

# Low-Dose Radiation Risks of Computerized Tomography and Cone Beam Computerized Tomography: Reducing the Fear and Controversy

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Regulations for protecting humans against stochastic biological effects from ionizing radiation are based on the linear no-threshold (LNT) risk assessment model, which states that any amount of radiation exposure may lead to cancer in a population. Based on the LNT model, risk from low-dose radiation increases linearly with increasing doses of radiation. Imaging procedures in medicine and dentistry are an important source of low-dose ionizing radiation. The increased use of computerized tomography (CT) and cone beam computerized tomography (CBCT) has raised health concerns regarding exposure to low-dose ionizing radiation. In oral and maxillofacial surgery and implant dentistry, CBCT is now at the forefront of this controversy. Although caution has been expressed, there have been no direct studies linking radiation exposure from CT and CBCT used in dental imaging with cancer induction. This article describes the concerns about radiation exposure in dental imaging regarding the use of CT.

**Key Words:** low-dose ionizing radiation, cancer, computerized tomography, cone beam computerized tomography (CBCT), hormesis, linear no-threshold (LNT) risk assessment model

## SCOPE OF THE PROBLEM

Most of the literature reviews in implant dentistry regarding medical multislice computerized tomography (MSCT) and cone beam CT (CBCT) focus on the benefits of this leading-edge technology in the diagnosis and treatment planning of both the surgical and prosthetic phases.<sup>1-3</sup> While these imaging modalities benefit patients, there is some concern regarding the health risks of low-dose ionizing radiation obtained from such technologies. Epidemiological evidence suggests a correlation between exposure of low-dose ionizing radiation and the risk of developing solid cancers and leukemia.<sup>4</sup> Several studies have reported an increased risk of developing cancer after radiation exposure from various imaging techniques used in medicine.<sup>5-7</sup> Because of the link between ionizing radiation and malignancies, health care employees are monitored and restricted to maximum effective biologic doses of 50 mSv per year.<sup>8,9</sup> For

patients who undergo such imaging procedures, radiation exposure is usually not monitored.

A well-publicized article in the *New York Times* in 2010 discussed the use of CBCT scans in adolescents and the potential risks of radiation-induced carcinogenesis.<sup>10</sup> The American Dental Association (ADA), American Academy of Oral and Maxillofacial Radiology (AAOMR), and the American College of Radiology all support the concept that health care professionals adhere to the “as low as reasonably achievable” principle in order to minimize exposure to ionizing radiation.<sup>3,11</sup> Although there are many medical MSCT and CBCT scanners on the market manufactured by different companies, there are no definitive or consensus guidelines to indicate what doses are reasonable.<sup>12</sup> A recent study released online in 2012 in the journal *Cancer* raised concerns about the association between conventional dental radiographs and the increased risk of developing meningiomas, or benign brain tumors.<sup>13</sup> To alleviate the public’s concern regarding the dangers of traditional dental X rays, the ADA and AAOMR released a statement in response to that article citing the flaws of the design and the questionable validity of the conclusions.<sup>14,15</sup> The goal of this article is to review the concerns about radiation exposure and provide some perspective on the controversy about the use of computerized tomography (CT) in implant dentistry.

The best interest of patients should always be the primary concern when regarding the principles of good radiation practice. Any misinformation to the public regarding the benefits vs risks of this leading-edge imaging technology is a

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TABLE 1  
Comparison of imaging procedures used in implant dentistry\*

Imaging Procedure	Estimated Effective Dose,† mSv	Comparison to Natural Background Radiation,‡ days
Single digital periapical film	0.006	1
Full-mouth series	0.0349–0.388	22
2D Panoramic	0.004–0.030	2–3
MSCT	0.474–1.410	8–134
iCAT CBCTs	0.1339	11
Natural background radiation (1 year)	3	360

\*MSCT indicates multislice computerized tomography; CBCT, cone beam computerized tomography.

†Radiation effective dose measured in milliSeiverts (mSv).

‡Daily exposure to natural background radiation.

