Measurement of scattered radiation from dental implants in dry human jaw during radiotherapy

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Abstract

Objective To investigate the scattered radiation at bone-implant interfaces irradiated with a therapeutic radiation dose from three different dental implant surfaces in human bone model.

Materials and methods Dry human mandible was used to measure the dose enhancement caused by scattered radiation from the three different implant surfaces [machined surface, titanium-coated (TiUnite) surface, hydroxyapatite (HA)-coated surface]. Radiation dose enhancement at distance of 0, 1, 2, and 3 mm from bone-implant interface was determined by thermoluminescent dosimetry using lithium fluoride single crystal chips as a radiation absorber. The absorbed radiation doses in the lithium fluoride chips at mesial, distal, buccal and lingual directions around dental implant were measured and compared using three-way ANOVA.

Results The HA-coated surface implant had the lowest scattered radiation at 0, 1, and 2 mm from the bone-implant interface. There was a statistically significant difference of scattered radiation between both HA-coated and TiUnite implant surface to machined implant surface at 0 mm from the bone-implant interface ($p < .05$). There was no statistically difference of dose enhancement between mesial, distal, buccal and lingual directions ($p > .05$).

Conclusion HA-coated surface implant demonstrated the lowest scattered radiation among three surfaces tested in dry human mandible. There was no significant difference in scattered radiation at 2 and 3 mm from the bone-implant interface for all the implant surfaces studied. There was no statistical difference of dose enhancement between mesial, distal, buccal and lingual direction. There was no cumulative effect of scattered radiation from the adjacent implant which placed at 7 mm distance (surface to surface).

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Introduction

Radiotherapy has been used with increasing frequency in the management of neoplasms of the head and neck region by exposing it to ionizing radiation. The radiation dose required to destroy the tumor, as well as its effect on the surrounding healthy tissue, must be closely observed. Even when radiation is properly used, side effects such as radiation caries, xerostomia, mucositis, tissue necrosis, etc, usually are unavoidable.[1-4]

The use of dental implants for anchorage of tooth prosthesis in odontology, for fixation of facial prosthesis and maxillo-facial reconstructions, is becoming increasingly popular in recent years. Many of the patients who receiving dental implants may one day require radiotherapy if they have oral cancer. Studies showed that 95% of people who has oral cancer are the age above 40.[5] According to this reason, it is important to assess the effect from radiotherapy around dental implants for clinical application and choose the suitable implant systems for patients.

Normally, if there are metallic materials such as metallic crowns or dental implants in the radiation field, dose enhancement at the tissue-metal interface will occur.[6,7] This enhancement is caused by the interaction of ionizing radiation with the atoms of the metal, liberating motion electrons from within the metal. When high-energy electrons or photons are liberated from the metal and set into motion in an opposing direction to that of the primary radiation beam, backscattered radiation results. The electrons set into motion in a direction that is the same or similar to that of the primary radiation beam are referred to as forwardscatter. Forwardscatter represents an increased dose to areas that lie on the exit site of the primary beam from the metal. Previous studies[8-10] have shown that the loss of osseointegration in patients with craniofacial implant after receiving a high dose of radiation [4,500-6,000 centigray (cGy)] resulting from decreasing blood supply. Doses above 4,000 cGy are known to cause changes in bone.[6] A 9% incident of osteoradionecrosis has been reported for doses above 7,000 cGy.[11] Beumer reported that, in 46 of the 82 incidents of necrosis, 75% or more of body of mandible was in the radiation treatment field due to fibrosis and vascular impairment after radiation.[12]

The scattering radiation is one of possible factors which causing impairment in osseointegration by reducing the number of bone cell at bone-implant interface. Changes in bone regeneration capacity after irradiation in experimental studies have been published.[13-15] A single dose of 500-800 cGy gave up to 20% lower regenerative capacity of bone. There was no change in the regenerative capacity after a single dose of 250 cGy.[6]

Nowadays, there are many different implant surfaces in dentistry such as machined surface, titanium-coated surface, sandblasted surface, acid-etched surface, and hydroxyapatite (HA)-coated surface. The surface topography is one of the properties which are proved to have an influence on the osseointegration.

