Radiation Backscatter of Zirconia

THESIS
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Abstract

Introduction:

Cancer is still the second cause of death worldwide with head and neck cancer being about 3% of the total number of diagnosed cases. Surgery is still one of the most effective treatment modalities. It often causes debilitating morbidity to the oral-pharyngeal structures. Currently, certain cases are being treated primarily with radiation and/or chemoradiation since the outcomes when compared to surgery are similar.

When high-energy radiation (photons) interact with electron-dense materials. Secondary electrons are produced from radiation interaction with these materials such as metals. This is termed “Radiation backscatter” and this results in adjacent tissues receiving an additional, unintended dose.

Also to be considered is the visual artifacts that are caused by electron dense materials during CT scanning adversely affect the quality of the scan and its diagnostic value.

Research has been done in the past to determine the amount of radiation backscatter caused by various dental materials and it was determined that gold and gold alloys causes the most scatter followed by amalgam and titanium respectively.

The use of Zirconium has increased significantly in medicine and dentistry during the past forty years. It was first introduced in medical prosthetics in 1969 as an orthopedic hip replacement implants. Currently, Zirconia restorations are a large percentage of the dental marketplace. There has been a great increase in the demand for zirconia-based restorations, both by patients, and dentists. Aggressive marketing programs for more esthetically pleasing restorations have driven this demand.
**The aim** of our study is to compare dose enhancement factor/ backscatter of Zirconia to other commonly used dental materials. Due to the density of Zirconia compared to other previously tested dental materials we hypothesize that there is a decrease in dose enhancement around Zirconia compared to gold and amalgam and an increase in dose enhancement when compared to titanium and lithium disilicate.

**Materials and methods:**

Two studies were conducted the first one was using Dosimetry (thin window parallel plate electron chamber) to measure the amount of ionizing radiation backscatter or dose enhancement factor at the tissue-material interface from radiation energies of 6MV and 10 MV on 50mm x 50mm x 2mm samples made of (amalgam, zirconia, titanium & lithium disilicate) with and without stent materials (1,2,3 mm thick).

The second experiment is aimed at obtaining computerized tomography (CT) images to determine the relative amount of scatter artifacts produced by each of the tested materials.

**Results:**

The first study showed that the highest radiation dose enhancement from backscatter was 60% for amalgam, 30% for zirconia, 20% titanium and only 10% for lithium disilicate when measured at the surface of the material. No difference was noticed in the amount measured between the two different radiation energies. When using a 2mm stent material all materials produced an insignificant amount of scatter except for amalgam that produced only 10% of increased radiation. A 3mm thickness reduced the backscatter by all tested materials to almost none.
Our second study showed a clear advantage of lithium disilicate crowns since they produced an insignificant distortion to the CT images in comparison to the extensive CT image distortion caused by metal artifacts produced by gold, zirconia and PFM crowns.

Discussion

Our date is in agreement with previous research done on amalgam and titanium. Knowing the harmful effect of high-energy ionizing radiation on healthy cells and the reduction of the quality of life that accompanies these effects; its more beneficial to use alternative materials like lithium disilicate to be able to produce clear and usable diagnostic CT images, and to reduce the amount of radiation overdose surrounding metallic restorations.

Conclusions

1. Gold, Zirconia and PFM restorations have a deteriorating effect on the quality of CT images due to artifacts produced by scatter from high-density and metallic restorations. Lithium disilicate restorations, on the other hand, cause minimal artifacts.

2. The greatest increase in backscatter radiation measured was in direct contact with the tested materials and was found to be:
   - 60% for amalgam.
   - 30% for zirconia.
   - 20% for Titanium.
   - 10% for Lithium Disilicate.
3. Within the limits of our study no difference was noticed in the amount of backscatter radiation measured between the two radiation energies 6MV and 10MV.

4. At a thickness of 2 mm all tested materials produced an insignificant amount of backscatter except for amalgam. However, most amalgam restorations are confined by tooth structure that reduces its backscatter effect.
Dedicated to:

My Mother and Father may Allah bless their souls
Acknowledgements

I would like to express all my gratitude for my research advisor Dr. Robert Seghi, and my committee members Dr. VanPutten Jr. and Dr. Chaudhry for their hard work, insight and knowledge that they shared with me during my work.

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I Personally owe this to God who always had his helping hands over me throughout my life. My beloved mother that raised my siblings and I to thrive for the best, and taught us the true meaning of courage and perseverance. I wish we could someday repay her for all she has done for us, without her I wouldn’t accomplish anything.

My brother and sisters whose support and encouragement were something I can always count on and my fiancé that loved me and supported me unconditionally through those tough days of my residency I can not thank you all enough.
VITA

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FIELDS OF STUDY

Major Field: Dentistry
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CHAPTER 1
INTRODUCTION
1.1. ZIRCONIA

Zircon has been known as a gem since ancient times. The name of the metal, zirconium comes from the Arabic Zargon (golden in color). Zirconia, (ZrO$_2$), was identified in 1789 by the German chemist *Martin Heinrich Klaproth* in the reaction product obtained after heating some gems, and was used extensively as pigment for ceramics when combined with rare earth oxides (C. Piconi, 1999).

The use of Zirconium has increased significantly in medicine and dentistry in during the past forty years. Zirconia (ZrO$_2$) was first introduced in medical prosthetics in 1969 as an orthopedic hip replacement implant (Manicone, Rossi Iommetti, & Raffaelli, 2007). It has gradually made its way as a restorative material into dentistry since then. Active research continues to uncover more and more uses of Zirconium in the ever-evolving field of dentistry.

Zirconia is present in three crystallographic forms at different temperatures: cubic (c) tetragonal (t) and monoclinic (m), the latter being the most stable form at room temperature (Kisi E, 1998).

Several elements were used to stabilize Zirconia, in dentistry. The use of Yttrium and cesium as stabilizers has proven to be successful; however, the Yttrium-tetragonal Zirconia poly crystal form 3Y-TZP is the most commonly used stabilized form (C. Piconi, 1999).
In 1975 Gravie used the term (ceramic steel) in his article while describing the mechanical properties of partially stabilized zirconia (Garvie, Hannink, & Pascoe, 1975). Currently Zirconium oxide (ZrO₂) or Zirconia is being falsely advertised as a metal free restoration due to its physical appearance since it doesn’t follow the expected metallic appearance of commonly used metals in Dentistry (gold, titanium, nickel-chromium, etc.). This quality alone was very appealing to both dentists and patients and was a catalyst for increased interest in discovering more about this material.

