ORIGINAL ARTICLE
DOI:10.5152/EssentDent.2025.24029

ISTANBUL UNIVERSITY CERRAHPAŞA

Comparison of Different Aperture Values in Dental Photography in Terms of Depth of Field, Sharpness, Diffraction, and Chromatic Aberration: A Preliminary Study

Onur Alp Yünük[1], Mustafa Demirci[2], Safa Tuncer[2], Merve Yünük[1], Neslihan Tekçe[3], Özge Duman Özbilgi[2]

[1]Department of Restorative Dentistry, İstanbul University, Institute of Health Sciences, Istanbul, Türkiye
[2]Department of Restorative Dentistry, İstanbul University, Faculty of Dentistry, Istanbul, Türkiye
[3]Department of Restorative Dentistry, Kocaeli University, Faculty of Dentistry, Kocaeli, Türkiye

Cite this article as: Yünük OA, Demirci M, Tuncer S, Yünük M, Tekçe N. Comparison of different aperture values in dental photography in terms of depth of field, sharpness, diffraction, and chromatic aberration: a preliminary study. *Essent Dent.* 2025; 4, 0029, doi: 10.5152/EssentDent.2025.24029.

Abstract

Background: Dental photography is a crucial tool in modern dentistry, used for documentation, communication, and education. This preliminary study aimed to determine the optimal aperture range for dental photography, considering depth of field, sharpness, diffraction, and chromatic aberration.

Methods: A Nikon D7500 camera with a Tokina AT-X M100 PRO D 100 mm F2.8 macro lens was used to capture images of a dental model. Photographs were taken at various aperture values ranging from f/3.3 to f/32. A survey was conducted with 14 dentists to evaluate the images for depth of field, sharpness, and diffraction.

Results: About 36% of participants considered f/13 as the lowest acceptable aperture value for adequate depth of field. Regarding diffraction, 50% of responses indicated that diffraction became clearly visible at aperture values of f/22 and above.

Conclusion: There is no clear consensus on aperture values that provide sharp photographs while maintaining sufficient depth of field in dental photography. The findings suggest that lower aperture values than those traditionally recommended may provide better image quality by reducing diffraction effects. Further research is needed to explore alternative techniques such as focus stacking or the use of tilt-shift lenses to overcome the limitations of depth of field and diffraction in dental photography.

Keywords: Aperture value, dental photography, diffraction, sharpness

What is already known about this topic?

- *There are aperture values at which lenses used in photography provide optimal sharpness; as the aperture value increases, the lens's optimal sharpness range is exceeded, and the sharpness in the photograph decreases.*
- *In dental photography, it is known that sharpness in the photograph decreases at recommended high aperture values; however, the aperture values at which optimal sharpness is observed also do not provide sufficient depth of field in dental photography.*

What does this study add to this topic?

- *Although different recommendations exist in the literature regarding the aperture value that provides sufficient depth of field and allows for sharp photographs in dental photography, there is no study that clearly proves this.*
- *Considering the results of our study, using f/22 and above values is recommended.*

INTRODUCTION

The history of photography began with the invention of the silver plate technique by French painter Louis J.M. Daguerre in 1839.[1] Photography also began to be used in the field of dentistry when Thompson and Ide published their pre- and post-operative photographs in the American Journal of Dental Science.[2]

Dental photography is used to document the procedures performed and to communicate with the technician. The doctor can take photos of the treatment stages during

Corresponding author: Onur Alp Yünük
e-mail: onuryunuk@gmail.com

Received: October 14, 2024
Revision Requested: November 26, 2024
Last Revision Received: December 17, 2024
Accepted: December 23, 2024
Publication Date: February 13, 2025

the procedure and also enlarge and examine these photographs in detail. Images suitable for enlargement are important in terms of quality control and institutionalization, as well as benefiting the dentist's own control mechanism. The images obtained can be used as educational materials. It is almost impossible to present conferences and publications in the field of dentistry without images. With the development of technology, photography has become digital today and digital cameras have become frequently used.[1,3]

It is possible to see the photo taken with digital cameras instantly. It is much easier for a beginner to learn photography. Photos can be easily transferred to electronic media, transferred between users, stored, printed, and reproduced. There are no film and laboratory costs. Values such as International Organization for Standardization (ISO) and color temperature can be changed.[3,4]

