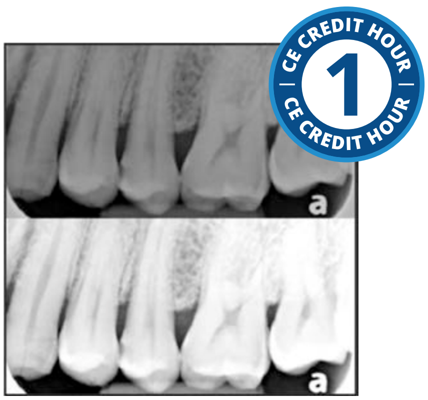
The Radiographic Image



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Conflict of Interest Disclosure Statement

- The author reports no conflicts of interest associated with this course.

Introduction – The Radiographic Image

The purpose of The Radiographic Image is to explain the basic concepts of image formation and the factors that affect image brightness, contrast, sharpness and overall quality.

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Overview

This course explains in detail the principle of image formation on any type of x-ray receptor starting from the interaction between the x-ray and the object that is radiographed. This course will also explain the factors that affect the image quality such as the kVp, mAs, spatial resolution, and contrast resolution and image sharpness.

Learning Objectives

Upon completion of this course, the dental professional should be able to:

- Describe how the x-ray image is formed.
- Explain the difference between contrast resolution and spatial resolution.
- Describe the effect of the exposure settings on the image quality.
- Describe the difference between magnification and distortion.

Introduction

On November 8, 1895, William C. Roentgen discovered the x-ray. About half a month after the announcement of this discovery Friedrich Otto Walkhoff took the first dental radiograph. It took him 25 minutes to get his own radiographic image. Since then, technological advances have dramatically improved radiographic image quality. However, the way the radiographic image quality is affected by the X-ray beam quality, quantity and intensity, and by the radiographic object, have not changed.

The purpose of this course is to explain the factors that are responsible of forming the radiographic image and how they affect the image quality.

How is a Radiographic Image Formed?

When an x-ray passes through an absorber, it gets differentially absorbed by what constitutes the absorber and the thickness of each component. When the x-ray beam exits this absorber, it will have varying levels of intensities. This variation will be recorded on a radiographic receptor as different densities generating the radiographic contrast. The densities related to a thick absorber (i.e., aluminum) will be brighter than the densities of the thin absorbers (Figure 1).[1-5]

Radiographic Density

Radiographic density is reflected by radiographic image darkness. In conventional film radiography, it is called "transmitted density" because it is a measure of the light transmitted through the film. In digital imaging, it refers to how much the overall histogram of the image is shifted towards the lower grey levels.[3,6-8]

There are common factors that affect the radiographic density of conventional film and digital receptor or plate, and there are other factors that depend on the nature of the receptor. We will only discuss common factors

Figure 1. Illustration of a radiographic image formation.

that relate to the exposure and to the subject and we will consider one variable at a time, keeping the other variables fixed.

Change in mA and in Exposure Time

When the mA or exposure time increases, the number of x-ray photons generated at the anode increases linearly without increasing beam energy. This will result in a higher number of photons reaching the receptor and this leads to an overall increase in the density of the radiographic image (Figure 2).[2,4,6,9]

Change in kVp

When the kVp increases, the number and energy of x-ray photons generated at the anode increase. This will result in a higher number of photons with higher energies reaching the receptor, and this leads to an overall increase of density of the radiographic image at a greater scale when increasing mA or exposure time (Figure 3).[2-4,8]

Change in Source to Object Distance

When the source to object distance increases, the intensity of the x-ray beam decreases following the inverse square law. This will result in decrease in the intensity of the beam reaching the object, and this results in a decrease in image density (Figure 4).[5-7,10,11]

Thickness of the Absorber

When the thickness of the absorber increases, the number of photons absorbed increases, leading to less photons reaching the receptor. This will result in a decrease in the image density (Figure 5).[3,710,11]

Radiographic Contrast

Contrast is the difference in density or difference in the degree of grayness between areas of the radiographic image.[7] The radiographic contrast depends on the following three factors:

1. **Subject Contrast:** it refers to the difference in the intensity transmitted through the different

