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REVIEW ARTICLE

New Classification of Intraoral Phosphor Plate Artifacts Based on Literature Review

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Abstract

Artifacts (error) encountered in phosphor plates (PSP) used in intraoral digital imaging were evaluated under a new classification. In this review, when obtaining images with intraoral phosphor plates, artifacts before, during, after the irradiation and artifacts caused by the scanner were determined according to the review of the literature. Intraoral radiographs are obtained while many artifacts are encountered. These artifacts can occur in both conventional and digital systems. Artifacts that occur before irradiation such as scratches, cracks, fingerprints, dust particles, bite marks, plate edge peeling; during irradiation such as positioning error, motion artifact, shooting from different angles errors, cone-cut, double image, light-dark images, glare, fading, revers irradiation, refraction, distortion; after irradiation such as irregular image density, noise, writing artifact, fingerprints, fading artifacts; and depending on the scanner artifacts such as inclined placement, a parallel line to scan direction, dust fragment, plate size determination error has been shown to be visible. An inaccurate image with no diagnostic value requires regeneration. For this reason, knowing the causes of artifacts in radiographic images is important for the patient, the environment, and the practitioner to prevent unnecessary x-rays (radiation).

Key words: artifact; digital radiography; phosphor plate

Introduction

Since the discovery of X-rays, radiology has entered a period of rapid development and change. Digital radiology has outpaced traditional film radiography since the 1980s.[1] Based on rapid technological advances in dental imaging, most x-ray based diagnostic technologies have not only been digitized but many new optical imaging techniques have been adopted in the dental imaging of patients. Clinicians can now easily plan and simulate treatments on screen, use 3D printed models and assistants to help accurately transfer virtual planning, and even track their treatment over time when combining and processing such different digital image data.[2] The main advantages of digital imaging over traditional radiography are that digital imaging is faster, allows real-time viewing and communication, does not require darkroom procedures and chemicals, can benefit from image enhancement tools, and results in dose reduction.[3] The most important reasons for the spread of digital radiography systems are; achieving the image quickly, achieving better image quality, decreasing shot repetition, better contrast resolution, ease of storing and transmitting the image, and technological advances in this regard.[4]

The difference between digital radiography from traditional radiography is due to the receptors used in image acquisition and the methods used to obtain the image.[5,6] In conventional systems, the image is formed directly on the film, while in digital systems the signal detected by sensors is digitized and the image consists of these values.[4] Dental digital images are available in various methods. Direct imaging method, with the help of CCD or CMOS sensors and flat-panel detectors, indirect imaging method where traditional radiography is re-imaged by a scanner and semi-direct imaging method obtained by using phosphor plate detectors are dental digital imaging methods.[7]

Phosphor plate imaging is obtained when the analog image is digitized through a browser and transferred to the computer environment. This imaging method is also called the semi-direct digital imaging method. Phosphor plate systems use phosphor luminescence plates that can be stimulated by light.[8] Phosphor plates contain europium and in addition barium fluorohalide. The plate stimulated by the X-ray absorbs and stores photon energy. When this stored energy is scanned with red and green laser lights,

fluorescent light is generated in proportion to the absorbed X-ray dose, which is translated into an elevated electrical signal. This analog signal is converted to a digital signal and transmitted to the computer and examined on the monitor. [9–11] Ghost images from the previous imaging process of phosphor plates should be removed before insulation. This can be accomplished by keeping the record in visible light. [12] The advantages of phosphor plates include having flexible plates, having structural characteristics similar to well-known traditional films, being easily manipulated, changing image settings, software, lower dose requirements, a wide dose width, elimination of chemical processes, ease of storage, sharing, and reproduction. [6,13]

Incorrect manipulations and technical errors during both the retrieval and processing of images can cause obvious radiographic errors. Therefore, the ideal radiographic examination for the area studied cannot be performed, which can lead to misrepresentation. It is essential to identify and clarify the mechanisms of errors in the elimination of these errors. [14] In this study, it was aimed to evaluate the artifacts in phosphor plates (PSP) used in intraoral digital imaging based on previous studies and place them in an appropriate classification.

Literature Review

First of all, the literature was scanned in order to make a new classification. The PubMed search engine was scanned with the keywords "phosphor plate, artifacts, digital radiography". A total of 13 articles related to phosphor plate artifacts were found from the results obtained. While three of these articles were directly classified, [14–16] one article generally evaluated the incidence of artifacts, [3] so three selected articles which directly aimed to classification of artifacts were evaluated. In this context, a new classification was created based on previous classifications. The mechanisms of formation of the artifacts in the new classification we created were revealed and the artifacts were obtained separately.

