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Research Article

Dosimetric Effect of Metal Implant on Absorbed Dose

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Abstract

Objectives: The aim of this study was to evaluate the effect of a metal implant on the absorbed dose in a homogeneous phantom.

Methods: Thin sheets of stainless steel 1.0 mm, 1.5 mm, and 2.0 mm in thickness were used in this study. They were reduced to 3 samples of a width of 1.0 mm and 9.0 mm in height for each thickness to serve as the metal implant. A Farmer chamber (FC65-G) was used to measure the absorbed dose of radiation in a solid water phantom 30x30x1 cm and 30x30x2 cm in size. The entrance window to the phantom was 1 mm from the center of the chamber with a 0.7-cm radius. The set-up was irradiated for 30 seconds using a Cobalt-60 unit at a Source to Surface Distance (SSD) of 80 cm. An electrometer produced by Wellhofer calibrated with the chamber was used to record the absorbed dose (mGy) in samples with the implant and without, in position at field sizes of 5x5 cm^2 and 10x10 cm^2. Depths of 1.7 cm, 2.7 cm, 3.7 cm, and 4.7 cm were used for each measurement.

Results: There was a greater variation in dose measured at higher depth (greater than 5 cm) with the 1-mm implant in the 10x10 cm^2 field. The absorbed dose measured decreased as the depth of the implant increased. Also, the dose measured for the 1-mm implant was within the recommended ±5% accuracy, except at a depth greater than 5 cm. However, for the 1.5-mm and 2-mm implants, deviations were higher at almost all depths. There was an increase in dose at large field sizes. Furthermore, a decrease in dose was observed as the thickness and depth of the implant increases.

Conclusion: The higher attenuation of a metal implant causes variations in dose.

Keywords: Absorbed dose, cobalt-60 unit, dosimetry, ionization chamber, metal implant, phantom

Dosimetry deals with methods for the quantitative determination of absorbed dose in a given medium by directly or indirectly ionizing radiation.[1] The success or failure of radiation therapy treatments depends upon the accuracy with which the dose prescription is fulfilled. For many diseases, the outcome of the treatment depends upon the dose being delivered to an accuracy of +3%–4% (one standard deviation).[2, 3] Some authors argued that metallic foreign bodies in irradiated individuals do not alter the tissue-adjusted irradiation by any measurable manner. Others stress the impact of implants on the route of the central beam of the irradiation source. It points to a quantitatively noteworthy deviation of X-rays following the collision of irradiation and implants, resulting in scattering radiation effects on tissues beyond the threshold of biological compensation.[4-7] Clinical studies usually address the risk of implant failures in irradiated jaws[6] and human studies on dental implants exposed to therapeutic irradiation are

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casuistic.[5] The presence of a high-Z inhomogeneity in an irradiated water phantom or patient results in attenuation of the radiation through the inhomogeneity as well as local perturbations known as interface effects.[8-12] Dental fillings, metal plates, portacaths and pacemakers are just a few examples of high-density implants that may be found in the human body. The presence of a high density object in a radiation field causes significant perturbations to the resulting dose distribution, so, high density implants are a matter of concern in radiotherapy treatment planning.[13-15] For metallic interfaces encountered in prosthetic implants, dose increases of up to 50% which are measured in the backscatter direction within the range of electrons set in motion by 18 MV x-rays. At such higher energies, the transition zone extends over several centimeters and can affect a significant volume of adjoining tissue, with a potential for adverse clinically observed reactions.[16-21] In this work we investigated the effect of metal implant on absorbed dose of a homogenous phantom with and without the presence of stainless steel metal implants.

Methods

Thin sheets of stainless steel of thickness 1.0 mm, 1.5 mm and 2.0 mm obtained from Rail Stainless steel works, Ikeja, Nigeria were used in this study. They were reduced to three samples of 1.0 mm width and 9.0 mm height for each thickness to serve as the metal implant. The entrance window in the phantom (Fig. 1) was made very thin, 1 mm and 0.7 cm radius from the centre of the ionization chamber. A calibrated FC65-G ionization chamber manufactured by IBA dosimetry, Germany was used to measure the absorbed dose delivered by the Gamma beam X200 cobalt-60 machine and the machine was calibrated following the formalism recommended by the International Atomic Energy Agency (IAEA) in their technical report series 398.[22] The absorbed

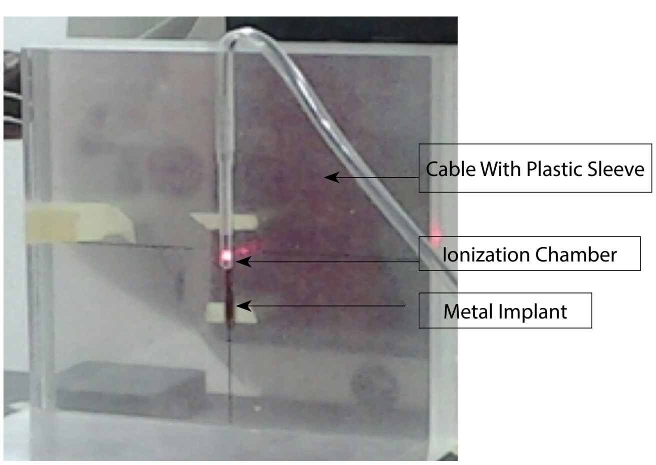

Figure 1. Solid water phantom.

