Original Articles

Comparison of Back- and Forward-scattered Radiation from Different Dental Materials Using Therapeutic Dose of Radiation, *In vitro*

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Abstract

This study compared back- and forward-scattered doses from nine contemporary dental materials from the noble alloy group (gold alloy type I, gold alloy type IV, palladium alloy); the titanium group (commercially pure titanium (grade 4), titanium alloy (milling), titanium alloy (laser sintering); and the ceramic group (3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP), lithium disilicate, feldspathic porcelain). A linear accelerator (LINAC) with a single exposure dose of 200 cGy and 6 MV of photon energy was used to irradiate nine dental materials. Five specimens of each dental material were prepared, and each specimen was sandwiched with Optically Stimulated Luminescence (OSL) dosimeters above and below for back- and forward-scattered dose measurement, respectively. All specimens were irradiated two times. Percentage dose enhancement and attenuation were calculated from the exposure dose and compared among nine dental materials by using the one-way ANOVA and Bonferroni test with a *p*-value below 0.01. The gold alloy type I showed the highest backscattered dose (37.41 %) followed by gold alloy type IV (33.35 %), palladium alloy (24.20 %), zirconia (16.44 %), commercially pure titanium (grade 4) (10.30 %), titanium alloy (milling) (10.03 %), titanium alloy (laser sintering) (9.84 %), lithium disilicate (2.53 %) and feldspathic porcelain (1.58 %). Feldspathic porcelain was observed for the lowest dose attenuation while palladium alloy was noted for the highest dose attenuation. The higher atomic number and density of materials, the more backscattered dose enhancement and the less of forward-scattered dose were found. Gold alloy type I and zirconia showed the most backscattered dose among the noble alloy and ceramic group, respectively.

Keywords: Backscatter, Dental materials, Forward-scatter, Linear accelerator (LINAC), Radiotherapy

Received Date: Sep 8, 2021 **Revised Date:** Oct 19, 2021 **Accepted Date:** Nov 23, 2021

doi: 10.14456/jdat.2022.40

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Introduction

Incidences of head and neck cancer in Thailand are found in people at the age of 45-75 years. The International Agency for Research on Cancer (IARC) 2018 showed that the incidence of oral cancer in Thailand was 2.7 % of all cancer sites per year and increasing. Age-standardized incidence rate (ASR) per 100,000 in Thai males (ASR=5.1) were found more than in females (ASR=3.1).[1] The most common head and neck cancer is squamous cell carcinoma in which the oral, nasopharyngeal and laryngeal area are commonly found in Thai males whereas the thyroid and oral area are commonly found in Thai females.[2] Tongue, floor of mouth and buccal mucosa are frequently affected by cancer in the oral cavity.

Treatment modality of squamous cell carcinoma includes the combination of wide resection and radiotherapy to remove a tumor mass and eliminate the residual tumor cells. Dosimetry and the field of radiation are calculated by radiotherapists to achieve an effective radiation dose. Total radiation dose for head and neck cancer treatment is between 5000-7000 cGy depending upon the stage and the aggressiveness of the cancer. "Fractionation" or separation of dose per day is used to deliver the total effective dose without destruction of the host cell. The standard of fractionated dose for curative radiotherapy in head and neck cancer is currently based on delivering a dose of 200 cGy per day, five days a week for 5-7 consecutive weeks.[3-6]

Total high energy beam is inevitably delivered to both host and tumor cells. Any high-scattering objects in the beam of x-ray deflect off the radiation causing secondary radiation demonstrated as scattered radiation, forward-scattered and backscattered radiation. Forward-scatter occurs at the opposite side from the radiation whereas backscatter occurs at the same side of radiation. Forward-scatter results in a decrease in dose to soft tissue or target cancer on the away side due to radiation deviation and attenuation absorbed by the high-scattering materials. This causes a reduction of dose to the tumor behind these dental materials from dose planning for treatment. Meanwhile, "dose enhancement" occurs when backscatter radiation enhances the dose from the original radiated dose to tissue in front of objects such as a restoration or implant.[7-10] Objects which have higher backscatter will show less forward-scattered radiation. Backscattered radiation could lead to oral complications such as mucositis resulting from high-scattering dental materials for restorations close to the soft tissue in the oral cavity (tongue, buccal mucosa). If backscattered radiation occurs around dental implants, it will lead to compromised osseointegration or osteoradionecrosis (ORN) resulting from dose enhancement surrounding dental implants in bone.[11] In general, studies showed that ORN occurs when the total radiation dose is more than 6500 cGy in mandible by 88.1 % in the first year after radiotherapy.[12,13] Moreover, it has been reported in literature reviews that the longer period post-irradiation beyond 6500 cGy, the lesser blood supply in the bone. This results from the decrease in blood supply and mesenchymal stem cells in bone.[12,14] Therefore, implant placement should be thoroughly considered in patients who have undergone radiotherapy.

