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Original Article

Comparison of image quality, color accuracy, and resolution in intraoral photography using digital single lens reflex camera and smartphone cameras: A pilot study

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Image resolution;
Shade accuracy

Abstract *Background/purpose:* Dental photography plays a key role in diagnosis, documentation, and communication in the field of dentistry. The digital single-lens reflex (DSLR) cameras are the gold standard for image quality, but advances in modern smartphone technology necessitate evaluating their performance in resolution, distortion, magnification, color accuracy, and overall image quality. The purpose of this study was to compare DSLR cameras and smartphone cameras regarding resolution, distortion, magnification, color accuracy, and overall image quality in intra- and extraoral dental photography.
Materials and methods: A Nikon Z5 full-frame DSLR with a 105 mm macro lens and twin flash (control) was compared with three flagship smartphones: iPhone 15 Pro, Google Pixel 8, and Samsung S24. Ten participants were photographed in five standardized dental views: maximum intercuspation, right lateral occlusion, maxillary anterior with black contrastor, mandibular arch (mirror view), and front profile. Images were analyzed using the GNU Image Manipulation Program (GIMP 2.1); statistical analysis was performed with Statistical Package for the Social Sciences (SPSS) 27.
Results: The Samsung S24 closely matched the DSLR in shade accuracy and distortion. Google Pixel 8 produced an acceptable resolution ($<$300 dots per inch). The iPhone 15 Pro demonstrated superior performance in reducing distortion and maintaining clarity ($P < 0.05$).

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Conclusion: Despite the convenience and affordability of smartphone cameras, DSLR systems demonstrate superior performance in terms of magnification, image resolution, and color accuracy. These advantages render DSLRs more suitable for clinical applications that demand high precision and diagnostic reliability in dental photography.

Introduction

Photographs are a symbol of memories and perspectives that the human eye is not able to hold permanently. Photography has been revolutionized by digital technology, ranging from old charged-coupled device (CCD) cameras to digital single-lens reflex (DSLR) cameras, and more recently, mirrorless macro lens cameras.[1] Digital technology has significantly surpassed the laborious and time-consuming orthodox procedures of photography. In dentistry, photographic documentation provides an emphasized view of routine clinical treatment plans. Photography is not only used for documentation purposes; it can also be used for communicating with lab technicians, self-evaluation of work, communication with colleagues, publishing and presenting cases, legal purposes, social media marketing, smile designing, diagnosis and treatment planning, and evaluating outcomes.[1–3] Moreover, dental photography is described as the best standard for learning from your own mistakes.[3,7–9]

DSLR cameras are the preferred gold standard in dental photography due to their high-resolution imaging, precise color accuracy, advanced manual controls, and minimal optical distortion. Their capability to integrate interchangeable macro lenses and external flash systems enhances image clarity and consistency, which is critical for shade selection, clinical documentation, and research applications. DSLR cameras with a full-frame or APS-C (advanced photo system type-C) sensor and a 100 mm macro lens, which allows for closeup shots with high detail. Ring or dual-point flashes are ideal for intraoral photography as they provide even lighting and reduce shadows. The recommended standards for DSLR cameras used for dental photography are low ISO (International Organization for Standardization standard for camera sensors and film), (e.g., ISO 100 or 200) to minimize noise, ensuring images are clear and detailed. High aperture size (e.g., f/22 or higher) for a deep depth of field to keep all parts of the image in sharp focus. It has a fast shutter speed of around 1/160 to 1/200 s to make it fast enough to avoid motion blur. Also, the white balance was set to a daylight setting to maintain consistent color accuracy, especially with the use of flashes.[5,6]

Nowadays, mobile dental photography (MDP) is seen as a promising alternative used for intraoral and extraoral photography. Due to their ease of operation and handling, dentists are increasingly turning to their smartphones for photography instead of investing in high-end DSLR equipment.[4,9] The high-end sensors and optimized lenses of recent smartphone cameras make them stand next to the gold standard DSLR cameras. DSLR cameras allow the user to adjust and modify elements like ISO sensitivity, exposure duration, and aperture, which means that their unique settings and features determine the procedures involved in taking a picture. Smartphone cameras, on the other hand, make automatic modifications so that the user may capture a photo in any condition.[6,7] Despite the increasing use of smartphone cameras in intraoral photography, they present certain limitations. The inherent shorter focal length and restricted aperture size often result in images that fail to meet the minimal accepted resolution, despite larger file sizes. Nevertheless, these devices continue to be widely adopted by dental practitioners, highlighting the need for further evaluation of their clinical reliability.