§Data in this table are effective dose using 2007 International Commission on Radiological Protection tissue-weighting factors for the iCAT Classic CBCT machine.

definite disservice to patients seeking dental treatment. Because of patient anxiety created by media inaccuracy and sensationalism, some patients will defer imaging procedures and treatment. The public assumes that all physicians and dentists are educated about the risks of ionizing radiation and will rely on the health care professional for safety and advice. However, in one study, fewer than 50% of radiologists and fewer than 91% of emergency department physicians were educated about the long-term increased risks of radiation-induced cancer from CT scans.<sup>16</sup> Recently, there have been attempts to increase physician awareness regarding the risks of ionizing radiation in medical education.<sup>17</sup> An increased understanding of the risks of ionizing radiation is also needed in the dental community, as CBCT has transformed the practice of oral and maxillofacial surgery and implant dentistry.

Ionizing radiation has been used in medicine for more than 100 years.<sup>18</sup> Diagnostic medical procedures represent the largest manmade source of radiation exposure for the average individual. In general, the benefits of radiation for diagnostic purposes far outweigh the risks regarding the health of patients.<sup>18</sup> Since CT was introduced into clinical medicine in 1972, there has been a marked increase in the use of this imaging technology.<sup>19,20</sup>

In dentistry, the use of CT has steadily escalated with the introduction of CBCT in oral and maxillofacial surgery and implant dentistry since 2001.<sup>1–4</sup> With the implementation of 3-dimensional (3D) interactive computer software, there is no doubt that this advanced technology has revolutionized the practice of implant dentistry. However, this state-of-the-art imaging technology has also resulted in increased low-dose ionizing radiation exposure for patients.

**RADIATION DOSE LEVELS**

There are many dental radiation dosimetry studies in the literature comparing traditional 2-dimensional (2D) dental radiographs and CBCT.<sup>21–31</sup>

Measuring patient effective dose allows the clinician to compare the radiation risk of different imaging modalities (Tables 1 and 2). The reported effective dose of a 2D panoramic radiograph ranges from 0.004 to 0.030 mSv (4.0 to 30 uSv).<sup>21,22,23,32</sup> A full-mouth radiographic series using D-speed film and round collimation produces an effective dose level

between 0.0349 and 0.388 mSv (34.9 and 388 uSv).<sup>24,32</sup> Standardized diagnostic reference levels for CBCT scanners are not yet available, and as a result, effective dose variations between the different CBCT units range from 0.027 to 1.073 mSv (27 to 1073 uSv).<sup>18,23–27</sup> This variation is based primarily on the following parameters: manufacturing unit, exposure factors, scan time, resolution of the scan, and field of view (FOV). However, some CBCT machines have fixed parameters. For example, the Classic iCAT CBCT (Imaging Sciences, Hatfield, Penn) has set parameters at a maximum FOV (13.0 cm, 20-second scan time, 0.3 voxel, 120 kv, and 5 mA) with a reported radiation exposure of 0.1339 mSv (133.9 uSv). Therefore, the use of traditional radiographs like a complete radiographic series may result in a radiation dose that is higher than that of a CBCT imaging study. In addition, CBCT technology also exposes patients to lower doses of ionizing radiation compared to medical CT scans.

**IMAGE ACQUISITION DIFFERENCES BETWEEN MEDICAL MSCT AND CBCT**

With a medical MSCT scan, the human body is exposed to ionizing radiation using a flat, fan-shaped X-ray beam in a helical progression to acquire image slices of the field FOV. With this technology, the patient’s head is exposed to overlapping radiation during image acquisition.<sup>17</sup> In contrast, with CBCT technology, anatomic information of the maxillofacial region is captured in one single cone-shaped 360° rotation to obtain multiple images. This technological advancement exposes the patient’s maxillofacial region to far less ionizing radiation compared with MSCT scans, because CBCT incorp-

TABLE 2  
Comparison of medical imaging procedures and effective dose levels (mSv\*)

Imaging Procedure	Estimated Effective Dose, mSv	Comparison to Natural Background Radiation, Days†
CT head	0.860	108
CT body	10	1080
CT abdomen	10	1080

\*Radiation effective dose measured in milliSeiverts (mSv). CT indicates computerized tomography.

