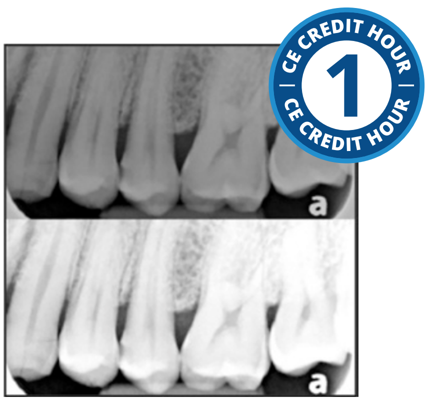
The Radiographic Image



Course Author(s): Hassem Geha, DDS, MDS, Diplomate of the ABOMR
CE Credits: 1 hour
Intended Audience: Dentists, Dental Hygienists, Dental Assistants, Dental Students, Dental Hygiene Students, Dental Assistant Students
Date Course Online: Feb 1, 2019
Last Revision Date: Jul 15, 2025
Course Expiration Date: Jul 14, 2028
Cost: Free
Method: Self-instructional
AGD Subject Code(s): 731

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

Disclaimers:

- P&G is providing these resource materials to dental professionals. We do not own this content nor are we responsible for any material herein.
- Participants must always be aware of the hazards of using limited knowledge in integrating new techniques or procedures into their practice. Only sound evidence-based dentistry should be used in patient therapy.

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?

When X-rays pass through an absorber, they are absorbed at different rates depending on the thickness and density of the absorber's components. As a result, the X-ray beam that exits the absorber will have varying intensity levels. These variations are recorded by the radiographic receptor as radiographic density. The contrast between different radiographic densities is known as radiographic contrast. Typically, areas with thicker absorbers appear brighter on the radiographic image compared to areas with thinner 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 milliampere (mA) or exposure time is increased, the number of X-ray photons produced at the anode rises linearly, without affecting the beam's energy. Consequently, more photons reach the receptor, resulting in a higher overall density of the radiographic image. (Figure 2).[2,4,6,9]

Change in kVp

Raising the kilovoltage peak (kVp) boosts both the number and energy of X-ray photons produced at the anode. This results in a higher number of high-energy photons reaching the receptor, leading to a greater increase in radiographic image density compared to changes in mA or exposure time (Figure 3).[2-4,8]

Change in Source to Object Distance

As the source-to-object distance increases, the intensity of the X-ray beam diminishes according to the inverse square law. This reduction in beam intensity leads to a corresponding 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).[3,710,11]

Radiographic Contrast

Radiographic contrast represents the variation in density or shades of gray between different areas of an image. It is influenced by three main factors:

1. **Subject Contrast:** This describes differences in X-ray absorption between different regions of an object. For example, in an intraoral radiograph, enamel absorbs more X-rays than dentin. Several factors influence subject contrast:
   - ***Thickness difference:*** When X-rays pass through materials of varying thickness, the thicker area absorbs more radiation, leading to higher contrast between regions.[1,4,5,12]
   - ***Density difference:*** The density of a

