Abstract
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Educational Objectives
During this course the participant will:
1. Define and understand dose creep
2. Discuss ALARA/ALADA principle as it pertains to digital imaging, cone beam CT, and the handheld portable x-ray unit
3. List best practice to minimize radiation dose of the patient and staff

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Abstract
As dental health care workers (DHCW), we need to keep up to date with the latest technology and how to use it safely. The use of medical radiation, including dental radiation procedures, has increased in recent years. It is imperative to employ best practices and to embrace scientifically-based principles to address the dose creep that is occurring in dental radiography as we implement the recent advances in digital, dental CT, and hand-held portable dental radiography.

Educational Objectives
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It is widely accepted that good dental health is an important part of living a long and healthy life.1 Dental imaging is important and beneficial to the practice of modern dentistry. Some of the benefits of radiographic imaging include early diagnosis of dental decay; documenting the presence of a dental abscess, cyst, or tumor; determining whether all permanent teeth have erupted; and determining the condition of supporting bone.1 As DHCW, one must understand the technology, be proficient in practice, and be aware of the possible dangers of cumulative low dose radiation. As with all healthcare interventions, the benefit of the imaging procedure should outweigh the risk (ADA FDA, 2012).

The impact of the discovery of x-radiation on healthcare is insurmountable. Within a month of Roentgen’s discovery in 1895 of these invisible rays, Friedrich Otto Walkhoff produced the first dental radiograph on himself.2 By the early 1900s those studying this new entity recognized the dangerous side effects of being in contact with ionizing radiation.3 Ionizing radiation is associated with cumulative long term biological damage that can result in early cataract formation, cancer, and genetic effects.3 According to the National Council on Radiation Protection and Measurements (NCRP) medical exposure, which includes dental exposure, increased seven-fold from 1980 to 2006.4 Even though dental radiographic procedures generally provide lower doses of ionizing radiation than medical imaging studies, technical advancements in recent years have led to greater use of dental imaging modalities, resulting in additional ionizing radiation doses to be delivered to patients.

X-ray energy is classified as ionizing electromagnetic radiation, since it is capable of knocking electrons out of their normal orbits, which can be associated with damage to living cells. X-rays have no weight or mass, travel in straight diverging lines at the speed of light, and can penetrate tissue, including skin, muscle, and other solid structures. X-rays are produced in an x-ray tube when electrons are thermionically emitted from a filament in the cathode. The number of electrons emitted is determined by the milliamperage-seconds (mAs) set on the unit. The average energy or quality of the primary x-ray beam is controlled by the set kilovolt peak, kVp. When x-radiation passes through a tissue, some of the x-ray photons are absorbed (especially by bone and teeth) and some of the x-ray photons are scattered after ionizing atoms in the tissue. Fat and soft body tissues such as organs like the thyroid usually scatter x-ray photons. Some of the scattered x-radiation will be directed towards the dental imager, some will be directed to a different area in the patient, and some will be detected by the image receptor. Scatter x-radiation is responsible for the grays on the radiographic image, whereas the whites on the radiographic image are due to absorption of x-radiation; both scattered and absorbed x-radiation can cause cellular damage.3 The risk of overexposure to ionizing radiation and improper use of dental x-radiation is burned skin, increased skin cancer, earlier cataract formation, increased chance of thyroid/salivary cancer, and increased chance of genetic mutations to future generations.2

It is desirable to eliminate all unnecessary radiation both to the patient and the dental imager. The most efficient equipment and techniques should be used along with minimum exposure to radiation while still producing diagnostic radiographs. Following the tenets of best radiation safety practice (time, distance, and shielding) was the norm before handheld units were used.5 With wall mounted units, the DHCW should always use the shortest exposure time possible, maintain a minimum distance of 6 feet from the x-ray source and the patient, with proper paralleling technique; and utilizing shielding (lead apron and thyroid collar) of sensitive areas from primary and secondary radiation. Retaking improperly exposed images can be avoided by improving techniques used by the dental imager.5 The authors of this article found some DHCW preforming 3-dimensional imaging after receiving insufficient in-service education. The individuals shared that they were unaware that they could make adjustments in the exposure techniques so they used the same settings for all sizes and ages of patients.

As dental imagers, we use the ALARA principle, “As Low As Reasonably Achievable.” The rationale for adhering to the ALARA concept is dependent upon scientific evidence acquired over the past one hundred years. Since radiation-induced cancer has no established dose limit, always using the least possible dose is the safest philosophy.4 A very important aspect of this optimization for radiation protection principle is being knowledgeable about setting proper radiographic techniques (kVp, mA and time) and using proper positioning of the patient and alignment with the image receptor, so that unnecessary retakes do not occur. ALARA is an acronym that we as DHCW use to remind ourselves to always use the lowest dose possible to achieve the highest quality image.

