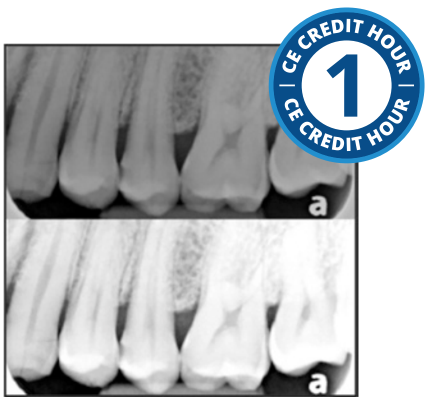
The Radiographic Image



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Online Course: *https://www.dentalcare.com/en-us/ce-courses/ce571*

Conflict of Interest Disclosure Statement

- Dr. Geha reports no conflicts of interest associated with this course. He has no relevant financial relationships to discolose.

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.

Course Contents

Overview

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

Learning Objectives

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

- Describe the formation of the x-ray image.
- 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 radiographic image. Since then, technological advances have dramatically improved radiographic image quality. However, the X-ray beam quality, quantity, and intensity affect the radiographic image quality. The radiographic object has not changed.

This course aims to explain the factors responsible for forming the radiographic image and how they affect the image quality.

How is a Radiographic Image Formed?

X-rays are differentially absorbed when they pass through an absorber. The absorption of x-rays is related to the absorber component's thickness and density. Therefore, when the x-ray beam exits this absorber, it will have varying intensity levels. The radiographic receptor will record the variation in the x-ray intensity as radiographic density. The difference between the radiographic densities is the radiographic contrast. The radiographic densities related to a thick absorber will be brighter than the densities of the thin absorbers (Figure 1).[1-5]

Radiographic Density

The amount of darkness in the radiographic image reflects the radiographic density. It is called "transmitted density" in conventional film radiography because it measures the light transmitted through the film. In digital imaging, it refers to the shift of the histogram to the lower grey levels.[3,6-8]

There are common factors that affect the radiographic density of conventional film and digital receptors or plates, and other factors depend on the nature of the receptor. We will only discuss common factors related to the exposure and the subject. We will consider one variable at a time, keeping the other variables fixed.

Figure 1. Illustration of a radiographic image formation.

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. The result will be 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 in density of the radiographic image at a larger 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 a 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 fewer photons reaching the receptor, which will result in a decrease in the image density (Figure 5).[3,7,10,11]

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

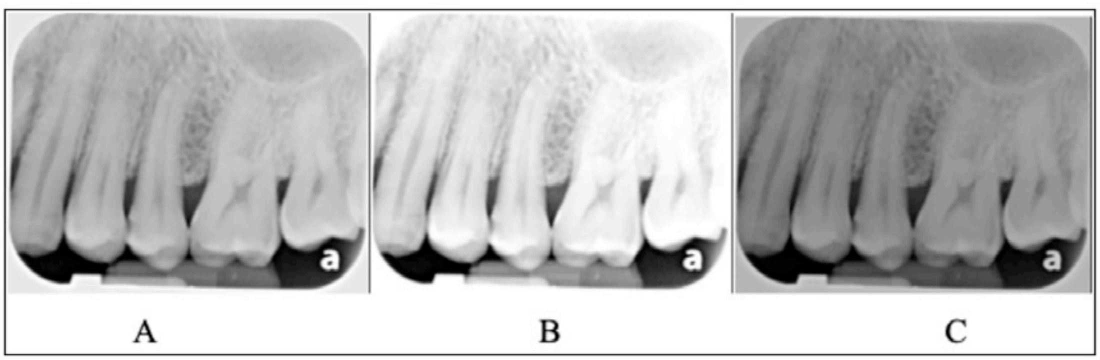

Figure 2. Change of image density related to change of mA and/or exposure time: Image A is used as reference. Image B shows a brighter image due to decrease in mA and/or exposure time. Image C shows a darker image due to increase in mA and/or exposure time.