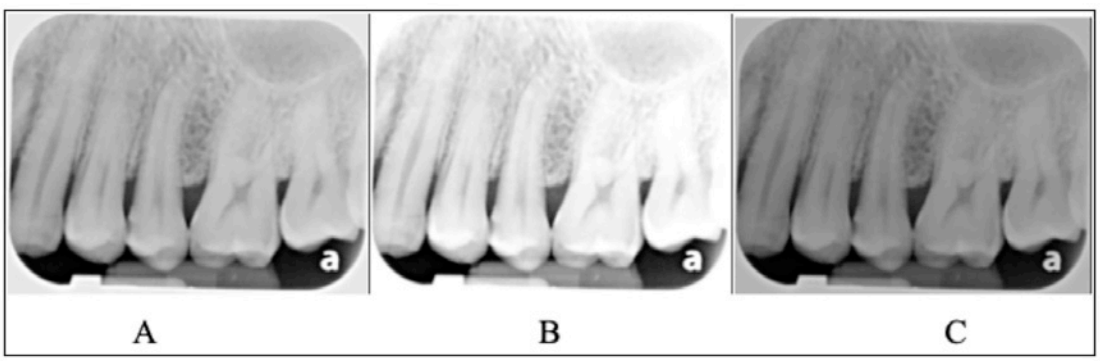


Figure 2. Change of image density related to change of mA and/or exposure time: Image A is used as reference. Image B shows a brighter image due to decrease in mA and/or exposure time. Image C shows a darker image due to increase in mA and/or exposure time.

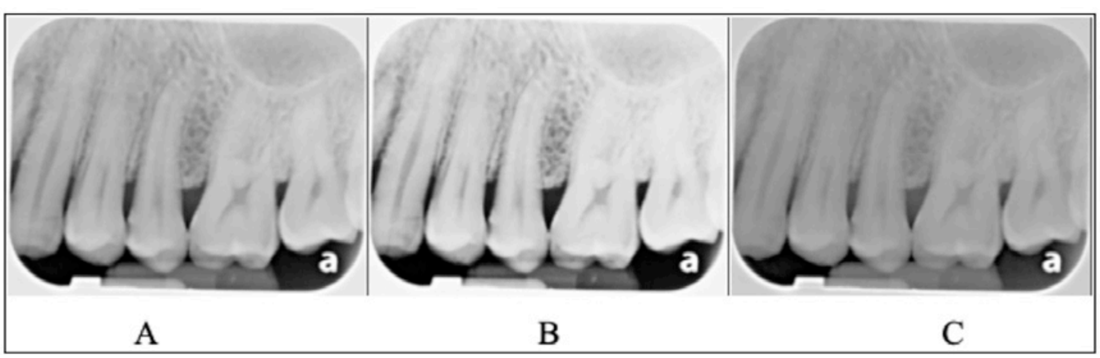


Figure 3. Change of image contrast related to change of kVp: Image A is used as a reference. Image B shows a higher contrast image due to a decrease in kVp. Image C shows a lower contrast image due to an increase in kVp.

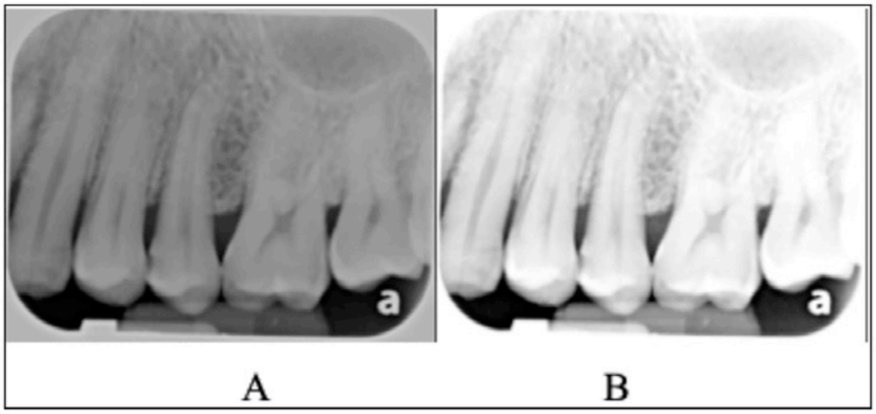


Figure 4. Change of image density related to change of source to detector distance: Image A is used as reference. Image B shows a brighter image due to increased source to detector distance.