Another more recent principle is that of ALADA, “As Low As Diagnostically Acceptable.” This concept takes the considerations of the ALARA philosophy one step further. Mindful that the imaging technology available today will yield beautiful images, it is important to remember that the imaging software
can produce diagnostically acceptable images that are not quite as pretty, using lower x-radiation doses than previously achievable. Modern techniques available for decreasing the radiation used includes decreasing the amount of exposure technique set (lower mA/times) as well as decreasing the area of the patient exposed (field of view size). The NCRP fiftieth annual meeting program in 2014 suggested the need to apply ALADA whenever possible. A year later, Jaju and Jaju7 boldly published the following statements an international publication.

“Implementing this concept of ALADA would require the strict regulation of guidelines on CBCT referrals followed by an evidence-based assessment of image quality for specific diagnostic tasks with exposure and doses associated with a given level of image quality. Two decades after the introduction of CBCT, it is time to move from ALARA to ALADA. (2015)”

Dose Creep
Over the last 30 years in the United States, there has been a documented trend of increased medical/dental radiation doses by a factor of six, which has been coined “dose creep”. The primary causes of dose creep are digital and CT imaging, with short procedure times, great contrast resolution, and excellent visibility of detail. Digital imaging units promised to decrease both processing time and patient dose, as electronic detectors are more sensitive to x-ray energy than film. While the advent of digital imaging was met with pronouncements of decreasing radiation dose, that is not what the data indicate.8 We will consider dose creep with each modality.

Digital
The first digital images were produced by NASA in the 1960s and depicted the moon. The first sensor system for dental radiography emerged in the late 1980s. Digital imaging is currently divided into two types, direct and indirect digital imaging.

**Direct Capture Digital** | **Indirect Capture Digital**
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**DETECTOR:** Charge-Coupled Device (CCD) or a Complementary Metal Oxide Semiconductor (CMOS) | **DETECTOR:** Storage Phosphor Plates (Photostimuable Sensor Plates, PSP).

There is direct conversion of x-ray energy to electronic signal | There is indirect conversion of x-ray energy to light energy to electronic signal

The electronic signal is displayed as the digital image | The data from the PSPs must be transferred to the computer by a laser reader

Each room requires a computer/monitor system for image processing and display | One laser reader is able to support all of the rooms used for imaging

One sensor can be moved around the patient’s mouth during the procedure | Multiple sensors or a sensor that is read/erased by the laser reader between each exposure

(Chart adapted from Iannucci & Howerton, 2017, p.292)2

The convenience and speed of digital image processing technology yields almost instant gratification to the dental health care team. One concern with direct digital is that it is too easy to delete and re-expose an image and pretend it never happened, thus increasing dose to the patient. The ability to manipulate digital images makes it easy to “fix” overexposed images as well as delete poor images for a quick “retake”. This may also lead to the routine use of higher exposure settings, since the only images that cannot be corrected by the software are those that are underexposed. Together, easily deleting poor images and manipulating over-exposed images may skew the perception of patient dose.

Another important consideration in decreasing patient dose is the use of collimation, or beam limitation. The size of the x-ray beam should always be no larger than the area of interest to the clinician nor the size of the image receptor.3 Round collimators vary in size but by law can be no larger than 2.75 inches (7 cm).2 The smaller the diameter of the collimator, the less radiation the patient receives. The latest addition to conventional x-ray units is rectangular collimation. Rectangular collimation of the beam is recommended by the NCRP Report No. 145 as the standard of care. Changing from 7cm round collimator to a 6cm round collimator decreases patient radiation dose by about 25%, whereas changing from a 7cm round collimator to a 4.5cm rectangular collimator decreases radiation dose by about 55%.9 All DHCW should use rectangular collimation when imaging children.6 and less scatter radiation dose to the patient. [See Figure 1] This is especially important for a child; whose anatomy is smaller and whose tissues are more radiosensitive.

Handheld Portable X-Ray Unit
Handheld intra-oral x-ray units were first used in US military combat zones.18 The introduction of light weight portable handheld x-ray systems that can be carried from room to room...
in a dental practice is an attractive innovation. With stationary digital x-ray units, the best practice recommendation for decreasing occupational dose is that dental healthcare workers stay about 6 feet from the primary beam and the patient, as this is the maximum distance the scattered radiation can travel. This practice protects the radiation worker from leakage radiation from the tube and from scattered radiation from the patient. However, with the use of the handheld portable unit, the recommendation of distancing oneself from the radiation source is impossible to achieve.