The camera consists of 2 main components: the body and the lens. The optical properties of the lens can affect the sharpness, color transfer, and contrast of the photo.[3] The aperture value is expressed with "f" and is shown with numbers such as f/22 and f/25. The aperture value is the ratio of the lens focal length to the aperture diameter. The aperture number indicates how many times the aperture diameter fits into the lens focal length. For example, in a lens with a focal length of 100 mm, the aperture diameter of the f/4 value is 25 mm.[2] The aperture blades inside the lens open and close, affecting the light reaching the sensor and the depth of field. Reducing the aperture decreases the image brightness and increases the depth of field.[3]

Depth of field can be defined as the distance between the closest and farthest points of a subject that are acceptably sharp.[5] Depth of field depends on the focal length of the lens, the distance of the object, and the aperture. The lenses used in dental photography and the distance to the object cannot vary much, so changing the aperture is the only option to control depth of field.[4] As the focal length of the lens increases, the depth of field decreases sharply, and in dental photography, the depth of field is reduced to millimeters, which is why photographs are taken with an aperture value of f/16 or larger.[3]

Although different researchers recommend different aperture values, the common goal of all of them is to increase the depth of field in photographs and to provide clarity in the photograph. However, as the aperture decreases, diffraction will occur in the light and the image will lose clarity. Contrary to popular belief, high aperture values do not help increase sharpness. The aperture values at which the best image can be obtained are called optimum aperture values, and optimum aperture values should be taken into consideration in dental photography.[3]

Most lenses exhibit various chromatic aberrations at their widest apertures. These chromatic aberrations decrease as the aperture narrows, but as the lens is closed, the diffraction effects in the light increase. Diffraction effects do not appear all at once; they will appear gradually as the aperture values are increased. This range in which the lens gives the best value is called the best performance range, the optimum aperture value (Figure 1).

Different lenses have different optimum apertures. The physical structure of the diaphragm is complex; when light rays touch the edge of the diaphragm blades, they are bent and split into separate colors due to the wave nature of light (Figure 2). Therefore, there must be a balance between depth of field and sharpness.[5]

Despite the optimum aperture range, there are recommended high aperture values in dental photography; however, it is unacceptable for the areas related to the operation to remain outside the depth of field and not be clear. The aim of this preliminary study is to determine the most suitable aperture range that can be obtained in terms of depth of field, chromatic aberration, and diffraction in dental photography. The null hypothesis is that the recommended high aperture values reduce the quality of the photograph and the aperture value should be lower.

MATERIAL AND METHODS

Ethics committee approval was not needed because this study used only inanimate (phantom model) materials.

In this study, a Nikon D7500 body and a Tokina AT-X M100 PRO D, 100 mm F2.8 macro lens were used. The maximum

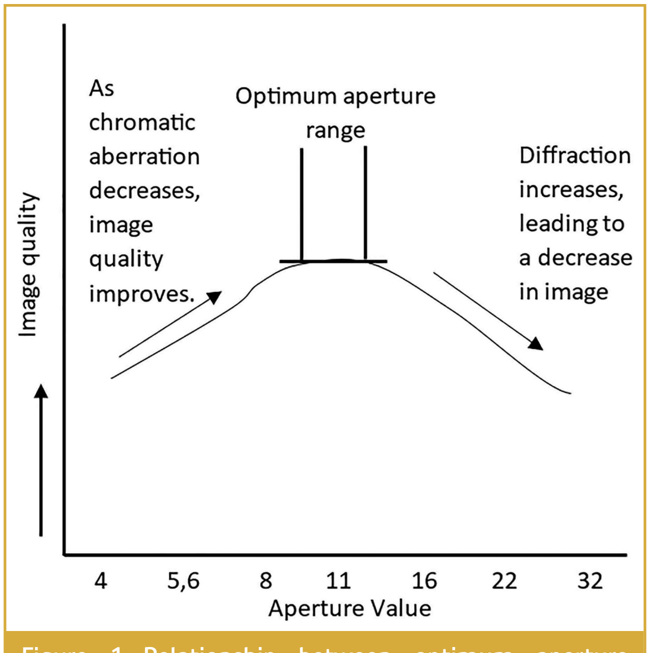

Figure 1. Relationship between optimum aperture range and aperture value.