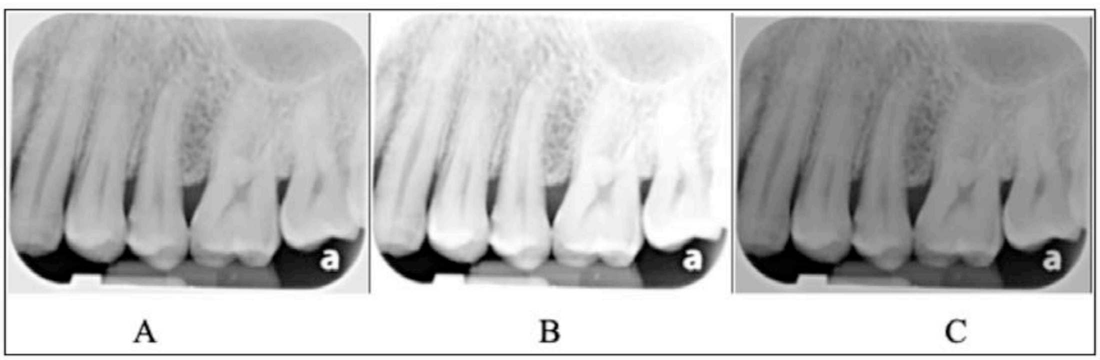

Figure 2. Change of image density related to change of mA and/or exposure time: Image A is used as reference. Image B shows a brighter image due to decrease in mA and/or exposure time. Image C shows a darker image due to increase in mA and/or exposure time.

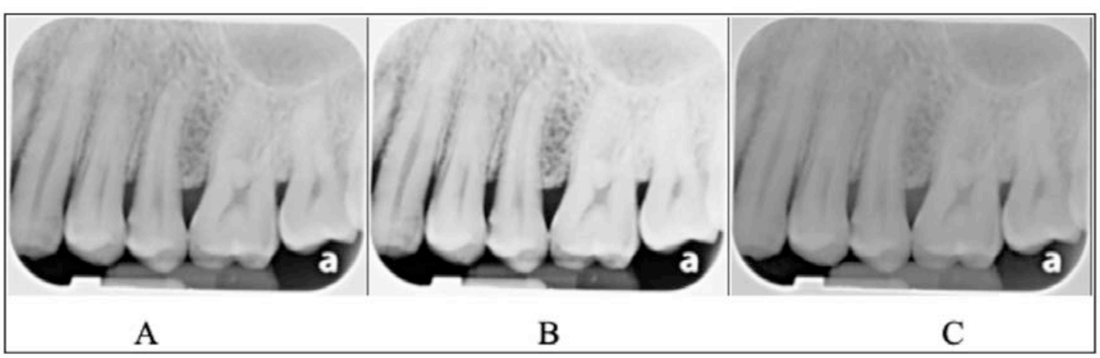

Figure 3. Change of image contrast related to change of kVp: Image A is used as reference. Image B shows a higher contrast image due to decrease in kVp. Image C shows a lower contrast image due to increase in kVp.

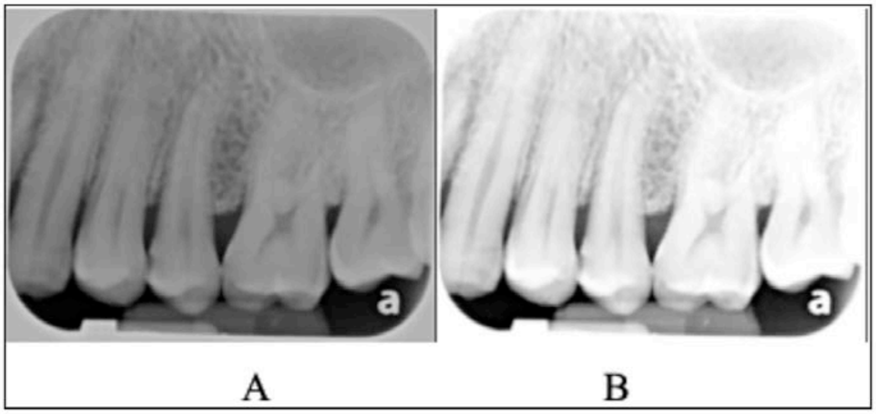

Figure 4. Change of image density related to change of source to detector distance: Image A is used as reference. Image B shows a brighter image due to increase of source to detector distance.

