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Evaluation of Dental Restorations: A Comparative Study Between Clinical and Digital Photographic Assessments

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Clinical Relevance

The digital photographic method is a useful tool for assessing the quality of dental restorations, providing information that goes unnoticed with the visual-tactile clinical examination method.

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SUMMARY

The aim of this study was to compare the efficacy of a direct clinical evaluation method with an indirect digital photographic method in assessing the quality of dental restorations. Seven parameters (color, occlusal marginal adaptation, anatomy form, roughness, occlusal marginal stain, luster, and secondary caries) were assessed in 89 Class I and Class II restorations from 36 adults using the modified US Public Health Service/Ryge criteria. Standardized photographs of the same restorations were digitally processed by Adobe Photoshop software, separated into the following four groups and assessed by two calibrated examiners: Group A: The original photograph displayed at 100%, without modifications (IMG100); Group B: Formed by images enlarged at 150% (IMG150); Group C: Formed by digital photographs displayed at 100% (mIMG100), with digital modifications (levels adjustment, shadow and highlight correction, color balance, unsharp Mask); and Group D: Formed by enlarged photographs displayed at

150% with modifications (mIMG150), with the same adjustments made to Group C. Photographs were assessed on a calibrated screen (Macbook) by two calibrated clinicians, and the results were statistically analyzed using Wilcoxon tests (SSPS 11.5) at 95% CI. Results: The photographic method produced higher reliability levels than the direct clinical method in all parameters. The evaluation of digital images is more consistent with clinical assessment when restorations present some moderate defect (Bravo) and less consistent when restorations are clinically classified as either satisfactory (Alpha) or in cases of severe defects (Charlie). Conclusion: The digital photographic method is a useful tool for assessing the quality of dental restorations, providing information that goes unnoticed with the visual-tactile clinical examination method. Additionally, when analyzing restorations using the Ryge modified criteria, the digital photographic method reveals a significant increase of defects compared to those clinically observed with the naked eye. Photography by itself, without the need for enlargement or correction, provides more information than clinical examination and can lead to unnecessary overtreatment.

INTRODUCTION

The use of digital photography is becoming a standard for today's modern dental practices[1] through the photographic documentation of clinical findings prior to initiating restorative treatment. Digital intraoral photography has greatly influenced the ease of documentation and the storage of clinical images of specific clinical situations. As a result, its use in dentistry is consistently increasing.[2-5]

Some of the uses of digital photography include evaluation of restorations,[6,7] color selection of composite resins[8], control of tooth whitening,[9] and evaluation of tooth wear.[10] It has also been used to measure the color of healthy gingiva[11] and for recording and analysis in orthodontics therapy.[2] Secondary uses include dento-legal documentation, education, communication, portfolios, and marketing.[12]

Additionally, because digital photography possesses many features that can improve the practice of dentistry,[2,13,14] including the ability for the clinician to edit images using software programs,[5,9,11,15,16] this technology could also be considered as an indirect method of detection, especially in the assessment of restorations, because direct evaluation alone has proven to be insufficient in identifying early changes in the development of defects on restorations.[17-20]

Although digital photography presents interesting features for indirect diagnosis, its correlation to clinical detection is still not clear. Moreover, the use of photography, along with the manipulation of images with Adobe Photoshop software—the ability to adjust an image to its intended brightness, contrast, and color without misrepresenting the original image and treatment outcome—has not yet been described in the field of operative dentistry.

The aim of this study was to compare the efficacy of direct clinical evaluation with indirect digital photographic assessment of amalgam and resin-based dental restorations. The research null hypothesis of this study was that direct clinical and indirect photographic assessment of the quality of amalgam and resin-based composite restorations presented similar performance.

MATERIALS AND METHODS

This study was conducted in permanent teeth of Caucasian adult patients in the city of Santiago, Chile. Approval and ethical permission were obtained from the Ethics Committee in the Dentistry Research Office of the Dental School at Chile University (UChile PRI-ODO-0207). The sample consisted of 89 restorations from 36 patients attending the Control Clinic of Operative Dentistry (maintenance) at the University of Chile. On arrival at the clinic, the purpose of the research and the procedures of the study were explained in detail to the patients, consent was requested for the photography and for a standard dental exam, and patients who accepted the conditions of the study signed an informed consent form.

Seven parameters, including color (only for resin-based restorations), occlusal marginal adaptation, anatomical form, roughness, occlusal marginal stain, luster, and secondary caries, were assessed in 89 Class I and Class II restorations (32 composite and 57 amalgam) from 36 adults using the modified US Public Health Service (USHPS)/Ryge criteria (Table 1). Inclusion criteria consisted of adult patients in good hygienic condition with Class I and Class II amalgam or resin-based composite restorations.