The Literature supports the use of smartphones for intraoral dental photography, suggesting their feasibility for routine clinical practice. However, their limitations have not been thoroughly examined or addressed.[6–9] Literature evidence on a systematic comparison of the performance of the flagship smartphone devices and the recommended DSLR cameras in terms of accuracy, image quality, distortion, magnification, resolution, and color accuracy is lacking. Hence, this research aims to assess, contrast, and examine the image quality (resolution), color accuracy, magnification, and distortion rate of intraoral photography taken with a smartphone and a DSLR macro lens camera. The null hypothesis of the study states that flagship smartphone cameras do not differ from a consumer DSLR camera setup for intraoral photography in terms of image quality, distortion, magnification ratio, color accuracy, and resolution.

Materials and methods

Using G* Power software, under Welch's ANOVA, it was advised to collect data from 10 participants with 4 measurements in each participant at a 95 % confidence level, assuming a moderate effect size (Cohen's d = 0.5621), an alpha of 0.05, and 80 % power was calculated using mean and standard deviations reported in the literature by Saincher et al.[4] A sensitivity analysis was also performed to determine the range of detectable effect sizes with the available sample size. Fully dentate male and female participants within the age group of 20–50 years were included in the study. The participants with prosthetic rehabilitation in the anterior tooth region, undergoing orthodontic treatment, trauma or developmental defect cases were excluded from the study. The study was initiated after obtaining ethical clearance from the Ethics Committee and registering at Clinical Trials Registry India (ctri.nic.in). The participants were given information sheets explaining the methodology and an informed consent form to sign.

Four study groups were used: Group 1 (control) used a DSLR camera (Nikon Z5 DSLR with 105-mm macro lens; Nikon Inc., Melville, NY, USA); Group 2 used a Google Pixel 8; GP8 (Google LLC, Mountain View, CA, USA); Group 3 used an iPhone 15 Pro; I15P (Apple Inc., Cupertino, CA, USA); and Group 4 used a Samsung S24 (Samsung Electronics Co., Ltd., Suwon-si, South Korea). Photographs were taken for each participant using the DSLR camera and each of the smartphone cameras, resulting in a total of 20 images per participant. The following five views were captured: maximum intercuspation, anterior teeth with black contrast, right lateral occlusion, mandibular occlusal view using an intraoral mirror, and extraoral portrait.

To ensure consistent imaging conditions, intraoral photographs were captured using both DSLR and smartphone cameras under standardized protocols. For the DSLR setup, a ring flash or twin flash system with a fixed color temperature of 5,500K (daylight equivalent) was used. The camera was operated in manual mode with exposure parameters set at ISO 200, aperture f/29, and shutter speed 1/200 s. White balance was manually set to 5,500K to maintain uniform color rendering. For smartphone photography, images were taken in Pro (manual) mode, with white balance fixed at 5,500K and exposure settings locked to avoid automatic adjustments. In both setups, ambient room lighting was minimized, and a neutral grey card (18 % grey) was photographed before imaging to allow for white balance correction during post-processing. Participants were asked to sit on a stool, and a plastic cheek retractor with a controlled 2—5 N force was used for standardized retraction. Suction tips were employed to control moisture and maintain a clear field of view for all intraoral photographs.

For an extraoral picture (portrait), the participant was asked to sit on a stool against a black background wall. The camera or smartphone was mounted on a tripod stand to maintain a fixed distance and angle. A Nikon Z5 full-frame DSLR camera with a 105 mm macro lens was used in manual mode at ISO 200, with a shutter speed of 1/200 s, an effective focal length of 105 mm, a magnification ratio of 1:2, and an aperture size of (f/29) for intraoral pictures. For extraoral portrait pictures, the same camera was used in portrait mode at ISO 800, a shutter speed of 1/60 s, and a magnification ratio of 1:10. The smartphone cameras were used in manual mode (manual focus at maxillary canine, central incisor teeth, for right lateral and maximum intercuspation images, respectively). The distance between the lens of the camera and the object was standardized using a measuring scale. The image size was standardized using the built-in image editing software on iPad 9 (Apple Inc., Cupertino, CA, USA; the intraoral image was cropped in a 4:3 ratio, and the extraoral image was cropped in a 3:4 ratio to avoid bias. The images were saved in Joint Photographic Experts Group (JPEG) file format and were uploaded to a secure folder in the investigator's laptop for data analysis. Digital software GIMP V2.1 was used for the data analysis.