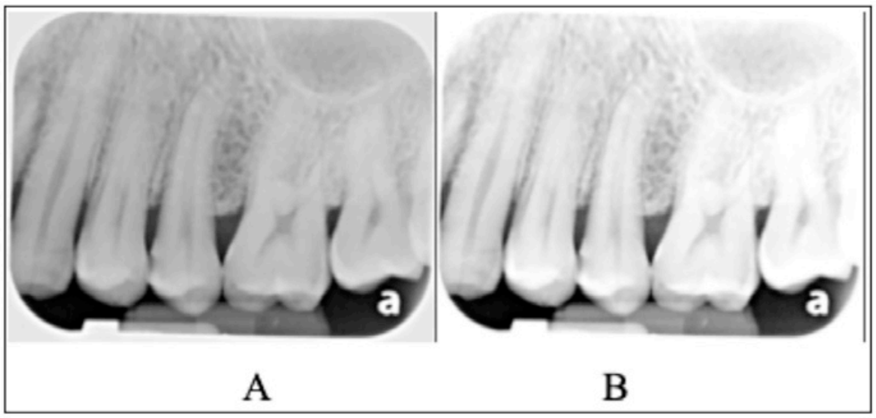


Figure 5. Change of image density related to change of absorber thickness: Image A is used as a reference. Image B shows a brighter image due to an increase in absorber thickness.

material, defined as mass per unit volume, is a crucial contributor to subject contrast. Denser materials absorb more X-rays, appearing brighter in the image.[5,6,10,11]

- ***Atomic number difference:*** A substance with a higher atomic number absorbs more X-rays than one with a lower atomic number, enhancing contrast.[2,6,7]
- ***Radiation quality or kVp:*** The energy level of the X-ray beam significantly impacts contrast. Lower kVp settings produce a less penetrating beam, leading to greater differences in attenuation and higher contrast. Higher kVp settings create a more penetrating beam, reducing attenuation differences and lowering contrast.[1,3,4,12]

2. **Receptor Contrast**: Receptor contrast describes the ability of a receptor to accurately display the information carried by transmitted photons. In conventional radiography, contrast is influenced by factors such as grain size, development time, the concentration and temperature of the developing solution, and overall film density. Since conventional film is now less commonly used, these factors are less frequently discussed. In digital imaging, contrast is primarily determined by the bit-depth of the receptor, which refers to the number of possible gray values stored in an image. A higher bit-depth allows for a greater number of gray values to be displayed, improving contrast resolution.

For example, a 1-bit image can only show two values: 0 (black) and 1 (white), while an 8-bit image can display 256 gray values, and a 12-bit image can store up to 4096 gray values, enhancing the ability to distinguish subtle differences in grayscale.[1,4,9]

3. **Factors that Affect Radiographic Contrast:** Scattered radiation contributes to image noise, leading to a reduction in radiographic contrast. The use of collimation can minimize scattered radiation, thereby enhancing image 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
Contrast resolution refers to an imaging system's ability to differentiate between multiple levels of density in a radiographic image. In digital imaging, contrast resolution is determined by bit-depth. An 8-bit system can display 256 shades of gray, whereas a 12-bit system presents 4096 shades. While an 8-bit system is considered high contrast due to its limited grayscale range, a 12-bit system—if capable of distinguishing subtle differences between nearby gray values—offers superior contrast resolution (Figure 6).[1,3,6,7]

Spatial Resolution
Spatial resolution in radiology defines an imaging system's capability to distinguish between two closely positioned objects. In digital imaging, it is determined by pixel size—larger pixels reduce resolution and make it harder to separate adjacent structures. Spatial resolution is measured in line pairs per millimeter (Figure 7).[1,4,7,9-11]

Image Magnification
Image magnification describes the proportional enlargement of a radiographed object in comparison to its actual size and is influenced by the following factors:

1. IAn increase in object-to-film distance leads to greater magnification of the radiographic image, whereas a reduction in this distance decreases magnification (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]

Image Distortion
Image distortion occurs when the proportions of a radiographed object are altered unevenly. This happens due to variations in the X-ray beam's angle of incidence or when the receptor is not parallel to the object (Figure 10).[2,4,5,7,8]

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.