The clinical detection of secondary caries (Charlie) was made according to Ekstrand's criteria.[21] The photographic secondary caries detection criteria

Table 1: *Modified Ryge/USPHS Clinical Criteria (N/A = Not Applicable)*

Clinical Characteristics	Alpha	Bravo	Charlie
Color	The restoration matches in color and translucency to adjacent tooth structure	The mismatch in color and translucency is within the acceptable range of tooth color and translucency	The mismatch is outside the acceptable range of color and translucency
Marginal adaptation	Explorer does not catch or has one-way catch when drawn across the restoration/tooth interface	Explorer falls into crevice when drawn across the restoration/tooth interface	Dentin or base is exposed along the margin
Anatomic form	The general contour of the restoration follows the contour of the tooth	The general contour of the restoration does not follow the contour of the tooth	The restoration has an overhang
Surface roughness	The surface of the restoration has no surface defects	The surface of the restoration has minimal surface defects	The surface of the restoration has severe surface defects
Marginal staining	There is no discoloration between the restoration and tooth	There is discoloration on less than half of the circumferential margin	There is discoloration on more than half the circumferential margin
Secondary caries	There is no clinical diagnosis of caries	Not applicable	There is clinical diagnosis of caries
Luster of restoration	The restoration surface is shiny and has an enamel-like, translucent surface	The restoration surface is dull and somewhat opaque	The restoration surface is distinctly dull and opaque and is esthetically displeasing

were based on surface staining, surface irregularities, and loss of dental tissue in the margins of the restorations.

Direct intraoral clinical examination was carried out by two calibrated examiners (Cohen's Kappa 0.76). Each restoration was clinically examined independently at the beginning of the study for the parameters of color, marginal adaptation, anatomic form, surface roughness, occlusal marginal stain, luster, and secondary caries. The quality of the restorations was evaluated according to USPHS/Ryge criteria (Table 1), which states the use of an eye without any magnification device, only a dental mirror and an explorer, in a proper isolated field following the directions to assess every parameter.[22] If any difference was found between both examiners, a third calibrated examiner (Cohen's Kappa 0.76) established the final diagnosis.

Teeth were examined after drying with the air of a triple syringe, using the artificial light of the dental unit (Forest Dental Products Inc, Hillsboro, OR, USA). The instruments used for the exam were plain number 5 ss mirrors (Zirc Dental Products, 3918 Highway 55, Buffalo, MN, USA), explorer no. 54 SE (Hu Friedy, Chicago, IL, USA), and tongue depressors (Henry Shein Inc, Melville, NY, USA).

Photographic Method

Standardized photographs were taken of each restoration on the same day of the clinical exam using a digital single-lens reflex camera (Nikon-D100, Tokyo, Japan) with a 105-mm Microlens (AF-S 1:2.8 VR Nikkor Nikon G) and with a Macro Speed flash SB-29s (Nikon Inc, Melville, NY, USA). The quality of the photos was set on JPEG fine and 12.0 megapixels. Camera settings included manual operation mode, ISO 400, F-8, speed 80, color space RGB.

Photographs were taken by an expert clinical photographer, with the patients sitting on a dental chair and leaning back to avoid movements during focusing and photography. An assistant provided retraction of the cheek and lips. Saliva and food fragments were removed with air or sterilized gauze when necessary. Pictures were taken by focusing on the center of the restorations. The camera was placed perpendicular to the occlusal surface or tilted no more than 20° to the tooth plane to minimize mirror reflection and burnout of the picture. Each photograph was evaluated for acceptability and quality; if it was not acceptable, the photograph was repeated.

Pictures were saved on an Apple MacBook laptop MC516CI/A (Apple Inc, Cupertino, CA, USA), which was calibrated using the spectrophotometer Efi es-1000 (EFS Inc, Foster City, CA, USA). Subsequently, the pictures were randomly edited using the software Adobe Photoshop CS3 Extended v10.0 (Adobe Systems Inc, San Jose, CA, USA), creating four groups of images from each original photograph:

Group A: Formed by the original photograph displayed at 100% (IMG100), without modifications;