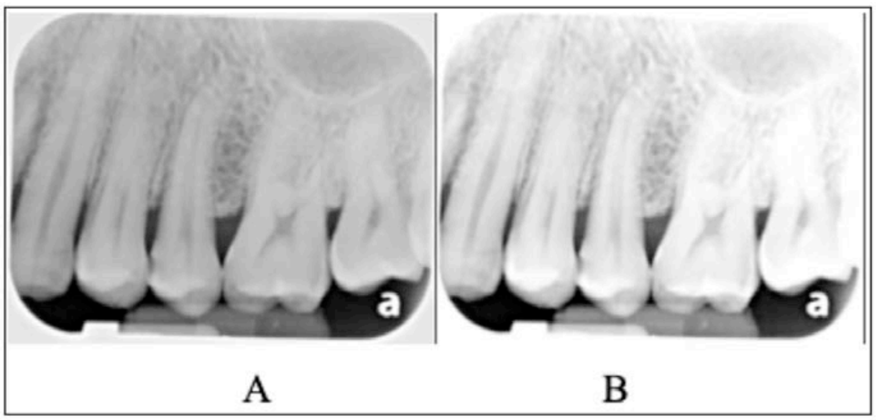

Figure 5. Change of image density related to change of absorber thickness: Image A is used as reference. Image B shows a brighter image due to increase of absorber thickness.

parts of an object. For example, in an intraoral radiograph, enamel will attenuate x-rays more than dentin. Subject contrast is affected by the following factors:

- ***Thickness difference:*** if the x-ray beam is attenuated by 2 different thicknesses of the same material, the thicker part will attenuate more x-rays than the thinner part.[1,4,5,12]
- ***Density difference:*** this is also known as the mass per unit volume. It is the most important factor contributing to subject contrast. A higher density material will attenuate more x-rays than a lower density material.[5,6,10,11]
- ***Atomic number difference:*** A higher atomic number material will attenuate more x-rays than a lower atomic number material.[2,6,7]
- ***Radiation quality or kVp:*** it has a great effect on subject contrast. A lower kVp will make the x-ray beam less penetrating. This will result in a greater difference in attenuation between the different parts of the subject, leading to higher contrast. A higher kVp will make the x-ray beam more penetrating. This will result in less difference in attenuation between the different parts of the subject, leading to lower contrast.[1,3,4,12]

2. **Receptor Contrast**: it refers to the ability of a receptor to show adequately the information that the photons transmitted through the subject. In conventional radiography, the contrast depends on the size of the grains, the development time, the concentration and temperature of

the developing solution, and overall film density.[2,47,12] As conventional film use has been reduced, we will not discuss the details of these factors.

In digital imaging, contrast depends on the bit-depth of the receptor. Bit-depth refers to the number of possible grey values that can be stored in an image. The higher the bit-depth, the more gray values it can store. The simplest image, a 1-bit image, can only show two colors, black and white. That is because 1-bit can only store one of two values, 0 (white) and 1 (black). An 8-bit image can store 256 possible gray values, while a 12-bit image can display 4096 gray values.[1,4,9]

3. **Factors that Affect Radiographic Contrast:** Scatter radiation will decrease the contrast of the radiograph; however, collimation can counterbalance this effect.[1,4,7,8]

Image Resolution

Image resolution is the details that an image can contain. The details depend on the following factors:

Contrast Resolution

It is the ability of an imaging system to distinguish between multiple densities in the radiographic image. In the case of digital imaging, it depends on the bit-depth of the system. As noted earlier, an 8-bit system can show only 256 gray values as opposed to a 12-bit system, which shows 4096 gray values. The 8-bit system shows less gray values and is a high contrast system than the 12-bit system that shows more gray values and is a low contrast system. However, if the 12-bit-system can clearly show two near-by gray value intensities, the system will have a high contrast resolution (Figure 6).[1,3,6,7]

Spatial Resolution

Spatial resolution in radiology refers to the ability of an imaging system to differentiate between two near-by objects. In digital imaging, it depends on the size of the pixel used. A large pixel size will be unable to resolve two near-by structures as compared to a small pixel size. Spatial resolution is measured in line-pairs per millimeters (Figure 7).[1,4,7,9-11]

Image Magnification

It refers to the proportional increase in the dimensions of a radiographed object relative to the actual dimensions of that object and depends on the following factors:

1. Increasing object to film distance **only** will result in an increase in magnification of the radiographic image. Decreasing object to film distance **only** will result in a decrease in magnification of the radiographic image (Figure 8).[2,4,7,8]

Figure 6. Comparison of 2 systems. In each rectangle, there is a square that has a grey value close to the grey value of the rectangle. A has a low contrast resolution. B has a high contrast resolution.