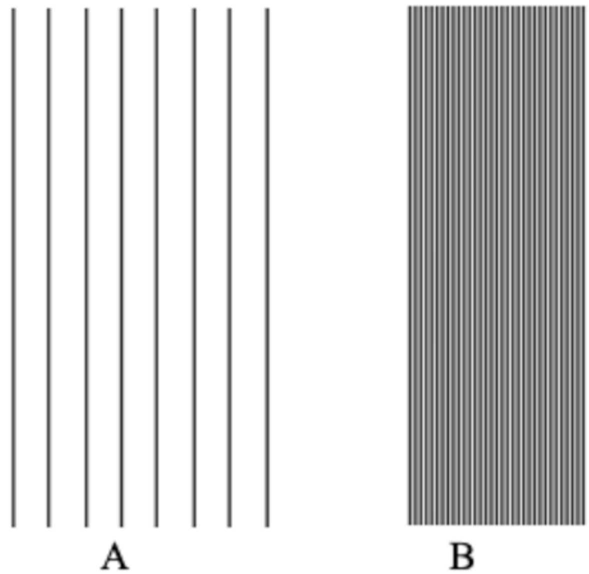


Figure 7. Comparison of 2 systems: A has a low spatial resolution, and B has a high spatial resolution.

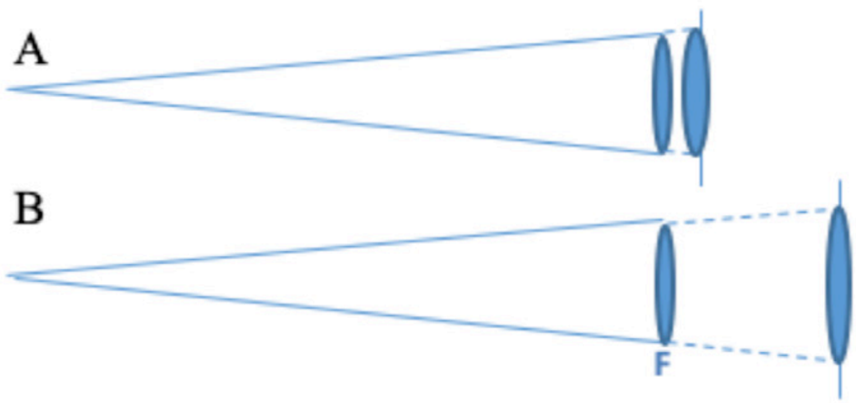


Figure 8. Comparison of magnification when the object to film distance changes. A short distance (A) shows less magnification than a long distance (B).

Image Sharpness

Sharpness plays a crucial role in image quality, as it determines the level of detail an imaging system can capture (Figure 11).

Image sharpness is defined by the dimensions of an object's partially shaded outer region, known as the penumbra. A broader penumbra results in a less sharp image (Figure 12).[1,2,5]

We will only discuss the properties of shadow-casting and the penumbra width related to the x-ray tube and sensor. We will not factor in the patient-related sharpness of the image.

Several factors influence image sharpness. Each factor can be assessed individually while keeping others constant:

1. ***The apparent focal spot size:*** A larger focal spot increases the penumbra, reducing sharpness.[1,3,6,11]
2. ***Source-to-object distance:*** A greater distance decreases the penumbra, enhancing image sharpness.[1,2,4,5,8,11]
3. ***Object-to-receptor distance:*** A larger distance increases the penumbra, lowering image sharpness.[2-4,7,9,11]
4. ***X-ray tube motion-related un-sharpness:*** Movement of the tube during image acquisition enlarges the apparent focal spot, increasing the penumbra and reducing sharpness.[2,5,12]

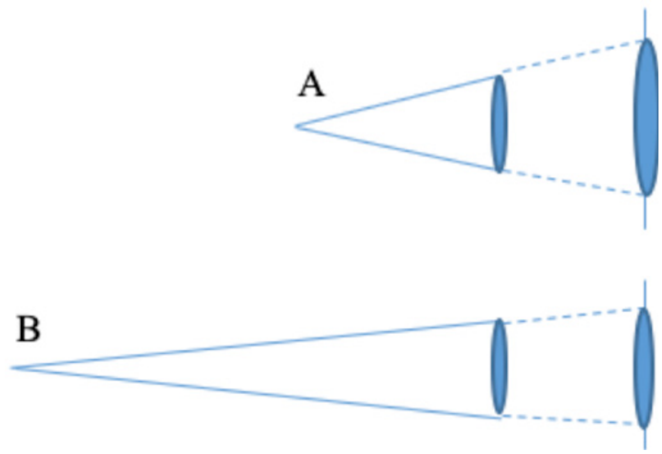


Figure 9. Comparison of magnification when the source to object distance changes. A short distance (A) shows more magnification than a long-distance (B).

