Thai Journal of Orthodontics

Original Article

Accuracy of Intraoral Scanner for Centric Relation Record in Comparison to Vinyl Polysiloxane

Rawinan Luangsukrerk* Napat Nalamliang**

Abstract

Background: Centric relation (CR) is a maxillomandibular position used in dental procedures. Conventional CR bite registration may be inaccurate due to material limitations, such as dimensional changes. Intraoral scanners (IOS) offer a modern alternative, minimizing these limitations and improving patient comfort. However, few studies have evaluated the accuracy of IOS for CR recording. **Objective:** To compare the accuracy of digital CR recordings from an IOS with conventional CR bite registration through quantitative occlusal contact analysis. **Materials and methods:** Twenty-nine healthy individuals participated. CR was recorded using bimanual manipulation with silicone bite indexes (Silagum-Putty; DMG, Germany). Conventional CR bite records were obtained using vinyl polysiloxane (O-Bite; DMG, Germany). IOS scans (iTero Element 2; Align Technologies, USA) recorded CR using the silicone bite index. Recordings were repeated over two visits. CR first contact and sites of close proximity (SCP) were identified. McNemar's test assessed trueness, and Cohen's kappa evaluated repeatability. **Results:** Significant differences in trueness were found between conventional and iTero scans for CR first contact ($P < 0.001$) and SCP detection ($P < 0.001$ in the first visit and $P = 0.027$ in the second visit). Repeatability was comparable for conventional methods (kappa = 0.860 for CR first contact and 0.880 for SCP) and iTero scans (kappa = 0.707 for CR first contact and 0.865 for SCP). **Conclusion:** While repeatability of both methods showed similar acceptable agreement, the trueness of identifying CR first contact and SCP was better in conventional bite registration.

Keywords: Centric Relation, Jaw Relation Record, Reproduction, Vinyl polysiloxane

Received: 24-Oct-2024 **Revised:** 4-Dec-2024 **Accepted:** 6-Dec-2024

Corresponding author: Napat Nalamliang

E-mail: Napat.na@chula.ac.th

* Postgraduate Student, Graduate School, Chulalongkorn University, Bangkok, Thailand

** Assistant Professor, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand

Introduction

Centric relation is a maxillomandibular relationship in which the condyles articulate in the anterior-superior position against the posterior slopes of the articular eminence.[1,2] It serves as a recordable and repeatable position, regardless of the presence or the position of teeth.[1,2] At this position, the centric occlusion, which is defined as the occlusion of opposing teeth when the mandible is in centric relation, is also developed. This position is universally accepted as the reference position of choice for many dental procedures, including full mouth rehabilitation, restoration of posterior teeth, orthodontic treatment and management of patients with temporomandibular disorders in both dentate and edentulous individuals.[3-6]

Centric relation bite registration is one of the most critical determinants of dental procedure success.[2,7] The selection of an appropriate mandibular guidance method and accurate, dimensionally stable recording materials is fundamental principles in bite registration.[7,8] A number of techniques including the tongue tip to soft palate technique, the chin point guidance technique, the anterior guidance technique using Lucia jig/leaf gauge, the Gothic arch tracing and the bimanual manipulation technique have been developed and used routinely for centric relation record.[9] Many studies have investigated the reproducibility of the centric relation. High reliability and reproducibility of the CR with small variations, which were considered as a clinically acceptable procedure, have been revealed.[4,7] Nowadays, the most acceptable techniques are bimanual manipulation, use of an anterior deprogramming device and chin point guidance which are comparable in reproducibility and accuracy.[4,7,9-11]

Although the conventional bite registration has been the standard of practice for many decades, bite registration materials inaccuracies in the reproduction of the CR bite registration have been found. The linear dimensional change, accuracy and surface hardness of various bite registration materials are measured over time.[8,12-14] Vinyl polysiloxane (PVS) and polyether were found to be dimensionally more stable than other materials but are obliged to be articulated within 24-48 hours for accurate registration.[7,8,12]

With advancements in digital dentistry technology, intraoral scanners have been introduced to provide digital dental model without the need for impression of maxilla and mandibular arch and new techniques for CR bite registration emerged.[15,16] Contrary to conventional bite registration, intraoral scanners allow clinicians to directly acquire data from the mouth, and the recording takes place without an interposed medium minimizing the potential errors and the impact of materials limitations.[15] Digital recording is easier to use for clinicians and is highly accepted by patients. It may potentially reduce the chair time, laboratory time, enhance patient comfort, and allow for visualizing the bite registration immediately.[17-19] The accuracy for full arch dentate scans and virtual interocclusal records has been previously evaluated.[20] A systematic review provided information about the accuracy of static virtual articulation. However, it presented some limitations due to the small number of clinical studies. Most of them used three-dimensional laboratory scanners to digitize the casts rather than an intraoral scanner.[21] The use of intraoral scanning for recording CR is a new technique and few studies have investigated the reliability or validity of CR bite registration using an intraoral scanner.[15,22] Though a previous study found equivalent accuracy of the maxillomandibular relationship recorded at the CR by intraoral scanners and the conventional method, only a single dentate participant was involved.[22] The clinical study comparing the accuracy of the CR position recorded using IOSs verified by occlusal contact remains sparse.