Figs. 1—5 depict images obtained with the control and test group devices: Fig. 1 shows the maximum intercuspation view, Fig. 2 the anterior teeth with black contrast, Fig. 3 the right lateral occlusion, Fig. 4 the mandibular occlusal view using an intraoral mirror, and Fig. 5 the extraoral portrait.

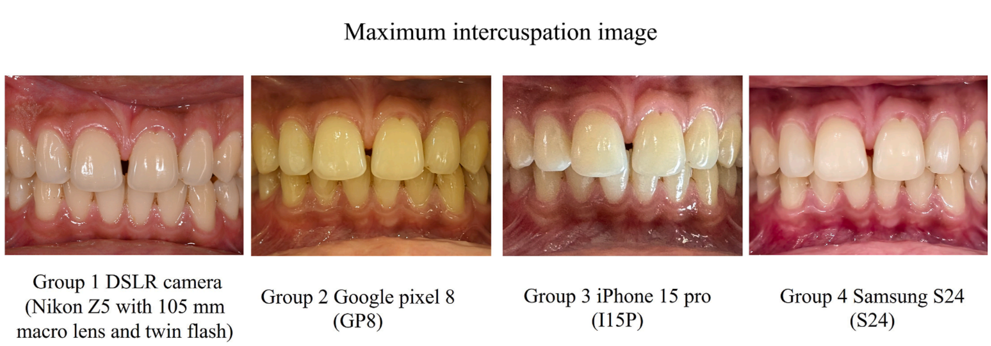

Figure 1 Depicting the maximum intercuspation image clicked by the control and test group devices.

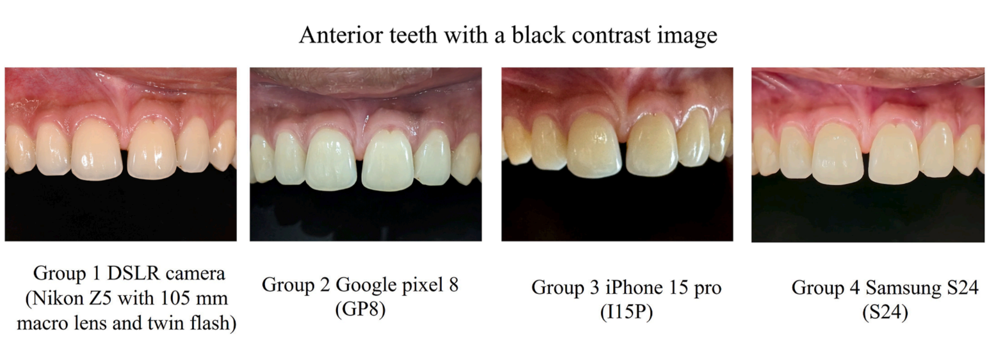

Figure 2 Depicting the anterior teeth image with a black contrast clicked by the control and test group devices.

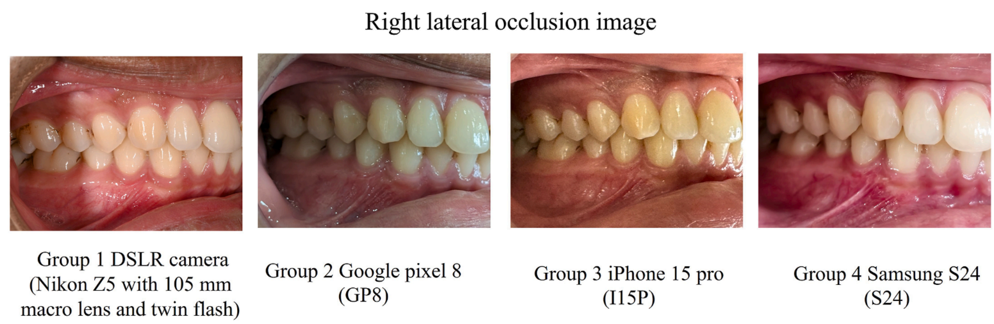

Figure 3 Depicting the right lateral occlusion image clicked by the control and test group devices.

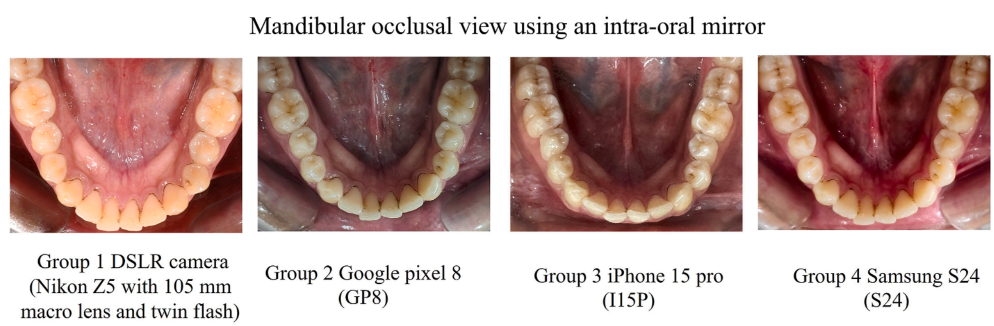

Figure 4 Depicting the mandibular occlusal view image clicked by the control and test group devices.