Previous studies have shown that the effect of scattered radiation on bone-implant interfaces among implant systems with different compositions is not the same.[5,6,16,17] Wang et al[16] examined the dose enhancement at bone-implant interfaces from scattered radiation by using artificial mandible in four different implant systems. The results showed that the high gold content transmandibular implant system had a significantly higher dose enhancement than the other groups tested. HA-coated implant system showed the lowest dose enhancement. Reitemeier et al[17] found the same results by using artificial teeth in the plaster based model. Rosegren et al[6] investigated human colon carcinoma cells and embryonic hamster cells on titanium disc and plastic control irradiated with ^{60}Co and proton beam. They found that there was no significantly change in cell survival at the interface between those two groups. However, this result may be different with other cell types. None of these studies has investigated scattered dose enhancement from different implant surfaces in human bone.

Since 1960 the use of thermoluminescent dosimetry (TLD) has increased rapidly to measure ionizing radiation.[18] Many crystalline materials such as lithium fluoride (LiF), lithium borate (Li2B4O7), and calcium fluoride (CaF2) exhibit the phenomenon of thermoluminescent. When such a crystal is irradiated, a very minute fraction of the absorbed energy is stored in the crystal lattice. Some of this energy can be recovered and measured later as visible light if the material is heated. This phenomenon of the release of visible photons by thermal means is known as thermoluminescent (TL).[19,20]

In this study, LiF crystal chips were used as TLD to measure the dose enhancement at bone-implant interface.

The purposes of this investigation were to determine (1) the dose enhancement of scattered radiation from three different dental implant surfaces irradiated with 6 MeV X-ray; (2) the effect of scattered radiation at four distances from bone-implant interfaces; and (3) the relative doses in buccal, lingual, mesial, and distal directions from three implant surfaces.

Materials and methods

A dry male human mandible with an adequate edentulous area for two implant placement at the posterior segment was used. Three different implant surfaces were studied: (1) two implant fixtures of machined surface (Branemark system, Nobel Biocare, Goteborg, Sweden); 3.75 mm in diameter and 10 mm in length, (2) two implant fixtures of TiUnite surface (Replace Select, Nobel Biocare, Goteborg, Sweden); 3.5 mm in diameter and 10 mm in length, and (3) two implant fixtures of hydroxyapatite coated surface (Replace Select, Nobel Biocare, Goteborg, Sweden); 3.5 mm in diameter and 10 mm in length. Two implant fixtures from each system were placed in left alveolar bone of the jaw. The distal surface of the first implant was separated from the mesial surface of the second implant by a distance of 7 mm. Because of implant fixture of machined surface is 0.25 mm larger in diameter, therefore, they were placed last in order to keep the same distance. The ground bone from implant placement procedure was collected and used to close any space between implant fixtures and TLD chips (Harshaw; Ohio, USA) specimens during this experiment. The troughs, 3x3x4 mm, were prepared on the mesial, diatal, buccal and lingual aspects of the second implant to accommodate LiF TLD chip specimens. The space between implant fixture and TLD chip was packed with ground bone.

Five LiF TLD chips, 3x3x1 mm in diameter, were used in each experimental group. Four of them were placed in the troughs surrounding the second implant in lingual, distal, buccal, and mesial directions at various distances (0, 1, 2 or 3 mm from implant surface). The fifth TLD chip specimen (observation TLD) was placed at the center between right and left body of the mandible as shown in Fig. 1. The purpose of this TLD chip was employed to observe the accuracy of radiation dose at the center of radiation field of each measurement (it was not used for calculation). This set up was applied to all tested implant systems. The configuration of the measurement setup is shown in Fig. 1.

The aim of TLD chip specimens placed between two implants is to detect the effect of scattered radiation from both implants. The control was also set to provide a baseline for comparison; TLD chip specimens and ground bone were placed in the mandible at the same locations and distances without implants.