Continued research and the successful use has proven the following significant advantages of ZrO₂:

1- **High Strength** numerous investigations showed superior strength of Zirconia in comparison to other dental materials [900-1200 MPa up to 200MPa] Table [1](C. Piconi, 1999; Guazzato, Albakry, Ringer, & Swain, 2004).

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Alumina</th>
<th>Mg-PSZ</th>
<th>TZP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition</td>
<td>99.9% Al₂O₃</td>
<td>ZrO₂</td>
<td>ZrO₂</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>g cm⁻³</td>
<td>≥597</td>
<td>5.74-6</td>
<td>&gt;6</td>
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<tr>
<td>Porosity</td>
<td>%</td>
<td>&lt;0.1</td>
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<td>&lt;0.1</td>
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<tr>
<td>Bending strength</td>
<td>MPa</td>
<td>&gt;500</td>
<td>450-700</td>
<td>900-1200</td>
</tr>
<tr>
<td>Compression strength</td>
<td>MPa</td>
<td>4100</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Young modulus</td>
<td>GPa</td>
<td>380</td>
<td>200</td>
<td>210</td>
</tr>
<tr>
<td>Fracture toughness Kᵥ</td>
<td>MPa m⁻¹</td>
<td>4</td>
<td>7-15</td>
<td>7-10</td>
</tr>
<tr>
<td>Thermal expansion coeff.</td>
<td>K⁻¹</td>
<td>8 × 10⁻⁶</td>
<td>7-10 × 10⁻⁶</td>
<td>11 × 10⁻⁶</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W mK⁻¹</td>
<td>30</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Hardness</td>
<td>HVI 0.1</td>
<td>2200</td>
<td>1200</td>
<td>1200</td>
</tr>
</tbody>
</table>

Table 1 Characteristics of some ceramics for biomedical applications.(C. Piconi, 1999)
2- **Transformation toughening phenomena:** has been described by several investigators (Denry & Kelly, 2008; Holloway, 2010; Porter, Evans, & Heuer, 1979).

If the material is stressed and a crack develops mechanically at room temperature, the induced stress causes the tetragonal crystal in the vicinity of the crack to transform into a (4-5%) larger volume grain and more stable monoclinic phase, by doing so it closes the crack and provides the much needed compressive stress that limit the crack propagation.

3- **Pleasing esthetics:** Zirconia inherently is white in nature, and can be layered with porcelain without the need for opaque that masks the noble metal substructure of the crowns.

The absence of metal collar in visible/esthetic areas of the mouth, and the lack of metallic coloring effects on the oral tissue all makes zirconia restorations much more desirable than traditionally used metallic counter parts (Christensen, 2007).

4- **Biocompatible:** Zirconia is not soluble in water, has been shown to lack cytotoxicity and does not enhance the bacterial adhesion when compared to titanium, as demonstrated by both in vitro and in vivo studies. Several studies have shown that zirconia has no adverse effects on hard or soft tissues (Dion et al., 1994; Hulbert, Morrison, & Klawitter, 1972; Ichikawa, Akagawa, Nikai, & Tsuru, 1992).
5- **Ease of fabrication:** CAD/CAM technologies are being used in the production of Zirconia restorations (Holloway, 2010). One method is the soft machining of pre-sintered blocks that are designed and milled 20-25% larger then shrink during the sintering process; Another method is hard machining of sintered blocks on normal size dies (F. Filser, 2003).

Both processes are less technique sensitive and cost effective when compared to the traditional casting process for porcelain fused to metal [PFM] crowns and fixed partial denture cases (waxing, casting, finishing & polishing all prior to porcelain layering).

6- **Low Cost:** Initially Zirconia was more costly than the traditional cast PFM restorations. However, since the advent of CAD/CAM technologies and due to the high prices of gold in recent years; the cost of producing zirconia restorations has significantly decreased.

Furthermore, the use of CAD/CAM allows for long-term data storage, which allows for identical duplication of the original restoration in cases of restoration failure or loss, this reduces chair time for the dentist and reduces lab production time and cost, hence the laboratories charge a lesser fee for such duplicates..

7- **No Galvanic effect:** Zirconia films are good insulators. The only competitor in the electrical insulator field is hafnium oxide, and both are being considered as insulators in micro- electronic devices because of their excellent resistivity and high band-gaps(L. B. Golden, 1953; Ron Adamson, 2007).
Due to these factors Zirconia has been considered one of the most important restorative materials used in dentistry (Christensen, 2007) Currently it’s being successfully used in:

- Crowns, inlays and onlays.
- Fixed partial dentures.
- Frameworks for dental prosthetics.
- Zirconia implants fixtures and abutments.

Some of the physical properties of concern with the use of Zirconia; are “Low temperature degradation” (Kobayashi, Kuwajima, & Masaki, 1981) which seem to change the zirconia crystal from meta stable tetragonal to a larger monoclinic more stable form; leading to grain pullout and micro cracking (Denry & Kelly, 2008). But such transformation can be reversed by process of annealing (Holloway, 2010).

Another concern is the opaque nature of zirconia. This creates a less than natural translucent effect (Michael J. Heffernan, Ana M. Diaz-Arnold, & Marcos A. Vargas, 2002)on Zirconia restorations. This has been overcome by the development of more translucent forms of zirconia restorations and the use of special porcelain to layer zirconia substructures.

Currently, zirconia restorations comprise a large percentage of the dental marketplace. There has been a great increase in the demand for zirconia based restorations. This is a result of both a strong marketing strategy by manufacturers and dentist/patient demands for more esthetically pleasing restorations.

One of the obscure aspects of zirconia is its backscatter effect during the exposure to radiation during CT scanning and cancer radiation therapy.
1.2. Radiation Therapy:

Medicine and dentistry have made significant discoveries in the treatment of head and neck cancer. However, cancer is still the second highest cause of death worldwide. It is estimated by The American Cancer Society that in 2013, head and neck cancer will be 3% of the total number of diagnosed cases in the USA. It is expected that in 2013 the total number of new diagnosed cases will be about 1,660,290, with about 580,350 expected deaths. Also in 2013 there is an estimated total of 41,380 new diagnosed oral cavity and pharynx cancer cases with an expected 7,890 deaths in the USA (Siegel, Naishadham, & Jemal, 2013).