New Classification

The data of 3 articles that provide information about the classification of artifacts that occur when obtaining images with PSP in the literature have been evaluated (Table 1). Based on this data, 26 different types of artifacts were determined. These artifacts were obtained by using individual radiology training phantom and the 26 types of artifacts determined within the scope of the classification were divided into 4 groups according to causal factors: 1- Artifacts seen before irradiation, 2- Artifacts seen during irradiation, 3-Artifacts seen after irradiation 4- Artifacts caused by the scanner (Table 2). The images of artifacts were obtained by using a size 2 phosphor plate in the Department of Oral and Maxillofacial Radiology of the Faculty of Dentistry of Ankara University and they were scanned (Gendex GXPS-500 phosphor plate device, Finland) and possibly different types of artifacts were observed. For this purpose, irradiations were carried out on the phantom head (Model 711HN ATOM MAX Dental & Diagnostic Head Phantom, CIRS, USA). Irradiations were made with an x-ray device with 65 kVp 7 mA parameters (Gendex Expert DC, USA).

Artifacts Before Irradiation

Artifacts that occur before irradiation are scratches, cracks, fingerprints, dust fragments, bite marks, peeling at the edge of the plate are artifacts that develop due to wear on the plate and excessive cleaning of the plate. Images of these artifacts are shown in Figure 1. These are artifacts caused by damage to the plate in general.

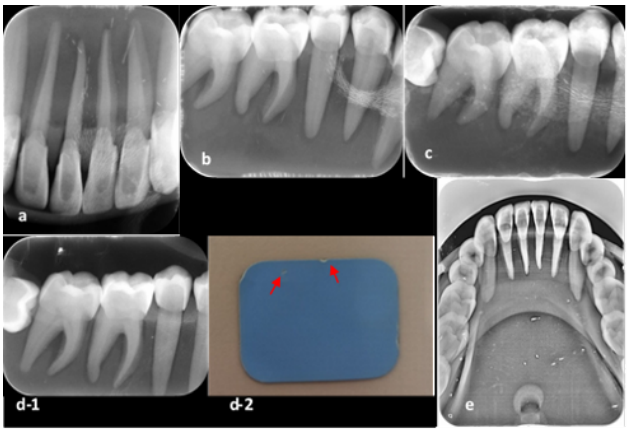

Figure 1. Artifacts Before Irradiation: Scratches, cracks (a) wear around the metal disc (b) artifact due to contamination of phosphor plate (c) peeling at the edge of the plate (d1 and d2) bite marks (e)

Artifacts due to damage to the phosphor plate

Mechanical stress is the main factor in the formation of artifacts due to damage to the phosphostimulated luminescence layer in the phosphor plate. [17] Various artifacts such as scratches, crack bite marks, peeling at the edge of the plate, wear and bending occur due to the damage of this layer.

Scratches, cracks

It appears as small, smooth linear, linear opacities anywhere in the image. They are artifacts that usually result from excessive bending of the plate, improper manipulation, or damage to the phosphostimulated luminescent layer during intraoral positioning of the plate. [17] There have been speculations about the sources of scratches and blemishes on PSP plates, but the exact cause of most of them has not been found. [18]

Attrition

These are artifacts that appear as a radiopaque scattering image around the metal disc that occurs due to the bending and twisting of the plate. This artifact is seen with long-term use of the plate.

Peeling at the edge of the plate

TLuminescence is seen in the form of deterioration and irregularity at the borders of the plate due to the damage of the layer. It occurs when the protective and photostimulating luminescence layer of the plate edges is peeled off as a result of friction during the placement of the plate on the cassette. [14]

Bite marks

They appear on the image as small multiple irregular radiopaque spots and small pits on the plate surface. It is usually seen on occlusal radiographs. They are artifacts that result in damage to the plate surface that occurs when patient cooperation is insufficient or the patient bites incorrectly. [16]

Artifacts due to the contamination of the phosphor plate

Dust particles, fingerprints, glove powder, sticky materials cause contamination on the plate surface. They appear as radiopaque spots anywhere in the image. [16]

Excessive cleaning of the plate surface

It occurs as a result of damage to the protective coating due to abrasive cleaning agents. A shadow-spot-like appearance emerges. [16]