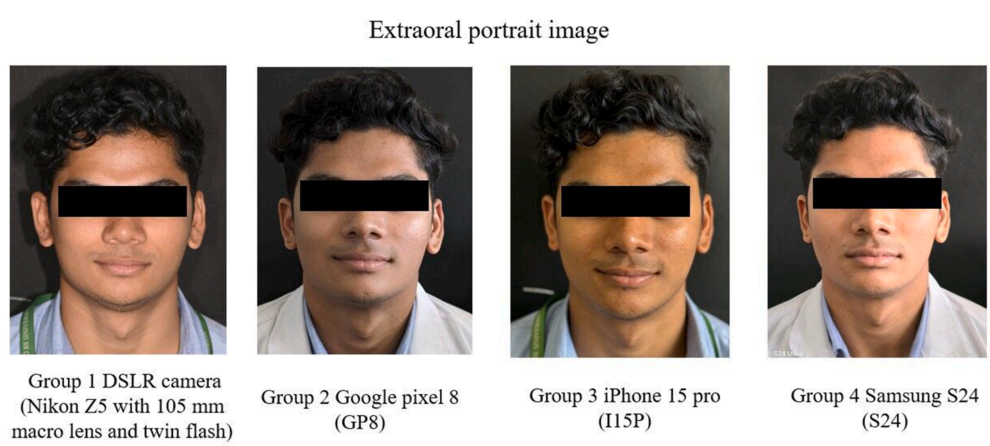

Figure 5 Extraoral portrait image.

Image distortion was assessed by measuring the height (in mm) of the maxillary right central incisor in the maximum intercuspation image. Intraoral magnification was determined by measuring the inter-canine width (in mm) in the mandibular occlusal view. Extraoral magnification was evaluated by measuring the intercanthal distance (in mm) in portrait mode images. To maintain consistency, participants' Frankfurt horizontal plane was aligned parallel to the floor, and they were instructed to look straight at the camera lens to minimize variability in positioning. Image resolution was measured in dots per inch (DPI) using GIMP 2.1 software in the right lateral occlusion image (RAW image file format), focusing on two specific sites. The maxillary right canine and the mandibular right first molar were divided into 3 equal segments mesiodistally and apico-coronally with the help of gridlines in GIMP 2.1 software, and their midpoint was selected. For shade evaluation, images of the anterior teeth taken with a black contrastor were used. To ensure standardization, the shade of the maxillary right canine was assessed in all images, and HSV (Hue, Saturation, Value) values were recorded using the color picker tool in GIMP software. A white balance calibration was done in Adobe Photoshop software for each image to ensure true color reproduction and eliminate the effect of ambient lighting variations.

All statistical analyses were conducted using International Business Machines (IBM SPSS 27 software). The Shapiro—Wilk test was used to assess variance, normality and homogeneity. Quantitative variables were summarized using counts, mean, or median, along with standard

Table 1 Descriptive values for Welch's ANOVA test for distortion of the image for all groups.

Distortion [central incisor height]								
Study group	Mean	Standard deviation	Standard error	95 % confidence interval for mean		Minimum	Maximum	*P*-value Welch's ANOVA
				Lower bound	Upper bound			
Group1	74.837	7.8082	2.7606	68.310	81.365	63.7	86.7	<0.001
Group2	33.638	6.6060	2.3356	28.115	39.160	24.4	45.0	
Group3	39.213	4.9006	1.7326	35.116	43.309	30.6	44.0	
Group4	42.575	4.0305	1.4250	39.205	45.945	36.0	48.0	

deviation or interquartile range, depending on the normality of the data. Levene's test was used to evaluate the homogeneity of variances across groups. Based on the distributional characteristics and variance assumptions, the following statistical procedures were applied to assess differences among groups: The data followed a normal distribution and met the assumption of homogeneity of variances; therefore, Welch's ANOVA was performed, followed by Bonferroni post hoc tests for pairwise comparisons. In cases where homogeneity of variances was not met despite normal distribution, Welch's ANOVA was conducted with Games-Howell post hoc tests for comparisons. *P*-value <0.05 was considered statistically significant.