Treatment of head and neck cancer has improved in the past twenty years. Prevention is the best approach. Overall, the five-year prognosis is higher. However due to the 1.2% increasing rate of the world population according to “The World bank”i and the increased life expectancy it will likely increase the total number of people being diagnosed.

The management of head and neck cancer patients requires the combined efforts of a multidisciplinary team consisting of otolaryngologists, oncologists, radiologists, pathologists, dentists, and speech and language therapists. The goal is to cure the disease while maintaining function by preserving as much healthy tissue as possible. However, current therapies often cause significant morbidity and reduce the patient’s quality of life.

Surgery is still one of the most effective treatment modalities. It often causes debilitating morbidity to the oral-pharyngeal structures. Currently, certain cases are being treated

i http://www.worldbank.org/
primarily with radiation and/or chemoradiation since the outcomes when compared to surgery are similar. Patients are treated with either an ionizing radiation source or radioactive isotopes, which have been shown to be very effective especially in the early stages of certain head and neck cancers.

When combined with chemotherapy, radiation has been shown to increase the curative effects equivalent to 6-9 Gys (Eisbruch et al., 2002), chemoradiation therapy has proven to increases the survival rates (Pignon, Maître, Maillard, & Bourhis, 2009).

**Ionizing radiation** is any radiation capable of displacing electrons from atoms or molecules thereby producing ions. These ions (electrons, protons) can either directly interact with the target cellular molecules causing damage; or indirectly by interacting with water molecules and releasing free radicals, causing oxidation/reduction reactions in target cells. It tends to affect the nucleus more than the cytoplasmic organelles and by doing so causes one of the following effects in the target cells (Beumer, 2011; Elkind & Sutton, 1959):

1. Kills the cell immediately (apoptosis).
2. Causes damage to the chromosomal component of the cell leading to long term effect on the cell reproduction cycle that can either:
   a) Cause disruption in the reproductive process (reproductive death), or
   b) Recovery if the injury is not beyond the repair capability of the cell and adequate time for full recovery is allowed.
The effects on the cellular level are apparent on the tissue at the macroscopic level as either early or late effect of radiation/ ionization therapy (Beumer, 2011; Scully & Epstein, 1996):

I. Early effects:
   1. Ulceration.
   4. Dysphagia.
   5. Changes in oral mucosa.
   6. Erythema, desquamation and increased skin pigmentation.

II. Late effects:
   1. Altered taste and smell.
   2. Edema.
   3. Trismus.
   4. Velopharyngeal incompetence and altered speech.
   5. Salivary glad dysfunction (thick ropy saliva, dry mouth, etc.)
   6. Altered oral flora/candidiasis.
   7. Bone changes (lower rate of bone remodeling capabilities, Osteoradionecrosis (Marx, 1983; O’Dell & Sinha, 2011), implant integration failure)
   8. Periodontal changes (decrease cellularity and vascularity, widening of PDL space & loss of attachments).
   9. Dental changes: decrease cellularity and vascularity, and depending on the tooth age may cause alteration of the tooth structure.
   10. Radiation caries due to a lack of adequate salivary function.
Fear, confusion, anxiety and depression are common findings in cancer patients, which is why it is considered a biopsychosocial illness (Bultz & Carlson, 2006). When you consider the patient’s inability to, masticate, swallow or speak properly it is easy to understand the decrease in their quality of life. There are also varying levels of pain combined with a degree of disfigurement in many head & neck cancer cases. Depression is a significant problem, which can alter the patient’s ability to fight their disease.

A reduction in the effects of radiation is one of the primary goals of the radiation oncologist. In the past a bilateral source of radiation was used which was directed toward the target site. It affected both diseased and healthy non-cancerous tissue in its path. Advancements in CT scanning, digital/computerized planning and treatment has lead to development of the new a new method of treatment called Intensity Modulated Radiation Therapy (IMRT). Radiation oncologists use IMRT to develop a detailed plan using a CT scan of the target site. IMRT modifies the fluence of the radiation beam to create conformal non-convex dose distributions. (Bourhis, Le Maître, Baujat, Audry, & Pignon, 2007). When combined with chemotherapy there is approximately a 6.5% improvement in 5 year treatment outcomes when compared to just induction chemotherapy alone (Pignon et al., 2009).

Even with these improvements there are times when radiation treatment affects non-targeted tissues. This is due to the unavoidable passage of radiation through tissues adjacent to the tumor, as it shows in [figure 1.a & figure 1.b]. The target is noted in the red marked area that represents the highest dose. The surrounding tissues, shown in yellow receive a significant dose of radiation.
Figure 1. a) IMRT radiation value horizontal, b) IMRT radiation value Sagittal
This is also noticed in areas adjacent to metallic dental restorations. These areas receive higher dosages than the original treatment plan intended. This phenomenon has been studied and identified as *Backscatter radiation* (Scrimger, 1977).

**Radiation backscatter** occurs when high-energy radiation (photons) interacts with electron dense materials such as metals. Secondary electrons detach from the atomic shell and scatters. This results in adjacent tissues receiving an additional, unintended dose.

The amount of backscatter varies with energy of the radiation source. This localized overdose of radiation leads to harmful effects to the surrounding tissues.

Metallic restorations cause image artifacts that affect the image quality of CT scans used in both diagnosis and planning of therapeutic radiation treatment. The artifacts present as black streaks/voids that forms around metallic materials that were positioned in the way of x-rays during Scan acquisition (Mehran Yazdi, 2008) Figure [2].

![Figure 2 Metal Artifacts from multiple metallic restorations](image_url)
The presence of high-density objects is common in the oral cavity. Metallic objects such as dental restorations, surgical plates and pins cause backscatter attenuation of the x-ray beam. When the resultant image is reconstructed, these metals cause artifacts, which shown as bright and dark streaks in CT images. These artifacts significantly degrades the image quality (Barrett & Keat, 2004; Mehran Yazdi, 2008).

As Gibson noted the following advantages of CAD/CAM technologies on cancer treatment (Gibson, 2006) they are:

1. Improve diagnosis and planning.
2. Serves as teaching tools.
3. Provide surgical simulation.
4. Are tactile references during surgery.
5. Reduce operating time.
6. Improve clinician's overall accuracy and efficacy.