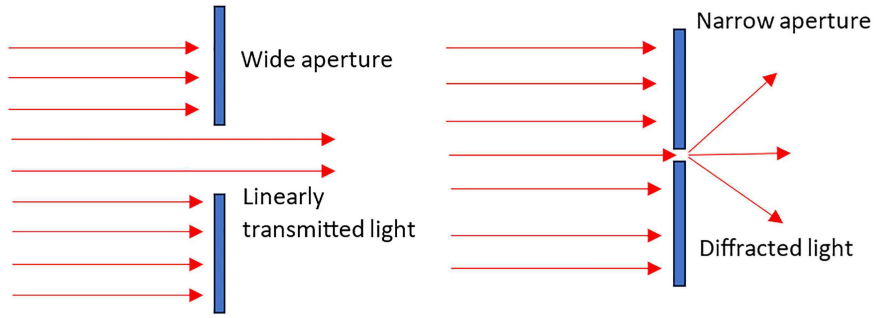

Figure 2. Diffraction phenomenon seen in light as the aperture decreases.

aperture value of the lens used is f/32. To ensure standardization of the photographs, the photographs were taken in a dark environment away from sunlight. In order for the camera to perform correct autofocus (AF), the model to be photographed was illuminated with a Godox RING48; the ring light remained fixed in place during the shooting of all photographs and was operated in the mode connected to the mains electricity to prevent decreases in light power. A Nikon r1c1 twin flash and trigger were used to shoot additional photographs for ambient lighting. The photographs were taken with the flash and trigger batteries fully charged. It was used with the FIXLITE TWIN bracket system, and the curtains were positioned to face each other at 45 degrees.

A tripod (Pro 500DX, SLIK and KF-25 ball head, K&F concept) and remote shutter release device were used to prevent shaking in the photo. The camera was adjusted to be parallel to the ground with the help of the spirit level on the tripod (Figure 3).

A template was prepared and modified by lens AF calibration test card[6] to help us reference different parts of the photographs and was printed as a high-resolution photo print on matte photo paper.

Figure 4. Depth of field and sharpness test chart modified by lens AF calibration card.[6]

The resulting test card was adjusted to the model in positions where we could measure the depth of field and sharpness (Figure 4).

All photographs were taken in manual shooting mode, 100 ISO, 1/125 shutter speed. through-the-lens (TTL) flash mode was used to obtain similarity in photo exposure. The center of the upper central incisors was focused on with the spot AF feature, and the AF was performed by the camera for each photograph. All photographs were taken in raw (RAW) format. One square photograph was taken with the values of f/3.3, f/3.5, f/4, f/4.5, f/5, f/5.6, f/6.3, f/7.1, f/8, f/9,

Figure 3. Camera and model setup.

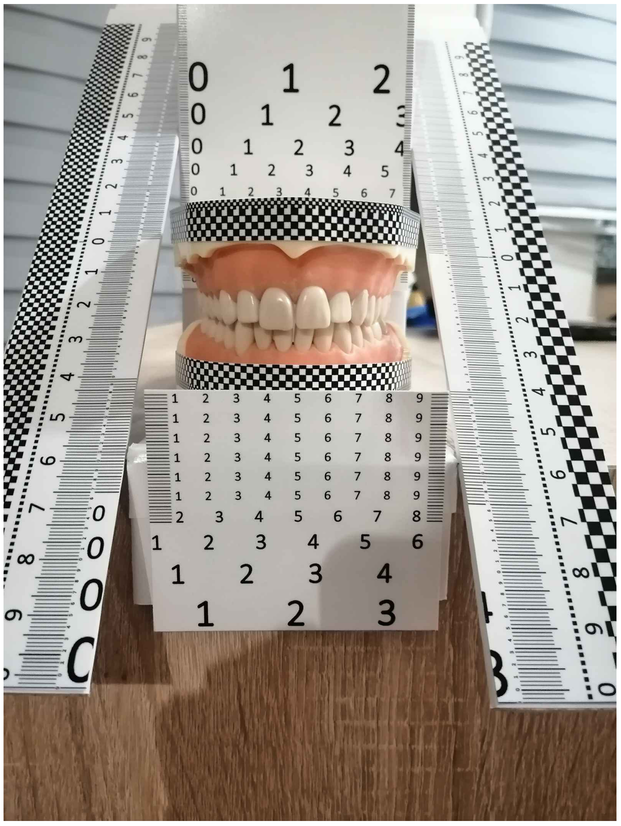

Figure 4. Adaptation of the test card to the tooth model.

f/10, f/11, f/13, f/14, f/16, f/18, f/20, f/22, f/25, f/29, f/32, respectively, from the widest aperture to the narrowest (Figure 5).

