0.0023±0.0007	0.043±0.013
Mandible	27	0.443±0.408	0.155±0.087	0.111±0.067	0.0012±0.0007	0.0015±0.0004	0.013±0.004

P: Phantom.
N: Number of volunteers.

large difference in results may be related to the angulation of the cone. The angulation we empolyed was 40° & 45° from occlusal plane. When examining upper incisor and canine, the central ray was directly passed through the thyroid gland. When the lower molars were examined, the cone was −5° from the occlusal plane and the central beam did not go through the thyroid tissue area. The only detectable radiation dose from this area probably came from the secondary radiation. The maximum absorbed thyroid dose of the volunteers was on maxillary occlusal radiograph but the maximum dose of the phantom was in the upper incisor or canine area. Maxillary occlusal film needs 0.35 seconds for exposure when compared to the upper periapical film which only required 0.20 seconds. That can be explained the reason why the maxillary occlusal film had received the maximum dose in the volunteers. However, the location of maximum dose in phantom was found in the upper incisor and canine area, it may be influenced mainly by the angulation of the cone. The overall doses absorbed from the volunteers were lower than those of the phantoms.

Protection of the thyroid gland is necessary because of its sensitivity to the oncogenic effects of radiation. Studies have suggested an increased incidence of thyroid neoplasms with radiation levels as low as 60,000 μGy[7,8]. The maximum dose (0.19 μGy) obtained during the examination of upper occlusal radiography of the volunteers, was far below the dose that may increase the incidence of thyroid neoplasm. According to the radiation protection principle of "ALARA" (as low as reasonably achievable), protection to the patients is still absolutely necessary, especially, when the patient is a child. The use of lead shields to protect the thyroid can reduce 40% to 55% of radiation to thyroid tissue[9].

The U.S. Public Health Service[10] reported that "no dental film in the survey produced an estimated gonad dose higher than two-tenths of a millirad". According to Alcox's report[11], only 0.0045 μGy to the gonadal area per radiograph was shown. In the present study, the average dose was calculated from the data of Table 2 for the gonad area of the female phantom was 0.0004 μGy, it was similar to that of the male phantom. But in the volunteers, the average gonadal dose was calculated from Table 3 which was about 0.0013 μGy. The average absorbed dose of the female was 0.0014 μGy per film which is higher than that of the male (0.0011 μGy). This may be related to the distance between the affected organ and the cone tip. Perhaps the difference in the body height between male and female is the explanation for such phenomenon. No matter whether on the phantom or the volunteers the gonadal dose from the upper jaw was slighly higher than from the lower jaw. This may be due to the angulation of the cone. The maximum dose (0.0023 μGy) was obtained from the upper occlusal film of the female volunteers, this may be related to the longer exposure time compared with the periapical film. The average dose of the volunteers was also slightly higher than that of the phantom. Gonadal doses in this study were much lower than those reported by Antoku who reported that the maximum gonadal dose in the upper incisor exposure was 0.011 μGy.

In review of the literature[2], it was shown that the dose to the spine has not been systematically measured in periapical radiography. A risk from low grade radiography is believed to be the potential induction of leukemia. This present study was also designed to measure the dose absorbed in different segments of the spinal cord in the phantom as a result of common radiographic procedure. This information should help to make an informed selection in terms of the risk of these procedures. The seventh cervical spine was chosen because of its protuberance which can be easily palpated and located for accurate placement of the TLD.

All the radiation doses obtained from the seventh cervical spine of the phantom and the human samples were within 0.1 μGy. We placed several TLD in different segments of the spinal cord in phantom model (Fig. 1). After each exposure, the values were recorded. A standardized curve (Fig. 2) according to different examinations were plotted. From this curve, assuming that the factor of the seventh cervical spine dose was one, we could observe that the greater distance below the seventh cervical spine the lesser dose absorbed. Among the three kinds of radiographic

