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CLINICAL RESEARCH

Accuracy of digital and conventional systems in locating occlusal contacts: A clinical study

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ABSTRACT

Statement of problem. The accuracy of methods used for locating occlusal contacts throughout the entire clinical procedure has been poorly studied.

Purpose. The purpose of this clinical study was to determine the reproducibility and criterion validity for different methods of locating occlusal contacts.

Material and methods. Thirty-two adults with natural dentitions participated in this cross-sectional test-retest study. In total, occlusal contacts at maximum intercuspation were recorded by using 15 methods: silicone transillumination with Occlufast Rock (40, 50, 100, and 200 μm) and Occlufast CAD (40 and 50 μm); virtual occlusion (100, 200, 300, and 400 μm); articulating film (12-, 40-, 100-, and 200-μm-thick); and T-Scan III. Images of the occlusal records were scaled and calibrated spatially, and the occlusal contacts of the right posterior mandibular teeth were delimited by using the FIJI software program. Reproducibility was expressed as 95% confidence intervals (95% CI) of the percentage of agreement in the location of the occlusal contacts between images from the test sessions against retest sessions using the same method. Criterion validity was expressed as 95% CI of the percentage of agreement in the location of the occlusal contacts between images from the test sessions against images from Occlufast Rock (criterion standard).

Results. Occlufast Rock achieved 85% to 95% agreement in the location of the occlusal contacts between the 2 sessions, whereas Occlufast CAD, 200-μm articulating film, and T-Scan offered 79% to 86%, 68% to 75%, and 65% to 75% agreement, respectively. The most valid method was Occlufast CAD (74% to 80%) followed by the 200-μm articulating film (57% to 63%), 400-μm virtual occlusion (53% to 62%), 100-μm articulating film (52% to 60%), and T-Scan (48% to 56%).

Conclusions. Conventional methods, such as 100- and 200-μm articulating film and digital methods, including 400 μm virtual occlusion and T-Scan, offer sufficient accuracy in locating the occlusal contacts. However, strategies are needed to improve accuracy. (J Prosthet Dent 2024;132:115-122)

Mastication is the main function of the oral system, with occlusal force and dental occlusion key factors.[1-3] Clinical practice often requires modifications to the dental occlusion for restorative or prosthetic treatment.[4,5] Although most patients adapt to their new occlusion easily, a few can develop discomfort and even pain, especially in the presence of an occlusal interference.[6] Therefore, occlusion analysis systems should meet minimal accuracy standards to detect, quantify, and locate occlusal contacts.

Articulating film has been the most widely used system because it is economical, available in different thicknesses, and allows rapid location of occlusal contacts.[7-9] However, silicone occlusal registration, scanned with a light source and analyzed

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Clinical Implications

The accuracy of occlusal contact location depends mainly on the occlusal system and interocclusal distances used. Although these methods are clinically acceptable, the accuracy of conventional methods can be improved with new protocols for clinical and interpretation procedures, while digital methods could benefit from improved software programs.

by using an image software program, has been reported to offer the highest reliability and validity for determining the occlusal contact area (OCA)[10-14] and has been claimed to be the criterion standard method.[12] Recently introduced digital systems, including the T-Scan and digital casts, have also become available for occlusal assessment.[15-17]

Static occlusal analysis comprises 3 steps. First, the patient closes in the maximum intercuspation position while an articulation indicator, a silicone material, or a sensor is placed in this position or scans are made with an intraoral scanner. Second, the dentist interprets the occlusal records by examining the marks intraorally or with a software program. Third, the occlusal record can be stored and transferred. However, each step can introduce variability and error that affects the results. Although studies have assessed the reliability and validity of different occlusal methods,[7,18-24] few have analyzed all steps.[10,12]

Most researchers have focused on the number of occlusal contacts and the OCA,[10,12,20] whereas the location of those contacts is often more relevant in clinical practice.[9,18,19,25-27] The reliability or reproducibility, concerning the extent to which scores remain unchanged over time, are key to the accuracy of an occlusal method.[28] Criterion validity, defined as how well location with a given method agrees with that for the criterion standard, is also useful.[28] Unfortunately, reports on the accuracy of methods for locating occlusal contacts throughout the entire clinical procedure are sparse.

The purpose of this clinical study was to determine the criterion validity of different digital and nondigital occlusal methods for locating occlusal contacts by using the Occlufast Rock transillumination system for reference. The reproducibility of different occlusal methods in locating the occlusal contacts was also assessed. The null hypothesis was that different methods would have similar criterion validity for locating occlusal contacts.

MATERIAL AND METHODS

This cross-sectional test-retest study recruited 35 adult predoctoral dental students with a minimum of 24 natural teeth, without edentulous spaces. Those with dental prostheses, extensive restorations, severe malocclusion, periodontal disease, excessive tooth wear, orofacial pain, or active orthodontic treatment were excluded. All participants were fully informed and signed the written informed consent form before participating in the study. The Ethics Committee of Barcelona University Dental Hospital approved the informed consent form and the study protocol (Ref. 11/2020). All procedures were conducted in accordance with the principles of the Helsinki Declaration, and the study was reported in accordance with the strengthening the reporting of observational studies in epidemiology (STROBE) guidelines.