The artifacts can adversely affect cancer diagnosis and treatment. Misdiagnosis, improper planning of radiation fields and algorithms to be used during radiation treatment, and improper surgical simulation/tactile reference may result.

Multiple studies that quantify the amount of enhanced radiation dose [backscatter radiation] of various materials have been reported.

In a study to determine backscatter effects of Titanium implants on the surrounding bone it was found that there is a 15% increase in dose to solid bone at the entrance side of the titanium (Mian, 1987).
Farahani et al. studied the enhancement of dose from $^{60}$Co gamma ray and 10MV x-ray beams to soft tissue (or water) close to high electron-density materials. 18-carat gold dental casting alloy; Ag-Hg dental amalgam alloy; Ni-Cr dental casting alloy; and natural human tooth structure were evaluated. The “dose enhancement factor” on the backscattered side of the interface for each material was found to be: 2.0 for Ag-Hg amalgam, 2.0 for gold, 1.4 for Ni-Cr, 1.2 for teeth and 1.0 for tissue-simulating polymer (Farahani, 1990).

Wang et al. has studied and compared backscatter of three dental materials [gold alloy Au-Cu-Ag, commercially pure titanium (CPT) and titanium alloy (Ti-6Al-4V)] at distances of 0, 1, 2 & 3mm using X-ray energies of 6MV and 10 MV and found that the highest point of enhancement of radiation dose was at a distance of 0 mm from the bone/implant interface, the Au-CU-Ag dental implant material had a more average radiation dose than did CPT & titanium alloy (Wang, Pillai, & Jones, 1996).

A study by Reitemeier et al. determined the degree of absorption and backscatter effect of therapeutic radiation used in the presence of 4 different dental materials (a high-gold alloy, pure titanium, amalgam, and a synthetic material). They found that the dose increase in front of the materials was a maximum of 30%, 60%, and 70% for pure titanium, amalgam, and the high-gold alloy, respectively (Bernd Reitemeier 2002).

This translates to a considerable total overdose of 170%; that suggests that soft tissue surrounding dental restorations should be protected from radiation.

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This factor is defined as the ratio of the maximum dose in water or soft tissue close to a high atomic-number interface material to the dose in water or soft tissue in the absence of any extraneous material.
Reitemeier also reported that the highest dose increase was measured at a distance of 0.1 mm in front of the material surfaces. At a distance of 3 mm, the overdose decreased to less than 10% for the high-gold alloy. For pure titanium, no dose increase could be measured at this distance.

1.3. Aim

The use of Zirconia as a restorative material in dentistry has increased because of its appealing qualities, promotion by dental companies and laboratories. However, no studies have been done to study backscatter from this material.

The aim of our study is to determine and compare dose enhancement factor/backscatter of Zirconia to other commonly used dental materials.

1.4. Hypothesis

Due to the density of Zirconia compared to other previously tested dental materials [Table 2].

We hypothesize that there is a decrease in dose enhancement around Zirconia compared to Gold and Amalgam and an increase in dose enhancement when compared to Titanium and Lithium Disilicate.
<table>
<thead>
<tr>
<th>Material</th>
<th>Density g/cm³</th>
<th>elements</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>19</td>
<td>Au traces</td>
<td></td>
</tr>
<tr>
<td>Amalgam (permite, SDI)</td>
<td>13-11</td>
<td>Ag, Sn, Cu, In, Zn, Hg</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27.9</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>47.9</td>
</tr>
<tr>
<td>Zirconia (Y-TZP)</td>
<td>5.8</td>
<td>Zr, O</td>
<td>74</td>
</tr>
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<td></td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>CPT</td>
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<td>Ti, O₂, Fe, C, H₂, N₂</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.7</td>
</tr>
<tr>
<td>Lithium Disilicate</td>
<td>2.4</td>
<td>Li, Si, O</td>
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</tr>
<tr>
<td>Li₂Si₂O₅</td>
<td></td>
<td></td>
<td>53.4</td>
</tr>
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<td></td>
<td>26.8</td>
</tr>
</tbody>
</table>

Table 2 Density of some commonly used restorative materials in dentistry
CHAPTER 2
Materials and methods
2. Materials and Methods:

Two experiments were done. The first one aimed at measuring the amount of ionized radiation backscatter at the tissue/material interface “the dose enhancement factor”.

The second experiment was aimed at obtaining computerized tomography images to determine the relative amount of scatter artifacts produced by each of the tested materials.

2.1. First experiment:

Four materials were tested:

1. Zirconium Oxide (3Y-TZP)\(^{iii}\).
2. Commercially pure titanium [CPT].
3. Amalgam (Permite)\(^{iv}\).
4. Lithium Disilicate (Li\(_2\)Si\(_2\)O\(_5\))

These materials were prepared in samples of 50 mm X 50 mm squares that were 2 mm thick. All of the samples were imbedded within 2 mm thick desks made out of Polymethyl methacrylate (Ortho-jet resin\(^{v}\)) to facilitate stability during testing.

\(^{iii}\) Aidite: Qinhuangdao Aidite High-Technical Ceramics Co., Ltd. Qinhuangdao, Hebei, China (Tel) +86-335-8587898.

\(^{iv}\) Permite: SDI Limited. Victoria, Australia. (Tel) +61 3 8727 7111

\(^{v}\) Orthojet: Lang Dental Manufacturing Co., Inc. Wheeling, IL, USA (Tel) 1- (800) 222-5264
We used a linear accelerator radiation unit TrueBeam™ STx system (Varian Medical Systems) \( ^{\text{vi}} \) Figure [3]. It’s a medically commissioned linear accelerator, with multi-leaf collimator (MLC); image guided capabilities and multiple Megavoltage (MV) photon energies. It is IMRT capable and is used to treat patients with H&N cancer using this technique.

Intensity Modulated Radiation therapy (IMRT) uses a rotational multi-radiation source. It modulates the fluence of the radiation beam to cover the planned treatment volume (PTV) and avoid or minimize dose to adjacent organs at risk (OAR).

\[ \text{Figure 3 TrueBeam™ STx system (Varian Medical Systems)} \]

\( ^{\text{vi}} \) TrueBeam™ STx system: Varian Medical Systems, Inc. Palo Alto, California, USA (Tel) 1-800-544-4636
The Dosimetry system used in this experiment is a thin window parallel-plate electron chamber. The charge collected was measured by an electrometer.