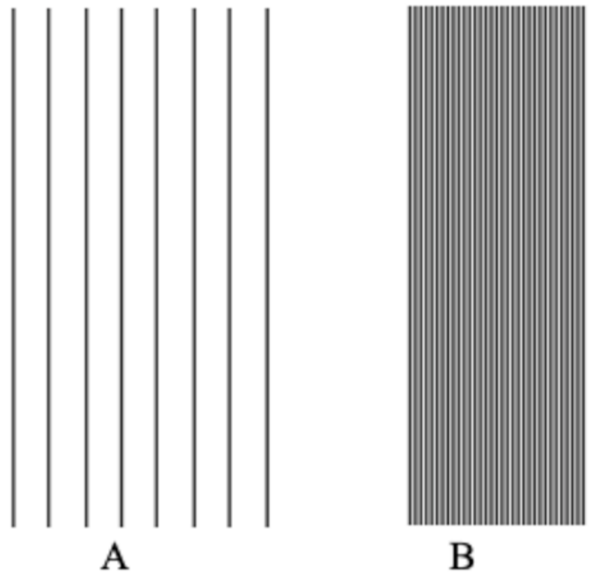

Figure 7. Comparison of 2 systems: A has a low spatial resolution and B has a high spatial resolution.

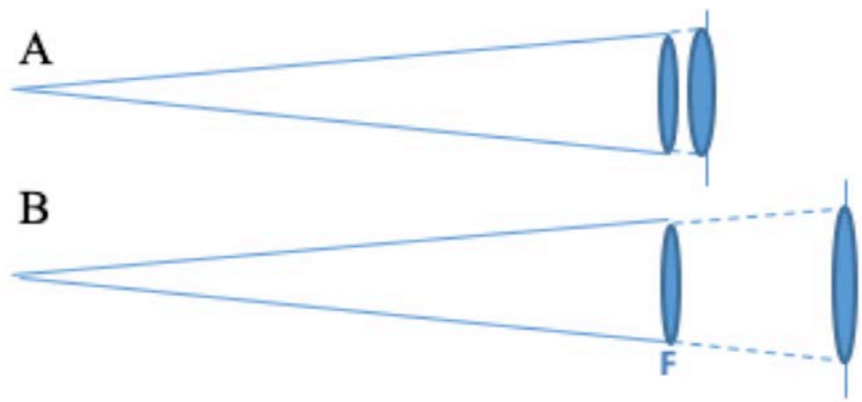

Figure 8. Comparison of magnification when the object to film distance changes. A short distance (A) shows less magnification than a long distance (B).

Increasing source to object distance **only** will result in a decrease in magnification of the radiographic image. Decreasing source to object distance **only** will result in an increase in magnification of the radiographic image (Figure 9).[2,4,7,8]

Image Distortion

It refers to the non-proportional increase in the dimensions of a radiographed object relative to the actual dimensions of that object. It can be seen when there is a change in the angle of the incidence x-ray beam or when the receptor is not parallel to the object (Figure 10).[2,4,5,7,8]

Image Sharpness

Sharpness is considered a major factor in determining image quality as it is the factor that determines the amount of detail an imaging system can reproduce (Figure 11).

Sharpness is defined by the dimensions of the partially shaded outer region or the penumbra of an object. The wider the penumbra, the less sharp the image (Figure 12).[1,2,5]

We will only discuss the properties of shadow-casting and the width of the penumbra that are related to the x-ray tube and sensor. We will

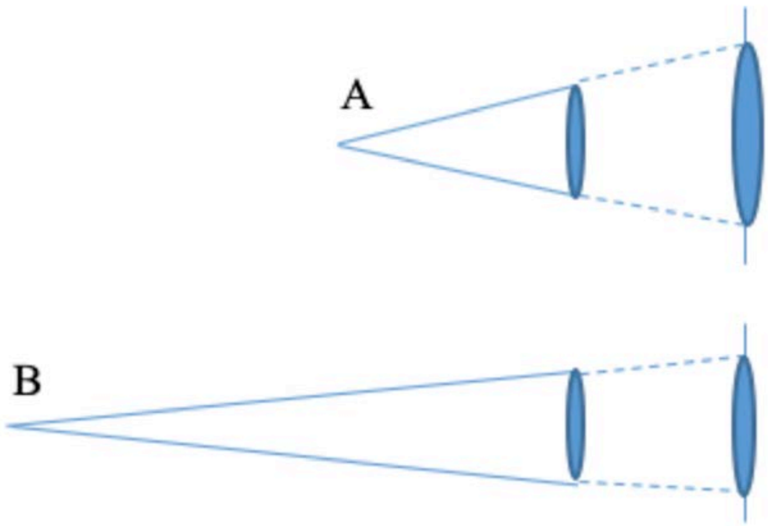

Figure 9. Comparison of magnification when the source to object distance changes. A short distance (A) shows more magnification than a long distance (B).