A single operator (B.R.-L.), with more than 10 years of clinical experience, performed all clinical procedures with participants seated in a dental chair at the 90-degree position with their Frankfort plane parallel to the floor. The participant's age and sex were recorded, and the distance between the most distal points of the mandibular canines was measured with digital calipers (Absolute; Vogel) to calibrate the scale for image processing. The operator ensured the occlusal surfaces had no debris before performing the occlusal recordings with 8 different systems in a random order determined with permuted blocks established with a web-based software program (http://www.randomization.com). Half of the participants were assigned to 1 of the 2 sequences and rested for 2 minutes between occlusal records to avoid muscle fatigue. To determine the reliability of the occlusal methods, all occlusal records were repeated once for each participant in a retest session, following the same sequence and at the same time of day, 2 weeks after the test session.

In system Occlufast Rock, a polyvinyl siloxane occlusal registration material (Occlufast Rock; Zhermack) was applied to the occlusal surfaces of the mandibular teeth. Participants were asked to occlude with maximum force at the maximum intercuspation position for 1 minute. System Occlufast CAD was comparable with system Occlufast Rock but used a scannable polyvinyl siloxane material (Occlufast CAD; Zhermack). Both occlusal registrations were trimmed and scanned by using the transparent materials adapter of a flatbed scanner (HP Scanjet G4050; Hewlett Packard).

For systems Articulating Film 12, 40, 100, and 200 μm, the participants were asked to close their mouth firmly 3 times while the operator placed 12-μm (Black and Red, Arti-Fol Metallic Shimstock-Film; Bausch), 40-μm (Blue, Arti-Check Micron-Thin; Bausch), 100-μm (Blue, Progress 100 μm; Bausch), or 200-μm (Blue, Articulating Paper BK01; Bausch) articulating film on each hemiarch held by 2 Miller forceps (Forceps f. articulating paper Miller; Carl Martin). Before placing the films, cheek retractors (Spandex; Hager Worldwide) were inserted, saliva was suctioned with a standard saliva ejector (Monoart; Euronda), and the occlusal surfaces were air dried with an air-syringe. After removing

the film, the marks on the assessed mandibular arch were scanned (TRIOS 3; 3Shape A/S). Before every occlusal test, the teeth were cleaned with a cotton roll and nylon brush (Proclinic; Stoddard Manufacturing Co) to remove any occlusal marks.

System T-Scan used an occlusal analysis system (T-Scan III; Tekscan, Inc) to obtain occlusal records. Participants were instructed to close in the maximum intercuspation position with maximum force on a 100-μm sensor foil. The software program (T-Scan 10.0.28; Tekscan, Inc) generated a dynamic report showing the relative occlusal force detected for each sensor. System Virtual Occlusion involved the intraoral scanning (TRIOS 3; 3Shape A/S) of all teeth in the maxillary and mandibular arches, together with the intermaxillary relationship when the teeth closed in the maximum intercuspation position.

For each participant, 1 image of the mandibular arch from each system was captured and saved in Joint Photographic Experts Group (JPEG) format (Fig. 1). For the T-Scan system, an image was captured from the dynamic record of the mandibular arch at maximum intercuspation. For the virtual occlusion system, 4 images of the mandibular occlusal contacts were captured at interocclusal distances of 100, 200, 300, and 400 μm (Fig. 1). Each color image was calibrated spatially and by scale with a reference image for articulating film or virtual occlusion in the FIJI software program (ImageJ; National Institutes of Health) (Supplemental Fig. 1 and Supplemental Video 1, available online). The reference image was first scale-calibrated with the known intercanine distances by using the FIJI software program, before selecting and saving the occlusal perimeter of the premolars and first to molars on the right in regions of interest (ROI) format. All color images were transformed by using multiple points of equivalence on the scale-calibrated reference image with the "transform" plugin, applying a similarity class transformation with the least squares transformation method. The selected occlusal perimeter (ROI file) was applied to the transformed image, cleaned, and saved as a spatially calibrated color image.