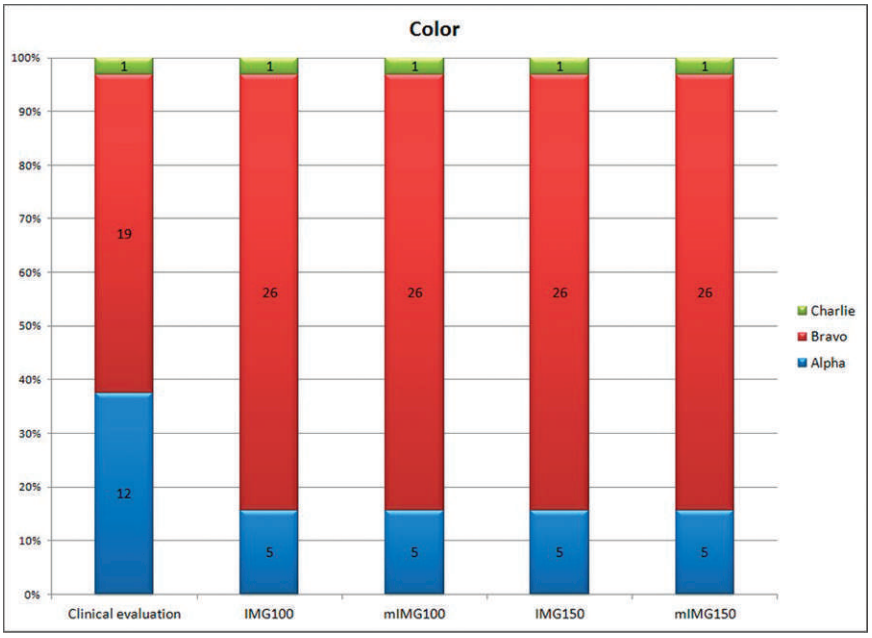

Figure 1. *Color observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

the photograph was cropped to leave the teeth and the restoration centered in the picture, using the following specifications: 866 × 630 pixels at a resolution of 100 pixels per inch (Figure 1).

Group B: Formed by images enlarged at 150% (IMG150), using the free transform tool from the editing command, without modifications (Figure 2).

Group C: Formed by digital photographs displayed at 100% (mIMG100), with digital modifications that included level adjustments, shadow and highlight correction, color balance, and unsharp mask (Table 2; Figure 3).

Group D: Formed by enlarged photographs displayed at 150% (mIMG150) with modifications; the same adjustments that were made to Group C were made in this group (Figure 4).

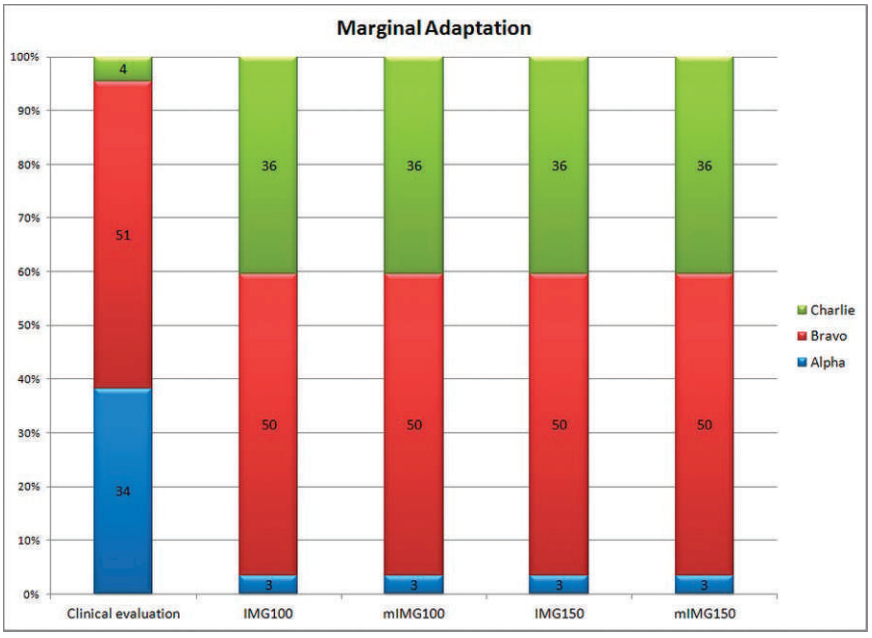

Figure 2. *Marginal adaptation observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

Table 2: *Digital Parameters Corrections Applied to Photograph of Groups C and D*

	Shadow Adjustment	Highlights Adjustment
Amount	50% ± 10%	Between 0% and 10%
Tonal width	50%	50%
Radius	30 pixels	30 pixels

Photographs in Groups C and D were obtained by the digital manipulation of IMG100 and IMG150 using the following four tools:

Levels Adjustment: Correction of tonal distribution of each photograph, using the command Image/adjustments/levels in the red, green, and blue channel, adjusting the histogram and bringing the image to a normal or Gaussian distribution.

Shadows, Highlights Adjustment: These were corrected separately without affecting the midtones optimized in the previous step. All images were stored in JPEG format.

Color Balance: The command image/adjustments/color balance was used to approximate the natural color image of the photographed structures using the gingival color as a reference.