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

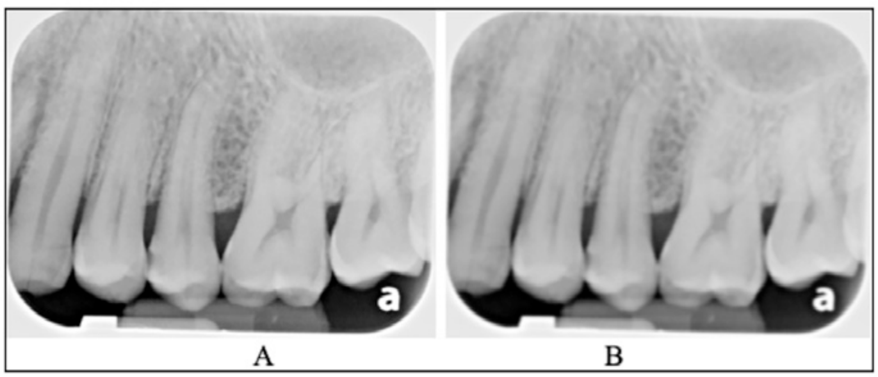


Figure 11. Image A is sharpness when compared to B.

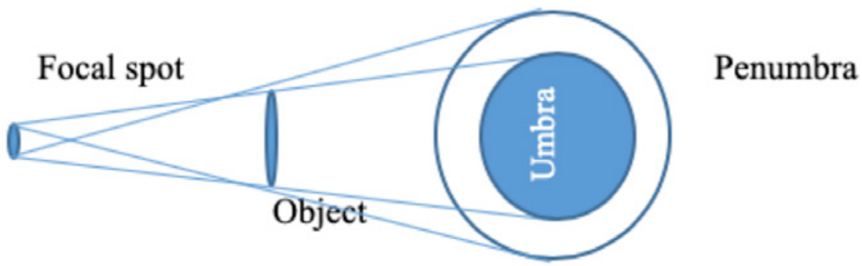


Figure 12. Shadow casting, umbra and penumbra.

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 simultaneously. Therefore, it is essential to understand how these settings affect each variable.

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 is false in relation to the formation of a radiographic image?

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 brighter than densities associated with thin absorbers.

D. Two different absorbers of the same thickness will have the different radiographic densities.

2. Which of the following statements is false in relation to factors affecting radiographic density?

A. When the mA or exposure time increases, the number of photons generated increases linearly without increasing beam energy.

B. An increase in the mA or exposure time will result in a darker 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. Which of the following statements is correct in relation to the source to object distance or thickness of the absorber?

A. When the source to object distance increases, the intensity of the x-ray beam increases following the inverse square law.

B. When related to a reference radiographic image, increasing the source to object distance will result in a brighter image.

C. When the thickness of the absorber increases, the number of photons absorbed decreases.

D. When related to a reference radiographic image, an increase in absorber thickness will result in a darker image.

4. Which of the following statements is false in relation to radiographic contrast, i.e., the difference in the degree of grayness between areas of the radiographic image?

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. Higher kVp will make the x-ray beam more 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, image density 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 8-bit receptor can only store one of two values, 0 (white) and 1 (black).

6. Which of the following does not affect image contrast.

A. kVp of the tube

B. Source-Object distance

C. Bit depth of the digital receptor

D. Nature and density of the tissues that attenuate x-rays.

7. Which of the following statements is incorrect concerning contrast resolution?

A. Contrast resolution is the ability of an imaging system to distinguish between two near-by densities in the radiographic image.