The handheld unit is lined with lead to absorb radiation and shield the operator. There is also an added lead-lined extension cone and backscatter shield at the site of the x-ray exit from the unit to absorb backscatter to the operator. Studies have demonstrated minimal dose readings for imaging personnel who use the equipment properly. Concerns for the safe use of handheld x-ray equipment include careful handling to prevent cracks in the housing, forgetting that the camera or toy-looking unit is emitting ionizing radiation, proper placement of the backscatter shield, using proper distances, proper placement of the backscatter shield, using proper distances, and mistakenly holding the unit at any angle other than at ninety degrees from the body of the imaging personnel.

From the images made by the authors of this article, the green areas indicate backscatter to the imaging professional. Image A represents best practice: the operator should hold the handheld unit ninety degrees to his or her body, with the backscatter shield pushed to the end of the collimator, and with the unit placed as close as possible to the patient to ensure the least dose possible is delivered to the operator. If the handheld unit is not positioned near the patient as in image B, the operator will receive an excessive dose from backscatter radiation. If the external shield is not properly placed at the end of the collimator, as in image C, again the operator will receive an excessive dose from backscatter radiation. If the external beam is not properly directed, as in image D, the dose to the operator, especially to eyes, thyroid, and gonadal region is increased. Of course the DHCW should never hold sensors during x-ray exposures. While the handheld unit has many advantages, continued education and training are imperative for occupational safety.

**Computed Tomography**

In the 1970s Godfrey N. Hounsfield invented the medical CT scanner for the use in medicine. The computer uses the captured attenuated x-ray energy data and imaging software to produce sectional images. The geometry of the x-ray beam and the detectors has evolved over the last 40 years to yield scanners that can scan the whole body in seconds and reconstruct every plane, produce contour maps, construct 3-dimensional images of parts of the anatomy, subtract parts that are in the way, and much more.

CT was introduced to dental radiography in 1999 and approved by the FDA in 2001. CBCT derives its name from the way in which the x-rays hit the image receptor detectors. CT units employed in medicine may use pencil beam, slit beam, fan beam, or cone beam geometry depending upon the resolution requirements of the procedure. Dental CT employs slit beam geometry for panoramic or 2-D images and cone beam geometry for the 3-D images. In cone beam CT (CBCT) the x-rays exiting the x-ray tube diverge, or spread out equally in all directions to cover the detectors. This cone beam x-ray beam shape allows the information to be gathered in only one or two revolutions of the x-ray tube. A volume of information is collected and then the computer assigns the data to the slice images.

The images gained from this volume data and sophisticated software was a game changer for dental radiography. With the production of conventional x-ray images the dentist could examine the roots of the teeth without having to remove the teeth from the oral cavity to see them. However, even after obtaining multiple views at different angles the dentist still might not be able to see each root without the superimposition of another
root. CT overcomes the superimposition of parts by gathering the information from the transmitted x-ray energy of the whole part and then using the computer programs to reconstruct images into slices of information.\(^{14}\)

**Figure 3. Beam Geometry**

As with conventional dental radiography equipment, only some CBCT manufacturers allow for the x-ray beam to be collimated to a smaller area than the detectors. Collimators are part of the equipment that regulates the size of x-ray beam exiting the tube housing. Proper collimation decreases the number of unnecessary photons reaching the patient. Proper collimation also decreases the number of scattered photons that would only take away from the sharpness of the image and add no diagnostic information. The DHCW controls collimation size and should always use this capability to minimize the dose to tissues outside the area of interest, such as the thyroid gland, breast tissue, and lens of the eye.\(^{15}\)

Collimating the beam changes the field of view (FOV). The field of view can be simply defined as the area being viewed. In the large FOV protocol, the patients head may be imaged from the top of the orbits through the hyoid bone in the neck. A medium FOV usually images from the bottom of the orbits through the chin. A small FOV protocol usually images only the teeth from the inferior portion of the maxilla through the superior portion of the mandible. In CBCT, collimation is set by the protocol chosen for the procedure.