Photos were opened with Adobe Photoshop 2021 (Adobe™), and no adjustments such as color, sharpness, or exposure intervention were made to the photos; only enlargement, cropping, and export operations were applied. Sample images were obtained from various parts of the photo in terms of depth of field, sharpness, diffraction, and chromatic aberration (Figure 6). A survey was conducted with 16 post-graduate students and dentists who had previously engaged in dental photography. Due to the responses provided, one participant was excluded from the survey after the first question, and another participant was excluded after the second question. The survey was continued with 14 participants who were informed about the subject (Table 1). For the survey study, the work of Sugawara et al[7] was modified. The survey was conducted with all participants face-to-face and on the same computer, with the same screen settings. Survey questions were not continued for photos where depth of field was not deemed sufficient in the part of the photos related to the model. The lowest accepted aperture value was determined for photos where depth of field was deemed sufficient. Photographs taken from different regions within the photos where depth of field was deemed sufficient were evaluated among themselves in terms of sharpness, diffraction, and chromatic aberration.

Distribution analysis has been performed to examine the data.[7]

RESULTS

The participants who participated in the survey determined the lowest aperture value at which all teeth can be seen clearly from anterior to posterior. The lowest accepted aperture value answers are shown in Figure 7, and the distribution of their answers is shown in Figure 8. Five out of 14 participants, 36% of the answers, determined the lowest accepted aperture value as f/13. In question 1 and question 2, all participants stated that the focus was correct and could be seen clearly in the photographs. From questions 3 to 10, participants determined the lowest aperture value at which diffraction was seen at an unacceptable level. The answers given by the participants from questions 3 to 10 are shown

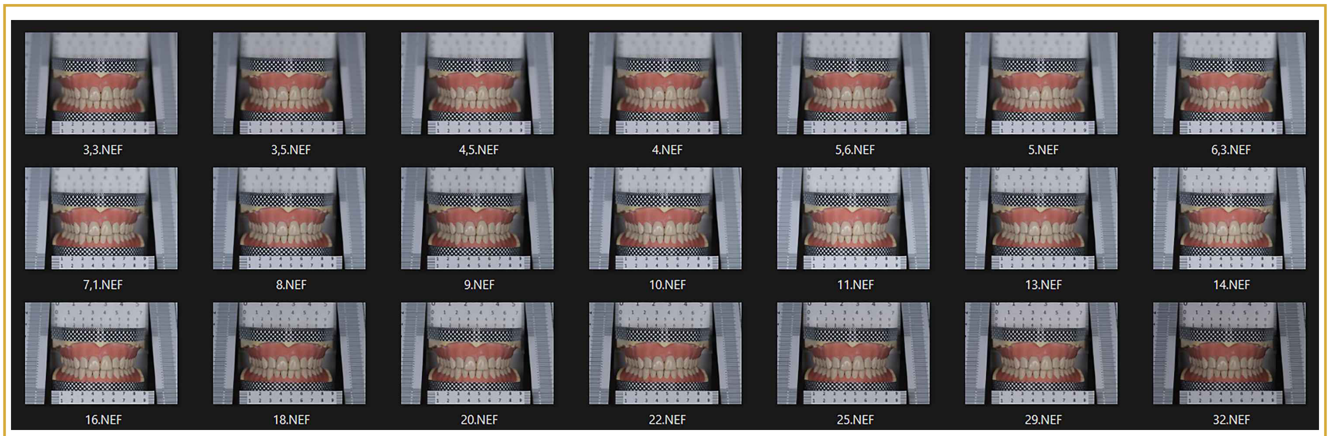

Figure 5. Photographs taken with different aperture values.