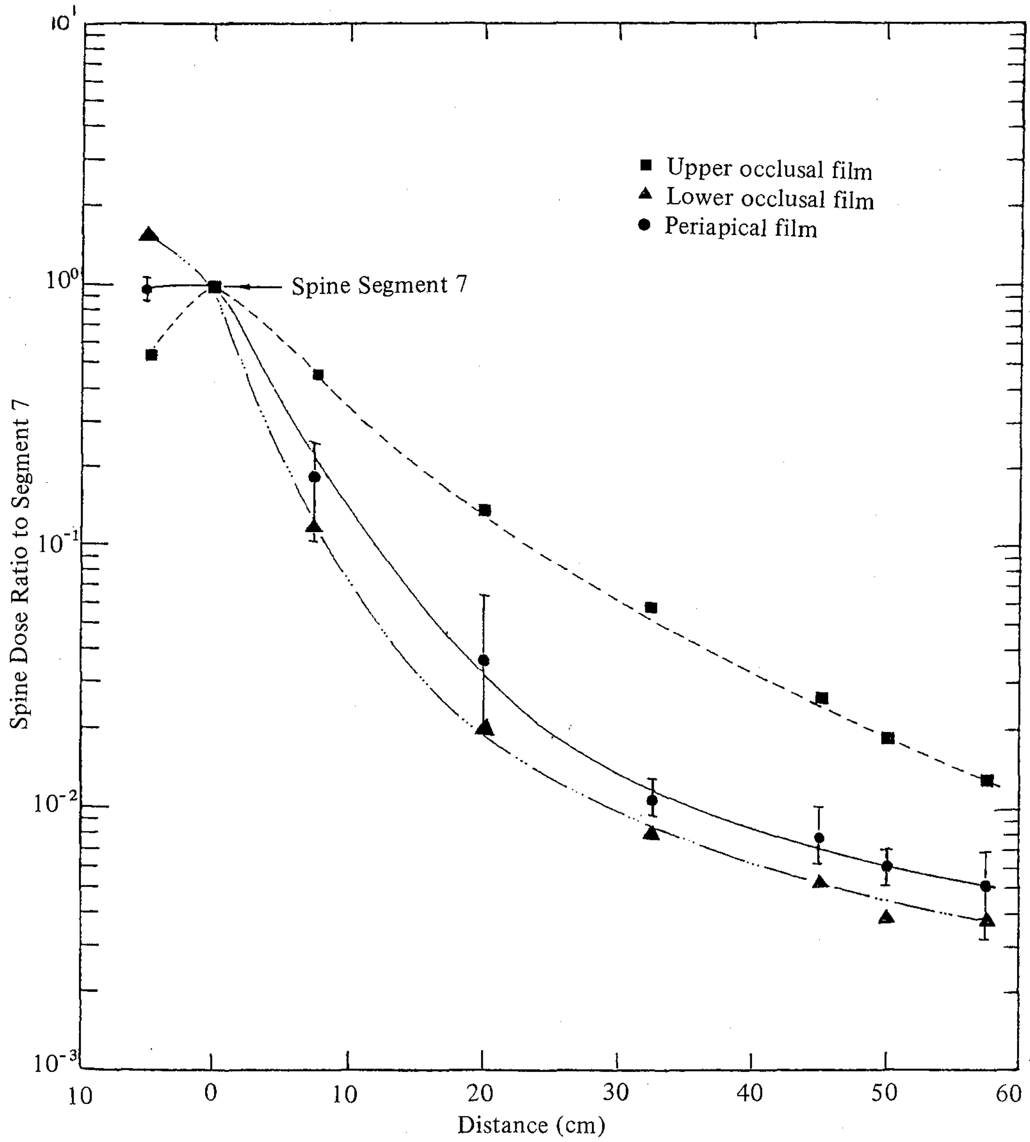

Fig. 2. Doses to different spinal segments during intraoral dental radiographic examination (μGy).

examination mentioned in materials and methods, with regard to the segments of spinal cord, a greater dose was received when using the upper occlusal film. This may be related to the distanse and the angulation of the cone. But the location above the seventh cervical spine absorbed much more dose when we performed the lower occlusal examination. This discrepancy may result from angulation and distance of the cone, which is negative from the occlusal plane when we examine the lower occlusal examination.

It is known that the average background radiation dose to the bone marrow for humans is 8.7 μSv per year[12]. Comparison of the doses from dental radiography with natural environmental radiation shows that twenty-one intraoral periapical films resulted in the same total dose to the bone marrow as sixty-five days of background exposure[13]. For the volunteers, the maximum absorbed dose of the seventh spinal cord (0.052 μGy) in our study was obtained from the maxillary incisor projection; while for phantom, the maximum absorbed dose was obtained from the lower molar projection (0.088 μGy). It seems that the distance between the seventh cervical spinal cord and the beam is shorter during lower molar exposure. It is a matter of fact that the shorter the distance, the higher the absorbed dose. We may expect that the highest absorbed dose would be obtained during the lower molar exposure both in the volunteers and the phantom. However, this is only true for the phantom study. In the volunteers, for some reason, probably the angulation of tube, the highest dose obtained was during the upper incisor exposure. Furthermore, all the phantom doses were higher than the volunteer doses.