Unsharp Mask Filter: To enhance the detail of important areas of the images, the unsharp mask filter was applied with the following values: amount: 100%-–170%; radius: 1.6 ± 0.5; threshold: 0.

Each photograph was assessed and scored independently by two calibrated examiners (Kappa = 0.76) with the same criteria used in the clinical method. Disagreements between examiners were solved by a similar system used in clinical detection.

Data Analysis

The results of all assessments (clinical, IMG100, mIMG100, IMG150, and mMG150) were compared to the differences detected using the nonparametric Friedman test. Additionally, to determine whether the enlargement of the image influenced the results of the evaluation, images at 100% (IMG100 and IMG100m) were compared to images at 150% (IMG150 and IMG150m). Furthermore, to evaluate the influence of image manipulation, edited images (mIMG150 and mIMG100) were compared to non-edited (IMG100, IMG150) images using the non-parametric Wilcoxon test. In all tests, the level of confidence was set at $p = 0.05$, and calculations were performed using the SSPS 11.5 software package (SPSS Inc, Chicago, IL, USA).

RESULTS

Seven parameters were evaluated with clinical photographic methods in 36 patients (mean age 26.7 years) with 89 posterior dental restorations, both Class I (n=51) and Class II (n=38); (32 composite and 57 amalgam). Only composite-based resin restorations were evaluated for color.

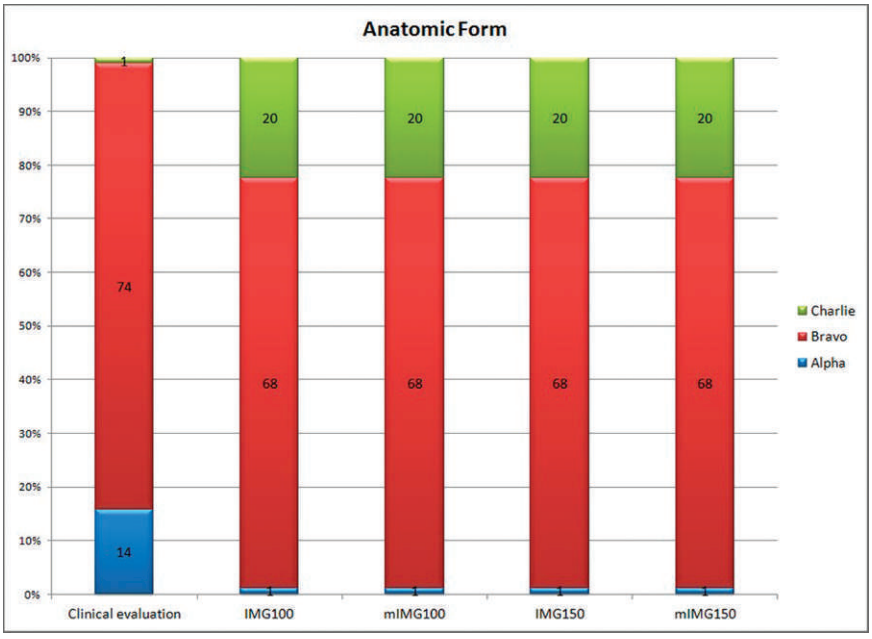

Figure 3. *Anatomic form observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

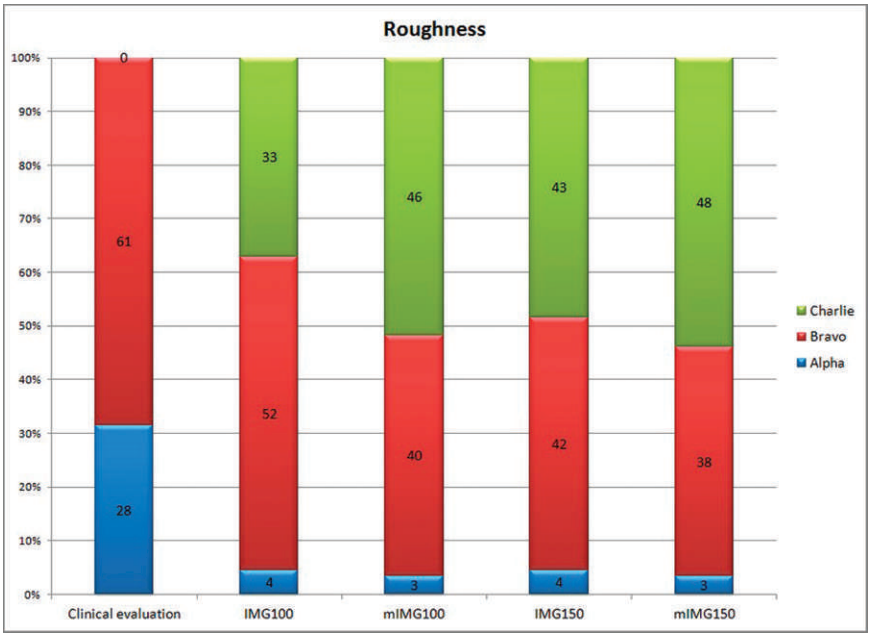

Figure 4. *Surface roughness observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

In general, the present study revealed a moderate agreement between clinical and photographic assessment methods for dental restorations.