Results

Welch's ANOVA test demonstrated a statistically significant difference in mean image distortion between the groups ($P < 0.001$, 95 % confidence interval) (Table 1). The mean height measured in the control group (Group 1) was 74.83 mm, while the Google Pixel 8 smartphone (Group 2) recorded the lowest distortion among the smartphone groups, with a mean height of 33.63 mm. The Samsung S24 (Group 4) exhibited a higher mean height of 42.57 mm. Overall, the DSLR camera showed the least distortion in intraoral images compared to all smartphone devices, while the Google Pixel 8 demonstrated superior image clarity and the least distortion among the smartphones (Table 1, Fig. 6).

Welch's ANOVA also revealed a statistically significant difference in intraoral image magnification among the study groups ($P < 0.001$) (Table 2). The Google Pixel 8 smartphone (Group 2) exhibited the least magnification, with a mean recorded height of 73.96 mm, followed by the Samsung S24 (Group 4) at 75.1 mm. These results indicate that the Google Pixel 8 provided significantly lower magnification and less variation from the actual object dimensions, demonstrating greater dimensional accuracy compared to the other devices evaluated (Table 2, Fig. 7).

For extraoral magnification, the mean intercanthal measurements showed statistically significant differences across the test groups ($P < 0.001$) (Table 3). Among the groups, the iPhone 15 Pro (Group 3) recorded the lowest intercanthal distance (71.61 mm), indicating the least extraoral magnification and better preservation of actual anatomical proportions. In contrast, the Samsung S24 (Group 4) exhibited the highest intercanthal measurement (80.5 mm), suggesting greater image magnification and noticeable distortion, resulting in a deviation from the true dimensions of facial structures (Table 3, Fig. 8).

The devices tested also exhibited variations in image resolution when assessed at two intraoral sites. At the

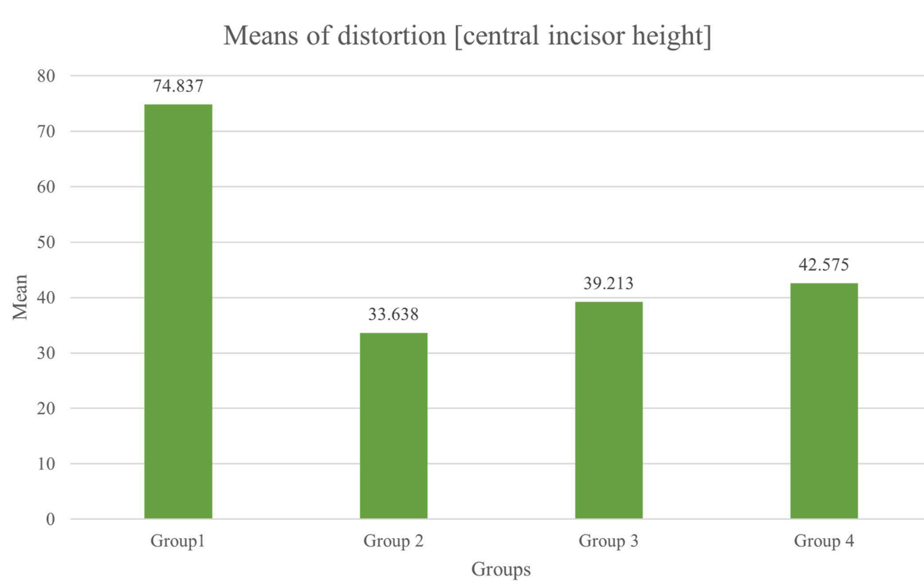

Figure 6 Bar graph showing the mean values of image distortion (central incisor height) for the control and test groups.

Table 2 Descriptive values for Welch's ANOVA test for intraoral image magnification for all groups.

Intraoral magnification [canine—canine tip]								
Study group	Mean	Standard deviation	Standard error	95 % confidence interval for mean		Minimum	Maximum	*P*-value (Welch's ANOVA)
				Lower bound	Upper bound			
Group1	185.53	28.2270	9.9797	161.939	209.136	132.0	220.0	<0.001
Group2	73.962	4.1925	1.4823	70.457	77.468	68.0	79.0	
Group3	78.388	4.9910	1.7646	74.215	82.560	69.6	83.4	
Group4	75.113	4.8212	1.7046	71.082	79.143	66.7	82.6	