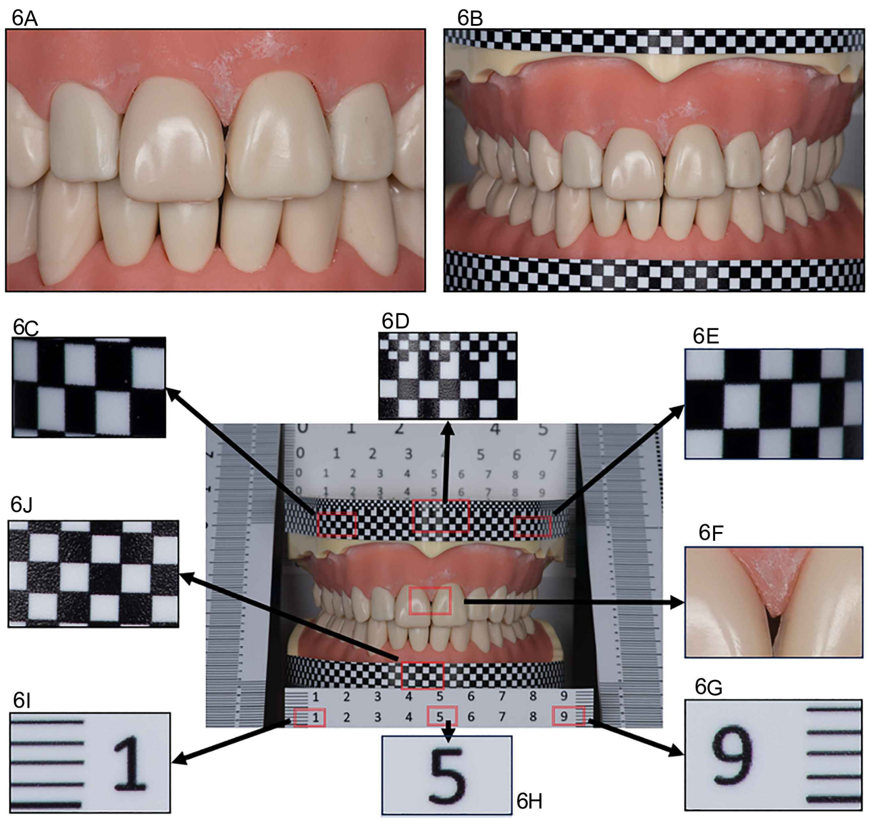

Figure 6. Each image is a question of the survey.

in Figure 9, and the distribution is shown in Figure 10. In the answers of 29 questions, participants stated that diffraction was clearly seen at aperture values of f/25 and above. In the answers of 27 questions, diffraction was clearly seen at aperture values of f/22 and above. In terms of distribution, the answer f/25 constituted 26% of all answers, and the answer f/22 constituted 24% of all answers. Answers f/25 and f/22 constitute 50% of all answers.

DISCUSSION

Dental photography is a specialized field that requires high-quality and detailed images. The choice of camera and lens to be used in this field directly affects the results obtained. In ideal dental photography, the camera body should preferably have a full-frame sensor. Sensor size is important in terms of light-gathering capacity and low-light performance. The resolution should be at least 18 megapixels, which gives the doctor enough space to capture details and crop when necessary.[8] The ISO performance of the camera is especially important in low-light conditions. It should be able to provide clear images at low ISO values (between 100 and 400) and show acceptable performance at high ISO values.[9] The AF system should be fast and sensitive, preferably with cross-type AF points. The camera should offer full manual control; it should be able to manually adjust aperture, shutter speed, and ISO values. The ability to make custom white balance settings is also important. RAW format support is preferred because it provides more flexibility in the post-production phase. Since flash use is critical in dental photography, the camera should have a high-speed flash synchronization feature and an external flash port (hot shoe).[8] The most important feature in lens selection is macro capability. A lens that offers a true 1:1 macro ratio should be preferred. A focal length between 90 mm and 105 mm is considered ideal for dental photography.[10] The maximum aperture should be f/2.8 or wider; this provides better performance in low light conditions. The minimum focusing distance should be as short as possible. The optical quality of the lens should be high, producing sharp images and minimizing lens defects such as chromatic aberration.[11] In addition, accessories such as a dual flash system specially designed for dental photography, special dental mirrors for intraoral shots, retractors to ensure mouth opening, and color calibration cards for accurate color reproduction are also important. A camera and lens system with these features is ideal for obtaining high-quality, detailed, and clinically usable images in dental photography.[12-15] Therefore, in our study, a Nikon D7500 body, a Tokina AT-X M100 PRO D, and a 100 mm F2.8 macro lens were used with a specially designed dual flash system.