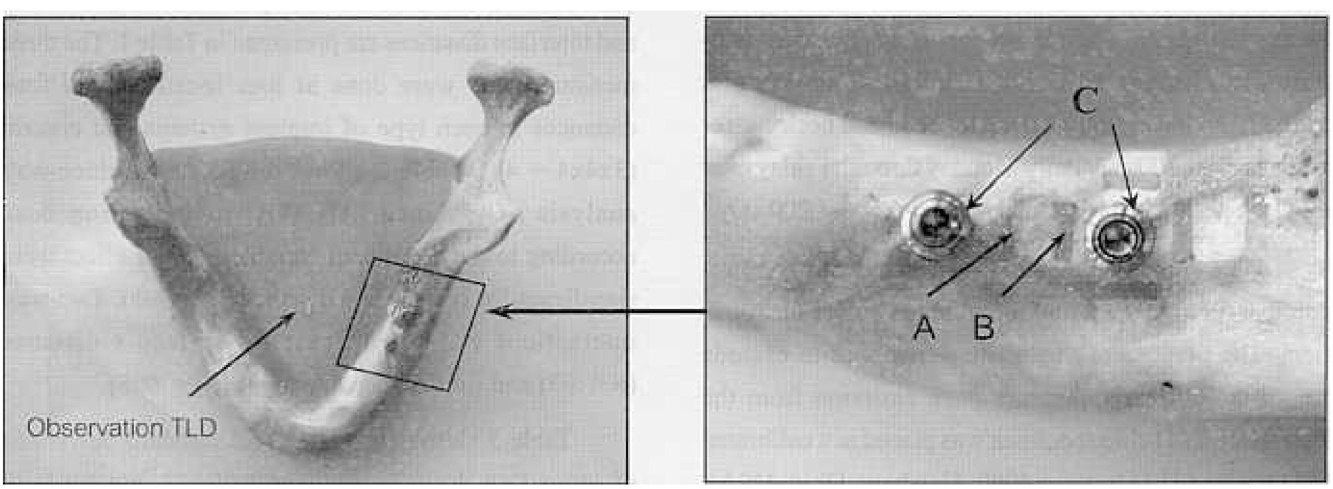

Fig. 1 Setup for measurement of scattered radiation: A = bone pack, B = TLD chip, C = implants

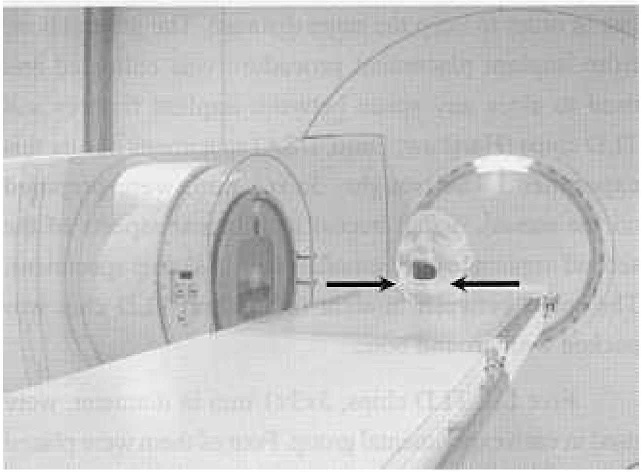

Fig. 2 Radiation setup; radiation source was from linear accelerator using bilateral beam (two arrows are directions of left and right beams).

The space between both sides of the mandible was filled with plasticine to mimic tongue and soft tissue. Each experimental setup was placed in the same position of a phantom head to simulate head and neck radiotherapy. The high-energy photon was from a 6 MeV linear accelerator (Philip SL20, Germany). A size of radiation field was 10x10 cm and the distance from the radiation source to the center of the mandible was 100 cm. Radiation dose was 200 cGy at the fifth TLD chip specimen using a pair-opposed bilateral field (each side of mandible was irradiated to 100 cGy); the angle of radiation tube was 90° on the left and 270° on the right (Fig. 2). The reason for using 200 cGy is to simulate clinical situation. Radiation oncologist normally divide a curative dose for head and neck cancer patient at 180-200 cGy daily Monday through Friday over a 7-week period to have a total dose of 6,500-7,200 cGy.[7]

After the radiation, TLD chip specimens were restored at room temperature for 24 hours before measurement. The purpose of this waiting time was to exclude the unstable low-temperature peak emission from the TLD. Each TLD chip specimen was placed in a calibrated TLD reader (TLD System 4000, Harshaw; Ohio, USA). This TLD reader heated the TLD chip from room temperature to 300°C. Then, light emitted from the TLD chip at temperature between 150°C and 300°C was detected by a sensor and converted to nanocoulomb unit. A relative comparison of TLD doses from the control and the experimental groups would indicate the level of scattered radiation absorbed by the TLD chips. Each group was measured three times.

A combination of three implant surfaces, four directions of scattered radiation, four distances of bone-implant interfaces, and three samples per group yielded 144 TLD chip specimens for the experimental groups. An additional 48 TLD chip specimens were used as the control samples; these specimens were irradiated without dental implants.