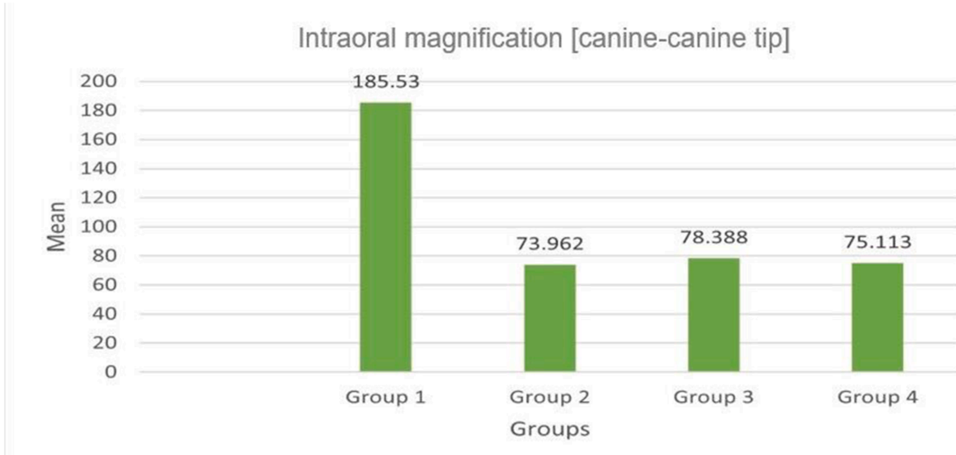

Figure 7 Bar graph showing the mean values of intraoral magnification (distance of maxillary canine to canine tip) for control and test groups.

Table 3 Descriptive values for Welch's ANOVA test for extraoral image magnification for all groups.

Extraoral magnification [canthus measure]								
Study group	Mean	Standard deviation	Standard error	95 % confidence interval for mean		Minimum	Maximum	*P*-value (Welch's ANOVA)
				Lower bound	Upper bound			
Group1	138.125	21.2077	7.4981	120.395	155.855	105.0	170.0	<0.001
Group2	74.813	12.9005	4.5610	64.027	85.598	45.0	86.0	
Group3	80.575	2.3765	0.8402	78.588	82.562	76.5	84.0	
Group4	71.613	12.0265	4.2520	61.558	81.667	48.0	83.0	

maxillary right canine, Welch's ANOVA indicated that the mean resolution values across all groups were comparable to the control DSLR (Group 1: 309 dots per inch), and the differences were not statistically significant ($P > 0.05$) (Table 4). Notably, the Google Pixel 8 smartphone (Group 2) showed a mean resolution of 309.75 dpi, identical to the DSLR, suggesting near-equivalent resolution performance at this site. At the mandibular right first molar, however, Welch's ANOVA revealed a statistically significant difference in image resolution among the devices ($P < 0.05$) (Table 5). The iPhone 15 Pro (Group 3) demonstrated the lowest mean resolution at 299.75 dpi, falling below the standard threshold of 300 dpi and indicating slightly reduced image quality compared to the DSLR and other smartphones (Table 5).

Analysis of tooth color based on hue, value, and chroma (HSV values) also demonstrated statistically significant differences among the groups ($P < 0.001$) (Table 6). For hue, the Google Pixel 8 smartphone (Group 2) recorded the highest mean value (85.55), which may contribute to perceptible inaccuracies in actual shade matching compared to the control. In terms of chroma, the Google Pixel 8 again showed the lowest mean chroma (11.87), indicating reduced color intensity, whereas the iPhone 15 Pro (Group 3) had a mean chroma of 22.58, closely matching that of the control group (21.95) and suggesting better shade fidelity. With respect to value, the Google Pixel 8 recorded the lowest mean value (80.32), indicating a darker image representation. The Samsung S24 (Group 4) showed a mean value of 88.12, which was closest to the