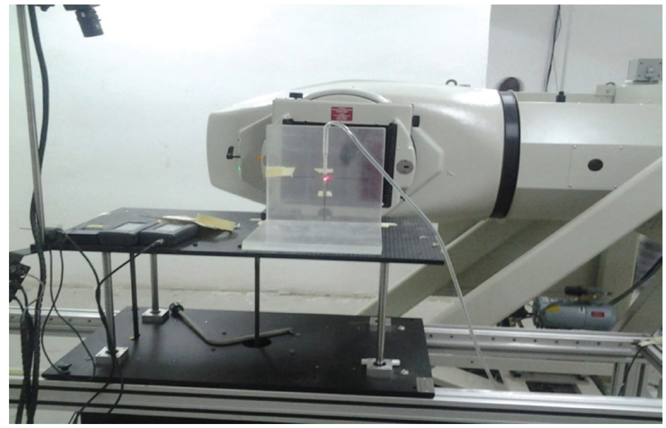

Figure 2. The solid water phantom set-up with ^{60}Co teletherapy facility at NIRPR, Ibadan.

dose to water calibration factor, $N_{D,W}$ obtained for the ionization chamber used is 48.21 mGy/nC. The absorbed dose to water was measured in solid water phantom arranged in dimension 30x30x10 cm at a reference depth of 5 cm, SSD=80 cm and field size 10x10 cm^2 setting the irradiating time to 30 seconds. Three uncorrected electrometer readings were obtained and the temperature and pressure were obtained to be 25.7 0C and 987.4 hpa respectively. An average of three (3) measurements corrected for temperature and pressure were used for the final calculation of the absorbed dose. The absorbed dose at reference depth of 5 cm was calculated as follows:

$$D_w (z_{ref})=MxN_{D,W}xK_{T,P} \quad (1)$$

$D_w (z_{ref})$ was obtained as 592.3 mGy, where corrected electrometer reading, M=11.75 nC and correction factor for ionization chamber, $K_{T,P}$=1.046. The absorbed dose rate to water at z_{ref} calculated was 19.74 mGy/sec.

Absorbed dose in homogenous phantom at predefined depth for set-up without implants and with implants are obtained and tabulated for different selected field sizes.

$$N_{D,W}=48.21 mGy/nC \text{ for the chamber} \quad (2)$$

$$K_{T,P}=\frac{(273.15+T)xP_O}{(293.15xP)} \quad (3)$$

where P_o=1013.15 hpa, P is pressure and T is temperature reading obtained from Hopewell designed monitor that gives the standard environmental conditions for which the ion chamber's calibration factor applies.

$$\text{Corrected reading, } M=RxK_{T,P} \text{ (nC/s)} \quad (4)$$

where R is uncorrected electrometer reading and M is the corrected electrometer reading.

$$\text{Absorded dose}=MxN_{D,W} \text{ (mGy)} \quad (5)$$

A Farmer chamber type FC65-G ionization chamber was placed in a milled track or hole inside the solid water phantom slabs of 30x30x1 cm and 30x30x2 cm behind the implants.

The set up (Fig. 2) was irradiated for 30 seconds using a Gamma beam X 200 (GBX 200) Cobalt 60 unit at SSD of 80 cm. A Dose 1 reference class electrometer produced by Wellhofer calibrated with the FC65-G ionization chamber was used to record the absorbed dose (mGy) of the setup for with implant and without implant, irradiated at field size 5x5 cm^2 and 10x10 cm^2. A depth of 1.7 cm, 2.7 cm, 3.7 cm and 4.7 cm was used for each measurement for the set-up with implant and without implant for 1 mm, 1.5 mm and 2.0 mm thickness.