The evaluation of digital images appeared to be more consistent with clinical assessment when the restorations were in acceptable condition with one or more defective parameters (Bravo), but the results of these methods were less consistent when the restorations were clinically classified to be in excellent condition (Alpha) or in cases of severely deficient restorations (Charlie).

In the evaluation of restoration color, the resin-based composite restorations were judged to be more acceptable when they were clinically evaluated ($p<0.05$). There were no statistically significant differences among the four groups of images (Figure 1).

Image examination resulted in a greater number of restorations that were judged as Charlie and fewer Alpha values when compared to clinical examination for the parameters marginal adaptation, anatomic form, and marginal staining ($p<0.05$). Among the groups of images, there was no difference observed when either enlargement or manipulation was applied (Figures 2, 3, and 5).

When roughness was evaluated, the image evaluation presented an increase of observed Charlie values and a decrease in Alpha and Bravo values when compared to the results of clinical examination ($p<0.05$). Among the groups of images, IMG150, IMG100m, and IMG150m revealed more restorations that were assessed as Charlie and fewer that were judged as Bravo than the IMG100 group ($p<0.05$). When comparing the five groups all together, the restorations evaluated on the images were considered to be more degraded than their clinical counterparts ($p<0.05$; Figure 4).

Luster assessment showed a similar trend; that is, restorations were judged to be in worse condition when images were evaluated ($p<0.05$). They showed an increase in Bravo and a decrease in Alpha values when compared to clinical examination ($p<0.05$). Among the groups of images, there was no difference when either enlargement or manipulation was analyzed (Figure 6). Some examples of photographic evaluation are included in Table 3.

When photographs were used to detect secondary caries, in all groups, an increase in the number of reported Charlie values was observed relative to the results obtained by direct clinical detection in which no caries lesions were detected. Statistically significant differences were observed for groups IMG100m, IMG150, and IMG150m ($p<0.05$). Those patients were clinically examined again, and no caries lesions were clinically observed.

DISCUSSION

Dental photography is a simple and inexpensive imaging method that does not involve ionizing radiation or discomfort. The use of photographs to

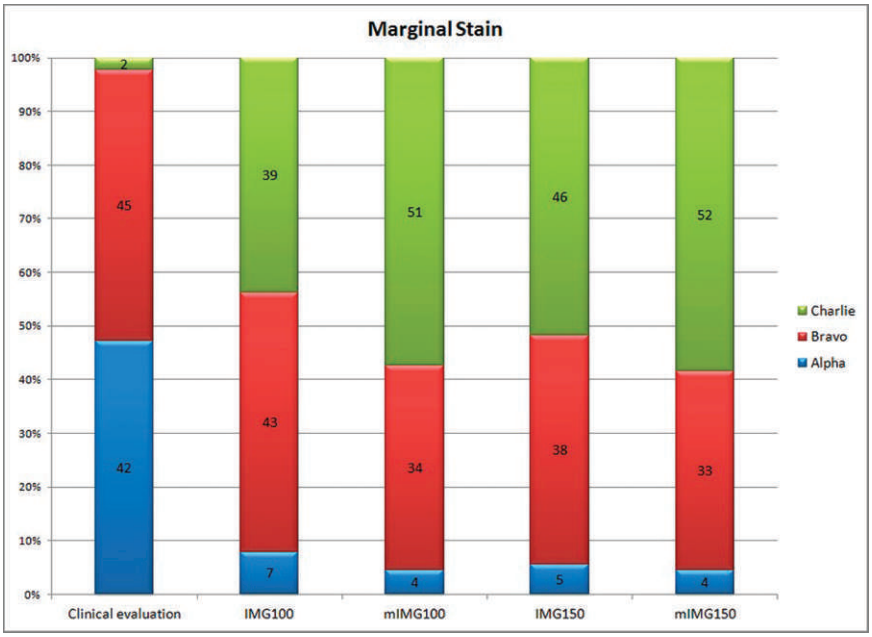

Figure 5. *Marginal stain observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

evaluate restorations is based on the belief that by standardizing the gathering and the processing of photographs, it would be possible to develop a reliable method suitable for use in operative dentistry. Although photography is not used routinely as a method of restoration evaluation, it appears to be a promising control and diagnostic tool in operative dentistry treatments.