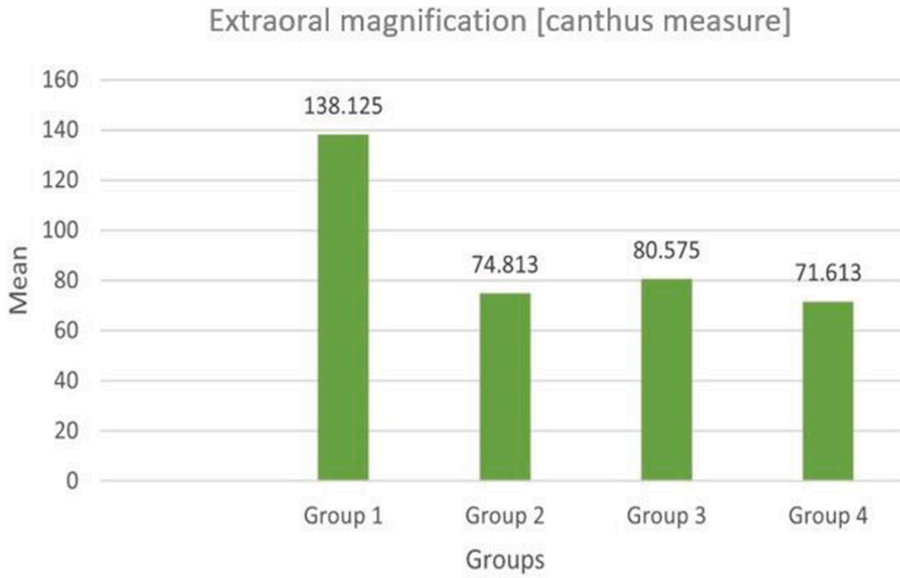

Figure 8 Bar graph showing the mean values of extraoral magnification (canthus measurement) for control and test groups.

Table 4 Descriptive values for Welch's ANOVA test for image resolution at canines for all groups.

Resolution [dots per inch]-canine								
Study group	Mean	Standard deviation	Standard error	95 % confidence interval for mean		Minimum	Maximum	*P* -value (Welch's ANOVA)
				Lower bound	Upper bound			
Group1	309.75	14.330	5.067	297.77	321.73	295	332	0.599
Group2	328.13	42.202	14.921	292.84	363.41	271	404	
Group3	309.75	20.624	7.292	292.51	326.99	281	330	
Group4	316.88	37.181	13.145	285.79	347.96	286	388	

Table 5 Descriptive values for Welch's ANOVA test for image resolution at mandibular first molar for all groups.

Resolution [dots per inch]-molar								
Study group	Mean	Standard deviation	Standard error	95 % confidence interval for mean		Minimum	Maximum	*P*- value (Welch's ANOVA)
				Lower bound	Upper bound			
Group1	323.50	18.807	6.649	307.78	339.22	285	348	0.616
Group2	322.38	45.456	16.071	284.37	360.38	265	388	
Group3	299.75	33.885	11.980	271.42	328.08	265	361	
Group4	315.25	52.418	18.533	271.43	359.07	264	396	

DSLR control group (90.35), suggesting better preservation of the tooth's brightness. These findings highlight variation in color accuracy among different smartphone cameras, with implications for clinical shade matching (Table 6, Fig. 9).

Discussion

This study compared the imaging capabilities of a DSLR camera with those of three leading smartphone models for dental photography. The DSLR consistently produced superior results in critical areas such as image distortion, resolution, and magnification accuracy. DSLRs with macro lenses provided 1:1 magnification, avoiding over- or undersized images and minimizing distortion due to the absence of a crop factor. Their larger sensor size (36 × 24 mm) and 5.97-micron pixel size enabled high light sensitivity and reduced image noise, producing sharper, more accurate images with consistent color reproduction.[10,11]

Among the smartphones, the Google Pixel 8 produced results most comparable to the DSLR, particularly in image resolution and reduced distortion. This is likely due to its 50-megapixel sensor and relatively larger 2.8-micron pixels, which enhance image clarity. Its longer focal length (25.4 mm) also helped minimize intraoral over-magnification, unlike wide-angle lenses in devices like the

Table 6 Descriptive values for Welch's ANOVA test for mean hue, saturation, and value for all study groups.

Shade-hue	Group 1	32.7	2.44	0.918	0.412
	Group 2	85.5	20.04	0.849	0.093
	Group 3	46.6	16.89	0.753	0.009
	Group 4	44.8	4.17	0.929	0.503
Shade saturation	Group 1	21.9	6.33	0.872	0.156
	Group 2	11.9	3.11	0.861	0.123
	Group 3	22.6	5.12	0.885	0.212
	Group 4	16.9	1.77	0.902	0.302
Shade value	Group 1	90.3	2.27	0.938	0.589
	Group 2	80.3	4.24	0.851	0.098
	Group 3	83.6	5.77	0.961	0.816
	Group 4	88.1	8.25	0.789	0.022

Samsung S24, which caused image constriction. For extraoral images, the iPhone 15 Pro showed the least magnification, aligning with the magnification formula based on focal length and distance. In terms of color accuracy, the Samsung S24 performed best in tooth shade reproduction, likely due to advanced features such as white balance and firmware optimisation.[12,13] While the DSLR camera still led in resolution with the highest DPI (323.5), the Google Pixel 8 followed closely, thanks to its high megapixel count and efficient pixel density.[13] Overall, DSLR cameras provided the best performance due to their superior hardware and manual settings.