†Daily exposure to natural background radiation.

rates the entire FOV to obtain data for image reconstruction.<sup>1,3,14</sup> Despite this technological advantage, CBCT should not be the primary radiographic image source replacing conventional plain radiographs. Such 3D imaging should be used to supplement existing information to enhance the patient diagnosis and treatment plan after weighing the benefits vs risks for each patient.<sup>3,28,29</sup>

### MEDICAL MSCT

Completing an imaging study of the maxillofacial region with a medical MSCT scan can produce a radiation effective dose between 0.474 and 1.410 mSv (474 and 1410 uSv).<sup>30,31,33</sup> There has been a steady increase in the number of CT scans performed each year since 1972, when this technology was first introduced into clinical medicine.<sup>19</sup> In 1990, approximately 13 million CT scans were completed in the United States.<sup>20</sup> That figure increased to 46 million scans in 2000.<sup>20</sup> It is estimated that 62 million CT scans were performed in 2006 in the United States, and the number of CT scans performed is estimated to continue to rise at 10% per year.<sup>20,34</sup>

The congressionally-chartered National Council on Radiation Protection and Measurements conducted 2 reviews on the radiation exposure of the United States population from various sources. The first report<sup>22</sup> estimated annual exposure from all medical radiation procedures to be approximately 0.53 mSv (530 uSv) per person as of 1980–1982. For comparison, the annual exposure to each person from natural background radiation was estimated to be about 3 mSv (3000 uSv). Approximately 25 years later, the follow-up report estimated that medical radiation had increased dramatically, to about 6.3 mSv (6300 uSv) per capita annually.<sup>23,34</sup>

### TYPES OF RADIATION EFFECTS

The effects of radiation are either deterministic or stochastic.<sup>8</sup> Deterministic biologic effects of radiation are based on cellular damage and characterized by a threshold dose.<sup>8,35</sup> Below a certain threshold, there is no detrimental health effect. But above the threshold dose, the severity of the injury increases with the increasing dose.<sup>19,36</sup> An example of a deterministic effect is cataract formation from radiation injury.<sup>36,37</sup> This type of radiation adverse effect does not occur with medical imaging procedures and should not be a consideration with dental CT and CBCT imaging procedures.

Low levels of radiation received from imaging diagnostic procedures such as CT do have the potential to cause stochastic effects, which essentially refer to various malignancies caused by genetic mutations.<sup>8,19,22,36,38</sup> Such stochastic effects are considered to have no radiation threshold and, although the probability of an effect increases with dose, the severity of any resulting biological detriment is not dose related. It is this type of radiation effect that is a concern when discussing radiation risk from CT scans, including CBCT. It should be noted, however, that no health detriments such as cancer have ever been directly determined to result from dental imaging procedures; such concerns are theoretical estimates.

### QUANTIFICATION OF IONIZING RADIATION

Ionizing radiation can be characterized by the dose absorbed by a given tissue organ. The type of dose reported in medical imaging procedures is the effective dose. Effective dose is a concept that can be used to relate radiation exposure to risk of cancer (accounts for the stochastic effect from exposure to ionizing radiation).<sup>20,39–43</sup> The unit of measurement is the Sievert (Sv).<sup>36,39</sup> MilliSieverts (mSv) and microSieverts (uSv) are commonly used to express dose in maxillofacial imaging.<sup>44</sup> The effective dose is widely used to compare radiation exposures between different imaging methods, as it accounts for different types of radiation, different tissues, and relative risks.<sup>8,9,20,36,39–44</sup>

### RADIATION DOSE IN CT

Although the benefit of CT scans would normally outweigh the very small risk of the individual patient developing cancer, the radiation doses of this imaging modality compared with conventional radiography have been reported to have increased health concerns.<sup>39,40–43</sup> Brenner and Hall<sup>20</sup> concluded that when patients have 2 or more medical CT scans with total doses between 30 and 90 mSv, their risk of developing cancer increases. These studies, as well as others,<sup>45,46</sup> have generated much public health concern in the media on the growing use of CT scans in medicine, and now in dentistry with the recent introduction of CBCT.<sup>10,11</sup> It is estimated that a sample size of approximately 100 000 to 10 million individuals exposed to between 5 and 50 mGy (50 mSv) is required to detect a significant increase in cancer due to such low radiation exposures.<sup>47</sup> However, some clinicians theorize that there are no associated risks with low-dose radiation from CT scans, and there may even be benefits.<sup>48–51</sup> To date, there are no prospective cohort studies correlating the risk of developing cancer and patients who have undergone CT scans.<sup>50,51</sup>

### RADIATION DOSE IN CBCT

In the past several years, the use of 3D CBCT has steadily increased in oral and maxillofacial surgery and implant dentistry.<sup>1–3,10,12,16,30</sup> Such advanced imaging technology allows the clinician to obtain an accurate 3D image of the patient's anatomy from a single cone beam scan. Compared with medical MSCT technology, the greatest advantage of CBCT imaging is that it allows the surgeon to obtain the same vital 3D anatomic information without exposing the patient to high levels of ionizing radiation.<sup>3,16,26,33</sup>