Statistical Analysis Three readings were made for each of 64 TLD specimens from varied combinations of implant surfaces, locations, and interface distances. The subtraction between the reading from TLD specimen with implant and control was a relative dose enhancement. Data were analyzed by a three-way analysis of variance (ANOVA) to evaluate the major factors (implant surfaces, locations and distances). All hypothesis testing was conducted at the significance level of 5%.

Results

The means and standard deviations of ionization dose (scattered radiation) of various implant surfaces, locations, and interface distances are presented in Table 1. The three measurements were done at four locations and four distances in each type of implant systems and control (3x4x4 = 48). Table 2 shows the results of three-way analysis of variance (ANOVA) of ionization dose according to the dependent variables. Major effect were significant for surface and distance ($p < .005$). Two-way interactions were significant for surface x distance ($p < .05$) and for distance x location ($p < .005$).

Table 3 shows the means and standard deviations of ionization dose for implant surfaces interact with distances. Table 4 presents a statistical summary of two-way ANOVA that examines the interaction of implant surfaces and distances. Table 5 is Bonferroni's Comparison in terms of surfaces (means of dose for each groups are displayed), the ionization dose from machined surface was significantly higher than that from HA-coated and control ($p < .05$), but was not significantly different from TiUnite. The TiUnite implant had a higher dose than the control ($p < .05$), but was not significantly different from HA-coated. Table 6 is Bonferroni's Comparison in terms of distances, the mean ionization dose at 0 and 1 mm was higher than that 2 and 3 mm ($p < .05$). The mean ionization dose at 2 mm and 3 mm was not significantly different. Figure 3 presents percentage of enhancement dose measurement of various implant surfaces at different distances from bone-implant interfaces. Machined surface showed the highest enhancement dose measurement of 11.5% at 0 mm. HA-coated showed the lowest enhancement dose measurement of 6.8% at 0 mm.

The radiation dose from observation TLD, placed at the center between both sides of body of the mandible in 48 observation ranged from 348.22 to 367.62 nanocoulomb. Mean (and standard deviation) was 356.51 (8.65) nanocoulomb.

Table1 Means and standard deviations of ionization dose of implant surfaces, locations, and distances

Variable	n	Mean (nanocoulomb)	Standard deviation
Surface			
Machined	48	428.56	14.35
TiUnite	48	427.12	7.76
HA-Coated	48	424.55	7.07
Control	48	424.55	10.19
Location			
Lingual	48	424.50	
Distal	48	423.15	
Buccal	48	424.85	
Mesial	48	423.00	10.88
Distance			
0 mm	48	427.69	
mm	48	424.65	6.19
2 mm	48	411.65	3.13
3 mm	48	431.48	.89

Table 2 Summary of three-way analysis of variance of ionization dose

Variable	DF#	F value	*p* value
Surface	3	2.14	< .005
Distance	3	4.23	< .005
Location	3	0.72	.565
Surface x Distance	9	72.86	< .05
Surface x Location	9	.39	.241
Distance x Location	9	4.96	< .05
Surface x Distance x Location	27		.807

#DF = degree of freedom.

Table 3 Means (and standard deviation) of ionization dose by implant surfaces and distances*

	Distances (mm)				
Surfaces	**0**		**2**	**3**	**Total#**
Machined	444.63 (7.52)	429.48 (2.76)	407.56 (1.71)	432.57 (3.01)	428.54 (3.75)
TiUnite	433.62 (1.41)	429.08 (1.66)	414.55 (1.17)	431.21 (0.58)	427.12 (1.21)
HA-coated	428. (3.40)	424.75 (0.83)	413.86 (1.19)	431.49 (1.57)	424.55 (1.75)
Control	404.42 (2.22)	415.30 (2.65)	410.67 (1.54)	430.66 (1.86)	415.26 (2.07)
Total##	427.70 (3.64)	424.65 (1.98)	411.66 (1.40)	431.48 (1.76)	

*Unit = nanocoulomb

#Total = means of ionization dose of each surface

##Total = mean of ionization dose of each distance

Table 4 Statistical summary of two-way analysis of variance (surface x distance)

Source	DF	Sum of Squares	F value	*p* value
Surface	3	713.65	78.52	< .005
Distance	3	3555.06	162.89	< .005
Surface x Distance	9	2394.07	36.56	< .05
Error	144	349.21		
Corrected total	191	8012.00		