The material tested was placed in between resin plates with a density equivalent to water. The electrometer was placed in a window within the top plate where it collected the charges of radiation near the tested material surface directly and then at various distances from the surface Figures [4 & 5].

Figure 4. Schematic of testing procedure 1
In order to simulate the effect of backscatter radiation at various distances, a resin material that had density equivalent to water known as a “solid water plates”, were placed in between the electrometer and the tested material surface at thickness of 1, 2, 3 and 5mm figures [6 and 7].
Testing was performed:

- With two different high-energy X-ray sources of 6MV, 10MV.
- At air pressure of 24.2 kPa.
- At a distance of 94cm from source to surface of sample.
- At a depth of 5.5-6mm
  - With the Electrometer voltage set to +300V.

A “backscatter factor” was calculated as the quotient of the ionization current scatter of the materials tested divided by the ionization current in the solid-water plates. The results are expressed as the factor by which the dose changed at the tissue-restorative material.
interface. This parameter is therefore expressed with reference to the tissue. This has been referenced as the 'dose enhancement factor' (Farahani, 1990).

The ionization current was then measured as the chamber was moved away from the material surface by insertion of 1, 2, 3 & 5 mm sheets of solid water plates acting as tissue equivalent materials.

To determine the effect of using a stent on the backscatter radiation dose, different thickness of commonly used occlusal stent (Great lakes Biostar® VI With Scan Technology Positive Pressure Thermal-Forming Machine and Great lakes Clear Mouthguard Material) were placed over the tested material samples. The same experiment was repeated to compare the results of using stent thickness of 1, 2 & 3 millimeters.

2.2. Second experiment:

Four crowns were made from the following materials Figure [8]:

1. Gold (Midas).
2. Zirconia (Cercon).
3. Lithium Disilicate (IPS e-max).
4. Porcelain fused to metal [PFM].

---

vii Great Lakes Orthodontics, Ltd. Tonawanda, NY, USA (Tel) 1-800-828-7626
viii Midas: J.F.Jelenko & Co. Armonk, NY, USA (Tel) 1-800-535-3656
ix Cercon® ht zirconia: DENTSPLY International, Inc. York, PA, USA. 1-800-243-1942
x IPS e.max® Press: Ivoclar Vivadent AG. Schaan, Principality of Liechtenstein (Tel) +423 235 35 35
xi Ceramco®3 porcelain: DENTSPLY International, Inc. York, PA, USA. 1-800-243-1942
xii Olympia alloy: J.F.Jelenko & Co. Armonk, NY, USA (Tel) 1-800-535-3656
All crowns had same dimensions and shape to fit a resin typodont of a lower right first molar [Figure 8].

The zirconia crown was fabricated by scanning the typodont and designing the crown on a 3Shape D800 3D Scanner 3. The remaining crowns were made to match the form and dimensions of the milled zirconia crown [Figures 10.a.b.c.d.e]

---

3. 3Shape D800™ 3D Scanner: 3Shape A/S, Copenhagen, Denmark (Tel) +45 7027 2620
Figures 10. a) typodont, c) scan, d) chosen tooth model, e) finished Zirconia crown
Two typodonts were arranged around a balloon containing water in a fashion that simulated the relationship of alveolar ridge and teeth with the tongue. The CT Scan was acquired with SOMATOM Sensation Open\textsuperscript{xiv}. It’s a multi-slice CT scanner, used specifically for radiation therapy.

Visual evaluation and comparison of the CT images of all four crowns was done.

\textsuperscript{xiv} SOMATOM Sensation Open: Siemens Medical Solutions USA, Inc. Malvern, PA, USA 1-800-888-7436
CHAPTER 3
RESULTS
3. RESULTS:

3.1. First experiment Radiation backscatter measurement:

3.1.1. Dose 6MV

The results obtained from testing backscatter from solid water for standardization were obtained:

Table 3 Radiation base readings without any dental materials at 6MV

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio of reading to 0 distance</th>
<th>Ratio comparing No material to material at same depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.494</td>
<td>1.495</td>
<td>1.494</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1.5102</td>
<td>1.504</td>
<td>1.507</td>
<td>1.008</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1.514</td>
<td>1.513</td>
<td>1.513</td>
<td>1.012</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1.531</td>
<td>1.525</td>
<td>1.528</td>
<td>1.022</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1.544</td>
<td>1.542</td>
<td>1.543</td>
<td>1.032</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4 Testing of Amalgam Dose enhancement factor at 6MV

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.357</td>
<td>2.346</td>
<td>2.351</td>
<td>1</td>
<td>1.573</td>
</tr>
<tr>
<td>1</td>
<td>1.887</td>
<td>1.886</td>
<td>1.887</td>
<td>0.802</td>
<td>1.251</td>
</tr>
<tr>
<td>2</td>
<td>1.742</td>
<td>1.736</td>
<td>1.739</td>
<td>0.739</td>
<td>1.149</td>
</tr>
<tr>
<td>3</td>
<td>1.653</td>
<td>1.652</td>
<td>1.653</td>
<td>0.703</td>
<td>1.081</td>
</tr>
<tr>
<td>5</td>
<td>1.598</td>
<td>1.593</td>
<td>1.596</td>
<td>0.678</td>
<td>1.034</td>
</tr>
</tbody>
</table>

Table 5 Testing of Zirconia Dose enhancement factor at 6MV

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.001</td>
<td>1.996</td>
<td>1.998</td>
<td>1</td>
<td>1.337</td>
</tr>
<tr>
<td>1</td>
<td>1.706</td>
<td>1.702</td>
<td>1.704</td>
<td>0.852</td>
<td>1.130</td>
</tr>
<tr>
<td>2</td>
<td>1.616</td>
<td>1.616</td>
<td>1.616</td>
<td>0.808</td>
<td>1.067</td>
</tr>
<tr>
<td>3</td>
<td>1.581</td>
<td>1.580</td>
<td>1.581</td>
<td>0.791</td>
<td>1.034</td>
</tr>
<tr>
<td>5</td>
<td>1.568</td>
<td>1.563</td>
<td>1.566</td>
<td>0.783</td>
<td>1.014</td>
</tr>
</tbody>
</table>
Table 6 *Testing of Titanium Dose enhancement factor at 6MV*