B. In digital imaging, contrast resolution depends on the bit-depth of the system - a 4-bit system can show 16 gray values as opposed to a 8-bit system, which shows 256 gray values.

C. In digital imaging, an 8-bit system is considered low contrast as opposed to a 12-bit 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. Which of the following statements is correct concerning spatial resolution?

A. Spatial resolution in radiology refers to the ability of an imaging system to differentiate between two far away objects.

B. In digital imaging, special resolution is independent of the size of the pixel used.

C. Small pixel size, will allow the imaging receptor to resolve two near-by structures, i.e., will have a higher special resolution as compared to a Large pixel size system.

D. Spatial resolution is measured in millimeters.

9. Which of the following statements related to image magnification is correct?

A. Image magnification refers to the non-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. Decreasing source to object distance only will result in an increase in the magnification of the radiographic image.

10. Which of the following statements related to image distortion is correct?

A. It refers to the non-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 size of the receptor.

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. Which of the following affects the image sharpness?

A. kVp

B. mA

C. Object-Film distance

D. Exposure time

12. Which of the following affects the dimensions of the penumbra?

A. Focal spot size

B. kVp

C. mA

D. Exposure time

13. Which of the following statements related to image sharpness is correct?

A. The larger is the size of the apparent focal spot, the smaller is the penumbra, resulting in a less sharp image.

B. The smaller 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.

References

1. S. C. Bushong, “Radiologic Science for Technologists,” in Radiologic Science for Technologists, 11th ed., Mosby, 2017.
2. Jerrold T. Bushberg, J. A. Seibert, Edwin M. Leidholdt, John M. Boone, “The Essential Physics of Medical Imaging,” in The Essential Physics of Medical Imaging, 3rd ed., Lippincott Williams & Wilkins, 2011.
3. Stuart C. White DDS PhD, Michael J. Pharoah DDS, “Oral Radiology: Principles and Interpretation,” in Oral Radiology: Principles and Interpretation, 7th ed., Mosby, 2013.
4. Thomas S. Curry, James E. Dowdey, Robert E. Murry, “Christensen’s physics of diagnostic radiology,” in Christensen’s physics of diagnostic radiology, 4th ed., Lippincott Williams & Wilkins, 1990.
5. Dale Miles, Margot Van Dis, Gail Williamson, Catherine Jensen, “Radiographic Imaging for the Dental Team,” in Radiographic Imaging for the Dental Team, 4th ed., Saunders, 2008.
6. Joen Iannucci, DDS, MS and Laura Jansen Howerton, RDH, MS, “Dental Radiography,” in Dental Radiography, 2nd ed., Saunders, 2017.
7. P. Sprawls, “The Physical Principles of Medical Imaging,” in The Physical Principles of Medical Imaging, 2nd ed., Medical Physics Pub Corp, 1995.
8. Olaf E. Langland, John Preece, Robert P. Langlais, “Principles of Dental Imaging,” in Principles of Dental Imaging, 2nd ed., Lippincott Williams & Wilkin, 2002.
9. W. Huda, “Review of Radiologic Physics Walter Huda,” in Review of Radiologic Physics Walter Huda, 3rd ed., Lippincott Williams & Wilkins, 2009.
10. R. P. Langlais, “Exercises in Oral Radiology and Interpretation,” in Exercises in Oral Radiology and Interpretation, 2nd ed., Saunders, 2003.
11. Herbert Frommer, Jeanine Stabulas-Savage, “Radiology for the Dental Professional,” in Radiology for the Dental Professional, 9th ed., Mosby, 2010.
12. John H. Juhl, Andrew B. Crummy, Janet E. Kuhlman, “Essentials of radiologic imaging,” in Essentials of radiologic imaging, 7th ed., Lippincott Williams & Wilkins, 1998.

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. Hassem'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.

Updated: March 2025

Email: geha@uthscsa.edu