Table 1. Survey Questions

Questions	How the Question is Asked	Purpose of the Question	Reply
Lowest depth of field (Uncropped photo)	Could you please tell me the first aperture value at which you can see all the teeth clearly from anterior to posterior?	Determine the lowest acceptable aperture value for the participant.	The lowest acceptable diaphragm value was determined by the diaphragm value where all teeth were visible from anterior to posterior. Diaphragm values before this diaphragm value were not included in the study for the participant.
Question 1 (Figure 6A)	Do you think the teeth in the photo are clear and visible?	Verification question for the accuracy of the camera's autofocus in the photographs and the participant's eyesight.	Yes/No The survey was not continued with participants who answered no.
Question 2 (Figure 6B)	Do you think the teeth in the photo are clear and visible?	Verification question for the accuracy of the camera's autofocus in the photographs and the participant's eyesight.	Yes/No The survey was not continued with participants who answered no.
Question 3 (Figure 6C	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 4 (Figure 6D)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 5 (Figure 6E)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 6 (Figure 6F)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 7 (Figure 6G)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 8 (Figure 6H)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 9 (Figure 6I)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.
Question 10 (Figure 6J)	Which photo shows the lines and texture starting to deteriorate?	Determine the lowest aperture value at which the participant sees diffraction.	From this photo onwards, lines and textures began to deteriorate.

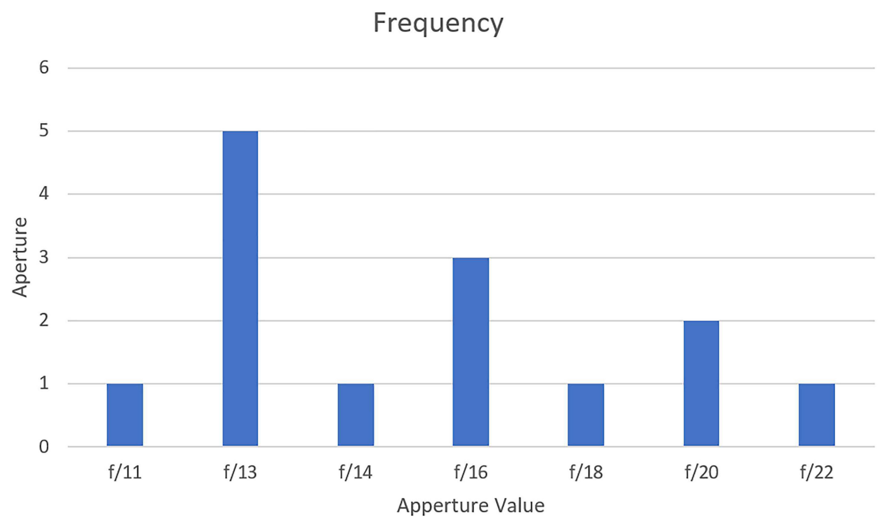

Figure 7. Answers for the lowest accepted aperture value.

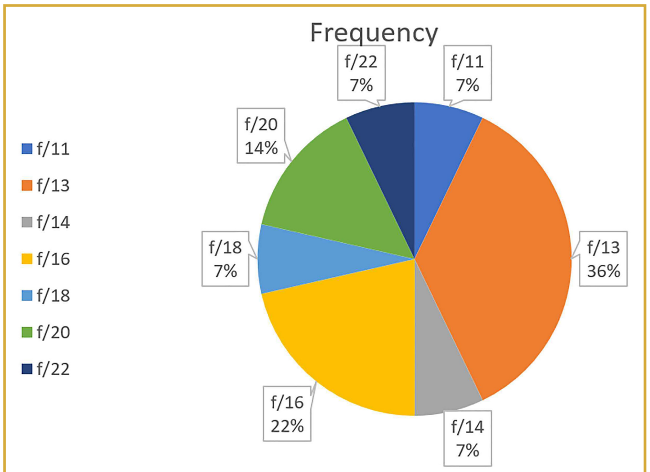

Figure 8. Distribution of answers for the lowest accepted aperture value.