Many researchers have studied the effect of backscattered radiation from several types of dental implant materials, such as commercially pure titanium (cpTi), titanium alloys (Ti-6Al-4V) and high gold content implant.[9,15,16] However, there were only two studies about the backscattering effect from zirconia and lithium disilicate materials.[17,18] Presently, metal alloys and ceramic are used for dental restorations in the oral cavity such as crowns (noble alloy or ceramic), implant fixtures (titanium or zirconia) and implant abutments (titanium or zirconia). Therefore, our study was aimed to investigate back- and forward-scattered dose from nine contemporary dental materials from the noble alloy group (gold alloy type I, gold alloy type IV, palladium alloy); the titanium group (commercially pure titanium (grade 4), titanium alloy (milling), titanium alloy (laser sintering)); and the ceramic group (zirconia, lithium disilicate, feldspathic porcelain). The null hypothesis was that there is no difference in back- and forward-scattered dose among nine dental materials. This study will be beneficial for the selection of proper dental restorative and implant materials in patients with a high risk of head and neck cancer.

Materials and Methods

Specimen preparation:

Nine dental materials (gold alloy type I, gold alloy type IV, palladium alloy, zirconia, commercially pure titanium (grade 4), titanium alloy (milling), titanium alloy (laser sintering), lithium disilicate and feldspathic porcelain; number 1-9 in order in Figure 1(A)) were prepared by different fabrication techniques with each specimen in dimension of 8x13x1 mm^3 (Fig. 1(A)). Gold alloy type I (Golden Ceramic, Ivoclar Vivadent, Schann, Liechtenstein), gold alloy type IV (Maxigold, Ivoclar Vivadent, Schann, Liechtenstein) and palladium alloy (Elektra, Ivoclar Vivadent, Schann, Liechtenstein) were produced by a manufacturer. Commercially pure titanium (grade 4) (Signer Titanium, Signer Titanium AG, Freienbach, Switzerland), titanium alloy (milling) (Signer Titanium, Signer Titanium AG, Freienbach, Switzerland) and feldspathic porcelain (Vitablocs Mark II, VITA Zahnfabrik, Bad Säckingen, Germany) were cut by a low speed cutting diamond disc. Titanium alloy (laser sintering) (Ti64 ELI-A LMF, Trumpf, Ditzingen, Germany) was made from laser sintering machine (TruPrint 5000, Trumpf, Ditzingen, Germany). Zirconia (3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP)) (Ceramill zi, Amann Girrbach AG, Koblach, Austria) was produced by a milling method (Ceramill mikro, Amann Girrbach AG, Koblach, Austria) and sintered with a sintering machine (Ceramill therm 3, Amann Girrbach AG, Koblach, Austria). Lithium disilicate (IPS e.max Press, Ivoclar Vivadent, Schann, Liechtenstein) was fabricated by a heat-pressed technique. The approximate composition of each dental material from each manufacturer is shown in Table 1. There were five specimens in each group of dental materials. Before the experiment, the external surface of each specimen was polished by a polishing machine (Minitech 233, Presi, France) for 30 seconds (using abrasive paper no.400, 600, 1000). After being polished, the flat surface of the specimen was examined without light transmission passing through by being attached with an Optically Stimulated Luminescence (OSL) dosimeter (nanoDot, Landauer, USA) (Fig. 1(B)).

$$Z_{eff} = \sqrt[2.94]{\alpha_1 Z_1^{2.94} + \alpha_2 Z_2^{2.94} + \dots + \alpha_n Z_n^{2.94}}$$

(Z_{eff} is effective atomic number, α_n is the fractional electron content of each element (Z_n), Z_n is atomic number of each element)

Radiation set-up:

Nine different types of dental materials were irradiated by linear accelerator or LINAC (Elekta Synergy, Stockholm, Sweden) from Horizon center at Bumrungrad Hospital, Bangkok, Thailand. The radiation dose was 200 cGy in single exposure with an antero-posterior beam which was perpendicular to specimens and OSL dosimeters. The photon energy used in this study was 6 MV with radiation field size of 10x10 cm^2, 5-cm depth dose and a 95-cm distance from the radiation source (source-to-surface distance or SSD). Before the experiment, the exact dose from LINAC had to be calibrated and evaluated in two ways, depth dose and calibration dose, to verify that the evaluated dose from OSL correctly correlates with the dose emitted from the LINAC machine. First, the evaluation of the depth dose determined the dose in each 1-cm depth from the outermost to the innermost of the plastic phantom by using OSLs placed in each depth. Second, calibration dose determined whether a different dose emitted from LINAC was equal to the dose measured by OSL. In this study, the dose was calibrated in 200 cGy as a baseline for all comparisons of dose measurement. During the experimental set-up, specimens were placed in the same location at the center of the radiation field. Each specimen was sandwiched with OSLs above and below, then they were placed within bolus (Bolx I Gel Bolus, Qfix, USA) of which five holes were made to prevent air gaps during radiation and OSL dose measurement. The five sheets of solid water (RW3 slab phantom, PTW, Freiburg, Germany) which represented 5-cm depth dose (1 sheet of solid water is 1-cm thickness) were placed over bolus and dental material specimens attached with OSLs while the other ten sheets of solid water were at the base of the experimental set-up in order to fully achieve scatter (Fig. 2). All five specimens in each group of different dental materials were irradiated two times and measured back- and forward-scattered dose by different OSL chips. Thus, all measurements were recorded.