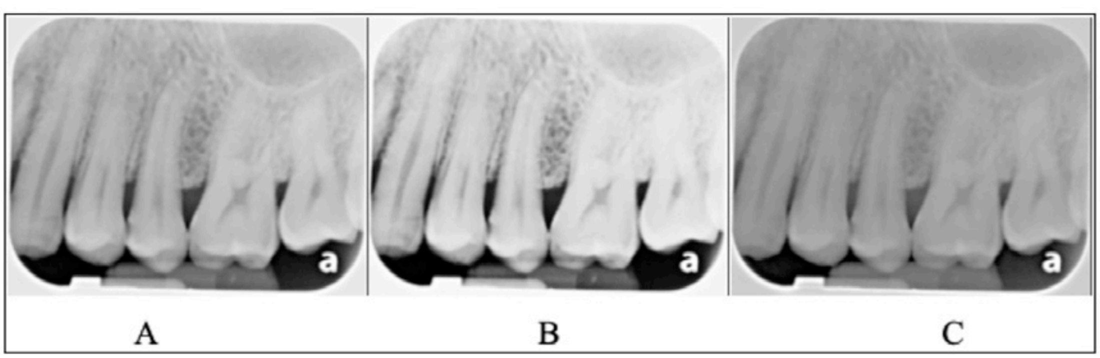

Figure 3. Change of image contrast related to change of kVp: Image A is used as a reference. Image B shows a higher contrast image due to a decrease in kVp. Image C shows a lower contrast image due to an increase in kVp.

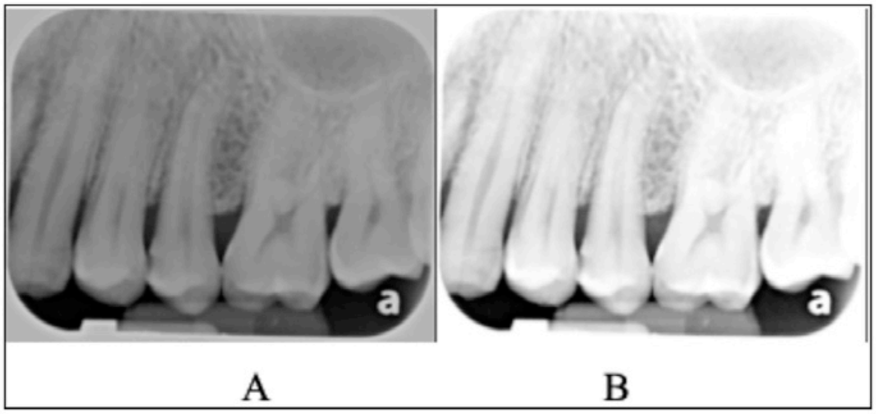

Figure 4. Change of image density related to change of source to detector distance: Image A is used as reference. Image B shows a brighter image due to increased source to detector distance.

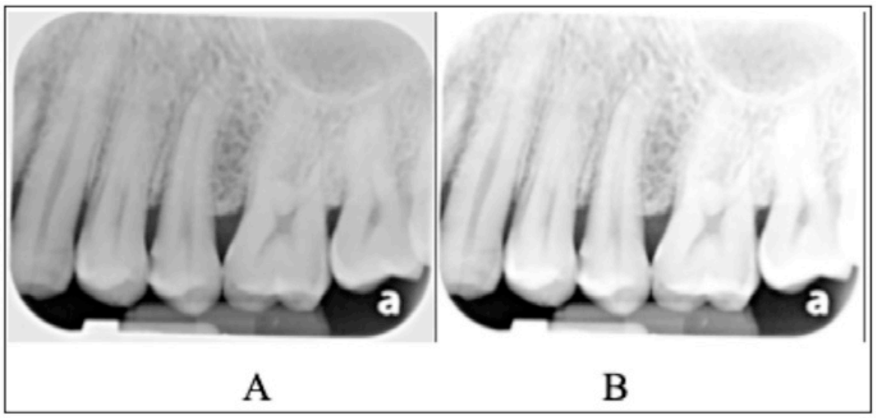

Figure 5. Change of image density related to change of absorber thickness: Image A is used as a reference. Image B shows a brighter image due to an increase in absorber thickness.