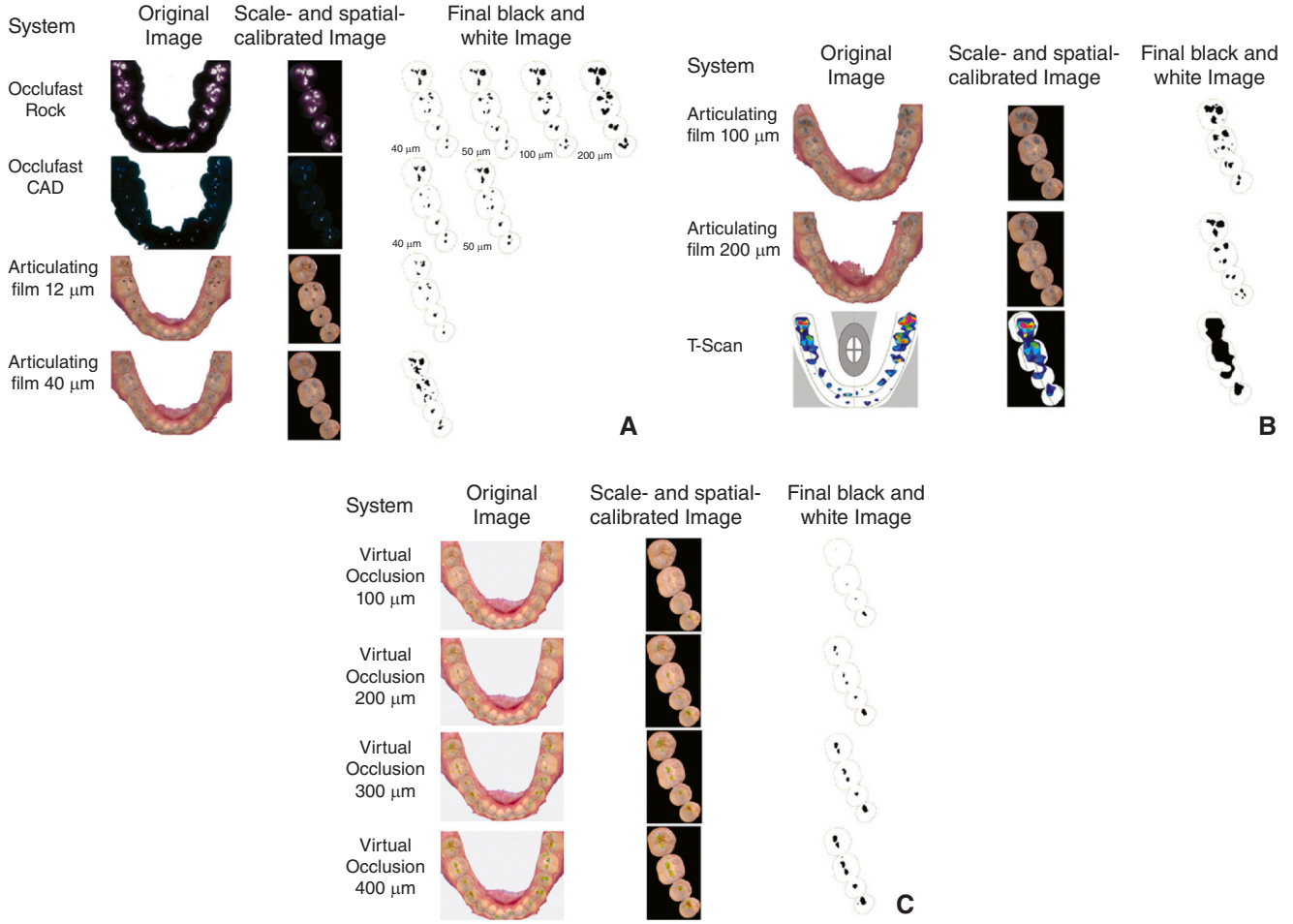

Figure 1. Image processing for occlusal records. A, Systems Occlufast Rock and Occlufast-CAD, Articulating film 12 and 40 μm. B, Systems Articulating Film 100 and 200 μm, and T-Scan. C, System Virtual Occlusion. CAD, computer-aided design.

Supplementary material related to this article can be found online at doi:10.1016/j.prosdent.2023.06.036.

Each color image was then converted to a grayscale 8-bit format showing the occlusal contacts as black marks (Supplemental Fig. 2, available online). Occlufast Rock images were converted to 8-bits and applied threshold values of gray levels of 183, 174, 146, and 111 to generate images with contact areas at interocclusal distances of 40, 50, 100, and 200 μm. The Occlufast CAD images were converted to 8-bit images and threshold values of gray levels of 38 and 31 were applied to obtain images with contact areas at interocclusal distances of 40 and 50 μm, respectively. These interocclusal distances were selected to be comparable with the 40-, 100-, and 200-μm articulating films and T-scan. These threshold values for both silicone materials were determined by using stepped wedges to establish the relationship between the 256-grayscale and the silicone thickness.[2] Images from the 12-μm articulating film were converted to 8-bits with a threshold value of gray levels of 105. The blue articulating marks of the 40-, 100-, and 200-μm articulating film were converted to grayscale by using the color threshold and the Commission Internationale de l'Eclairage (CIE)Lab color space with threshold values of 1 to 255, 0 to 255, and 0 to 130 for L*; a*, and b*. Color on the T-Scan images was also converted by using the color threshold, but with the hue–saturation–brightness (HSB) color space, and threshold values of 112 to 255, 71 to 255, and 0 to 255 for hue, saturation, and brightness. Pixels representing occlusal contact in the virtual records were converted to black by using the color threshold and CIELab color space with threshold values of 100 to 246, 0 to 137, and 163 to 248 for L*, a*, and b*. When converting the colored and spatially calibrated images to grayscale, the same colored and spatially calibrated image was added as an overlay with 90% transparency to correct the occlusal mark boundaries with the FIJI brush options if needed.

The OCAs on the grayscale images were measured in mm^2. The percentages of false-negative and false-positive contact areas were calculated for each method by considering the Occlufast Rock as the criterion standard (Fig. 2). Transillumination methods with silicone-based material showed the highest accuracy in determining the occlusal contact area.[10-14] To calculate the percentage of false-negative, the grayscale image of a test method was overlaid with the grayscale image of the criterion standard as a reference. The number of black pixels in the reference image paired with white pixels in the test image divided by the number of black pixels in either image was the fraction of false negative, which was multiplied by 100 to calculate the percentage of false negative. Similarly, the number of black pixels in the test image paired with white pixels in the reference image divided by the number of black pixels in either image was the fraction of false positive, which