Data collection and interpretation:

All 180 OSL dosimeters, 10x10x2 mm^3 in size, were deleted from all signals prior to the experiment and then used for dose measurement at 0 mm distance from each specimen. After irradiation, they were read by an OSL reader (MicroStar, Landauer, USA). The data were shown back- and forward-scattered dose in cGy. Then the percentage dose enhancement and attenuation were calculated from the following formula:

Percentage dose enhancement = [(backscattered dose (cGy) – 200 cGy) / 200 cGy] * 100

Percentage dose attenuation = [(forward-scattered dose (cGy) – 200 cGy) / 200 cGy] * 100

Statistical analysis:

SPSS version 22.0, SPSS Inc., USA, statistical analysis program was used in this study. One-way ANOVA and Bonferroni tests were used to compare the data of back- and forward-scattered doses together with percentage dose enhancement and attenuation among nine dental materials. *P*-value below 0.01 (two-sided test) was considered as significant in all comparisons.

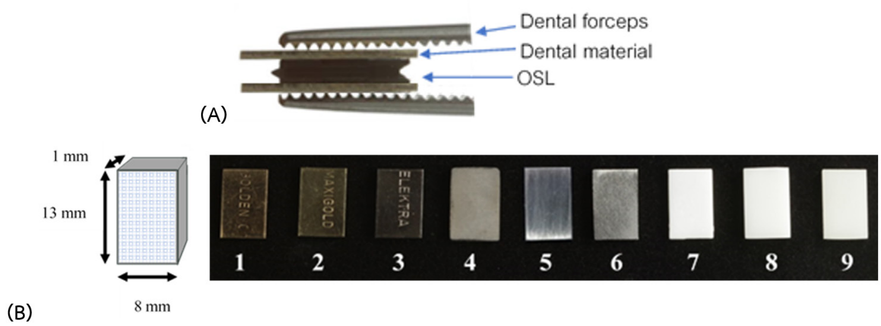

Figure 1 *(A) Nine dental metal materials with dimension of 8x13x1 mm^3, (B) Specimen flat surface attached with Optically Stimulated Luminescence (OSL) no light transmission passing through*

Table 1 *Dental materials composition*

Group	No.	Dental material	Lot number	Approximate composition (wt%) from manufacturers	Approximate density (g/cm^3)	Effective atomic number (Zeff)*
Noble alloy	1	Gold alloy Type I (Golden Ceramic, Ivoclar Vivadent)	V37595	86.9% Au, 8.0% Pt, 2.5% Pd, <1.0% Ag, <1.0% In, <1.0% Sn, <1.0% Ru, <1.0% Re, < 1.0% Ta, <1.0% Fe, <1.0% Li	18.4	77.81
	2	Gold alloy Type IV (Maxigold, Ivoclar Vivadent)	W36653	59.5% Au, 26.3% Ag, 8.5% Cu, 2.7% Pd, 2.7% Zn, <1% In and <1% Ir	13.9	68.77
	3	Palladium alloy (Elektra, Ivoclar Vivadent)	X41625	58.3% Ag, 25% Pd, 14.7% Cu, 2% In, <1% Ru, <1% Re and <1% Li	10.4	44.92
Titanium	4	Commercially pure titanium (Grade 4) (Signer titanium)	W16013	98.96% Ti, 0.50% Fe, 0.40% O, 0.08% C, 0.05% N, 0.015% H	4.51	21.98
	5	Titanium alloy (Ti-6Al-4V ELI) (milling) (Singer titanium)	S8255	88-91% Ti, 5.5–6.5% Al, 3.5–4.5% V, 0.25% Fe, 0.13% O, 0.08% C, 0.05% N, 0.012% H, 0.005% Y	4.43-4.47	21.67
	6	Titanium alloy (Ti-6Al-4V ELI) (laser sintering) (Trumpf)	17-E361 / 15-45	88-91% Ti, 5.5–6.5% Al, 3.5–4.5% V, 0.25% Fe, 0.13% O, 0.08% C, 0.05% N, 0.012% H	4.30	21.67

Table 1 Dental materials composition (cont.)