All the absorbed doses of the phantom were higher than those of the volunteers with the exception of gonadal dose. Possible reasons may be the difference in tissue density and other unknown factors.

A comparison of the findings of this study with some other results reported in the early literatures indicated that much lower doses were obtained in our findings. This may be due to the fact that substantial progress has been made in reducing unnecessary exposure from dental radiography. Also, it may be related to many variations that are widely accepted and recognized as important factors for minimizing unnecessary exposure. These factors include filtration, collimation of the beam, adequate tube head shielding, ultra-speed film and higher kVp. White[14] also stated that the use of rectangular collimator could reduce the cervical spine and mandibular bone marrow absorbed dose from an intraoral survey by about 60%.

According to Bushong *et al*[15], the average thyroid dose during full-mouth examination when comparing the use of intermediate speed film to ultra-speed film and higher kVp, the dose was reduced by a factor of five to eight. Direct comparisons are difficult to make because of the lack of uniformity in conditions under which the various studies were performed. We encountered wide variations in technical factors used in dental radiography. Therefore, data obtained by dosimetry showed large variance, the maximum and minimum skin dose per exposure were being 290 μGy and 9 μGy respectively[16].

In conclusion, all the values of radiation exposure dose of the phantom and human volunteers obtained in this study were lower than the previous reports. We found that the doses of the lens were greatly affected by both the angulation of the main beam and the distance between the cone tip and the affected organ. But the doses to the thyroid gland were mainly related to the angulation of the cone and the exposure time. The gonadal doses were related to the angulation and the distance between the affected organ and the central beam. In addition, the time factor may need to be considered. The radiation doses to the spinal cord were mainly influenced by the angulation of the central beam and the distance to the affected segment. The reason for such overall reduction in exposure dose may be related to the improvement of collimator, beam filtration, increased kilovoltage, sensitivity of the film, increased focal-film distance and other related factors. We must continue our efforts to improve dental radiographic practices so that we may obtain the maximum benefits from the use of diagnostic x-ray with the least hazard to our patients.

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牙科X光攝影術對人體及假體的放射線劑量的研究

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由於醫學科技的發展及牙科治療方法的進步、在一般醫療及診斷過程中，X光扮演著非常重要的角色。爲協助牙醫師對病人的病情診斷，治療計畫的安排及治療結果的評估：病人接受X光檢查成爲一項不可或缺的步驟。爲提昇醫療品質，病人接受X光檢查的機會也相對增加。故評估病人在做過X光檢查後，有多少放射線劑量被身體的敏感器官所吸收，並造成可能的傷害，成爲今日一項熱門的課題。國外曾有很多這方面的報告，但大多是用假體（phantom）或是作全口14張根尖片照射的放射線劑量的分析，少有單張X光的劑量報告。國內這方面資料相當缺乏。本研究主要的目的是在測定一般常用的牙科X光攝影術，測量被眼球，甲狀腺，性器官和脊髓等器官所吸收之劑量。以熱發光劑量計（thermoluminescent dosimeter, TLD）置於假體的各個需要測量器官內及相對的體表位置上，以不同的方法照射，包括口內不同位置的牙根尖片，上顎和下顎的咬合片。利用清華大學原子科學研究所的Harshaw 2000 B&C型的TLD測定器計讀其劑量。然後在志願待測者的相對體表位置上貼TLD，利用數學的原理，計算出待測者實際上各器官所吸收的放射線劑量。結果顯示眼球的吸收劑量主要是受主射線的入射角度和受測器官與主射線的距離有關；甲狀腺主要與主射線角度和X光底片暴射時間有關。性腺的吸收劑量主要是受射線角度，受測器官的距離和X光底片暴射時間等因素有關。脊髓的吸收劑量和射線的距離有穩定的關係，但因爲不同的射線角度而有所差別。本研究所有的結果和其他報告比較都顯得低，這可能與目前X光機性能的改良，X光片敏感度的提昇等因素有關。雖然本研究中各器官所接受的劑量很低，且在原子能委員會所規定的範圍內，然而爲符合輻射線保護的原則，對於受檢者的眼球、甲狀腺和性腺等都應加以防護，如鉛衣、鉛頸布、鉛眼罩等都可以減少受檢者的輻射劑量。以期在對病人造成最少傷害的情況下得到最大的診斷價值。

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