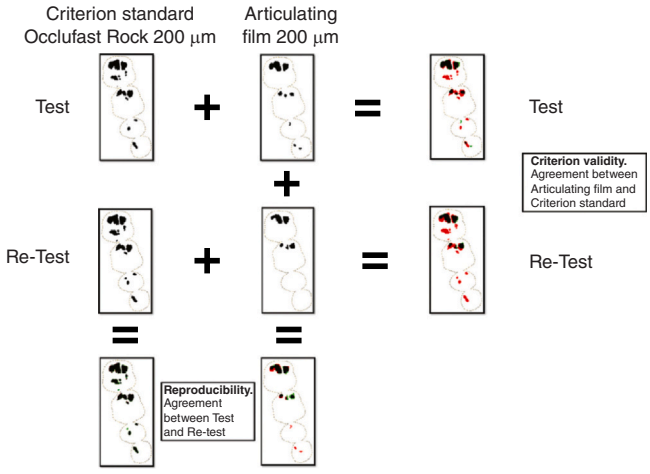

Figure 2. False negatives, false positives, and agreement in occlusal contact location between images. *Red:* Occlusal contact area (OCA) only in reference/template image (false negatives). *Green*: OCA only in test/source image (false positives). *Black*: Coincident OCA between images (true positives). Occlusal total contact area=*red+green+black*. OCA reference=*red+black*. Occlusal contact area test=*green+black*. False negatives (%)={[(total area)–(test area)]×100}÷(Reference area). False positives (%)={[(Total area)–(Reference area)]×100}÷(Test area). Agreement (%)=100–[(false negatives)+(false positives)]÷2.

was multiplied by 100 to calculate the percentage of false positive (Fig. 2). The percentage of agreement in occlusal contact location was assessed as 100 minus the average between the false-negative and false-positive percentages for the method. The higher the percentage of agreement, the better the criterion validity of the method in locating occlusal contact compared with the criterion standard. Finally, each occlusal record obtained in the retest session was calibrated (spatial and for scale) against the registration obtained in the original test for a given method, calculating the percentages of false negatives, false positives, and location agreement for occlusal contacts between test and retest. The reproducibility of each method in locating occlusal contact was expressed as the percentage of agreement between test and retest images. Image processing and data analysis from the test and retest sessions were performed by a single researcher (J.M.-G.) with over 20 years of clinical experience. To assess the inter-rater reliability of the image processing and interpretation of occlusal contact area, another researcher (B.R.-L.) measured the OCA, percentage agreement against the criterion standard, and percentage agreement between Occlufast Rock test and retest sessions for 19 participants.

Test-retest reliability for the OCA was assessed by the intraclass correlation coefficient (ICC) for single measurements, with a 2-way random effects model and absolute agreement.[29] The inter-rater reliability only in the image processing and occlusal interpretation parts of

the measurement process were also tested by using the ICC for the OCA, for the percentage agreement against the criterion standard, and for the percentage agreement between Occlufast Rock sessions.[29] A mean test-retest value was calculated for the OCA, agreement in occlusal contact location, and comparison of the different techniques. All analyses were performed with a statistical software program (IBM SPSS Statistics, v27; IBM Corp) (α=.05).

RESULTS

Among the 35 individuals examined, 3 were excluded (1 woman had an interim restoration in the mandibular right first molar, and 2 women had poor quality images because of stitching defects in the virtual casts). The 32 remaining participants (25 women and 7 men) had a mean age of 24.5 years (95% confidence interval, 23.1 to 25.9) and a mean of 28.5 teeth (standard deviation, 1.4; range, 25 to 32), and most had bilateral Angle class I occlusion (n=20). Three participants in the test session and 3 more in the retest session had at least 1 virtual occlusion record without an occlusal mark.

Table 1 shows the OCAs for each system and interocclusal distance. Average contact areas in the right mandibular posterior teeth ranged from 4 mm^2 with virtual occlusion (100 µm) to 79 mm^2 with the T-Scan. The test-retest reliability of the Occlufast Rock was excellent for measuring the OCA, whereas the T-Scan, Occlufast CAD, and articulating films (40- and 100-µm-thick) offered good reliability (Table 1). Occlufast Rock and CAD, virtual occlusion, and T-Scan were rated as having excellent inter-rater reliability (ICC>0.9) for measuring the OCA, whereas the reliability of articulating films was good (ICC, 0.75 to 0.90).

The percentage of false negatives, false positives, and agreement in occlusal contact location with different occlusal methods and Occlufast Rock as the criterion standard are shown in Table 2. Occlufast CAD showed the lowest percentages of false-negative and false-positive occlusal contacts (18% to 30%) compared with similar interocclusal distances obtained by Occlufast Rock. Among the nontransillumination methods, only 400-µm virtual occlusion and 200-µm articulating film provided false negatives and positives below 50% compared with the Occlufast Rock at 200 and 100 µm. The highest agreement was found with Occlufast CAD, followed by the 200-µm articulating film, 400-µm virtual occlusion, 100-µm articulating film, T-Scan, 300-µm virtual occlusion, and 40-µm articulating film (Table 2). Inter-rater reliability of percentage of agreement against the criterion standard were excellent for T-Scan and for virtual occlusion, good for articulating film, and poor to moderate for Occlufast CAD.

Table 3 shows the percentages of false negatives, false positives, and agreement in occlusal contact location for each method between test and retest sessions. Transillumination with Occlufast Rock achieved agreement of 85% to 95% in occlusal contact location between sessions, whereas Occlufast CAD, 200-µm articulating film, and 400-µm virtual occlusion offered agreements of 79% to 86%, 68% to 75%, and 56% to 74%, respectively. Occlufast Rock was rated to have excellent interrater reliability (ICC>0.9) for measuring the percentage of agreement between sessions by the same method.