- ***Thickness difference:*** when two different thicknesses of the same material attenuate an x-ray beam, 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 critical 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:*** this has a significant effect on subject contrast. A lower kVp will make the x-ray beam less penetrating. It will result in a more substantial 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. It will also 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 a receptor's ability to adequately show 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 there is limited usage of conventional film, 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 stored in an image. The higher the bit-depth, the more gray values it can show. A 1-bit image can only show two colors, black and white. 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:** Scattered radiation will increase the image noise and decrease the radiographic image's contrast. Radiographic collimation can reduce the amount of scattered radiation and improve the radiographic contrast.[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

An imaging system can distinguish between multiple densities in the radiographic image. In the case of digital imaging, it depends on the bit-depth of the system. An 8-bit system can show only 256 gray values instead of a 12-bit system, which shows 4096 gray values. The 8-bit system shows fewer gray values and is a high contrast system than the 12-bit system, which shows more gray values and is a low contrast system. However, if the 12-bit-system can clearly show two nearby 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 nearby objects. In digital imaging, it depends on the size of the pixel used. A large pixel size will be unable to resolve two nearby structures compared to small pixel size. The measuring unit of spatial resolution is in line pairs per millimeter (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 increase the magnification of the radiographic image. Reducing object to film distance only will result in a decrease in magnification of the radiographic image (Figure 8).[2,4,7,8]

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

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

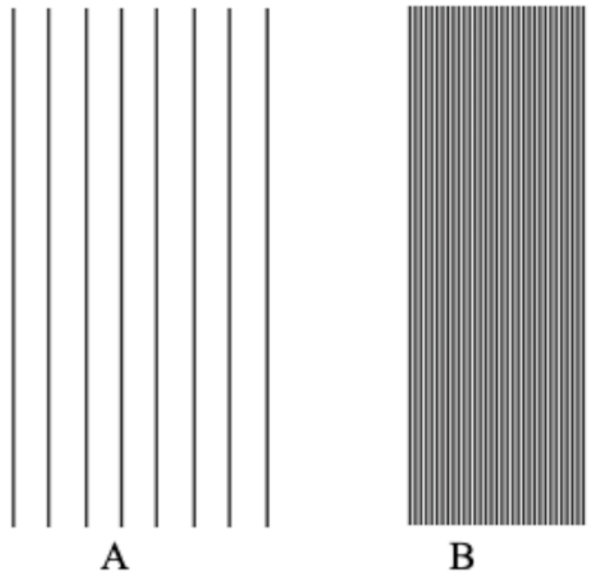

Figure 7. Comparison of 2 systems: A has a low spatial resolution, and B has a high spatial resolution.

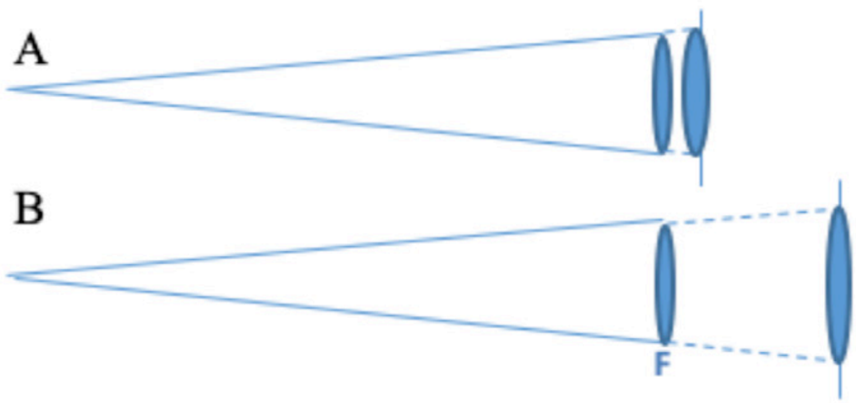

Figure 8. Comparison of magnification when the object to film distance changes. A short distance (A) shows less magnification than a long distance (B).

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

Sharpness refers to the dimensions of an object's partially shaded outer region or the penumbra. 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 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 the apparent focal spot, the larger the penumbra, resulting in a less sharp image.[1,3,6,11]