Table 1. Classifications used in 3 articles in the literature that provide information on the classification of artifacts that occur during image acquisition with PSP are given

Classification groups in the literature	*Chiu et al. (2008)*
1 Operator errors	1 Cone cut image 2 Bending of the intraoral sensor plate within the mouth 3 Opposite side of the cassette wrongly placed facing the x-ray tube 4 Sensor plate incorrectly placed upside down within the cassette 5 Cassette incorrectly placed upside down within the cassette holder of the x-ray machine 6 Surface of the sensor plate exposed to x-ray incorrectly inclined during the scanning process 7 Miscellanous (retained denture or earring artifact, leaded apron artifact, and so on) 8 Repeated x-ray exposure of the sameintraoral sensor plate 9 Image obtained was too bright owing to delayed sensor plate scanning 10 Intraoral sensor plate placed upside down for periapical projection
2 Scanning machine errors	1 An additional horizontal white line was noted after scanning 2 Image obtained was too bright despite scanning with optimal conditions and procedures 3 Only half of the intraoral image was displayed after scanning 4 Reduction in image size of an intraoral image was displayed after scanning 5 After scanning of two different intraoral sensor plates in two different slots, the two resulting images overlapped 6 Uneven brightness of an extraoral image after scanning
3 PSP defects	1 Defective image resulting from sensor plate damaged by scratches or bite mar 2 Defective image resulting from sensor plate damaged by teeth of the jaws of a Snap- A-Ray 3 Defective image resulting from partial peeling of the coating of the intraoral sensor plate
Classification groups in the literature	*Caliskan et al. (2017)*
1 Operator and patient induced	1 Mirror image 2 Double exposure 3 Projection errors
2 Ambient light induced	1 Cracking 2 Scratches 3 Peeling of the plate borders 4 Bite-marks 5 Crescent-shaped bending
3 PSP Plate induced	1 Dust particles on the plate 2 Glove powder contamination 3 Fingerprint 4 Adhesive contamination
4 Scanner induced	1 Lines parallel to the slow scan direction 2 Ridging 3 Skipped image part 4 Peeling of the conveyor belt 5 Erasure artefact 6 Plate size determination errors
Classification groups in the literature	*Deniz et al. (2019)*
1 Operator errors	1 Placement of PSP to mouth 2 Bend marks 3 Mirror image 4 Incorrect dot position 5 Movement 6 Projection geometry
2 Superposition of undesirable structures	1 Tongue artifact 2 Phalangioma 3 Piercing, eyeglasses 4 Amalgam residuals 5 Holding devices
3 Plate artifacts	1 Short scratches 2 Wide scratches 3 Bite marks 4 Partial stripping 5 Crescent-shaped bending 6 Reticulation 7 Excessive cleaning of plate surface 8 Contamination of PSP 9 Using mismatch PSP with scanner
4 Ambient light errors	1 Whiting 2 Shining 3 Text pattern 4 Light exposure of PSP before x-ray 5 Non-uniform density 6 Noise
5 Scanner artifacts	1 Roller artefacts 2 Straight radiolucent lines 3 Transport belt artifact 4 Eraser unit artifact 5 Laser unit faults 6 Plate size determination error 7 Peeling of the conveyor belt
6 Software artifacts	1 Incorrect histogram normalization 2 Incorrect dynamic range scaling 3 Incorrect output film density 4 Edge masking defect 5 Bisection 6 Communication error artifact 7 Data cable malfunctioning