Group	No.	Dental material	Lot number	Approximate composition (wt%) from manufacturers	Approximate density (g/cm^3)	Effective atomic number (Zeff)*
Ceramic	7	Zirconia (Ceramill zi, Amann Girrbach AG)	1904003	≥99% ZrO_2+HfO_2+Y_2O_3, 4.5-5.6% Y_2O_3, ≤5% HfO_2, ≤0.5% Al_2O_3 and ≤1% other oxides	6.73	38.7
	8	Lithium disilicate (IPS e.max Press, Ivoclar Vivadent)	Y37266	70 vol% of lithium disilicate crystals ($Li_2Si_2O_5$)	2.5±0.1	9.68
	9	Feldspathic porcelain (Vitablocs mark II, VITA Zahnfabrik)	72600	56-64% SiO_2, 20-23% Al_2O_3, 6-9% Na_2O, 6-8% K2O, 0.3-0.6% CaO and 0.0-0.1% TiO_2	2.44±0.01	12.13

*Effective atomic number (Zeff):[35,36] $Z_{eff} = \sqrt[2.94]{\alpha_1 Z_1^{2.94} + \alpha_2 Z_2^{2.94} + \ldots + \alpha_n Z_n^{2.94}}$

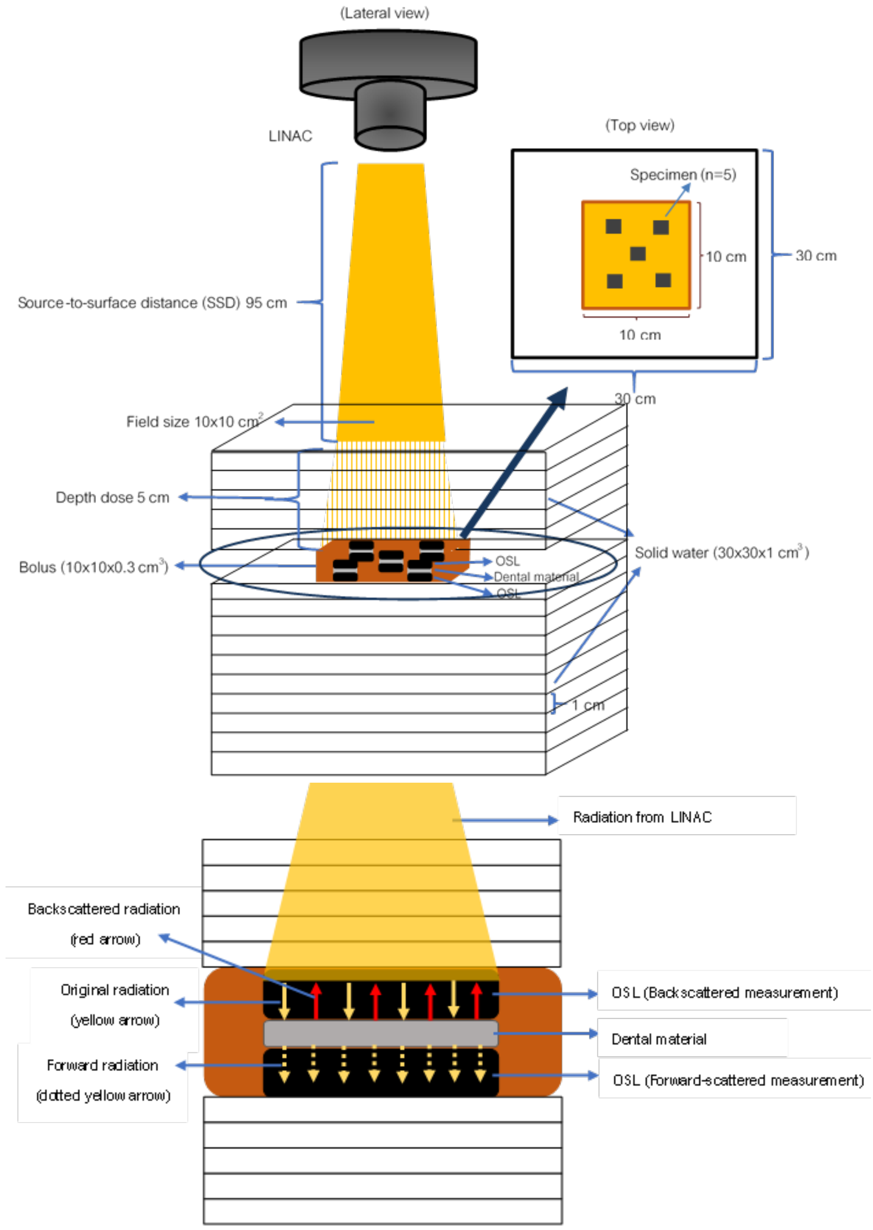

Figure 2 (A) Illustration of experimental set-up (not to scale), (B) Dental material was sandwiched with OSLs for back- and for ward-scattered measurement (enlarge from (A))