Some of the important advantages of using photographic images as an indirect detection method include the fact that it allows for more evaluation time, in stable conditions, which is not always possible in a direct clinical examination.[15] Furthermore, well-composed images that are reviewed on a large monitor away from the treatment room's extraoral and intraoral distractions can ensure that

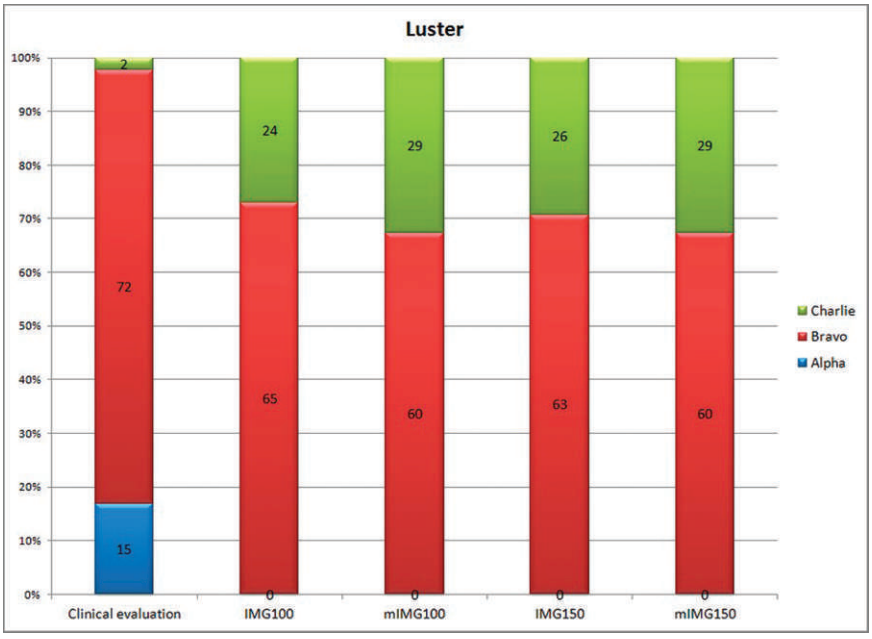

Figure 6. *Luster observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

Table 3: *Images Evaluation, by USPHS/Ryge Criteria, of Amalgam and Resin-Based Composite Restorations, Separated by Parameters (N/A = Not Applicable)*

	Amalgam Restorations					Composite Restorations				
	Figure 8 (Group A)	Figure 9 (Group B)	Figure 10 (Group C)	Figure 11 (Group D)	Clinical Evaluation	Figure 12 (Group A)	Figure 13 (Group B)	Figure 14 (Group C)	Figure 15 (Group D)	Clinical Evaluation
Color	N/A	N/A	N/A	N/A	N/A	Alpha	Bravo	Bravo	Bravo	Alpha
Marginal adaptation	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo
Anatomic form	Alpha	Bravo	Alpha	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo
Surface roughness	Bravo	Charlie	Charlie	Charlie	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo
Marginal stain	Bravo	Bravo	Charlie	Charlie	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo
Luster	Bravo	Charlie	Bravo	Charlie	Bravo	Bravo	Bravo	Bravo	Bravo	Bravo
Secondary caries	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha

an accurate diagnosis is formulated.[8] Other studies that focused on the detection of developing enamel defects have shown the same trend observed in the current study, concluding that photographic methods were more sensitive than direct clinical examination in permanent teeth.[23]

In addition, the advent of image editing software, such as Adobe Photoshop, has made it possible to manipulate images to either correct or enhance them. This study applied both enlargement and photo correction. Enlargement is performed by interpolation using algorithms to obtain a larger image, whereas correction is applied to bring an image back to its intended brightness, contrast, and color.

Concerning enlargement, it might be claimed that this process can cause image deterioration, altering the perceived status of the restoration. However, this concern is alleviated by capturing images with a high quality and quantity of pixels, recording as much detail as possible at the outset. This way, enlargement can be considered to be a valuable tool for assessing the status of restorations over time at a size that is larger than the real object, revealing