While FOV is a very important contributor to total dose, the range of dose at different fields of view is dependent upon the manufacturer of the unit. A recent study comparing scans using the same technical factors but performed on units from more than 20 different manufacturers demonstrates a wide range of dose. Different units using a small FOV exhibited dose ranges of 0.019 to 0.652mSv, with a medium FOV dose ranges were 0.028 to 0.56mSv, and with a large FOV dose ranges were 0.068 to 1.073mSv.\(^{16}\) Another factor to consider when using the largest FOV is that the dentist or radiologist has the legal and ethical responsibility for reporting any pathology captured on the image.\(^{17}\)

Whether the common term, CBCT, used in dental imaging discussion of CT is due to the type of beam geometry employed most often or an attempt to distance the perception of high dose associated with medical CT is an interesting question. While dental CT dose is almost always much less than medical CT dose, dental CT offers more dose than conventional dental imaging just as medical CT dose offers more dose than conventional medical imaging. While the dose imparted with different imaging procedures is dependent upon the unit and the operator, we can make some general comparisons among some common radiation doses. For instance a conventional chest radiography yields about 0.05-0.08mSv, whereas a Chest CT procedure yields about 7-9mSv. Likewise, a full mouth dental digital series yields about 0.06mSv, while a dental CBCT yields about 1.3-8.2mSv.\(^{18}\)

**Conclusion**

In order to reverse dose creep in dental imaging, DHCW must remember what they have been taught about ionizing radiation, become educated about the current technology, and serve as advocates for decreased dental radiation dose by utilizing the concepts of ALARA and ALADA. In conventional digital image capture, the lowest possible exposure factors and greatest collimation, combined with proper tube alignment and patient cooperation, yield the lowest dose to the patient. Proper use of dental x-ray equipment is associated with minimal risk. With the handheld x-ray units, using the lowest possible exposure factors, best distances, and proper angles are required for delivering the least possible dose to the patient and the DHCW. In CBCT, appropriate FOV and the consideration of diagnostic versus beautiful image, are the most important factors to consider for consistently delivering the lowest possible radiation dose. DHCW should take the leadership role in improving training in the use of the new dental imaging technology and in increasing awareness of the radiation safety issues facing dentistry today.

**References**


Questions

1. Which of the following is considered a benefit of dental radiography?
   a. early diagnosis of dental decay
   b. determination of supporting bone condition
   c. documentation of the presence of an abscess
   d. all of the above

2. When were x-rays discovered?
   a. in the late 1700s
   b. in the late 1800s
   c. in the early 1800s
   d. in the mid-1900s

3. What is the name of the council that provides scientific reports regarding ionizing and non-ionizing radiation?
   a. national council on radiation protection and measurements
   b. national council on radioactive materials
   c. national congress on radiation protection of mammals
   d. national council on responsible programs in radiation

4. How much has medical/dental radiation dose increased from 1980 to 2006?
   a. five times
   b. seven times
   c. ten times
   d. one hundred times

5. Which of the following is caused by x-ray absorption?
   a. ionization
   b. magnetization
   c. electrification
   d. polarization

6. Which of the following tissue types is associated with a greater amount of absorption of x-rays?
   a. bone
   b. fat
   c. liver
   d. heart

7. When were the dangerous side effects of x-radiation recognized?
   a. early 1900s
   b. mid 1900s
   c. late 1900s
   d. early 2000s

8. Where are x-rays produced?
   a. in cellular phones
   b. in high tension electrical lines
   c. in the decaying nucleus of a radionuclide
   d. in an x-ray tube

9. Which of the following conditions cannot be correlated to overexposure to ionizing radiation?
   a. improved eyesight
   b. earlier cataract formation
   c. increased risk of thyroid cancer
   d. increase chance of genetic mutation to future generations

10. Which of the following is not a technique of best radiation safety practice?
    a. time
    b. distance
    c. shielding
    d. wearing a personnel dosimeter badge

11. What is minimum safe distance for the operator to stand from the x-ray source and the patient during a radiographic exposure produced with a stationary x-ray unit?
    a. 3 feet
    b. 6 feet
    c. 10 feet
    d. 20 feet
12. Which term best describes the measurement of dose based on the absorbed x-ray dose to tissue?
   a. limit dose  
   b. rectification dose  
   c. equivalent dose  
   d. biological dose

13. Which unit of measured is used most often for occupational and patient absorbed dose?
   a. sievert  
   b. rad  
   c. gray  
   d. roentgen

14. What does the acronym for the principle of alara represent?
   a. as low as reasonably achievable  
   b. as low as reasonably acceptable  
   c. as low as reasonably attainable  
   d. as low as reasonably applicable