Results

The means and standard deviations of backscattered dose, forward-scattered dose, percentage dose enhancement and attenuation are presented in Table 2. Back- and forward-scattered doses were measured at 200 cGy single exposure from the LINAC machine and shown in bar-graph in Figure 3. The percentage dose enhancement and attenuation among nine dental metal materials showed increasing/decreasing of back- and forward-scattered dose from these materials from 200 cGy as an exposure dose of the LINAC machine. Different types of dental materials resulted in various dose enhancement and dose attenuation which are shown as bar-graph in Figure 4. For backscattered dose measurement, the highest percentage dose enhancement was 37.41 % observed in gold alloy type I while the lowest percentage dose enhancement was 1.58 % observed in feldspathic porcelain.

Table 2 *Means and standard deviations of backscattered dose, forward-scattered dose, percentage dose enhancement and percentage dose attenuation from nine dental materials from exposure dose of 200 cGy*

Group	Dental materials	Backscattered dose (cGy)	Forward-scattered dose (cGy)	Percentage dose enhancement (%)	Percentage dose attenuation (%)
Noble alloy	Gold alloy type I	274.82 ± 4.25^{A}	162.29 ± 2.53^{AB}	37.41 ± 2.13^{A}	-18.86 ± 1.27^{AB}
	Gold alloy type IV	266.69 ± 4.34^{B}	163.28 ± 5.72^{ABC}	33.35 ± 2.17^{B}	-18.36 ± 2.86^{ABC}
	Palladium alloy	248.41 ± 5.56^{C}	160.01 ± 2.30^{A}	24.20 ± 2.78^{C}	-19.99 ± 1.15^{A}
Titanium	Commercially pure titanium (Grade 4)	220.60 ± 2.19^{D}	175.40 ± 2.36^{D}	10.30 ± 1.10^{D}	-12.30 ± 1.18^{D}
	Titanium alloy (Milling)	220.07 ± 2.72^{D}	167.82 ± 1.39^{C}	10.03 ± 1.36^{D}	-16.09 ± 0.69^{C}
	Titanium alloy (Laser sintering)	219.67 ± 3.27^{D}	174.49 ± 3.34^{D}	9.84 ± 1.63^{D}	-12.75 ± 1.67^{D}
Ceramic	Zirconia	232.87 ± 5.21^{E}	166.22 ± 1.83^{BC}	16.44 ± 2.60^{E}	-16.89 ± 0.92^{BC}
	Lithium disilicate	205.06 ± 3.54^{F}	181.16 ± 2.90^{E}	2.53 ± 1.77^{F}	-9.42 ± 1.45^{E}
	Feldspathic porcelain	203.15 ± 3.59^{F}	185.66 ± 2.80^{E}	1.58 ± 1.80^{F}	-7.17 ± 1.40^{E}

Different superscript letters in the same column show a significant difference between groups (P < 0.01)