In dental photography, the selection of ideal aperture values is a critical decision that directly affects the quality and usability of the image to be obtained. Many factors need to be taken into account when making this selection. First of all, the need for depth of field should be taken into account. Since the intraoral structures are at different depths, a wide depth of field is usually required. It is important to clearly view all teeth and soft tissues. The type of exposure also affects aperture selection; full mouth exposures, single tooth exposures, or detail exposures may require different depth of field requirements. Depth of field becomes more critical, especially in macro exposures. From the actual focus point, the depth of field range extends one-third in front and two-thirds behind. Therefore, in order to focus on all teeth (from molars to central incisors) in a close-up anterior view, the focus point should be on the canine teeth.[4,13]

The equipment used is also an important factor. Camera sensor size (full frame, APS-C, etc.) and lens characteristics (focal length, maximum aperture) affect depth of field and, therefore, aperture selection. Lighting conditions should also be taken into account. Sufficient light allows for the use of smaller apertures (higher f-numbers). Using flash provides flexibility in aperture selection. Since diffraction can reduce image quality, especially at very small apertures (e.g. f/22 and above), a balance must be struck between diffraction and depth of field. The need for sharpness should also be considered. Medium apertures (usually f/8-f/11) provide the best lens performance and sharpness, but smaller apertures are generally preferred in dental photography.[3,11,16]

ISO value and shutter speed are also factors that affect aperture selection. High ISO values can reduce image quality, so aperture selection will affect ISO value; thus, this balance should be taken into account. Similarly, a fast enough shutter speed is required to prevent hand shake or patient movement, and aperture selection will affect shutter speed. Chromatic aberration may be more pronounced at wide apertures, while small apertures reduce this effect. Different aperture values may be optimal for different purposes, such as diagnosis, treatment planning, or patient education. Experienced photographers can determine the optimal aperture values according to their own equipment and shooting style. In addition, if post-production techniques such as focus stacking are to be used, aperture selection can be made accordingly.[3,5,16,17]

Different authors have made different recommendations regarding aperture values in dental photography. Ahmad[16] recommended the aperture value of f/16 for intra-oral section photographs, while f/22 for photographs containing all teeth taken from the front. Bengel[3] recommended that standard aperture values should be in the range of f/16-22.

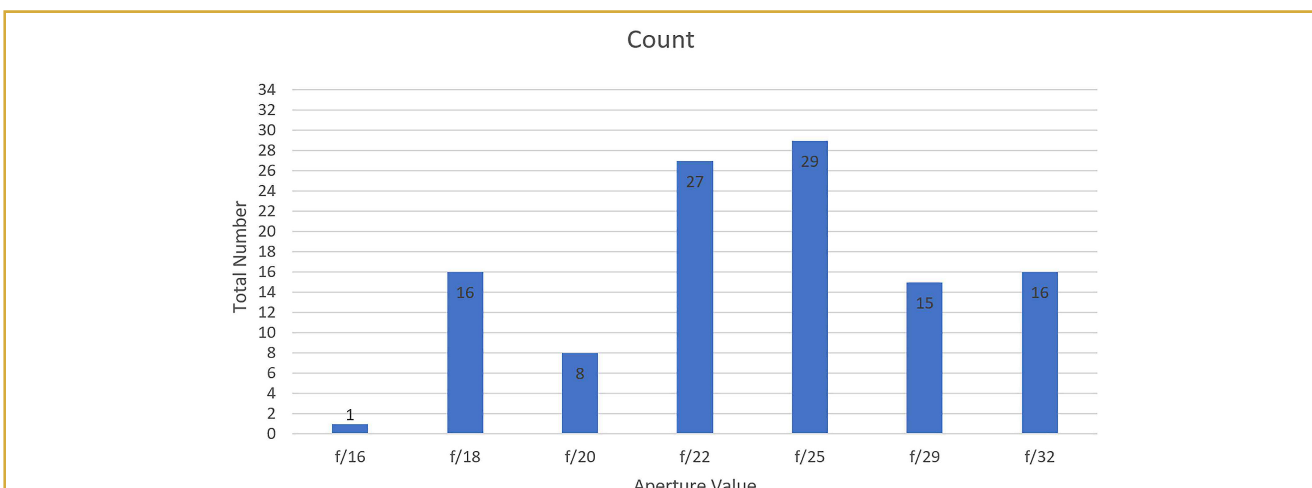

Figure 9. Responses for the lowest aperture value at which diffraction is clearly visible.