DISCUSSION

The accuracy of occlusal contact location was found to depend mainly on the occlusal system and interocclusal

Table 1. Mean occlusal contact areas of right posterior mandibular teeth by method and thickness or interocclusal distances with test-retest and interrater reliability of methods used to measure occlusal contact areas

Method	Occlusal Contact Area		
	Mean (mm^2) (95%CI)	Test-Retest Reliability ICC (95%CI)	Inter-rater Reliability ICC (95%CI)
Occlufast Rock 40 µm	13.5 (10.7-16.3)	0.92 (0.84-0.96)	0.99 (0.98-1.00)
Occlufast Rock 50 µm	15.1 (12.0-18.1)	0.94 (0.88-0.97)	0.99 (0.98-1.00)
Occlufast Rock 100 µm	21.1 (17.1-25.1)	0.98 (0.96-0.99)	0.99 (0.98-1.00)
Occlufast Rock 200 µm	35.6 (30.0-41.3)	0.98 (0.96-0.99)	0.99 (0.98-1.00)
Occlufast CAD 40 µm	12.4 (10.0-14.7)	0.76 (0.54-0.88)	0.99 (0.97-1.00)
Occlufast CAD 50 µm	14.8 (12.0-17.6)	0.79 (0.61-0.89)	0.99 (0.96-0.99)
Virtual Occlusion 100 µm	4.0 (2.6-5.4)	0.33 (−0.02 to 0.61)	1.00 (0.99-1.00)
Virtual Occlusion 200 µm	12.7 (9.3-16.1)	0.55 (0.25-0.75)	1.00 (0.99-1.00)
Virtual Occlusion 300 µm	23.7 (18.6-28.9)	0.55 (0.25-0.75)	1.00 (0.99-1.00)
Virtual Occlusion 400 µm	37.0 (30.3-43.7)	0.55 (0.25-0.75)	1.00 (0.99-1.00)
Articulating film 12 µm	7.4 (5.9-8.8)	0.72 (0.50-0.58)	0.82 (0.43-0.94)
Articulating film 40 µm	18.7 (15.4-22.0)	0.83 (0.67-0.91)	0.77 (0.24-0.92)
Articulating film 100 µm	23.1 (19.3-26.9)	0.78 (0.60-0.89)	0.78 (−0.03 to 0.94)
Articulating film 200 µm	23.1 (19.5-26.8)	0.63 (0.38-0.80)	0.84 (0.14-0.96)
T-Scan	79.4 (65.7-93.2)	0.88 (0.75-0.94)	0.99 (0.96-0.99)

95%CI, 95% confidence interval; ICC, intraclass correlation coefficient.

Table 2. Percentages of false negatives, false positives, and agreement with criterion standard for occlusal contact location of different occlusal systems by thickness and interocclusal distance

	Occlufast Rock 40 µm			Occlufast Rock 50 µm		
Measurement Method	**% of False-Negative Contact Area**	**% of False-Positive Contact Area**	**% of Agreement With Standard**	**% of False-Negative Contact Area**	**% of False-Positive Contact Area**	**% of Agreement With Standard**
Occlufast CAD						
40 µm	25.6 (21-30)	21.7 (18-26)	76.4 (73-80)	30.3 (26-35)	17.8 (14-22)	75.9 (73-79)
50 µm	18.2 (14-22)	27.7 (24-32)	77.1 (74-80)	22.3 (18-26)	23.0 (19-27)	77.3 (74-80)
Virtual occlusion						
100 µm	84.9 (80-90)	59.9 (54-66)	26.2 (21-31)	85.6 (81-91)	56.1 (50-62)	27.6 (23-32)
200 µm	65.7 (58-73)	65.5 (60-71)	34.2 (29-39)	66.4 (59-74)	62.3 (57-68)	35.4 (30-41)
300 µm	46.7 (39-54)	70.9 (67-75)	41.0 (36-46)	47.6 (40-55)	67.9 (64-72)	42.1 (37-47)
400 µm	31.0 (24-38)	75.6 (73-79)	46.5 (41-51)	31.8 (25-39)	73.0 (70-76)	47.4 (43-51)
Articulating film						
12 µm	72.9 (68-77)	55.3 (50-60)	35.9 (32-40)	74.3 (70-78)	52.4 (47-57)	36.7 (33-40)
40 µm	44.6 (38-51)	63.8 (60-68)	45.8 (42-50)	46.5 (40-53)	60.7 (57-64)	46.4 (43-50)
100 µm	34.5 (27-42)	63.9 (60-68)	50.8 (46-56)	36.1 (29-43)	60.6 (56-65)	51.7 (47-57)
200 µm	31.1 (25-37)	61.7 (57-67)	53.6 (50-57)	32.5 (27-38)	58.2 (53-63)	54.6 (51-59)
T-Scan	19.7 (14-25)	86.4 (84-88)	47.0 (44-50)	20.6 (15-26)	84.9 (83-87)	47.3 (44-50)
	Occlufast Rock 100 µm			Occlufast Rock 200 µm		
Measurement Method	% of False-Negative Contact Area	% of False-Positive Contact Area	% of Agreement With Standard	% of False-Negative Contact Area	% of False-Positive Contact Area	% of Agreement With Standard
Occlufast CAD						
40 µm	45.9 (41-50)	9.4 (7-12)	72.4 (69-75)	66.6 (63-70)	3.3 (2-5)	65.1 (63-67)
50 µm	37.9 (33-43)	12.7 (10-16)	74.7 (72-78)	60.7 (57-65)	4.8 (3-6)	67.3 (65-70)
Virtual occlusion						
100 µm	87.8 (84-92)	45.4 (38-52)	31.5 (26-36)	90.6 (88-94)	25.2 (18-33)	38.7 (34-43)
200 µm	69.2 (63-76)	51.3 (45-57)	39.4 (34-45)	74.7 (69-80)	31.2 (25-37)	46.2 (41-52)
300 µm	51.0 (44-58)	57.5 (53-62)	45.5 (40-50)	57.6 (51-64)	37.2 (33-42)	52.0 (47-57)
400 µm	34.8 (28-41)	63.5 (60-67)	50.5 (46-55)	40.9 (35-47)	43.3 (39-47)	57.3 (53-62)
Articulating film						
12 µm	78.0 (75-82)	41.8 (37-47)	40.1 (36-44)	84.2 (82-87)	26.8 (23-31)	44.5 (42-47)
40 µm	53.5 (48-59)	51.3 (48-55)	47.6 (44-51)	64.3 (60-69)	35.0 (31-39)	50.3 (47-53)
100 µm	43.0 (37-49)	50.2 (45-55)	53.4 (49-58)	55.4 (51-60)	33.0 (28-38)	55.8 (52-60)
200 µm	38.6 (33-44)	46.7 (42-52)	57.4 (54-61)	52.1 (48-57)	28.5 (24-33)	59.7 (57-63)
T-Scan	23.3 (17-29)	79.4 (77-82)	48.7 (45-52)	28.8 (22-35)	67.2 (64-71)	52.0 (48-56)