Results

The result of the absorbed dose (mGy) for 1 mm implant at 5x5 cm^2 field size and percentage deviation in solid water phantom for set-up with and without implants is presented in Table 1. The result of the absorbed dose (mGy) for 1.5 mm implant at 5x5 cm^2 field size and percentage deviation in solid water phantom for set-up with and without implants is presented in Table 2. The result of the absorbed doses (mGy) for 2 mm implant at 5x5 cm^2 field size and percentage deviation in solid water phantom for set-up with and without implants is presented in Table 3. The result of the absorbed doses (mGy) for 1 mm implant at 10x10 cm^2 field size and percentage deviation in solid water phantom for set-up with and without implants is presented in Table 4. The result of the absorbed doses (mGy) for 1.5 mm implant at 10x10 cm^2 field size and percentage deviation in solid water phantom for set-up with and without implants is presented in Table 5. The result of the absorbed dose (mGy) for 2 mm implant at 10x10 cm^2 field size and percentage devi-

Table 1. Measured absorbed dose and percentage deviation for homogeneous solid water phantom irradiated at 5x5 cm^2 with 1 mm thickness implant at various depths

	Measured Absorbed Dose (Mgy)		
Depth (cm)	Without Implant	With 1 mm Implant	%Dev
1.7	633.85	607.06	-4.2
2.7	588.57	561.83	-4.5
3.7	545.34	525.19	-3.7
4.7	501.23	483.18	-3.6
5.7	462.02	446.46	-3.4

Table 2. Measured absorbed dose and percentage deviation for homogeneous solid water phantom irradiated at 5x5 cm^2 with 1.5 mm thickness implant at various depths

	Measured Absorbed Dose (Mgy)		
Depth (cm)	Without Implant	With 1.5 mm Implant	%Dev
1.7	633.85	598.35	-5.6
2.7	588.57	556.90	-5.4
3.7	545.34	524.99	-3.7
4.7	501.23	476.97	-4.8
5.7	462.02	444.14	-3.9

Table 3. Measured absorbed dose and percentage deviation for homogeneous solid water phantom irradiated at 5x5 cm^2 with 2 mm thickness implant at various depths

	Measured Absorbed Dose (Mgy)		
Depth (cm)	Without Implant	With 2 mm Implant	%Dev
1.7	633.85	594.72	-6.2
2.7	588.57	557.01	-5.4
3.7	545.34	507.09	-7.0
4.7	501.23	475.95	-5.0
5.7	462.02	437.80	-5.2

Table 4. Measured absorbed dose and percentage deviation for homogeneous solid water phantom irradiated at 10x10 cm^2 with 1 mm thickness implant at various depths

	Measured Absorbed Dose (Mgy)		
Depth (cm)	Without Implant	With 1mm Implant	%Dev
1.7	668.91	642.26	-4.0
2.7	627.69	599.84	-4.4
3.7	587.13	568.05	-3.2
4.7	546.98	527.38	-3.6
5.7	509.67	482.90	-5.3

Table 5. Measured absorbed dose and percentage deviation for homogeneous solid water phantom irradiated at 10x10 cm^2 with 1.5 mm thickness stainless steel implant at various depths

	Measured Absorbed Dose (Mgy)		
Depth (cm)	Without Implant	With 1.5 mm Implant	%Dev
1.7	668.91	632.10	-5.5
2.7	627.69	594.41	-5.3
3.7	587.13	558.06	-5.0
4.7	546.98	521.54	-4.7
5.7	509.67	491.19	-3.6

Table 6. Measured absorbed dose and percentage deviation for homogeneous solid water phantom irradiated at 10x10 cm^2 with 2 mm thickness implant at various depths

	Measured Absorbed Dose (Mgy)		
Depth (cm)	Without Implant	With 2 mm Implant	%Dev
1.7	668.91	628.76	-6.0
2.7	627.69	594.11	-5.3
3.7	587.13	558.06	-5.0
4.7	546.98	520.90	-4.8
5.7	509.67	485.02	-4.8

ation in solid water phantom for set-up with and without implants is presented in Table 6.

Discussion

Comparison of absorbed doses measured for various depths at field size 5x5 cm² for metal implant.

From Table 1, the deviation of the absorbed dose for the 1 mm implant at depth of 1.7 cm from the measurement without implant was 4.2%, deviation at depth of 2.7 cm was 4.5%, at 3.7 cm the deviation was 3.7%, at 4.7 cm the deviation was 3.6%, and at 5.7 cm the deviation is 3.4%.

From Table 2, the deviation of the absorbed dose for the 1.5 mm implant at depth of 1.7 cm from the measurement without implant was 5.6%, deviation at depth of 2.7 cm was 5.4%, at 3.7 cm the deviation was 3.7%, at 4.7 cm the deviation was 4.8%, and at 5.7 cm the deviation is 3.9%.

From Table 3, the deviation of the absorbed dose for the 2 mm implant at depth of 1.7 cm from the measurement without implant was 6.2%, deviation at depth of 2.7 cm was 5.4%, at 3.7 cm the deviation was 7.0%, at 4.7 cm the deviation was 5.0 %, and at 5.7 cm the deviation was 5.2%.