Table 5 Bonferroni's Multiple Comparisons in terms of surfaces

(I) Surface[$]	(J) Surface	Mean Difference (I-J)	$\bar{p}$ value
Machined	TiUnite	.42	.818
	HA-Coated	3.09*	< .05
	Control	13.28*	< .05
TiUnite	Machined	-1.42	
	HA-Coated	2.57	.059
	Control	11.86*	< .05
HA-Coated	Machined	-3.09*	< .05
	TiUnite	-2.57	.059
	Control	9.29*	< .05
Control	Machined	-13.28*	< .05
	TiUnite	-11.86*	< .05
	HA-Coated	-9.29*	< .05

[$] Based on observed means (Unit = nanocoulomb);

Machined = 428.54, TiUnite = 427.12, HA-Coated = 424.55, Control = 415.26

* The mean difference is significant at the .05 level.

Table 6 Bonferroni's Multiple Comparisons in terms of surfaces

(I) Distance[$]	(J) Distance	Mean Difference (I-J)	*p* value
0 mm	mm	3.05	.091
	2 mm	16.04*	
	3 mm	-3.78*	
mm	0 mm	-3.05	.091
	2 mm	12.99*	
	3 mm	-6.83*	
2 mm	0 mm	-16.04*	
	mm	-12.99*	
	3 mm	-19.82*	
3 mm	0 mm	0.78*	
	1 mm	6.83*	
	2 mm	19.82	.067

[$] Based on observed means (Unit = nanocoulomb);

0 mm = 427.70, 1 mm = 424.65, 2 mm = 411.66, 3 mm = 431.48

* The mean difference is significant at the .05 level.

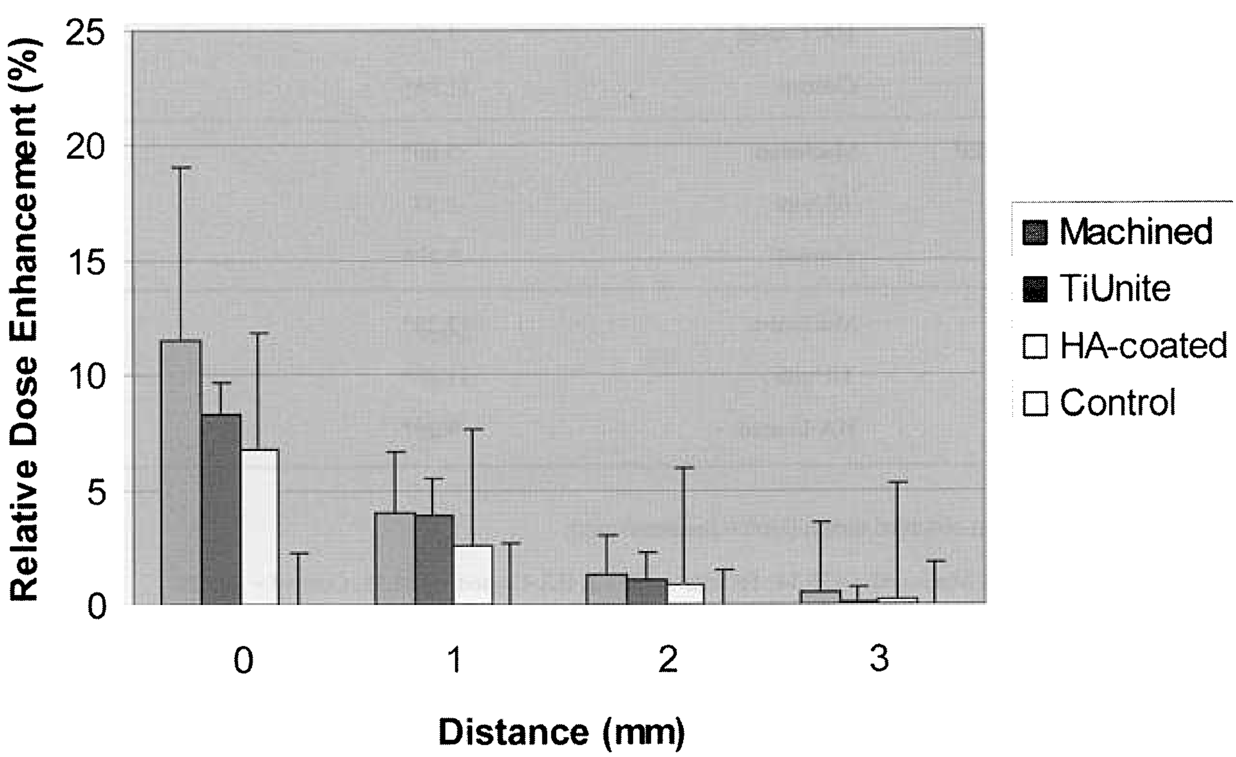

Fig. 3 Relative dose enhancement with different implant surfaces at bone-implant interfaces