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.841</td>
<td>1.834</td>
<td>1.838</td>
<td>1</td>
<td>1.229</td>
</tr>
<tr>
<td>1</td>
<td>1.626</td>
<td>1.626</td>
<td>1.626</td>
<td>0.885</td>
<td>1.079</td>
</tr>
<tr>
<td>2</td>
<td>1.578</td>
<td>1.573</td>
<td>1.576</td>
<td>0.857</td>
<td>1.041</td>
</tr>
<tr>
<td>3</td>
<td>1.557</td>
<td>1.554</td>
<td>1.556</td>
<td>0.846</td>
<td>1.018</td>
</tr>
<tr>
<td>5</td>
<td>1.559</td>
<td>1.553</td>
<td>1.556</td>
<td>0.846</td>
<td>1.008</td>
</tr>
</tbody>
</table>

Table 7 *Testing of Lithium Disilicate Dose enhancement factor at 6MV*

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.646</td>
<td>1.645</td>
<td>1.645</td>
<td>1</td>
<td>1.101</td>
</tr>
<tr>
<td>1</td>
<td>1.577</td>
<td>1.557</td>
<td>1.567</td>
<td>0.952</td>
<td>1.039</td>
</tr>
<tr>
<td>2</td>
<td>1.550</td>
<td>1.549</td>
<td>1.550</td>
<td>0.941</td>
<td>1.023</td>
</tr>
<tr>
<td>3</td>
<td>1.545</td>
<td>1.544</td>
<td>1.544</td>
<td>0.938</td>
<td>1.010</td>
</tr>
<tr>
<td>5</td>
<td>1.545</td>
<td>1.544</td>
<td>1.544</td>
<td>0.938</td>
<td>1.001</td>
</tr>
</tbody>
</table>
### Table 8: Comparing Dose enhancement factor [DEF] for all materials at 6MV

<table>
<thead>
<tr>
<th>Distance from source</th>
<th>Amalgam</th>
<th>Zirconia</th>
<th>Titanium</th>
<th>Lithium Disilicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.57</td>
<td>1.33</td>
<td>1.22</td>
<td>1.10</td>
</tr>
<tr>
<td>1</td>
<td>1.25</td>
<td>1.13</td>
<td>1.07</td>
<td>1.03</td>
</tr>
<tr>
<td>2</td>
<td>1.14</td>
<td>1.06</td>
<td>1.04</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>1.08</td>
<td>1.03</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>5</td>
<td>1.03</td>
<td>1.01</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 11: Plot showing the dose enhancement factors of all test materials at 6MV x-ray energy
3.1.2 Testing at dose 6 MV with stent materials:

Table 9 Amalgam + stent Dose enhancement factor at 6MV

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.335</td>
<td>2.337</td>
<td>2.336</td>
<td>1.168</td>
<td>1.567</td>
</tr>
<tr>
<td>1</td>
<td>1.859</td>
<td>1.859</td>
<td>1.859</td>
<td>0.930</td>
<td>1.238</td>
</tr>
<tr>
<td>2</td>
<td>1.718</td>
<td>1.717</td>
<td>1.717</td>
<td>0.859</td>
<td>1.136</td>
</tr>
<tr>
<td>3</td>
<td>1.638</td>
<td>1.6637</td>
<td>1.650</td>
<td>0.825</td>
<td>1.085</td>
</tr>
</tbody>
</table>

Table 10 Zirconia + Stent Dose enhancement factor at 6MV

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.992</td>
<td>1.99</td>
<td>1.991</td>
<td>0.996</td>
<td>1.336</td>
</tr>
<tr>
<td>1</td>
<td>1.685</td>
<td>1.686</td>
<td>1.685</td>
<td>0.843</td>
<td>1.123</td>
</tr>
<tr>
<td>2</td>
<td>1.605</td>
<td>1.606</td>
<td>1.605</td>
<td>0.803</td>
<td>1.062</td>
</tr>
<tr>
<td>3</td>
<td>1.567</td>
<td>1.566</td>
<td>1.566</td>
<td>0.783</td>
<td>1.029</td>
</tr>
</tbody>
</table>
Table 11 **Titanium + Stent Dose enhancement factor at 6MV**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.834</td>
<td>1.834</td>
<td>1.834</td>
<td>0.917</td>
<td>1.230</td>
</tr>
<tr>
<td>1</td>
<td>1.611</td>
<td>1.611</td>
<td>1.611</td>
<td>0.805</td>
<td>1.073</td>
</tr>
<tr>
<td>2</td>
<td>1.562</td>
<td>1.562</td>
<td>1.562</td>
<td>0.781</td>
<td>1.033</td>
</tr>
<tr>
<td>3</td>
<td>1.543</td>
<td>1.543</td>
<td>1.543</td>
<td>0.771</td>
<td>1.014</td>
</tr>
</tbody>
</table>

Table 12 **Lithium Disilicate + Stent Dose enhancement factor at 6MV**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.651</td>
<td>1.652</td>
<td>1.651</td>
<td>0.826</td>
<td>1.108</td>
</tr>
<tr>
<td>1</td>
<td>1.542</td>
<td>1.542</td>
<td>1.542</td>
<td>0.771</td>
<td>1.027</td>
</tr>
<tr>
<td>2</td>
<td>1.527</td>
<td>1.527</td>
<td>1.527</td>
<td>0.763</td>
<td>1.010</td>
</tr>
<tr>
<td>3</td>
<td>1.527</td>
<td>1.526</td>
<td>1.526</td>
<td>0.763</td>
<td>1.003</td>
</tr>
</tbody>
</table>
Table 13 comparing [DEF] of all tested materials with stents at 6MV

<table>
<thead>
<tr>
<th>Stent thickness</th>
<th>Amalgam</th>
<th>Zirconia</th>
<th>Titanium</th>
<th>Lithium Disilicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.56</td>
<td>1.33</td>
<td>1.23</td>
<td>1.10</td>
</tr>
<tr>
<td>1</td>
<td>1.23</td>
<td>1.23</td>
<td>1.07</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>1.13</td>
<td>1.06</td>
<td>1.03</td>
<td>1.01</td>
</tr>
<tr>
<td>3</td>
<td>1.08</td>
<td>1.02</td>
<td>1.01</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 12 Plot showing all tested materials DIF with stents at different thickness at 6MV
The stent material results were almost identical to tests done with solid water plates due to similar density. Therefore, further testing of stent material was not needed when testing under different dose strengths.
3.1.3 Dose 10MV