Registrations obtained by transillumination method with Occlufast Rock and measured at different interocclusal distances used as reference. Data reported as means (95% confidence intervals).

Table 3. False negatives, false positives, and agreement between test and retest registrations in occlusal contact location obtained by each method

Method		**% False-Negative Contact Area**	**% False-Positive Contact Area**	**% Agreement Between Sessions**
Occlufast Rock	40 µm	11.9 (8.6-15.3)	13.7 (10.3-17.1)	87.2 (84.5-89.8)
	50 µm	10.8 (7.8-13.8)	12.8 (9.4-16.2)	88.2 (85.5-90.8)
	100 µm	8.0 (6.1-9.9)	10.2 (7.1-13.3)	90.9 (88.6-93.1)
	200 µm	6.4 (4.9-7.9)	7.7 (5.5-9.9)	92.9 (91.4-94.5)
Occlufast CAD	40 µm	14.7 (11.0-18.5)	21.3 (15.5-27.0)	82.0 (78.8-85.3)
	50 µm	14.8 (10.8-18.8)	19.2 (14.1-24.3)	83.0 (79.9-86.1)
Virtual Occlusion	100 µm	66.8 (55.0-78.6)	61.0 (47.9-74.1)	32.7 (23.0-42.4)
	200 µm	47.2 (34.7-59.7)	48.3 (36.5-60.2)	49.8 (40.4-59.2)
	300 µm	37.6 (25.7-49.6)	40.2 (29.2-51.2)	59.2 (49.9-68.4)
	400 µm	32.3 (21.9-42.7)	33.3 (22.8-43.8)	65.1 (56.1-74.2)
Articulating film	12 µm	49.1 (42.8-55.3)	53.6 (46.5-60.7)	48.7 (43.8-53.6)
	40 µm	41.4 (35.8-47.0)	42.5 (37.1-47.9)	58.0 (53.5-62.6)
	100 µm	35.7 (29.5-42.0)	35.5 (31.0-40.0)	64.4 (60.6-68.2)
	200 µm	26.7 (21.2-32.1)	30.7 (26.0-35.4)	71.3 (68.1-74.5)
T-Scan		26.2 (20.7-31.7)	33.1 (27.2-39.1)	70.3 (65.4-75.2)

Registrations from first session considered as reference images and those from retest session considered as test images. Data reported as means (95% confidence intervals).

distances used. Therefore, the null hypothesis that different methods would have similar criterion validity for locating occlusal contacts was rejected. Transillumination with Occlufast Rock demonstrated not only excellent reliability when measuring the OCA but also excellent reproducibility in occlusal contact location. The average 7% inaccuracy probably reflects the sum of clinical variabilities, including participant differences during the procedures (different forces and mandibular positions during registrations) and measurement errors (image processing). Thus, the present data support the continued use of silicone transillumination as the criterion standard for analyzing occlusal contacts.[12] However, it was notable that transillumination with Occlufast CAD did not improve the reliability or reproducibility. The physical characteristics of this material also made it impossible to detect occlusal contacts with distances larger than 50 µm.