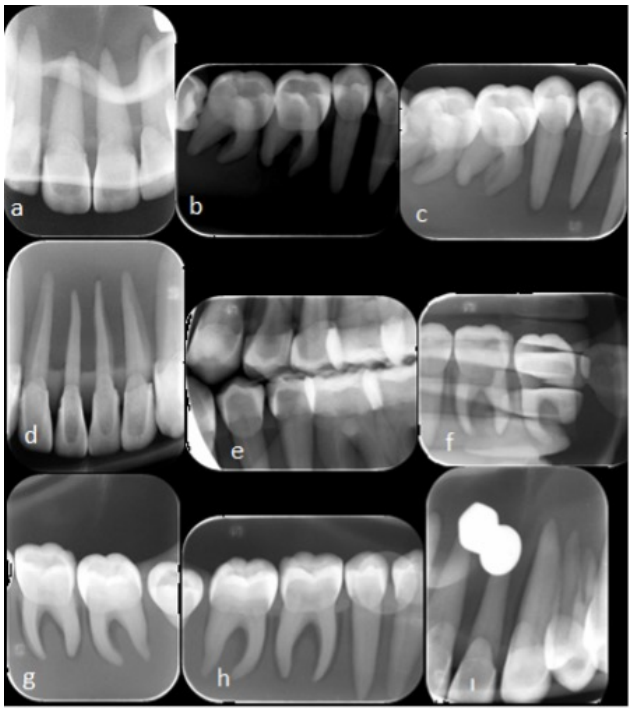

Figure 2. Artifacts During Irradiation: Light image(a) dark image (b) ımage shortening (c) ımage elongation (d) superposition-cone cut (e) double expose (f) placement error (g) placing the plate upside down in the mouth (h) foreign body (i)

Artifacts during irradiation

Artifacts formed during irradiation are positioning error, motion artifact, angulation errors, concave, double image, light-dark image, glare, reverse irradiation, and distortion. The appearances of these artifacts are shown in Figure 2.

Positioning error

Artifacts occur due to incorrect positioning of the receptor in the mouth. When placing its receptor in the mouth, it should be positioned 3-4 mm below (for the upper jaw) or above (for the lower jaw) the occlusal levels of the teeth, and it should be placed vertically for the anterior region and horizontally for the posterior region.

Motion artifact

They are artifacts due to the movement of the patient, the receptor, or the X-ray device. It results in a loss of detail in the image. [11]

Angle errors

AIn the bisecting technique, the central beam is directed perpendicular to the bisection of the angle between the long axis of the tooth and the image receptor. Inappropriate angulation in the vertical direction results in elongation or shortening of the image. If the central beam is perpendicular to the tooth, the image lengthens, and if the central beam is perpendicular to the receptor, the image shortens. At the same time, the central beam must pass through the interproximal space. Otherwise, horizontal angulation errors will occur. This will result in the formation of superposition. [19]

Cone-cut

As a result of the receptor being outside the irradiated area, those areas do not receive radiation and appear radiopaque.

Double Irradiation

It occurs as a result of irradiation of the same plate more than once without performing the scanning process. [14]

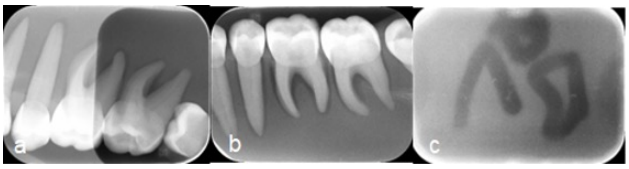

Figure 3. Artifacts After Irradiation: Irregular image density (a) noise (b) writing artifact(c)

Light-Dark image

Various irradiation parameters (kVp, mA, sec, distance) are available during image formation. Variations in these parameters can cause the image to appear lighter or darker. If the receptor is not irradiated for sufficient time a light image or, If it is irradiated too much, a dark image is obtained.

Glare

It appears as pure white areas, usually at the center of radiopaque structures and at the peripheral margins of the image. Attenuation values occur in the center of high radiopaque structures and at the peripheral borders of the image. It is the total loss of the acquired signal due to excessive spontaneous oscillation in these areas. [14]

Reverse Irradiation

The image, which is observed as the embossed pattern of the lead plate in conventional films, appears as a metal disc image due to the reverse placement of the plate in the patient's mouth in phosphor plate systems. These images can be corrected diagnostically with the mirror image function in the computer environment, but the metal disk image cannot be removed. [15]

Distortion

It appears in the form of an image as if caught in the wind due to the bending of the plate in the mouth. The plate should be gently supported to prevent it from twisting in the mouth. [20]

Incorrect placement of the plate

The plate should be placed vertically in the anterior and canine region, and it should be placed horizontally in the premolar-molar region as in conventional systems.

Superposition of unwanted structures

Appliances such as removable prostheses, glasses, earrings, piercing in the area to be examined give a radiopaque image and prevent the image of the area, making diagnosis difficult. [20] Foreign bodies in the examined area must be removed during image acquisition.

Artifacts After Irradiation

Artifacts after irradiation are irregular image density, noise, text artifact, fingerprint, and fading. The appearances of these artifacts are shown in Figure 3.