Table 14 **Radiation base readings without any dental materials AT 10MV**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio of reading to 0 distance</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.602</td>
<td>1.599</td>
<td>1.601</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1.606</td>
<td>1.607</td>
<td>1.607</td>
<td>1.003</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1.619</td>
<td>1.616</td>
<td>1.618</td>
<td>1.010</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1.624</td>
<td>1.625</td>
<td>1.624</td>
<td>1.014</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1.644</td>
<td>1.641</td>
<td>1.643</td>
<td>1.026</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 15 **Amalgam Dose enhancement factor at 10MV**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.524</td>
<td>2.522</td>
<td>2.523</td>
<td>1</td>
<td>1.575</td>
</tr>
<tr>
<td>1</td>
<td>2.16</td>
<td>2.16</td>
<td>2.16</td>
<td>0.856</td>
<td>1.343</td>
</tr>
<tr>
<td>2</td>
<td>1.989</td>
<td>1.988</td>
<td>1.988</td>
<td>0.788</td>
<td>1.229</td>
</tr>
<tr>
<td>3</td>
<td>1.882</td>
<td>1.879</td>
<td>1.880</td>
<td>0.745</td>
<td>1.157</td>
</tr>
<tr>
<td>5</td>
<td>1.770</td>
<td>1.769</td>
<td>1.770</td>
<td>0.701</td>
<td>1.077</td>
</tr>
</tbody>
</table>
Table 16 **Zirconia Dose enhancement factor at 10MV:**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.132</td>
<td>2.127</td>
<td>2.129</td>
<td>1</td>
<td>1.329</td>
</tr>
<tr>
<td>1</td>
<td>1.887</td>
<td>1.884</td>
<td>1.886</td>
<td>0.885</td>
<td>1.173</td>
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<td>1.785</td>
<td>0.838</td>
<td>1.103</td>
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<td>1.731</td>
<td>0.813</td>
<td>1.065</td>
</tr>
<tr>
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<td>1.688</td>
<td>1.689</td>
<td>0.793</td>
<td>1.028</td>
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</tbody>
</table>

Table 17 **Titanium Dose enhancement factor at 10MV:**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
</tr>
</thead>
<tbody>
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<td>1.946</td>
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<td>1.946</td>
<td>1</td>
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</tr>
<tr>
<td>1</td>
<td>1.777</td>
<td>1.774</td>
<td>1.776</td>
<td>0.912</td>
<td>1.105</td>
</tr>
<tr>
<td>2</td>
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<td>1.709</td>
<td>1.710</td>
<td>0.878</td>
<td>1.056</td>
</tr>
<tr>
<td>3</td>
<td>1.681</td>
<td>1.681</td>
<td>1.681</td>
<td>0.863</td>
<td>1.034</td>
</tr>
<tr>
<td>5</td>
<td>1.666</td>
<td>1.664</td>
<td>1.665</td>
<td>0.855</td>
<td>1.013</td>
</tr>
</tbody>
</table>
Table 18 **Lithium Disilicate Dose enhancement factor at 10MV**

<table>
<thead>
<tr>
<th>Distance from Material</th>
<th>Rdg1</th>
<th>Rdg2</th>
<th>Average</th>
<th>Ratio</th>
<th>Dose enhancement factor</th>
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<td>1.091</td>
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<tr>
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<tr>
<td>2</td>
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<td>1.658</td>
<td>0.949</td>
<td>1.025</td>
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<td>1.648</td>
<td>1.648</td>
<td>0.943</td>
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<td>1.646</td>
<td>1.647</td>
<td>0.942</td>
<td>1.002</td>
</tr>
</tbody>
</table>

Table 19 **all tested materials at 10 MV**

<table>
<thead>
<tr>
<th>Distance from source</th>
<th>Amalgam</th>
<th>Zirconia</th>
<th>Titanium</th>
<th>Lithium Disilicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.57</td>
<td>1.32</td>
<td>1.21</td>
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<td>1</td>
<td>1.34</td>
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<td>1.22</td>
<td>1.10</td>
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</tr>
<tr>
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<td>1.15</td>
<td>1.06</td>
<td>1.03</td>
<td>1.01</td>
</tr>
<tr>
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<td>1.07</td>
<td>1.02</td>
<td>1.01</td>
<td>1.00</td>
</tr>
</tbody>
</table>
3.2. Second Experiment, CT scan image metal artifact:

As mentioned earlier the purpose of the second experiment is to visually analyze and compare the effects of using different restorative materials on the quality of CT scan images.

We compared the CT images of different tested crowns strategically placed to mimic 2 crowns, on opposite sides of the tongue. It was clear that full gold, PFM & zirconia crowns were responsible for excessive backscatter and black voids that made considerable parts of the tissue equivalent [water bag] unrecognizable. The difference between various crowns was negligible.
When CT images from full gold, PFM, & zirconia crowns were compared to images of lithium disilicate crowns the difference was significant. While gold, PFM, & 3Y-TZP crowns created remarkable scatter obscuring the area between them; images of lithium disilicate crowns had minimal scatter and almost no distortion allowing complete evaluation of the shape of the prepared tooth, and tongue-equivalent structure. [Figures 15, 16 & 17].

Figure 14 **Comparing metal artifacts between Lithium Disilicate and gold crowns**

<table>
<thead>
<tr>
<th>Lithium Disilicate</th>
<th>Gold</th>
</tr>
</thead>
</table>

![Comparing metal artifacts between Lithium Disilicate and gold crowns](image-url)
Figure 15 **comparing metal artifacts between Lithium Disilicate and Zirconia crowns**

Lithium Disilicate  

Zirconia
Figure 16 comparing metal artifacts between Lithium Disilicate and PFM crowns.
CHAPTER 4
DISCUSSION
4. Discussion

Cancer treatment modalities have improved over the years with the aim to provide a cure with minimal harmful effects to healthy tissues. The use of radiotherapy as first line of treatment reduces the debilitating effects of irreversible surgical treatment.