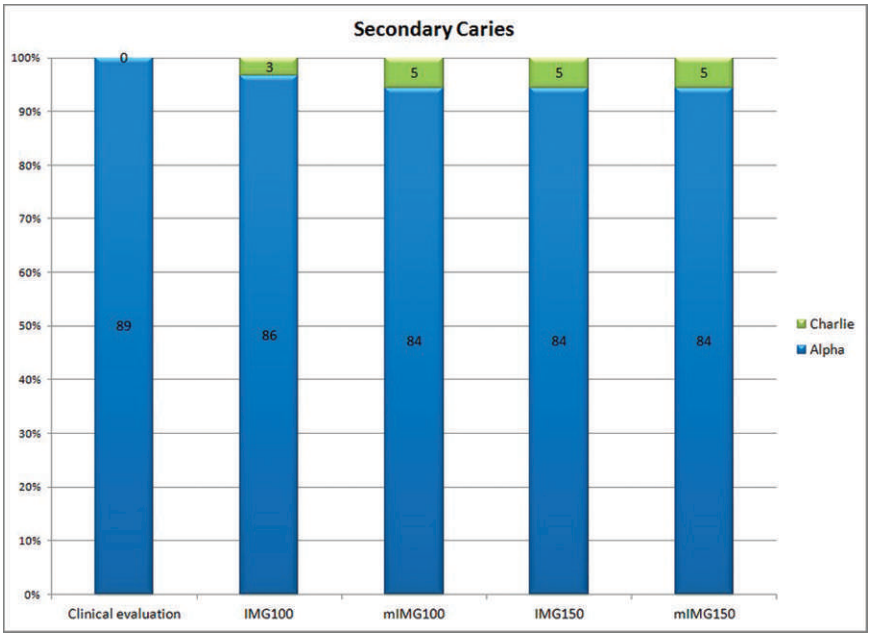

Figure 7. *Secondary caries observations separated by groups and quality evaluation expressed as a percentage of USPHS/Ryge criteria.*

Figure 8. *Group A: The original photograph of amalgam restoration displayed at 100%, without modifications (IMG100).*

Figure 10. *Group C: Digital photographs of amalgam restoration displayed at 100% (mIMG100), with digital modifications.*

information that usually goes unnoticed.[15] In fact, in this study, enlargement increased the number of restorations that were judged to be unsatisfactory when compared to the results of clinical evaluation.

With regard to photo correction, it is important to remember that dental images are dento-legal documents. Therefore, manipulation should be kept to a minimum, ensuring that the original image is not altered to an extent that it hides pathology or alters the clinical situation to camouflage what was present in the oral cavity.[15] In the current study, correction did not alter the results of evaluation when compared to the original image (IMG100), except for the parameters of roughness and secondary caries. In other words, an image of good quality at 100% of its pixels would be enough to evaluate the quality of restorations. Nevertheless, it must be noted that a picture is a two-dimensional representation of a three-dimensional structure; therefore, photos should be used only in an indirect or complementary evaluation method.[24]

The results of this study indicate that more problems were detected in restorations when they were evaluated by means of images than by clinical examination, agreeing with the results of the study by Smales;[6] thus, the use of digital imaging resulted in a significant increase in the number of restorations that received Bravo and Charlie values. These results suggest that the clinician should consider the differences between both methods of evaluation and relate them to treatment decisions.

Regrettably, no previous study has compared these two methods of assessing the quality of dental

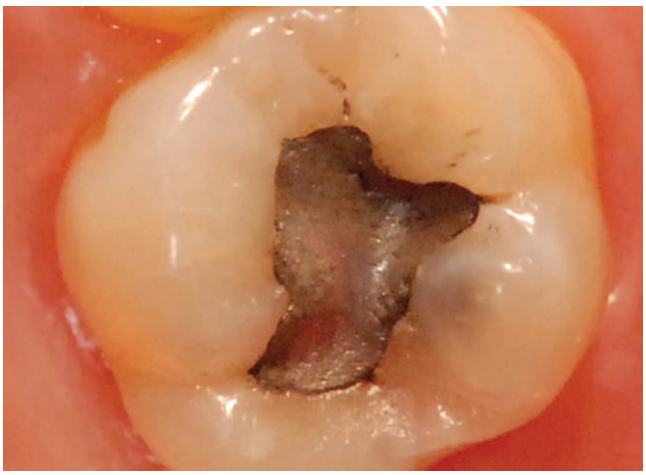

Figure 9. *Group B: Images of amalgam restoration enlarged at 150% (IMG150).*

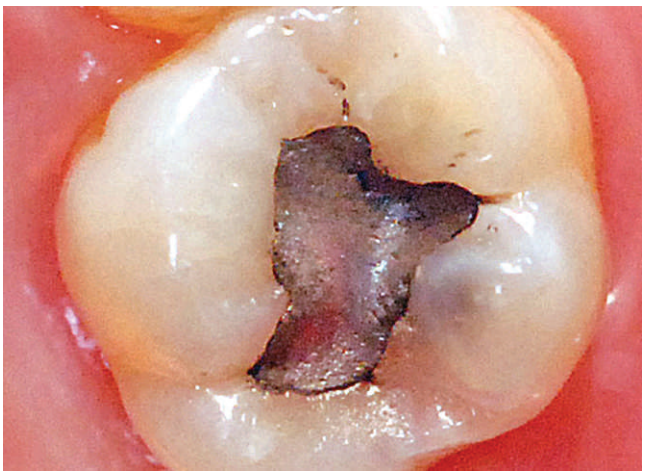

Figure 11. *Group D: Enlarged photographs of amalgam restoration displayed at 150%, with modifications (mIMG150).*