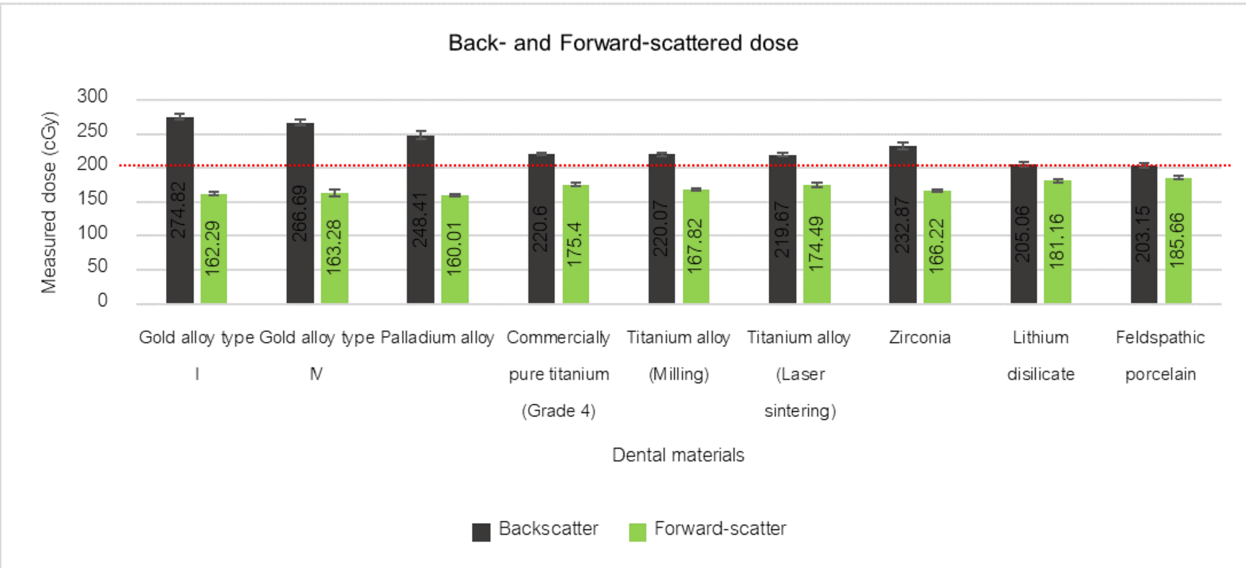

Figure 3 *Back- and forward-scattered dose among nine dental materials (exposure dose at 200 cGy)*

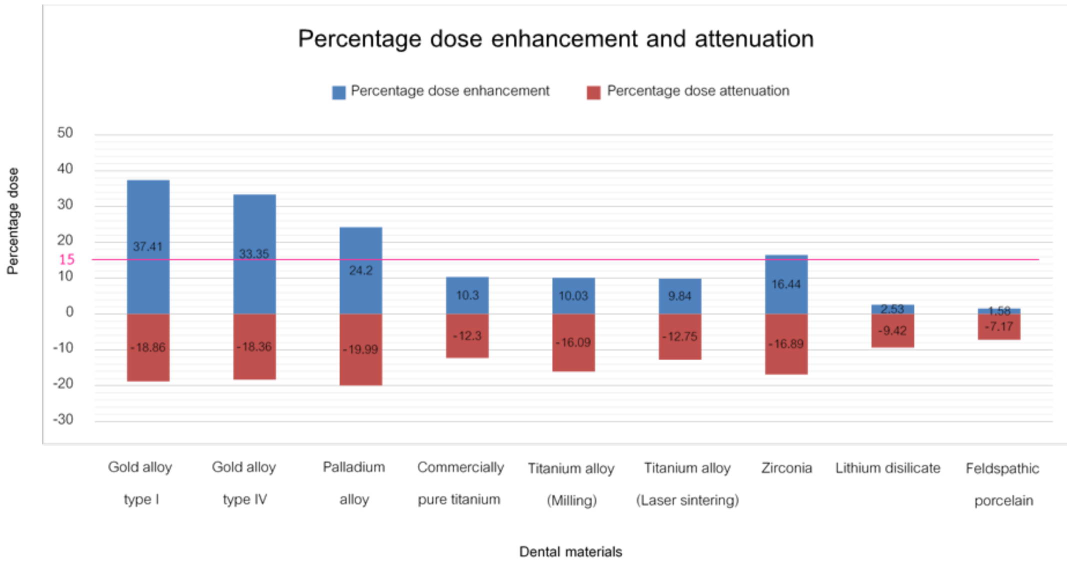

Figure 4 *Percentage dose enhancement and percentage dose attenuation among nine dental materials. (15 % dose enhancement leads to osteoradionecrosis)*

Comparison among nine dental materials using one-way ANOVA with p-value below 0.01 showed that there was a statistically significant difference of percentage dose enhancement among gold alloy type I, gold alloy type IV, palladium alloy and zirconia. However, there was no statistically significant difference of percentage dose enhancement among commercially pure titanium (grade 4), titanium alloy (milling) and titanium alloy (laser sintering). Again, there was no statistically significant difference between lithium disilicate and feldspathic porcelain. For forward-scattered measurement, feldspathic porcelain was observed for the highest forward-scattered dose (185.66 ± 2.8 cGy) while palladium alloy was noted for the lowest forward-scattered dose (160.01 ± 2.30 cGy). There was no statistically significant difference of percentage dose attenuation among gold alloy type I, gold alloy type IV, and palladium alloy. Percentage dose attenuation between commercially pure titanium (grade 4) and titanium alloy (laser sintering) were not significantly different. Moreover, lithium disilicate and feldspathic porcelain showed no statistical difference in percentage dose attenuation.