Irregular image density

If the ambient light has partially affected the surface of the plate, a decrease in the density of the image occurs in the areas exposed to light, while it appears at normal density in the protected area. It appears in the image as two or more radiographic areas that exhibit different intensities for the same structures. [14]

Noise

It is random signals that affect real signals and distort the image. [21] In digital images, the image appears more grainy due to the delayed scanning time. [14]

Table 2. Classification of artifacts that occur during image acquisition with PSP in our study is given

Artifact Groups	Group 1	Group 2	Group 3	Group 4
1 Artifacts Before Irradiation	1 Scratch, crack	1 Positioning error	1 Irregular image density	1 Slant Placement on Scanner
2 Artifacts During Irradiation	2 Attrition	2 Motion artifact	2 Noise	2 Line Parallel To Scan Direction
3 Artifacts After Irradiation	3 Peeling at the edge of the plate	3 Angle errors	3 Writing artifact	3 Dust particles
4 Scanner-Induced Artifacts	4 Bite marks	4 Cone cut	4 Fading	4 Plate Sizing Error
	5 Artifacts due to contamination of phosphor plate	5 Double expose		5 Roller Artifact
	6 Excessive cleaning of the plate surface	6 Light dark image		
		7 Flare		
		8 Reverse irradiation		
		9 Distortion		
		10 Incorrect placement of the plate		
		11 Superposition of unwanted structures		

Figure 4. Artifacts Due to the Scanner: Plate size determination error (In a2, a reduction in image size is observed as a result of the scanner cutting the excessive concave area.)

Writing artifact
It occurs due to writing with a felt-tip pen on the protector of the record. At the same time, when the PSP is exposed to visible light from a piece of paper with writing on it, more light passes through the area without writing, and the text on the paper appears in the latent image.[16]

Fading
Fading occurs at the edges of the plate as a result of delayed scanning and exposure of the unsheathed plate to ambient light.

Scanner-Induced Artifacts

Scanner artifacts are inclined placement on the scanner, a line parallel to the scanning direction, dust particles, and plate size determination errors. The appearances of these artifacts are shown in Figure 4.

Inclined Placement on the Scanner
It occurs as a result of the inclined placement of the plate on the scanner by the practitioner. It may cause the plate to jam in the device. The image appears obliquely on the screen.

Line Parallel to Scanning Direction
This appears as a radiopaque straight line on the radiographic image parallel to the scanning direction. It is caused by dust and dirt particles in the narrow scanning window of the scanner, which remains constant during scanning.[14]

Dust particles
It appears as granular radiopaque clumps on the image.

Plate Size Determination Error
This error occurs when the scanner detects a size other than the plate size.[16] In images with excessive concave, scanning of the concave area is stopped by the scanner and the image size is reduced as a result of cutting this area.

Roller Artifact
Incorrect scanning occurs because the rollers in the scanner are broken or the plate is damaged by the roller during scanning. To remove this artifact, the scanner rollers must be cleaned periodically.[22]

Discussion

The advent of digital imaging revolutionized radiology. This revolution is the result of both technological innovations in image acquisition processes and the development of networked computing systems for image acquisition and transmission.[13] Solid state detectors and phosphor plates are used in digital intraoral systems today. Although solid state detectors have been used for a very long

time, phosphor plates have been used recently. For this reason, it was inevitable to reveal the errors that may occur in the phosphor plates.

Gülşahi and Seçgin [3] evaluated the presence, frequency, and causes of artifacts in intraoral images obtained by using PSP plates. They found that the most common artifacts were uneven image brightness, uneven image density, and artifacts caused by the movement of phosphor plates in disposable packages. A reduction in image size after scanning was seen in 0.7% of all images in the study. Delayed phosphor plate screening and plate surface contamination-related artifacts were the 5th and 6th most frequently observed artifacts. Only a few images showed artifacts due to noisy images, the presence of an additional horizontal black line after scanning, the use of damaged plates, and reverse irradiation. Artifact caused by the movement of phosphor plates in disposable packages was most frequently observed in the pediatric age group, while irregular image brightness was found to be the most common artifact in adults. According to the study, the most common areas of artifacts are primary maxillary molar, primary mandibular molar, and primary maxillary anterior regions. Artifact due to non-uniform image brightness was most frequently seen in primary maxillary molars and primary maxillary anterior region images, while artifact due to the movement of the phosphor plate was most frequently seen in primary mandibular molar images.