Even a complete full-mouth series of conventional radiographs (D-speed film and round collimation) typically used in dentistry may produce radiation doses that are comparable or even higher than CBCT.<sup>50</sup> The effective dose of a digital panoramic radiograph ranges from 0.004 to 0.030 mSv (4–30 uSv).<sup>26</sup> Depending on the CBCT unit, published effective doses range from 0.027 to 1.073 mSv (27–1073 uSv).<sup>33</sup>

### ADVERSE BIOLOGICAL EFFECTS OF LOW-DOSE RADIATION

The adverse biological effects of ionizing radiation are most pronounced during cell division, or mitosis, although they can

also be problematic during DNA replication.<sup>52</sup> When X rays encounter cells of the human body, they liberate electrons and produce free radicals that can interact with cellular DNA, which may lead to double-strand breaks in the double helix or produce other types of damage that could lead to chromosome translocations, or mutations. These events can result in the development of cancer in somatic cells unless DNA repair mechanisms can maintain the fidelity of the DNA.<sup>52-54</sup>

The US National Academy of Science initiated a series of reports to study the health effects from low levels of ionizing radiation.<sup>4</sup> These reports were divided according to various types of radiation exposure: survivors of the atomic bombings of Japan, workers exposed to radiation in industry, individuals exposed to medical radiation, and populations of individuals exposed to environmental radiation, such as Three Mile Island and Chernobyl. Many years after the nuclear accident at Three Mile Island, studies have shown there have been no increases in cancer mortality.<sup>55,56</sup> It is estimated that greater than 5 million individuals may have been exposed to excess radiation in the area around Chernobyl. Studies monitoring leukemia and nonthyroid solid cancers have not increased in the population around Chernobyl.<sup>57,58</sup> There are important differences between the type of radiation exposure and dose rate between individuals exposed to a nuclear reactor incident vs atomic bomb exposure. However, most of the epidemiological data regarding low-level radiation risk have been obtained from Japanese atomic bomb survivors in a study sponsored by the Radiation Effects Research Foundation (RERF).<sup>36</sup> The RERF studies are the primary source of information regarding the health effects of individuals exposed to ionizing radiation and support much of the BEIR VII report and previous BEIR reports and the linear no-threshold (LNT) risk model of carcinogenesis.

#### EPIDEMIOLOGY OF LOW-DOSE RADIATION AND CANCER RISK

Most of what we have learned about the risks and carcinogenic effects of ionizing radiation have come from epidemiological studies, such as those from the RERF and Life Span Study (LSS) of the 100 000 Japanese survivors of the Hiroshima and Nagasaki atomic bomb explosions of World War II.<sup>4,36,47,59,60</sup> The RERF and LSS data suggest that cancer risk persists many years after ionizing radiation exposure, and that most types of cancer are inducible.

The average dose of radiation of the Japanese atomic bomb blasts to individuals is estimated to be about 200 mSv. The RERF data do provide statistically significant data indicating that, at doses greater than 100 mSv to the entire body, there is an increased incidence of different types of cancers. However, at doses less than 100 mSv, it has not been scientifically illustrated and is difficult to predict with confidence that such low doses of ionizing radiation will induce cancer.<sup>4,51</sup> In a study by Preston et al,<sup>59,60</sup> 11% of all solid cancers in their cohorts could be attributed to exposure to ionizing radiation from the atomic bomb blasts. Although at radiation doses between 5 and 150 mSv, there are reports of an increase in solid cancer mortality,<sup>61-64</sup> strong epidemiological evidence linking radiation and cancer induction does not occur at doses below 100 mSv.<sup>36,60,65</sup> It should be noted that tumors resulting from radiation exposure cannot generally be distinguished from

cancers that arise spontaneously or by other environmental factors.<sup>47</sup>

The use of medical imaging, such as CT scans in children, has also increased.<sup>65</sup> In a study by Brenner and Hall,<sup>20</sup> the authors concluded that ionizing radiation from pediatric CT scans would result in an increase in cancer deaths. This risk evaluation study was also based on projection models of the survivors of the atomic bombings of Hiroshima and Nagasaki. A recent retrospective pediatric cohort study by Pearce et al<sup>65</sup> demonstrated a significant linear association between an increased risk of brain cancer and leukemia after radiation doses of 10 mGy. Based on this study, there is concern that radiation-induced cancers may develop later in life for these children as they develop into adults.<sup>41,65-68</sup>