Comparison of absorbed dose measured for various depths at field size 10x10 cm² for metal implant.

From Table 4, the deviation of the absorbed dose for the 1 mm implant at depth of 1.7 cm from the measurement without implant was 4.0%, deviation at depth of 2.7 cm was 4.4%, at 3.7 cm the deviation was 3.2%, at 4.7 cm the deviation was 3.6%, and at 5.7 cm the deviation was 5.3%.

From Table 5, the deviation of the absorbed dose for the 1.5 mm implant at depth of 1.7 cm from the measurement without implant was 5.5%, deviation at depth of 2.7 cm was 5.3%, at 3.7 cm the deviation was 5.0%, at 4.7 cm the deviation was 4.7%, and at 5.7 cm the deviation was 3.6%.

From Table 6, the deviation of the absorbed dose for the 2 mm implant at depth of 1.7 cm from the measurement without implant was 6.0%, deviation at depth of 2.7 cm was 5.3%, at 3.7 cm the deviation was 5.0%, at 4.7 cm the deviation was 4.8%, and at 5.7 cm the deviation was 4.8%.

Comparative analysis of absorbed dose for all thicknesses and field sizes.

Across the tables, deviations increased with increase in implant thickness; this is as a result of increase attenuation caused by the implant materials. This was in accordance with Khan[23] who showed that there would be reduction in the number of photons when interacting with an absorber (metal) is proportional to the number of incidence photons and to the thickness of the absorber.

There was a higher variation in absorbed dose measured at higher depth (greater than 5 cm) with the 1 mm implant in 10x10 cm² field size as shown in Table 4. The absorbed dose measured decreases down the table; as the depth of the implant increases. Also, the absorbed dose measured for 1 mm implant was within the recommended±5 % accuracy except at depth above 5 cm. However, for the 1.5 and 2 mm implant, deviations were higher for almost all depths.

Cheung et. al.,[24] observed dose deviation from 32 % to 68 % close to the platinum implant for 4, 6, and 10 MV energies when using a 12.5 mm collimator. Comparatively higher dose deviation were observed when using smaller collimators and it was suggested that field size and energy should be taken into account when planning radiation therapy treatment for patients with dental implants. This is in agreement with part of our findings, because the measured absorbed dose increased with increase in field size as shown in Tables (1–6). Main et al.,[25] report showed that; an increase in dose fell off rapidly at the distance of 1–2 mm from the interface between solid bone and titanium implant, Mimura et. al.,[26] reported that palladium plate for dental disease resulted in maximum 150% change in dose at 5 mm behind the plate, and Tamada et. al.,[17] reported scattering on dose at 4 to 10 mm from stainless plates and reduction in dose with depth was compensated for using opposing portal irradiation. These show that there are variations in absorbed dose with increasing depth as shown in our findings.

The uniqueness of this work was in the consideration of the effect of depth from the implant to the surface of irradiation. It was shown in all the thicknesses of implant used that dose decreases with the increasing depths and are within the tolerance level in some cases especially with 1 mm implant but depth should be taken into consideration when treating patients with metal implants especially when the thickness is greater than 1 mm in cobalt units.

Conclusion

A study on the dosimetric effect of metal implant on absorbed dose has been carried out. There was an increase in absorbed dose at larger field sizes. There was decrease in absorbed dose as the thickness and depth of the implant increases. These variations in absorbed dose are caused by the higher attenuation of the metal implant. Correction factor should be applied for stainless steel metal implants of thicknesses greater than 1 mm for all field sizes and if the insert is at a distance greater than 5 cm from patients' surface. This correction is necessary to prevent under-dose of the patients with implants and for the optimization of radiotherapy when treating patients with metal implants.

Disclosures

Ethics Committee Approval: The study is a laboratory work and therefore requires no ethical approval.

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

Authorship contributions: Concept – M.O.A., A.D.O., M.Y.H.; Design – M.O.A., A.D.O., M.Y.H.; Supervision – M.O.A., A.D.O., M.Y.H.; Materials – M.O.A., A.D.O., M.Y.H.; Data collection &/or processing – S.O.A., M.A.A., T.A.O., A.E.O.; Analysis and/or interpretation – S.O.A., M.A.A., T.A.O., A.E.O.; Literature search – S.O.A., M.A.A., T.A.O., A.E.O., M.E.E., O.B.A; Writing – M.O.A., A.D.O., M.Y.H., S.O.A., M.A.A., T.A.O., A.E.O.; Critical review – S.O.A., M.A.A., T.A.O., A.E.O.

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