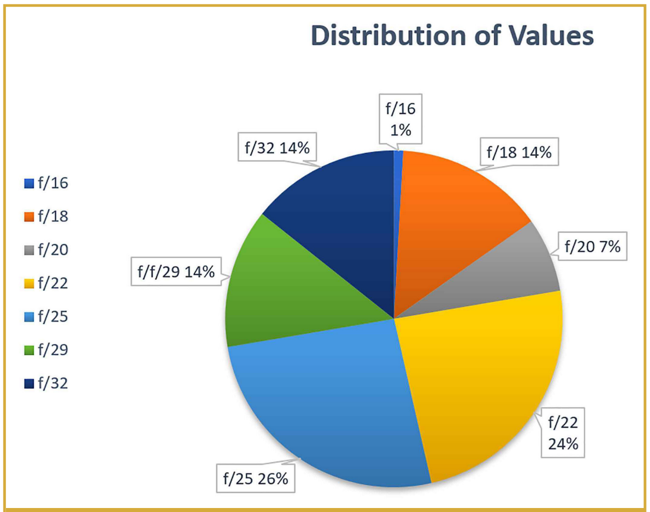

Figure 10. Distribution of responses for the lowest aperture value at which diffraction is clearly visible.

Tabata et al[18] recommended the aperture value of f/22 and stated that the maximum aperture value in lenses can be f/38 and more, but it usually reaches f/22. Liu[1] recommended the values of f/22, f/25, f/32, f/36, and f/40 for different intra-oral photographs. Ortiz[19] recommended the aperture value as f/32.

A rule of thumb for minimizing diffraction effects is to keep the aperture below the diffraction limit.[5] Reznick[11] says that the optimum aperture range for the Nikkor 105 mm f/2.8D mcro lens, which is also frequently used in dental photography, is between f/5.6 and f/11, while the optimum aperture range for the Nikkor 55mm f/2.8 AIS micro lens is between f/2.8 and f/16.

Bengel[3] stated that aperture values should be f/16 or larger for sufficient depth of field, but based on the findings of our study, f/13 provided sufficient depth of field in photographs containing all teeth. Ortiz[19] advocated that a photograph containing all teeth should be taken at f/32. However, the majority of the participants in our study (86%) stated that they saw unacceptable diffraction at values lower than f/32. Ahmad[16] recommended f/22 for photographs containing all teeth taken from the front, yet diffraction was clearly seen at f/22 and above in 24% of the responses. This result also contradicts the f/22 recommended by Tabata et al,[18] Liu[1] as stated by Bengel[3], Reznick,[11] and Davies[5], a loss of sharpness was observed in the photograph with diffraction at high aperture values. As a result of the limited possibilities of our study, it is understood that there is no clarity about the aperture values that can provide sharp photographs for dental photography. Different macro lenses can be tried to overcome the limitations of depth of field and diffraction. Tilt shift lenses can be tried to increase depth of field, or sharp photographs can be obtained by focus stacking.[4,17] More extensive studies are needed on the relevant subject.

Availability of Data and Materials: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethics committee approval was not needed because this study used only inanimate (phantom model) materials.

Informed Consent: Informed consent was not needed because this study used only inanimate (phantom model) materials.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – O.A.Y., M.D., S.T., N.T., M.Y.; Design – O.A.Y, M.D., S.T., N.T.; Supervision – M.D., S.T., N.T.; Resources – O.A.Y., M.D., S.T.; Materials – A.F.İ., M.D., S.T.; Data Collection and/or Processing – A.F.İ., M.D., S.T., M.Y., Ö.D.Ö.; Analysis and/or Interpretation – M.D., S.T., N.T., M.Y.; Literature Search – O.A.Y., S.T., Ö.D.Ö.; Writing Manuscript – O.A.Y., M.D., S.T.; Critical Review – M.D., S.T., N.T., M.Y.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

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