Chemoradiation is becoming more of a standard protocol to fight cancer although it increases the risk for developing complications (Eisbruch et al., 2002; N P Nguyen et al., 2009; Nam P. Nguyen et al., 2006). In many cases combining all three treatment modalities is needed to provide the best treatment.

Early diagnosis is key to successful cancer treatment. Cross-sectional imaging including CT scans are an important diagnostic tool in cancer detection and planning for IMRT. Employing IMRT delivers maximum radiation dose to the tumor and minimal dose to healthy normal structures in the vicinity of the tumor. Radiation therapy in head and neck region is challenging even with IMRT due to its compact size, which is densely packed with a variety of important structures [muscle layers, nerves, blood vessels, bones].

This makes it difficult to avoid irradiating healthy structures. The presence of metallic restorations causes various artifacts in CT image, and may compound the problem by potentially obscuring the area of interest (Barrett & Keat, 2004; Mehran Yazdi, 2008)
Our study has shown significant artifacts from gold, PFM & zirconia crowns in the form of streaks and voids especially when the crown/restorations were present bilaterally.

This causes the effects to obscure the tongue structure in CT scan images, except in the case of lithium disilicate, where its minimal scatter had negligible effect on the image quality, allowed for a clear and thorough evaluation and proper planning of the radiation therapy target.

The standard therapeutic dose used in treatment of most head and neck cancers requires about 50 – 70 Gy (Beumer, 2011). The early harmful effects of radiation include ulceration, mucositis, pain, dysphagia, change in oral flora, skin erythema, desquamation, and pigmentation. Delayed affects are altered taste and smell, edema, trismus, velopharyngeal incompetence, altered speech, salivary gland dysfunction, candidiasis, bone changes, periodontal changes, dental changes, and radiation caries.

The sum of these adverse effects and complications is an inevitable significant decrease in the quality of life of these patients both during and after the treatment. Some adverse effects including social embarrassment and depression may continue throughout the life of survivors.

As a general rule, the higher the radiation dosage, the higher the chance of developing and/or increase in severity of harmful side effects. This can be further complicated when high-density materials cause a localized overdose of radiation to the adjacent area due to radiation Backscatter
In our first experiment we noted the following enhancement in the radiation dosage to tissues in direct contact with tested materials (0 mm distance):

- 60% for amalgam.
- 30% for Zirconia.
- 20% for Titanium.
- 10% for Lithium Disilicate.

In regards to our results with titanium, we were in agreement with very close ratio with the findings of Mian et al (Mian, 1987). Our results for amalgam we were in agreement with the findings of Farahani et al (Farahani, 1990) and Reitemeier et al (Bernd Reitemeier 2002).

Our data supports the Hypothesis about zirconia backscatter. This material has caused an increase in dose enhancement to the surrounding tissue more than titanium and lithium disilicate but less than gold alloys and amalgam restorations.

Nevertheless, the use of zirconia in dentistry can potentially be harmful if patient undergoes radiation therapy for head & neck cancer. When the standard doses of 50 – 70 Gy are given during radiotherapy, there could be as much as 30% enhancement in radiation exposure to the surrounding tissues in direct contact with the restoration. This translates to approximately 65 – 91 Gy, which can carry a risk of developing the aforementioned complications.

Our data raises the question about using zirconia restorations without a good reason especially when safer alternatives such as lithium disilicate are available. The potential adverse effects of fabricating large implant frameworks made either of gold alloy casting...
or milling of zirconia should be kept in mind. Using only lithium disilicate crowns in full-mouth rehabilitations or a combination of lithium disilicate, PFM, or Zirconia crowns is preferable.

The short and long term effects of restorative dental treatment especially full-mouth rehabilitations and multiple dental implants fabricated from highly dense materials should be considered during treatment planning. Patients both young and old are at risk of developing head & neck cancer. The world population growth rate is increasing and is currently 1.2% reported by The World Bank Inc. this combined with increase life expectancy, means that more people will be at risk of developing head and neck cancer each year.

All previous studies agreed that an increase in distance from the surface of the material leads to reduction in dose of radiation from backscatter. Mian et al, found out that the increase in dose fell significantly and became negligible at 1-2 mm from the tissue-material interface (Mian, 1987). Wang et al. suggested that the backscatter radiation decreased as the thickness of the bone substitute between the implant material and the ionization chamber increased (Wang et al., 1996).

Reitemeier et al, found that at a distance of 3 mm, overdose decreased to less than 10% for the high-gold alloy. For pure titanium, no dose increase could be measured at this distance (Bernd Reitemeier 2002).

The current protocol regarding the dentition and radiotherapy entails the use of stents to cover the teeth to reduce backscatter. The idea is to increase distance around the restorative materials to decrease the amount of radiation reaching surrounding tissues.
During our testing a stent thickness of 2mm all tested materials produced an insignificant amount of scatter except for amalgam that produced approximately 10% dose enhancement.

It is worth mentioning that although amalgam is proven to have high backscatter most amalgam restorations are embedded within the confines of a tooth structure, the backscatter is reduced by absorption from the surrounding tooth structure (Farahani, 1990).

An option in case of dental implant restorations is the use of screw retained implant restorations. This allows the use of large zirconia frameworks and restorations but allows for ease of removal prior to radiation treatment.
CHAPTER 5
CONCLUSIONS
Conclusions

1. Gold, Zirconia and PFM restorations have a deteriorating effect on the quality of CT images due to artifacts produced by scatter from high-density and metallic restorations. Lithium disilicate restorations, on the other hand, cause minimal artifacts.

2. The greatest increase in backscatter radiation measured was in direct contact with the tested materials and was found to be:
   - 60% for amalgam.
   - 30% for zirconia.
   - 20% for Titanium.
   - 10% for Lithium Disilicate.

3. Within the limits of our study no difference was noticed in the amount of backscatter radiation measured between the two radiation energies 6MV and 10MV.

4. At a thickness of 2 mm all tested materials produced an insignificant amount of backscatter except for amalgam. However, most amalgam restorations are confined by tooth structure that reduces its backscatter effect.
References


23. *U. S. Bureau of Mines*

24. *Metals Corrosion Laboratory*

25. *College Park, Maryland*

26. , Quarterly Report for October - December 1953, 17.