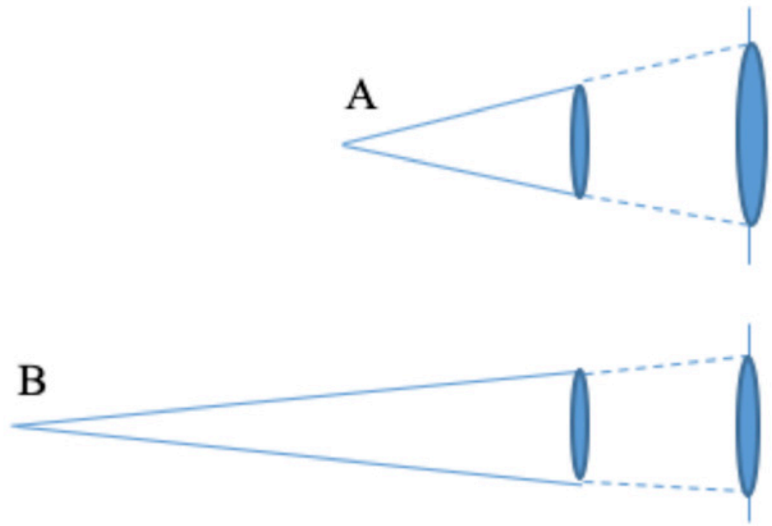

Figure 9. Comparison of magnification when the source to object distance changes. A short distance (A) shows more magnification than a long-distance (B).

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

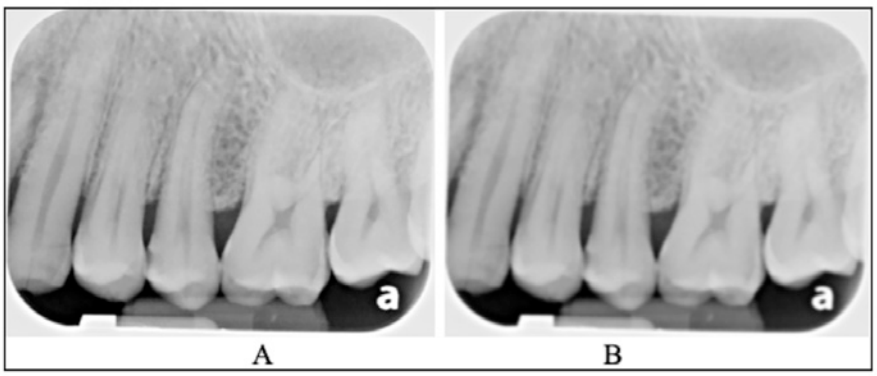

Figure 11. Image A is sharpness when compared to B.

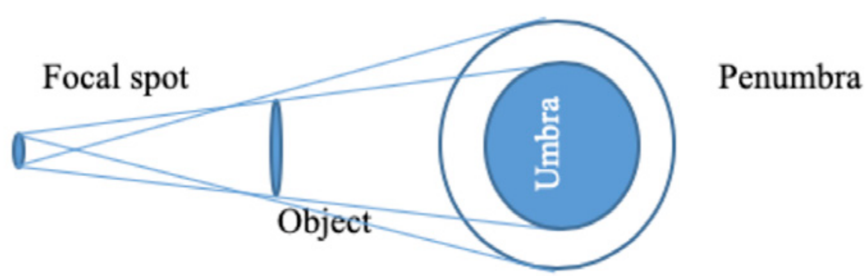

Figure 12. Shadow casting, umbra and penumbra.

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 during image acquisition, 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: *https://www.dentalcare.com/en-us/ce-courses/ce571/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 evenly by the absorber.
B. When the x-ray beam exits an absorber, it will have varying intensities. The radiographic receptor will register the intensities as different densities, generating the radiographic contrast.
C. Radiographic densities associated with thick absorbers will be darker than densities associated with thin absorbers.
D. Two different absorbers of the same thickness will have the same radiographic density.

2. Which of the following statements related to factors affecting radiographic density is correct?

A. When the mA or exposure time decreases, the number of photons generated increases linearly without increasing beam energy.
B. An increase in the mA or exposure time will result in a brighter radiographic image related to a reference radiographic image.
C. When the kVp decreases, the number and energy of x-ray photons generated decrease.
D. A decrease in kVp will result in a radiographic image with lower density when compared to a reference radiographic image.

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 less penetrating resulting in lower contrast.
D. Higher kVp will make the x-ray beam less penetrating resulting in higher contrast.

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 decrease in magnification of the radiographic image
   C. Increasing source to object distance only will result in a increase in magnification of the radiographic image.
   D. Decreasing source to object distance only will result in a decrease in magnification of the radiographic image.

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

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 a Professor in the Department of Comprehensive Dentistry, and the director of the Advance Oral and Maxillofacial Radiology program 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. He 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. Hashem's main research focuses on enhancing 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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