Discussion

The results from this study were not corresponded to previous studies which used different experimental model. Allal et al[21] reported maximum dose enhancement of 5-7% at bone/titanium interfaces using titanium hollow screw osseointegrating reconstruction plates in bovine femoral diaphysis after irradiated from both 6-MV photon and ^{60}Co. Dose enhancement in their results was 3-6% less than that in this study. The possible explanations would be both differences in bone density of the bovine femoral diaphysis and human mandible and implant material. Rosengren et al[6] found that there was no significant difference in human colon carcinoma and embryonic hamster cell survival rate at tissue-titanium interfaces after irradiated using ^{60}Co. The irradiation dose used in their study was in the interval of 0-100 cGy. This irradiation dose was 80-100 cGy less than normal used in one session for the patient who received 6,500-7,000 cGy. The irradiation dose in tissue-titanium model should be the dose from the delivered irradiation plus that from the additional of scattered radiation. According to the data from this study, the irradiation dose in tissue-titanium model should be in the interval of 215-225 cGy.

The results from this investigation corresponded to the previous study[16] that HA-coated surface implant presented the lowest dose enhancement from scattered radiation. However, those studies were done in artificial models whereas our investigation used human bone model which can provide a better relative dose enhancement for further experiment using human bone cell-titanium interface model.

The ionization doses obtained from observation TLDs; ranged from 348.22 to 367.62 nanocoulomb, mean = 356.51, standard deviation = 8.65 (2.42% from mean) shows that there was a little variation between each sample in this study. This variation may be due to the fluctuation of radiation dose at the center of radiation field and/or the inconsistency of ionization dose absorbed by TLDs.

The results of the present study indicated that the effects from forward and backscattered radiation were similar. Dose enhancement at buccal direction was more than that at lingual direction. However, there were no statistical differences of doses among mesial, distal, buccal and lingual locations. The possible explaination would be that the bilateral beams used in this study may cause direct even exposure on both buccal and lingual aspects.

The highest amount of scattered radiation for all studied implant surfaces occurred at 0 mm from the bone-implant interface (ranged from 6.8% to 11.5%). At 1 mm from the bone-implant interface, dose enhancement from the three implant surfaces ranged from 2.6% to 3.9%. At 2 and 3 mm from bone-implant interface, dose enhancement ranged from 0.9% to 1.3% and 0.2% to 0.5% respectively. In this investigation, there was no significance at mesial and distal location, so scattered radiation from adjacent implant can be clinically ignored. However, when clinicians place a dental implant adjacent to another implant, 7 mm of mesiodistal separation of the two implants is required. These results corresponded to the previous study in artificial bone model.[12] But, there were differences in percentages of dose enhancement.

Machined surface implant (Branemark) had the highest scattered radiation (11.5%), TiUnite surface implant had lower scattered radiation (8.3%) and HA-coated surface implant had the lowest scattered radiation (6.8%) at distance of 0 mm from bone-implant interfaces. The possible explaination would be both machined and TiUnite surface have direct contact of metal surface to TLD chip while HA-coated has hydroxyapatite layer contact instead. The further investigation for thickness and type of hydroxyapatite should be conducted. According to authors' calculation, if the increasing cumulative dose of scattered radiation is a linear relationship, that of 7,000 cGy total dose from HA-coated surface is 476 cGy while that from machined surface is 805 cGy. The machined surface may affect regenerative capability of bone cell more than HA-coated surface. However, this speculation needs to be investigated in human bone cell experiment. From this study, HA-coated surface implant may be a suitable implant used for patient who has a high risk on having head and neck radiotherapy in the future.

Conclusion

Within the limitation of this study, the following conclusions can be drawn:

1) HA-coated surface implant demonstrated the best results under the irradiation in human bone.

2) Bone around dental implant at the distance of 0-1 mm recieves overdosage from scattered radiation. There was no significant difference in scattered radiation at 2 and 3 mm from the bone-implant interface for all the implant surfaces studied.

3) There was no statistical difference of dose enhancement between mesial, distal, buccal and lingual direction.

4) There was no cumulative effect of scattered radiation from the adjacent implant which placed at 7 mm distance (surface to surface).