Figure 12. *Group A: The original photograph of resin-based composite restoration, displayed at 100%, without modifications (IMG100).*

Figure 14. *Group C: Digital photographs of resin-based composite restoration, displayed at 100% (mIMG100), with digital modifications.*

restorations. The present study used a powerful digital camera, well equipped with accessories and settings that allowed the photographer to easily zoom and focus to obtain the best possible pictures of the restorations. These images allowed the examiners to view the photographs at different conditions without the technical problems that might be encountered when using nondigital photos. Additionally, the photographic method provided permanent records of the restorations and the teeth, with less bias than other methods; photography also accelerated the time of the clinical exam, as it did not include laboratory processing, and there was no need to consider the possibility of cross infection.[25]

When evaluating color, the teeth were subjected to different lighting conditions: the flash of the camera during the photography and the light source of the dental unit in the clinic, which may generate the phenomenon of metamerism.[26,27] Also, when marginal adaptation was evaluated, the clinical approach has the advantage of probing with an explorer in addition to visual assessment.

Concerning luster, the restorations were judged to be duller (matte) when assessed photographically; in fact, in this evaluation, there were no restorations that received Alpha values for this parameter. According to Ahmad,[28] this may be due to the use of a circular flash unit, which has a uniform light output, creating an image devoid of shadows, which appears flat, smooth, and dull.

Importantly, through the evaluation of images without amplification (IMG 100), some defects that

Figure 13. *Group B: Images of resin-based composite restoration, enlarged at 150% (IMG150).*

Figure 15. *Group D: Enlarged photographs of resin-based composite restoration, displayed at 150%, with modifications (mIMG150).*

went unnoticed clinically were detected, especially for the parameters of marginal adaptation, anatomic form, roughness, and staining of margins. However, it is not possible to establish whether this situation corresponds to overdetection or whether it constitutes evidence that the evaluation of images definitely allows for the detection of defects that can remain unseen clinically, in this way revealing the limitations of clinical evaluation.

The comparison between groups for the evaluation of secondary caries demonstrated that all photographic groups showed a significant overdetection compared with clinical detection. Additionally, in the photographic groups, there were no observed differences between the magnified, modified, or unaltered pictures. In light of these results, patients were clinically examined again, and marginal caries lesions were not detected. This discrepancy is significant, as it suggests that photographic methods may promote unnecessary dental overtreatment, especially in populations with low caries risk. It must be stressed that photographic detection of secondary caries presents a huge disadvantage, as it is not possible to probe dental tissue hardness; therefore, it provides only limited information for this parameter.

For many years, professionals in the field of operative dentistry have known that dental restorations present a limited range of life, representing an important concern for the patients, institutions and clinicians involved. The early detection of localized restoration defects could facilitate the repair of such restorations instead of replacement.[29-32] "Using photographs as a way to store visual information after finishing dental restorations can help the clinician for monitoring its ageing throughout time. This method allows for implementing proper maintenance measures to improve restoration longevity.[33,34] It is useful for determining the mean life of restorations and for providing basic information for long-term studies and teaching.

Examiners of the current study reported that photography, as a complementary exam tool, provides additional information when they were in doubt, allowing them to make better decisions.

CONCLUSIONS

Digital photography is a useful tool for assessing the status of restorations, providing information that goes unnoticed with the visual-tactile clinical examination method. But this information can lead to unnecessary overtreatment.

When analyzing restorations using the Ryge modified criteria, the digital photography method reveals a significant increase in the number of detected defects. The digital photography method by itself, without the need for enlargement or correction, provides more information than clinical examination.

Finally, the evaluation of digital images is more consistent with clinical assessment when the restorations have some moderate defect (Bravo) and are less consistent when the restorations are clinically classified as either satisfactory (Alpha) or in cases of severely deficient restorations (Charlie). This is the first study that provides information of the comparison between clinical assessment and photographic evaluation of dental restorations under USPHS/ Ryge modified criteria.

Conflict of Interest
The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.
Study ascribed to research project UChile-PRI-ODO-0207.

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