#### BEIR VII AND THE LNT RISK MODEL OF CARCINOGENESIS

Adverse biological radiation effects, such as carcinogenesis and mortality, are based on the BEIR VII-supported LNT hypothetical risk estimate model developed from epidemiological studies on the Japanese survivors.<sup>36</sup> The risk estimate model assumes there is no threshold dose below which radiation exposure is safe and that the risk increases linearly with higher doses of absorbed ionizing radiation. Based on this model, the risk associated with low-dose radiation levels is considered low but greater than zero. Increasing the radiation dose effectively increases the incidence of cancer in a population. In contrast, reducing the dose by a factor of 10 will also reduce the risk factor of developing cancer by that same amount.

Based on the extrapolation of cancer data obtained from atomic bomb survivors exposed to high levels of ionizing radiation, and by using the LNT risk assessment model, it is estimated that 1.5% to 2.0% of future cancers in the United States will be from increased use of medical MSCT scans.<sup>20</sup> It is worth noting that X rays have been classified as a carcinogen by the World Health Organization's International Agency for Research on Cancer, the Agency for Toxic Substances and Disease Registry of the Centers for Disease Control and Prevention, and the National Institute of Environmental Health Sciences. Use of medical or dental X rays should always be justified.<sup>69-73</sup>

#### HORMESIS (RADIATION-INDUCED NATURAL PROTECTION)

It is well accepted that high-dose radiation is carcinogenic. However, the cancer risk for low-dose radiation exposure less than 100 mSv remains uncertain.<sup>36</sup> Most single medical CT scans (excluding nuclear medicine) have effective dose estimates in the range of 10 to 25 mSv per study.<sup>74-76</sup> In medical diagnostic imaging that is commonly used to save lives, many patients have multiple imaging studies that could exceed 50 mSv. This increased exposure to ionizing radiation has raised concerns regarding the increased risk of developing cancer.<sup>36,54,59,60,77,78</sup>

Few, if any, of these studies consider the biological adaptive response of cells and tissues to low doses of ionizing radiation.<sup>78,79</sup> It is postulated that irradiated cells have the capability to protect themselves through adaptive responses.

Such protective adaptive responses of the human body to ionizing radiation are known as radiation hormesis (the hypothesis that low doses of radiation are beneficial) or radiation-activated natural protection (ANP).<sup>80</sup> Such a protective beneficial effect may occur for doses up to 250 mSv.<sup>80</sup>

Radiation ANP may protect the human body from developing some cancers because of the repair of DNA double-strand breaks, removal of selective aberrant cells via p53-mediated apoptosis, and epigenetically anticancer-stimulated immunity. Selected removal of aberrant cells occurs through intercellular signaling of reactive oxygen species and nitrogen species and cytokines, such as transforming growth factor beta.<sup>81,82</sup> The action of radiation ANP may therefore reduce the incidence of cancer development.<sup>78-82</sup>

#### THE CONTROVERSY OF LOW-DOSE RADIATION AND CARCINOGENESIS

It is presumed that the LNT risk model overestimates the actual number of cancers that could develop from imaging procedures, such as medical CT in healthy patients.<sup>83</sup> Based on the LNT hypothetical model, cancer risk increases linearly with increased doses of radiation.<sup>84</sup> Therefore, even the smallest radiation dose may induce cancer. Extrapolation of cancer risk using the LNT model assumes a low dose of radiation will have the same carcinogenic effect on exposed individuals as high doses. There is now a wealth of evidence that contradicts the LNT risk estimate model for carcinogenesis at low radiation doses.<sup>48,78,83-87</sup>

The BEIR VII report<sup>4</sup> supports the use of the LNT model of risk assessment regarding exposure to low-dose ionizing radiation and carcinogenesis despite our improved understanding of radiation injury and the wealth of data supporting hormesis, presumably in an effort to be very overprotective in its estimates.<sup>80-86</sup> With low levels of ionizing radiation used in medical imaging procedures, the LNT model may not be able to accurately predict cancer risk.<sup>66</sup>