15. What does the acronym for the principle of alada represent?
   a. as low as diagnostically acceptable  
   b. as low as distinguishably acceptable  
   c. as low as discriminatingly acceptable  
   d. as low as discreetly acceptable

16. Which of the following terms best describes the documented pattern of radiation exposure levels increased over time in an attempt to achieve better quality diagnostic radiographic images?
   a. latent radiation dose  
   b. dose creep  
   c. radiation hormesis  
   d. linear energy transfer

17. What is a common component of a direct capture digital image receptor?
   a. charge-coupled device  
   b. photostimuable sensor plate  
   c. thin-film transistor  
   d. cesium iodide phosphor array

18. Which of the following processes occurs only in indirect capture digital systems?
   a. light energy is converted to x-ray energy  
   b. x-rays are converted to light energy  
   c. x-ray energy is converted to electronic signal  
   d. electric charge is converted to light energy

19. What component is required for a direct capture digital system?
   a. a laser reader to transfer and process the data  
   b. a darkroom for processing  
   c. erasure of the image receptor between each exposure  
   d. none of the above

20. How might a digital image acquired with inadequate numbers of x-rays be manipulated for diagnostic use?
   a. it cannot be  
   b. by increasing the overall brightness of the image  
   c. by changing the contrast on the final image  
   d. by decreasing the overall darkness of the image

21. Which of the following best describe the method used to shield the patient from unnecessary x-radiation by primary x-ray beam limitation?
   a. collimation  
   b. rectification  
   c. proper tube angle  
   d. proper part to image receptor alignment

22. What is the legal limit for the round collimator maximum size?
   a. 1.00 in (2.5 cm)  
   b. 3.4 in (8.64 cm)  
   c. 2.50 in (6.35 cm)  
   d. 2.75 in (7 cm)

23. What is the resultant decrease in x-radiation dose when decreasing the round collimator diameter by 1cm from its maximum allowable diameter?
   a. 25%  
   b. 33%  
   c. 55%  
   d. 75%

24. What is the resultant decrease in x-radiation dose when replacing the round collimator from its maximum allowable diameter to a 4.5cm rectangular collimator?
   a. 55%  
   b. 25%  
   c. 33%  
   d. 75%

25. What is the best way to hold the handheld portable dental x-ray unit during an exposure?
   a. at 90 degrees to the operator’s body  
   b. at 45 degrees to the operator’s body  
   c. at 30 degrees to the operator’s body  
   d. at 120 degrees to the operator’s body

26. Which of the following arrangements of the handheld portable dental x-ray unit will offer the least radiation dose to the operator?
   a. the backscatter shield situated toward the patient end of the collimator  
   b. the backscatter shield situated toward the operator end of the collimator  
   c. the backscatter shield situated in the middle of the collimator length  
   d. the backscatter shield removed from the unit

27. What was the greatest benefit of ct for dental imaging?
   a. its ability to overcome the superimposition of objects  
   b. its ability to allow for image manipulation  
   c. its ability to offer the highest spatial resolution  
   d. its ability to the least radiation dose of all imaging procedures

28. Which aspect of the ct image is controlled by collimation?
   a. field of view  
   b. contrast resolution  
   c. overall image brightness  
   d. the ability to acquire reconstructed images

29. Why is ct linked to dose creep in dental imaging?
   a. it requires longer exposure times and therefore increased radiation dose for adequate image data  
   b. it requires much higher x-ray energy for the flat panel detector system used  
   c. it requires less numbers of x-rays for data reconstruction  
   d. it uses a fixed field of view setting that cannot be decreased, even for pediatric patients

30. Which of the following statements is true?
   a. in general, dental ct offers more radiation dose than conventional dental imaging.  
   b. in general, dental ct procedures offer more radiation dose than medical ct procedures.  
   c. in general, dental film exposures offer more radiation than digital capture exposures.  
   d. in general, dental rectangular collimation use offers more radiation dose than dental round collimation.
Dose Creep in Dental Radiography

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Course Evaluation

1. Were the individual course objectives met?
   - Objective #1: Yes No
   - Objective #2: Yes No
   - Objective #3: Yes No

Please evaluate this course by responding to the following statements, using a scale of Excellent = 5 to Poor = 0.

2. To what extent were the course objectives accomplished overall? 5 4 3 2 1 0
3. Please rate your personal mastery of the course objectives. 5 4 3 2 1 0
4. How would you rate the objectives and educational methods? 5 4 3 2 1 0
5. How do you rate the author’s grasp of the topic? 5 4 3 2 1 0
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