Figure 10. Distortion of the shape of the rectangle due to a change in the angle of incidence of an x-ray beam.

Figure 11. Image A is sharpness when compared to B.

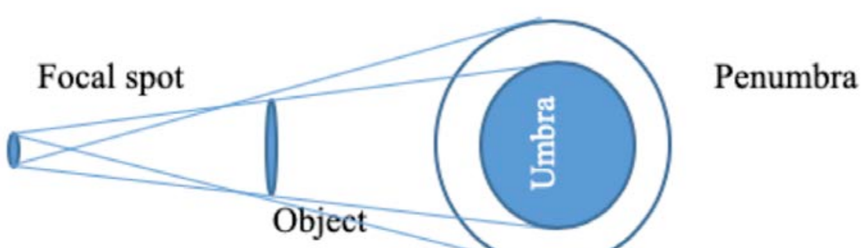

Figure 12. Shadow casting, umbra and penumbra.

not factor in patient-related sharpness of the image.

The sharpness of the image depends on multiple factors. We will consider one variable at a time, keeping the other variables fixed:

1. ***The apparent focal spot size:*** The larger is the size of the apparent focal spot, the larger is the penumbra, resulting in a less sharp image.[1,3,6,11]
2. ***Source-to-object distance:*** The greater is the source-to-object distance, the smaller is the penumbra, resulting in a sharper image.[1,2,4,5,8,11]
3. ***Object-to-receptor distance:*** The greater is the object-to-receptor distance, the larger is the penumbra, resulting in a less sharp image.[2-4,9,7,11]
4. ***X-ray tube motion-related un-sharpness:*** If the tube moves when the x-ray image is being taken, the apparent focal spot size will become larger resulting in a larger penumbra and a less sharp image.[2,5,12]

Conclusion

Radiographic image quality is a combination of the following: density, contrast, spatial resolution, contrast resolution, magnification, distortion and sharpness. The x-ray settings can affect many of those factors at the same time and it is important to understand how these settings affect each of these variables.

Course Test Preview

To receive Continuing Education credit for this course, you must complete the online test. Please go to: *www.dentalcare.com/en-us/professional-education/ce-courses/ce571/start-test*

1. **Which of the following statements related to the formation of a radiographic image is correct?**
   A. When an x-ray passes through an absorber, it is absorbed differentially by what constitutes the absorber and the thickness of each component.
   B. When the x-ray beam exits an absorber, it will have varying levels of intensities recorded on a radiographic receptor as different densities, generating the radiographic contrast.
   C. Radiographic densities associated with thick absorbers will be brighter than densities associated with thin absorbers.
   D. All of the above.

2. **All of the following statements related to factors that affect radiographic density are correct EXCEPT which one?**
   A. When the mA or exposure time increases, the number of photons generated increases linearly without increasing beam energy.
   B. When related to a reference radiographic image, a decrease in the mA or exposure time will result in a brighter radiographic image.
   C. When the kVp increases, the number and energy of x-ray photons generated decrease.
   D. When related to a reference radiographic image, an increase in kVp will result in a radiographic image with lower contrast.

3. **All of the following statements related to source to object distance or thickness of the absorber are correct EXCEPT which one?**
   A. When the source to object distance increases, the intensity of the x-ray beam decreases following the inverse square law.
   B. When related to a reference radiographic image, increasing the source to object distance will result in a darker image.
   C. When the thickness of the absorber increases, the number of photons absorbed increases.
   D. When related to a reference radiographic image, an increase in absorber thickness will result in a brighter image.

4. **Which of the following statements related to radiographic contrast, i.e., the difference in the degree of grayness between areas of the radiographic image are correct?**
   A. When the x-ray beam is attenuated by 2 different thicknesses of the same object, the thicker part will attenuate more x-rays than the thinner part.
   B. An important contributing factor is the density of the object - high density material will attenuate more x-rays than low density material.
   C. Higher kVp will make the x-ray beam more penetrating resulting in lower contrast.
   D. All of the above.

5. **Which of the following statements related to receptor contrast, i.e., the ability of a receptor to show adequately the information that the photons transmitted through the subject is incorrect?**
   A. In conventional radiography, receptor contrast depends on the size of the grains, development time, concentration and temperature of the developing solution, and overall film density.
   B. In digital imaging, contrast depends on the bit-depth of the receptor, i.e., the number of possible grey values that can be stored in an image.
   C. In digital imaging, the higher the bit-depth of the receptor, the less gray values it can store.
   D. In digital imaging, a 1-bit receptor can only store one of two values, 0 (white) and 1 (black).