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การวัดปริมาณรังสีกระเจิงจากรากเทียมในกระดูกขากรรไกรมนุษย์แบบแห้งที่ได้รับรังสีรักษา

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หน่วยบูรณะช่องปากและใบหน้า โรงพยาบาลคณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ผู้เชี่ยวชาญด้านรังสีรักษา แผนกรังสีรักษา โรงพยาบาลบำรุงราษฎร์

บทคัดย่อ

วัตถุประสงค์ เพื่อสำรวจปริมาณรังสีกระเจิงกลับ และรังสีกระเจิงไปข้างหน้า ที่พื้นผิวรากเทียม 3 ชนิดต่างกัน ในกระดูกขากรรไกรมนุษย์แบบแห้ง ซึ่งฉายด้วยรังสีที่มีขนาดและชนิดเดียวกับรังสีที่ใช้รักษามะเร็งบริเวณช่องปากและใบหน้า

วัสดุและวิธีการ ทำการวัดปริมาณรังสีที่เพิ่มขึ้นจากรังสีกระเจิง จากรากเทียมที่มีพื้นผิวที่แตกต่างกันทั้ง 3 ชนิด ซึ่งได้แก่ พื้นผิวเรียบ พื้นผิวที่เคลือบด้วยไททาเนียม และพื้นผิวที่เคลือบด้วยไฮดรอกซีแอปพาไทต์ โดยทำการฝังในกระดูกขากรรไกรล่างของมนุษย์แบบแห้ง ปริมาณรังสีกระเจิงที่เพิ่มขึ้นจะวัดที่ระยะทาง 0, 1, 2, และ 3 มิลลิเมตร จากพื้นผิวระหว่างรากเทียมและกระดูก โดยวิธีการเทอร์โมลูมิเนสเซนต์โดสิเมทรี โดยการใช้ผลึกลิเทียมฟลูออไรด์เป็นตัวเก็บรังสี และวัดปริมาณรังสี ปริมาณรังสีที่กักเก็บจากผลึกลิเทียมฟลูออไรด์ที่ทิศทางใกล้กลาง ไกลกลาง ใกล้แก้ม ใกล้ลิ้น และรอบรากเทียม ได้ถูกวัดและนำมาเปรียบเทียบโดยใช้สถิติวิเคราะห์ความแปรปรวนแบบหลายทาง

ผลการศึกษา รากเทียมที่พื้นผิวเคลือบด้วยไฮดรอกซีแอปพาไทต์จะทำให้มีรังสีกระเจิงน้อยที่สุดที่ระยะทาง 0, 1, และ 2 มิลลิเมตร จากพื้นผิวรากเทียม มีความแตกต่างอย่างมีนัยสำคัญ ($p > .05$) ของรังสีกระเจิงจากรากเทียมระหว่างพื้นผิวที่เคลือบด้วยไฮดรอกซีแอปพาไทต์ และพื้นผิวที่เคลือบด้วยไททาเนียม กับพื้นผิวเรียบที่ระยะทาง 0 มิลลิเมตร จากผิวรากเทียม ปริมาณรังสีที่เพิ่มขึ้นจากรังสีกระเจิงที่ทิศทางใกล้กลาง ไกลกลาง ใกล้แก้ม และใกล้ลิ้น มีค่าไม่แตกต่างอย่างมีนัยสำคัญทางสถิติ ($p > .05$)

สรุป รากเทียมที่พื้นผิวเคลือบด้วยไฮดรอกซีแอปพาไทต์แสดงผลที่ดีที่สุดภายใต้แบบจำลองการฉายรังสีรักษาในกระดูกขากรรไกรมนุษย์แบบแห้ง ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติของรังสีกระเจิงที่ระยะทาง 2 และ 3 มิลลิเมตร จากผิวรากเทียม ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติของรังสีกระเจิงระหว่างตำแหน่งใกล้กลาง ไกลกลาง ใกล้แก้ม และใกล้ลิ้น กระดูกรอบ ๆ รากเทียมไม่ได้รับรังสีกระเจิงจากรากเทียมซี่อื่นที่ฝังใกล้กันในระยะห่าง 7 มิลลิเมตร ระหว่างผิวถึงผิวรากเทียม

ว ทันต จุฬาฯ 2547;27:235-46)

คำสำคัญ: การฉายรังสีรักษ รังสีกระเจิง รากเทียม