Discussion

It was shown that radiation can pass through all specimens. Objects which have higher backscatter radiation showed less forward-scattered radiation (Fig. 3). The null hypothesis testing that back- and forward-scattered doses among nine dental materials were not different was rejected. From the results of this study (Fig. 4), among the noble alloy group, the results corresponded to the previous studies that gold alloy type I showed the highest backscattered dose enhancement compared to other materials.[8,9,17,19] Among the titanium group, backscattered dose in commercially pure titanium was little higher than both of the titanium alloys, but there no significant differences, which was similar to previous studies.[9,16] Among the ceramic group, zirconia was observed as the highest backscattered dose enhancement. It can be explained that the backscattered dose was strongly dependent on the effective atomic number of dental materials (Zeff) or atomic number (Z) of the element which the highest dose was found in high Z material.[20]

The density of materials also affects scattered radiation. The higher the density of materials, the higher the dose was found.[17,20] For the same type of dental materials such as titanium alloy (milling) and titanium alloy (laser sintering) which have different fabrication processes, though they have the same effective atomic number of these dental materials, the densities are different. The density of milled titanium alloy is slightly higher than laser sintered titanium alloy (Table 1). Selective laser sintering (SLS) is an additive technique which results in more porosities in this internal structure than milled titanium alloy which is fabricated by a milling technique from titanium block. In this study, it was found that dose enhancement in titanium alloy (milling) was slightly higher than titanium alloy (laser sintering) but there was no statistically significant difference between these materials. It could be inferred that the density of dental materials influences the different backscattered dose despite their identical compositions. Similar to a previous study which compared backscatter between titanium sheet and mesh, backscattered dose in titanium sheet was higher than titanium mesh.[21] Therefore, the differences in the atomic number, compositions and densities of dental materials influence the difference in backscattered dose enhancement.[17,20,22]

Backscattered radiation is the reversed radiation beam existing at tissue-material interface resulting in increased dose which is caused by scattered secondary electrons from higher atomic number material.[7-9] This photon interaction was a result of Compton effect, pair production and photoelectric effect. The Compton effect is the effect in which a photon interacts with an outer orbital electron (low-binding energy) resulting in scattering in different directions between photons and electrons. The effect of high photon energy (excess of 1.02 MeV) attacks to either the field of the nucleus in atoms or the orbital electrons was pair production. When the incident photon interacts with the field of the atomic nucleus, this energy transforms into an electron and a positron, moving in the opposite directions. When the incident photon interacts with an orbital electron in an atom, three particles, two electrons and one positron, are produced from the interaction site. The Photoelectric effect is the effect that a photon interacts with a firmly bound inner orbital electron of atomic shells (high-binding energy electron) and transfers all energy to that electron. The Compton effect was predominant in the wide photon energy range from ~20 KeV to 20 MeV and was dependent on electron density of the material but independent on atomic number (Z) while pair production together with the photoelectric effect were dependent on atomic number (Z2).[23-25] Increasing the dose originated by backscattered radiation of the head and neck cancer treatment has undesirable outcomes. It could lead to oral complications such as mucositis for metal restorations and bone necrosis around a dental implant.[11] An increase in the incidences of bone necrosis around the osseointegrated titanium implants was reported as a result of dose enhancement of 10 - 15 % and 15-21 %.[26,27] Based on observations, gold alloy type I, gold alloy type IV, palladium alloy and zirconia showed more than 15 % increasing dose (Fig. 4). Hence, dentists should be aware when using these materials which could lead to oral mucositis and osteoradionecrosis. There were some recommendations of management for the implant system during radiotherapy. Removal of implant superstructures (all prostheses, frameworks and abutments) should be done prior to irradiation whereas the remaining implant substructures (implant fixtures) in bone should be covered with intact skin or mucosa.[10] A HA-coated implant was suggested to be utilized for high-risk head and neck cancer patients because it has the lowest scattered radiation.[15,16] Moreover, since mucositis resulting from backscattered-dose-enhancement effect is a major complication of radiotherapy, a fluoride tray without fluoride gel or protective stent or dental guard in thickness of 3 or 5 mm is recommended for these patients during radiotherapy.[17,19,28,29] In addition, placing a cotton roll soaked in water between restorations and soft tissue is also able to decrease the dose to the mucosa.[7] The reason is that the backscattered radiation dose significantly increased with the reduction of distance between tissue-metal interface. At 0 mm from tissue-metal interface was the distance of the highest dose enhancement.[15,17] Tso *et al.* found that at least a 50 % decrease in dose enhancement was observed in 1-mm distance from the interface and the lowest dose enhancement at 5-mm distance interface was noted.[17] One study noticed that the scattered radiation of 3-mm distance interface was rarely observed for backscattered dose.[15] Thus, this study measured dose at 0 mm interface because this distance was the highest back- and forward-scattered dose observation.