6. **Factors that affect radiographic contrast include scatter radiation, which will decrease the contrast of the radiograph; however, collimation can counterbalance this effect.**
   A. True
   B. False

7. **All of the following statements related to contrast resolution are correct EXCEPT which one?**
   A. Contrast resolution is the ability of an imaging system to distinguish between multiple densities in the radiographic image.
   B. In digital imaging, contrast resolution depends on the bit-depth of the system - an 8-bit system can show 256 gray values as opposed to a 12-bit system, which shows 4096 gray values.
   C. In digital imaging, an 8-bit system shows less gray values than a 12-bit system and is, generally, a low contrast system.
   D. In digital imaging, a 12-bit system that shows more gray values than an 8-bit system and is, generally, a low contrast system, but if it can clearly show two near-by gray value intensities, the system will have a high contrast resolution.

8. **All of the following statements related to special resolution are correct EXCEPT which one?**
   A. Spatial resolution in radiology refers to the ability of an imaging system to differentiate between two near-by objects.
   B. In digital imaging, special resolution depends on the size of the pixel used.
   C. Larger the pixel size, the more likely that the system will resolve two near-by structures, i.e., will have a higher special resolution as compared to a small pixel size system.
   D. Spatial resolution is measured in line-pairs per millimeters.

9. **Which of the following statements related to image magnification is correct?**
   A. Image magnification refers to the proportional increase in the dimensions of a radiographed object relative to the actual dimensions of that object.
   B. Increasing object to film distance only will result in an increase in magnification of the radiographic image.
   C. Increasing source to object distance only will result in a decrease in magnification of the radiographic image.
   D. All of the above.

10. **Which of the following statements related to image distortion is correct?**
   A. refers to the non-proportional increase in the dimensions of a radiographed object relative to the actual dimensions of that object.
   B. can be seen when there is a change in the angle of the incidence x-ray beam.
   C. can be seen when the receptor is not parallel to the object.
   D. All of the above

11. **Image sharpness is considered a major factor in determining image quality as it is the factor that determines the amount of detail an imaging system can reproduce.**
   A. True
   B. False

12. **Image sharpness is defined by the dimensions of the partially shaded outer region or the penumbra of an object– an image with a narrow penumbra is less sharp.**
   A. True
   B. False

13. All of the following statements related to image sharpness are correct EXCEPT which one?

A. The larger is the size of the apparent focal spot, the larger is the penumbra, resulting in a less sharp image.
B. The greater is the source-to-object distance, the greater is the penumbra, resulting in a less sharp image.
C. The greater is the object-to-receptor distance, the larger is the penumbra, resulting in a less sharp image.
D. If the tube moves when the x-ray image is being taken, the apparent focal spot size will become larger resulting in a larger penumbra and a less sharp image.

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Additional Resources

- No Additional Resources Available

About the Author

Hassem Geha, DDS, MDS, Diplomate of the ABOMR

Hassem Geha is an Associate Professor in the Department of Comprehensive Dentistry at the University of Texas Health Sciences Center. He received his dental degree from Saint Joseph University, School of Dental Medicine – Beirut in 1997, and two specialty degrees in oral biology and Maxillofacial radiology from the Lebanese University, School of Dentistry in Beirut in 2001. In 2002, he relocated to the United States. He became a Diplomate of the American Board of Oral and Maxillofacial Radiology in 2004 and received a Master of Dental Sciences (MDS) degree from the University of Connecticut Graduate School in 2005. Dr. Geha was appointed Assistant Professor at New York University College of Dentistry. In 2010 he joined UTHSCSA where he is Oral Radiology course director for the DS3 and he is heavily involved in the post-graduate program at the dental school. He also is a Clinical Associate in Otolaryngology and Head and Neck Surgery at the American University of Beirut Medical Center. Dr. Geha was the recipient of Albert G. Richards Award in 2003 and the Radiology Centennial Scholarship Award in 2004 given by the American Academy of Oral and Maxillofacial Radiology. He has given many presentations and continuing education courses at national and international meetings and authored many scientific manuscripts and abstracts in national and international journals. Hassem's main research focuses on enhancement of digital imaging based on mathematical models. He chaired and served in several academic committees including many MS theses supervising committees in Oral and Maxillofacial Radiology.

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