The T-Scan system showed good reliability in measuring the OCA and an acceptable 70% agreement in occlusal contact location between sessions. Nevertheless, dentists in clinical practice must account for the high OCA, as also reported in other studies,[10,12] and the high percentage of false-positive contacts (>67%) compared with transillumination with Occlufast Rock. Although the thickness and rigidity of the T-Scan sensor have been significantly improved since it was first introduced 35 years ago, the recently introduced sensors are not flexible enough to avoid some false positives, especially in the areas where the sensor flexes. An advantage of the T-Scan system is that it can measure relative occlusal forces over time, with its software program allowing the integration of digital scanning.[15] Future studies should focus on improving the criterion validity and reproducibility of the T-Scan system for occlusal contact location.

Virtual occlusion with an intraoral scanner offered poor reliability for interocclusal distances of 100 or 200 μm, but acceptable validity at 300 and 400 μm for occlusal contact location compared with the Occlufast Rock at 200 μm. The algorithms used to generate the 3D casts did not consider periodontal ligaments and tooth mobility when applying occlusal force. Other studies have used an external software program to relocate each segmented tooth to improve the relationship between the maxillary and mandibular casts in the maximum intercuspation position.[12,21,27] Such a software program could be incorporated with the intraoral scan kit to improve accuracy in occlusal contact location at 100 or 200 μm.

Articulating film at 100 and 200 μm showed similar OCAs to that obtained with Occlufast Rock considering at 100 μm. The 200-μm articulating film also provided good reproducibility in occlusal contact location and moderate validity compared with transillumination with Occlufast Rock at 50, 100, and 200 μm. However, both the inter-rater reliability for OCA measurement and the construct validity for occlusal contact location were lower than those obtained with digital systems. These results confirm the subjective natures of interpreting articulating film markings, where the accuracy of this method depends on whether chromatic intensity or marks on the opposing teeth are considered.[4,9,15] In addition, this technique is sensitive to clinical changes, with the possibilities of false negatives associated with saliva and false positives because of contact with the teeth during insertion.[7,22] Therefore, how dentists place the articulating film and how the patients move their jaws can influence the accuracy of occlusal contact assessment.[23,24] Future studies should aim to enhance the accuracy and efficiency of articulating film considering both its clinical procedure and interpretation. Applying artificial intelligence models could improve accuracy.[30,31]

This study included all clinical procedures for an assessment of variability and error. However, the use of dental students to optimize mandibular movements may have limited the extrapolation of the data to the whole population. In addition, only the posterior and the right side of the mandible were assessed. Although no great lateral asymmetries were expected,[13,14] failure to consider anterior teeth might have increased the accuracy reported. Future studies should consider the occlusal contacts of anterior teeth. Occlusal force was not measured objectively, and this probably increased the observed variability in occlusal contact location between sessions and methods. Another limitation reflects the physical differences between traditional and digital methods, where there is no interposition of any material between the occlusal surfaces. The physical characteristics of the occlusal registration methods such as articulating film, Occlufast Rock, and CAD and T-Scan could modify the occlusal relationship between teeth compared with the intraoral scan registration, where there is no interference between occlusal surfaces.[32]

CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. Using the Occlufast Rock transillumination system as the criterion standard for assessing adults with natural dentitions, Occlufast CAD (74% to 80%) was the most valid method for occlusal contact location, followed by 200-μm articulating film (57% to 63%), 400-μm virtual occlusion (53% to 62%), 100-μm articulating film (52% to 60%), and T-Scan (48% to 56%).
2. Reproducibility in occlusal contact location with Occlufast Rock was high (85% to 95%), followed by Occlufast CAD (79% to 86%), 200-μm articulating film (68% to 75%), T-Scan (65% to 75%), 400-μm virtual occlusion (56% to 74%), and 100-μm articulating film (61% to 68%).
3. Although these were clinically acceptable, the accuracy of conventional methods can be improved with new protocols for clinical and interpretation procedures, while the digital methods could benefit from including an additional software program.

PATIENT CONSENT

Informed patient consent has been obtained.

APPENDIX A. SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prosdent.2023.06.036.