Nowadays, ceramic has become more popular for dental restorations even for implant abutment and fixtures such as zirconia material. Zirconia, with its tooth-like color or white color, is recognized as ceramic composed of metal oxide (ZrO_2) combined with rare earth oxides as pigment for ceramics. Zirconium is one of the transitional metal elements in the periodic table of which its' atomic number is 40.[30] In this study, the backscattered dose in zirconia was as high as other metal materials like gold alloy, palladium alloy, commercially pure titanium and titanium alloys. Especially, zirconia backscattered dose was significantly higher than commercially pure titanium and titanium alloys. This can be assumed that zirconia characteristically was conducted like metal. In ceramic materials, zirconia, lithium disilicate, feldspathic porcelain, dose enhancement in zirconia was 16.44 % which was higher than 15 % that might lead to osteoradionecrosis while the other ceramics were lower than 15 %.

On the contrary, a forward-scattered dose was generally reduced when the atomic number of dental materials was increased. In other words, percentage dose attenuation was mostly diminished by a decreasing atomic number. In this present study, the highest percentage dose attenuation was found in palladium alloy while the lowest one was found in feldspathic porcelain which was found as the lowest backscattered dose as well. This means that the higher the atomic number of dental materials is, the less the radiation penetration passing through these materials to the cancer target is found. It should be taken into account the dose attenuation to the cancer behind these scattering dental materials in order not to provide an under-prescribed dose to the cancer target. These results resembled other studies. Friedrich *et al.* found that a titanium implant absorbed almost 16 % of the dose behind it which were similar to the present study (approximately 12.30 % - 16.09 %).[31] Again, Çatli *et al.* said that the dose attenuation behind pure titanium and titanium alloy prostheses were 14.8 % and 14.2 %, respectively.[32]

The research design of this study tried to eliminate some errors in previous studies about dose measurement in antero-posterior beam from flat dosimeter attached to a curved specimen like a dental implant fixture which the measured dose was undervalued.[9,16] According to the flat surface of the OSL dosimeter in this study, the specimen was designed to also be a flat surface in order to magnify the OSL sensitivity. Consequently, a full scattered dose could be measured. A backscattered dose represented a dose at a direct surface of dental materials which was perpendicular to radiation, but did not depend on the surface area or size of dental materials.[26] Since intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) with rotating beam around the patient are used for radiotherapy for head and neck cancer[33], the total backscattered dose around the dental implant surface is observed as the same as flat specimens in this study. However, the limitation of this study was that even though the OSL dosimeter had several advantages such as high sensitivity, simple, small size and erasable measurement device, its accuracy was about ±10 % in which there were some errors of the measurement.[34]

Among the tested titanium groups, any titanium can be used in implant dentistry since backscattered doses were not statistically significantly different. However, zirconia (3Y-TZP) should be carefully used in the oral cavity because it has a higher backscattered dose than titanium material. Especially with increasing demands for esthetics, zirconia dental implants should be used with caution. Multidisciplinary care between a radiotherapist and a dentist is essential for radiotherapy treatment planning for radiation dose, field of radiation and dental management prior to radiotherapy. Moreover, as several side effects from radiotherapy can occur, periodic dental care in patients who have undergone radiotherapy is also significant to get a better quality of life. Further study should be conducted on the back- and forward-scattered dose of dental materials in the cadaver model which represents human soft tissue and bone.

Conclusion

Within the limitation of this *in-vitro* study, the following conclusions were drawn:

1. There were only four dental materials (gold alloy type I, gold alloy type IV, palladium alloy and zirconia) of which percentage dose enhancement was more than 15 %.
2. Among ceramic groups, zirconia showed the most backscattered dose enhancement of more than 15 %.
3. The higher atomic number and density of materials, the more backscattered dose enhancement and the less of forward-scattered dose were found.
4. Selection of proper dental restorative and implant materials in patients with high risk of head and neck cancer was important. Since zirconia (3Y-TZP) was observed in a higher backscattered dose than titanium material leading to osteoradionecrosis, zirconia dental implants should not have existed in the field of radiation with high dose to bone.
5. Due to backscattering effect at 0 mm from high atomic number of dental materials, metal alloys or zirconia framework on implant is recommended to remove from oral cavity during radiotherapy. Metal alloys or zirconia crowns or bridges are required to have a dental guard to prevent oral mucositis.

Acknowledgment

- Linear accelerator (Elekta Synergy, Stockholm, Sweden) was kindly supported by Assist. Prof. Dr. Sunantha Srisubat-Ploysongsang, Boonrut Vutiprasertpong and Sanchai Lookkaew; Radiation physicist from Horizon Regional Cancer Center, Bumrungrad Hospital, Bangkok, Thailand.

- OSL dosimeters (nanoDot, Landauer, USA) were kindly supported by Waraporn Sudchai, Nittima Rungpin and Natch Rattanarungruangchai; Nuclear scientist, Thailand Institute of Nuclear Technology (Public Organization).

- Statistical analysis was kindly provided by Dr. Nareudee Limpuangthip; Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University.

- Language assistance was kindly provided for by Dr. Wareeratn Chengprapakorn; Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University.

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