Deniz and Kaya examined the digital images obtained by Phosphor plate, [16] and they have divided the errors into 6 groups according to their causes: images with operator error, superposition of undesirable structures, ambient light errors, plate artifacts (physical deformations and contamination), scanner artifacts, and software artifacts. The groups were then re-examined and divided into 45 sub-headings. This study found that the most common errors were operator errors, and projection geometry errors predominated within this group. The second most common error was found to be whitening caused by inappropriate ambient light. If scanning of an exposed PSP is delayed without protection from ambient light, the hidden electrons in the image are self-released. These electrons cause noisy and whiter image appearances. In this study, similar to the findings of Çalışkan and Sümer [14], artifacts due to ambient light result from the removal of the plate from its protective cover after irradiation to prevent contamination. 34 types of image errors and artifacts were detected in the study of Caliskan and Sümer [14], and they were divided errors into 4 groups according to the causative factors. The most common image artifacts were fading in the ambient light-induced group (44.1%), peeling of plate borders in the PSP plate-induced group (53.4%), and straight lines in the scanner-induced group (42.2%).

Chiu et al. [15] classified image artifacts as: 1) operator errors; 2) crawl errors; 3) PSP plate defects. In this study, it was determined that the image artifacts were mostly caused by operator errors (86.2%, n = 554/643), the most frequently observed artifacts in this group were cone-cut (27.62%, n = 153/554) and distortion (%). 25.45, n = 141/554). Operator errors were followed by plate (n = 60) and scan (n = 29) defects. According to the results of the study, scanning errors can usually be corrected by rescanning, but many other artificial images need to be re-acquired. Thang et al. [23] evaluated how physical photostimulable phosphor (PSP) plate artifacts, such as scratches and surface peeling, affect the radiological interpretation of periapical inflammatory disease. It has been shown that there is a significant relationship between the severity of PSP plate artifacts and clinicians' confidence levels. As plate artifacts increased, clinicians lost confidence in their radiological interpretation and were, therefore, more likely to discard plates.

Zhang et al. [24] aimed to compare the technical errors of x-rayed film and photo-excitable phosphor plates(PSP). Compared to film, PSP showed significantly less shortening, elongation, and bending errors, but significantly more placement and overlapping errors.

In the current studies evaluating the artifacts in digital images, classifications are mostly based on the cause and frequency of the artifact. The irradiation parameters and at which stage of the irradiation the artifact occurs have not been revealed. In order to eliminate this deficiency, we created a new classification based on the stage of the irradiation that artifacts occur.

In our study, we tried to classify the artifacts that we may encounter while taking images in the intraoral region with phosphor plates from a new perspective. Artifacts are divided into 4 main groups: artifacts occurring before irradiation, artifacts formed during irradiation, artifacts formed after irradiation, and artifacts due to the scanner. These 4 main groups are included in the classification as 26 sub-headings by collecting some artifact types under certain groups. It has been revealed that artifacts before irradiation such as scratches, cracks, bite marks, peeling at the edge of the plate, wear, artifacts due to contamination of the phosphor plate, artifacts due to excessive cleaning of the plate surface; artifacts during irradiation such as positioning error, motion artifact, angulation errors, concave, double irradiation, light-dark radiograph, glare, reverse irradiation, distortion, misplacement of the plate, superposition of unwanted structures; artifacts after irradiation such as uneven image density, noise, text artifact, fading; artifacts depending on the scanner such as inclined placement on the scanner, line parallel to the scanning direction, dust particle, plate size determination error, cylinder artifact can be seen.

Although there are many studies in the literature on artifacts in images taken with film-based radiology, there are few studies on artifacts seen in digital images. Therefore, considering the frequent use of phosphor plates in today's digitalization era, we aimed to comprehensively identify and classify the image errors and artifacts.

Conclusion

An image without diagnostic value requires a refresh. For this reason, knowing the artifacts and their causes that can be encountered in PSP systems, which are quite frequently used today, can reduce the repetition of irradiation procedures and the unnecessary exposure of the patient, dentist, radiology personnel and the environment to unnecessary radiation. The new classification we have introduced in this review provides the clinician with information about the stage at which errors occur. Thus, in order to eliminate the errors, it is understood at which stages to be improved and attention should be paid.

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Author Contributions

Study Idea / Hypothesis: H.E.,B.I. Study Design: H.E.,B.O. Data Collection: B.I. Literature Review: B.I., H.E. Analysis and / or Interpretation of Results: H.E., B.O. Article Writing: B.I. Critical Review: H.E.,B.I.

Conflict of Interest

The authors declare that there were no conflict of interest.

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