REFERENCES

1. Lee HS, Ko KH, Huh YH, Cho LR, Park CJ. Correlation between occlusal contact area at various levels of interocclusal thicknesses and masticatory performance. *J Oral Rehabil.* 2022;49:522–528.
2. Lujan-Climent M, Martinez-Gomis J, Palau S, Ayuso-Montero R, Salsench J, Peraire M. Influence of static and dynamic occlusal characteristics and muscle force on masticatory performance in dentate adults. *Eur J Oral Sci.* 2008;116:229–236.
3. Martinez-Gomis J, Lujan-Climent M, Palau S, Bizar J, Salsench J, Peraire M. Relationship between chewing side preference and handedness and lateral asymmetry of peripheral factors. *Arch Oral Biol.* 2009;54:101–107.
4. Mpungose S, Geerts G. Analyzing complete denture occlusal contacts: Accuracy and reliability. *Int J Prosthodont.* 2016;29:50–52.
5. Prieto-Barrio P, Khoury-Ribas L, Rovira-Lastra B, Ayuso-Montero R, Martinez-Gomis J. Variation in dental occlusal schemes two years after placement of single-implant posterior crowns: A preliminary study. *J Oral Implantol.* 2022;48:110–116.
6. Avivi-Arber L, Lee JC, Sessle BJ. Dental occlusal changes induce motor cortex neuroplasticity. *J Dent Res.* 2015;94:1757–1764.
7. Millstein P, Maya A. An evaluation of occlusal contact marking indicators: A descriptive quantitative method. *J Am Dent Assoc.* 2001;132:1280–1286.
8. Bozhkova T, Musurlieva N, Slavchev D, Dimitrova M, Rimalovska S. Occlusal indicators used in dental practice: A survey study. *Biomed Res Int.* 2021;2021:2177385.
9. Brizuela-Velasco A, Álvarez-Arenal Á, Ellakuria-Echevarria J, del Río-Highsmith J, Santamaría-Arrieta G, Martín-Blanco N. Influence of articulating paper thickness on occlusal contacts registration: A preliminary report. *Int J Prosthodont.* 2015;28:360–362.
10. Ayuso-Montero R, Mariano-Hernandez Y, Khoury-Ribas L, Rovira-Lastra B, Willaert E, Martinez-Gomis J. Reliability and validity of T-Scan and 3D intraoral scanning for measuring the occlusal contact area. *J Prosthodont.* 2020;29:19–25.
11. Kordaß B, Amlang A, Hugger A, Behrendt C, Ruge S. Number and localization of occlusal contact areas on natural posterior teeth without dental findings-evaluations of the regional baseline study (SHIP-1) with the Greifswald Digital Analyzing System (GEDAS). *Int J Comput Dent.* 2022;25:47–56.
12. Wang Q, Zhao Z, Zhou M, et al. In vivo evaluation of the reliability and validity of three digital occlusion analysis methods. *J Dent.* 2022;127:104355.
13. Rovira-Lastra B, Flores-Orozco EI, Ayuso-Montero R, Peraire M, Martinez-Gomis J. Peripheral, functional and postural asymmetries related to the preferred chewing side in adults with natural dentition. *J Oral Rehabil.* 2016;43:279–285.
14. Khoury-Ribas L, Ayuso-Montero R, Willaert E, Peraire M, Martinez-Gomis J. Changes in masticatory laterality 3 months after treatment with unilateral implant-supported fixed partial prosthesis. *J Oral Rehabil.* 2020;47:78–85.
15. Qadeer S, Özcan M, Edelhoff D, VanPelt H. Accuracy, reliability and clinical implications of static compared to quantifiable occlusal indicators. *Eur J Prosthodont Restor Dent.* 2021;29:130–141.
16. Bostancıoğlu SE, Toğay A, Tamam E. Comparison of two different digital occlusal analysis methods. *Clin Oral Investig.* 2022;26:2095–2109.
17. Morsy N, El Kateb M. Accuracy of intraoral scanners for static virtual articulation: A systematic review and meta-analysis of multiple outcomes. J Prosthet Dent, 2022 Nov 1:S0022-3913(22)00608-4. doi: 10.1016/j.prosdent.2022.09.005. Online ahead of print.
18. DeLong R, Ko CC, Anderson GC, Hodges JS, Douglas WH. Comparing maximum intercuspal contacts of virtual dental patients and mounted dental casts. *J Prosthet Dent.* 2002;88:622–630.
19. Edher F, Hannam AG, Tobias DL, Wyatt CCL. The accuracy of virtual interocclusal registration during intraoral scanning. *J Prosthet Dent.* 2018;120:904–912.
20. Sigvardsson J, Nilsson S, Ransjö M, Westerlund A. Digital quantification of occlusal contacts: A methodological study. *Int J Environ Res Public Health.* 2021;18:5297.
21. Zhao Z, Wang Q, Zheng X, et al. Reliability and validity of two computerised occlusion analysis systems. *J Dent.* 2022;118:104051.
22. Saraçoğlu A, Özpinar B. In vivo and in vitro evaluation of occlusal indicator sensitivity. *J Prosthet Dent.* 2002;88:522–526.
23. Saad MN, Weiner G, Ehrenberg D, Weiner S. Effects of load and indicator type upon occlusal contact markings. *J Biomed Mater Res - Part B Appl Biomater.* 2008;85:18–22.
24. Kerstein RB, Radke J. Clinician accuracy when subjectively interpreting articulating paper markings. *Cranio.* 2014;32:13–23.
25. Davies S, Al-Ani Z, Jeremiah H, Winston D, Smith P. Reliability of recording static and dynamic occlusal contact marks using transparent acetate sheet. *J Prosthet Dent.* 2005;94:458–461.
26. Arslan Y, Bankoğlu Güngör M, Karakoca Nemli S, Kökdoğan Boyacı B, Aydın C. Comparison of maximum intercuspal contacts of articulated casts and virtual casts requiring posterior fixed partial dentures. *J Prosthodont.* 2017;26:594–598.
27. Li L, Chen H, Wang Y, Sun Y. Construction of virtual intercuspal occlusion: Considering tooth displacement. *J Oral Rehabil.* 2021;48:701–710.
28. Mokkink LB, Terwee CB, Patrick DL, et al. The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. *J Clin Epidemiol.* 2010;63:737–745.
29. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med.* 2016;15:155–163.
30. Krois J, Garcia Cantu A, Chaurasia A, et al. Generalizability of deep learning models for dental image analysis. *Sci Rep.* 2021;11:6102.
31. Schwendicke F, Cejudo Grano de Oro J, Garcia Cantu A, Meyer-Lueckel H, Chaurasia A, Krois J. Artificial intelligence for caries detection: Value of data and information. *J Dent Res.* 2022;101:1350–1356.
32. Helms RB, Katona TR, Eckert GJ. Do occlusal contact detection products alter the occlusion? *J Oral Rehabil.* 2012;39:357–363.

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