On the other hand, some national bodies have included a consideration of radiation hormesis in their recommendation on radiation doses. For example, the French Academy of Sciences,<sup>87</sup> the National Academy of Medicine,<sup>88</sup> and the United Nations Scientific Committee on the Effects of Atomic Radiation,<sup>89</sup> among other groups, have determined that radiation hormesis is worthy of consideration and do not support the findings of BEIR VII.<sup>90,91</sup> They support the hypothesis that hormesis may have a protective effect for very low radiation doses (generally less than 100 mSv, and especially if the radiation dose is less than 10 mSv). Therefore, with low levels of ionizing radiation USED in medical and dental imaging procedures, the LNT model may be overestimating cancer risk.<sup>66</sup>

#### EPIDEMIOLOGICAL DATA AND ESTIMATION OF CANCER RISK FROM CT

There is no absolute evidence that use of CT (and CBCT) as practiced in the United States will lead to increased rates of cancer.<sup>83</sup> As previously mentioned, exposure to low doses of ionizing radiation in medical diagnostic imaging procedures, such as CT, may actually reduce the risk of carcinogenesis.<sup>82,92</sup>

The Japanese Ministry of Health, Labor and Welfare in their LSS produced a large cohort study to correlate the adverse biological effects of radiation exposure and cancer risk, but in a healthy population exposed to a wide range of radiation doses. Variables like the distance from the hypocenter and acute biologic injury effects from the atomic blasts were analyzed for more than 40 years. For individuals 2000 (1.8 km) and 3000 (2.7 km) yards from the hypocenter, the estimated mean radiation dose was 29 mSv. During the LSS, there were more than 4,500 solid cancers observed.

With such data available to analyze throughout a 4-decade time frame, the epidemiological data used by the LNT risk model does not consider acute radiation injuries due to thermal waves and radiation blast projectiles that are not experienced by patients completing a CT scan.<sup>93-95</sup> Such combined injuries from an atomic blast would include the following: whole-body hard- and soft-tissue wounds, thermal burns, and infections in addition to high-energy gamma rays, neutrons, and charged particles. In addition, immediately after the atomic bomb blast, medical care was virtually nonexistent, there was an acute shortage of food, and much of the population of Hiroshima and Nagasaki became malnourished, greatly compromising their health.<sup>93-95</sup>

Therefore, many individuals died of other variables and may have survived under more favorable conditions.<sup>66</sup> Such variables make it extremely difficult to extrapolate the health effects experienced by the Japanese atomic bomb survivors compared to individuals completing a CT scan for dental implant surgery.

Risk estimates for children using the LNT model data from atomic bomb survivors are also questionable if combined injuries or the radiation hormetic effects to radiation exposure are not considered.<sup>83</sup> In the retrospective pediatric cohort study by Pearce et al,<sup>65</sup> children who had multiple CT scans and received 10 mSv of ionizing radiation were at greater risk of developing leukemia and brain cancer. However, it is difficult to accurately predict cancer risk and mortality in individuals exposed to low levels of radiation below 100 mSv from medical imaging procedures, such as CT and nuclear medicine procedures.<sup>4,66,86</sup> At doses below 50 mSv for single procedures and 100 mSv for multiple procedures, such low levels of ionizing radiation may be too low to detect and may be nonexistent.<sup>48</sup> It is therefore questionable whether the LNT risk model can still be used as the standard, given the contradictory experimental data.<sup>77,86-91</sup>

#### CONCLUSION

At present, there are no prospective studies that correlate low doses of ionizing radiation of less than 100 mSv from dental CT and CBCT to increased risks of cancer. Imaging procedures, such as CT and CBCT, result in doses well below 100 mSv based on individual manufacturer reporting. Therefore, given the current uncertainty regarding an increased cancer incidence from the use of dental imaging, including CBCT, it is unwarranted to discontinue the use of such procedures. However, as clinicians, we must also continue to make every effort to ensure that CBCT scans are clinically justified. To ensure the best practice principles, clinicians must continue to

educate themselves on the issues of radiation biology and become proficient in this topic.

#### ABBREVIATIONS

2D: two-dimensional  
 3D: three-dimensional  
 AAOMR: American Academy of Oral and Maxillofacial Radiology  
 ADA: American Dental Association  
 ANP: activated natural protection  
 CBCT: cone beam computerized tomography  
 CT: computerized tomography  
 FOV: field of view  
 LNT: linear no-threshold  
 LSS: Life Span Study  
 MSCT: multislice computerized tomography  
 mSv: milliSieverts  
 RERF: Radiation Effects Research Foundation  
 Sv: Sievert  
 uSv: microSieverts

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