One of the study's strengths was the use of a standardized photographic protocol, including consistent lighting conditions, fixed object-to-camera distance, use of retractors and mirrors, and standardized exposure settings, which adds rigour and reproducibility to the comparisons. Photographs were captured under controlled clinical conditions (in vivo), enhancing the study's clinical relevance. Real intraoral and extraoral conditions were used, adding clinical relevance. Additionally, this study evaluated three of the latest-generation smartphone models (iPhone 15 Pro, Google Pixel 8, Samsung S24), offering updated comparative data that reflects current market-leading technology—a point that addresses the gap in previous literature and advances understanding of how recent smartphone advancements measure up to DSLR systems.

The results highlight the ongoing value of DSLR cameras for clinical dental photography, especially where precision and consistency are crucial. However, the narrowing performance gap between smartphones and DSLRs indicates that high-end smartphones may serve well in routine documentation and patient consultations. These findings contribute to the current body of research by offering direct in vivo comparisons under standardized conditions and suggesting a more nuanced approach to choosing imaging devices based on clinical needs. This study questions the common perception that smartphones can universally replace DSLR systems in dental photography. This study also challenges the assumption that smartphones can fully replace DSLR systems in dentistry. While they offer convenience, affordability, and improved accessibility, they may still fall short in cases demanding high image fidelity, such as documentation for publications, medico-legal purposes or image-dependent shade matching and diagnosis, treatment planning and laboratory communication in aesthetic dentistry.

Several limitations of the study should be noted. Color assessment was performed using HSV values without spectrophotometric validation, which may limit shade accuracy. Time required for image capture and ease of use were not evaluated, though these factors influence clinical workflow. The evaluator was not blinded to the devices, introducing potential bias. Additionally, the impact of smartphone processing features like Artificial Intelligence (AI) and high dynamic range (HDR) was not independently analyzed. Only one prosthodontist performed all evaluations for consistency, but inter-evaluator reliability was not assessed. Further studies with larger, more diverse populations, blinded multi-evaluator designs and additional smartphone models are necessary to validate these findings. Incorporating technologies such as digital spectrophotometers, AI-assisted imaging, and consistent

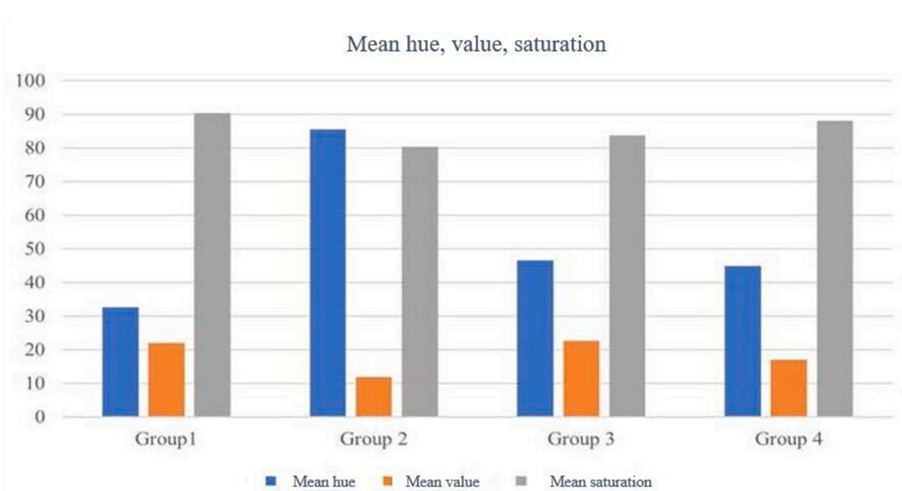

Figure 9 Bar chart for descriptive values of Welch's ANOVA test for mean hue, saturation, and value for all groups.

environmental setups could enhance image quality and reproducibility. Future work may also explore the integration of these tools in areas like restorative dentistry, orthodontics, and trauma assessment to assess broader clinical utility.

In conclusion, this study demonstrated significant differences in image quality, magnification, resolution, and shade accuracy between DSLR cameras and smartphone devices in both intraoral and extraoral dental photography. Although modern smartphones provide a convenient and cost-effective alternative, their limitations may compromise diagnostic accuracy and shade matching. Performance varied notably across the tested smartphones; however, DSLR cameras remain the preferred choice for clinical situations requiring high precision, particularly for documentation, diagnosis, and shade selection. Clinicians who rely on smartphones should recognize these limitations and adhere to standardized imaging protocols to optimize clinical outcomes.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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