To further evaluate the new technology of bite registration record techniques, the aim of this study is to evaluate the accuracy of digital recordings of centric relation obtained from an intraoral scanner through the quantitative comparison of occlusal contacts in normal adult patients.

Materials and methods

Subjects

This cross-sectional study was approved by the Human Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (Ethical Approval Number: HREC-DCU 2023-015). The sample size was determined by n4Studies application (version 2.3)[23] based on data from a pilot study at the 95 % level of significance with 80 % power. The calculated sample size was 26 subjects. Considering a drop-out rate of 10 %, the total sample size was 30 subjects. The subjects were healthy and cooperative adults with permanent dentition. The inclusion criteria were the following: 1) adults aged 20-25 years; 2) permanent dentition with a minimum of 24 teeth; 3) no acute dental disease or periodontal disease; 4) no cuspal-coverage dental restoration; 5) no posterior open bite. The exclusion criteria were the following: 1) the presence of signs and symptoms of temporomandibular disorders; 2) active orthodontic treatment; 3) the presence of tooth mobility; 4) dental restoration during the experiment.

All subjects were fully informed about the objectives of the study and were required to provide signed consent.

Centric relation technique

The bimanual manipulation was selected as a centric recording technique for this study with the subject in a supine position. A single dental specialist, possessing over three years of experience in regular clinical application of this technique, performed all manipulations. Prior to initiating the centric relation manipulation, silicone bite indexes were made by placing additional Vinyl Polysiloxane (Silagum-Putty; Dental Material-Gesellschaft, Germany) in the area of the anterior teeth (canine to canine).

To obtain centric relation through the bimanual manipulation technique, the operator positioned themselves behind the subject, placing four fingers of each hand along the lower border of the subject's mandible near the gonial angles. The thumbs were laid over the mandibular symphysis. The operator then applied upward pressure at the gonial angles with the fingers, while simultaneously exerting gentle downward pressure with the thumbs at the chin. This coordinated force guided the mandible into centric relation by seating the condyles in the most superior position within the glenoid fossa.[7] The subject was instructed to hold this position until the materials were set.

Centric relation bite registration

Operators captured two recordings of centric relation on each subject under the same clinical settings. Each centric relation recording was repeatedly performed in two visits, scheduled for 7 days after the first visit at approximately the same time of day.

Conventional centric relation bite registration

Centric relation bite records were obtained from each subject using vinyl polysiloxane bite registration material (O-Bite; Dental Material-Gesellschaft, Germany) since this method since this method had demonstrated high accuracy compared to other contemporary materials for centric relation (CR) bite records.[7] The PVS material was applied onto the occlusal surface of the mandibular teeth, then the silicone bite index was placed at the anterior teeth. The subject was instructed to close and hold their bite until the material was fully set, and the bite record was carefully removed from the mouth to minimize any risk of distortion or tearing, especially in thin areas near the sites of close proximity (SCP). Immediate photographing and analysis were performed within 24 hours.

Digital intraoral scanner

The intraoral scanner system used in this study was iTero Element 2 (Align Technologies, San Jose, California, USA), carried out by a single operator following the manufacturer's instructions. Whole maxillary and mandibular arches were initially scanned. Subsequently, silicone bite indexes were placed at the anterior teeth. Once the position was achieved, the head of the intraoral scanner was placed on the right

and left sides of the arches to record the interarch relationship.

Data Analysis

Comparing the centric relation first contact

Centric relation first contact (CR first contact) was identified at areas where the teeth were in contact with the opposing teeth (no interocclusal space) when the mandible was in the CR position. For the conventional centric relation bite registration, the CR first contact was identified and recorded by the perforation of bite registration using anatomical landmarks (Figure 1). For the digital recording of centric relation, the iTero software provided the occlusogram, an image of the casts with color-coded markings identifying the interocclusal space between the arches. According to the manufacturer, red represented no interocclusal space. In this way, the occlusogram showed the presence of CR first contact at similar anatomical sites on the virtual casts as on the bite records. Then, the CR first contact present at the same anatomical sites was recorded for further analysis.[24]

Comparing the Sites of close proximity

Sites of close proximity (SCP) were identified in areas where the interocclusal space was less than or equal to 200 µm. For the conventional centric relation bite registration, the bite registration and calibration molds made from the same PVS material of known thickness were placed together on a lightbox (Figure 2). A camera was set at a fixed distance to capture the image for further analysis using the ImageJ software program (U.S. National Institutes of Health, Bethesda, Maryland, USA). The image was converted from color to grayscale. Thresholding and particle analysis tools were used to identify areas of the bite records with a 200 µm thickness and represent them as red.[24,25]

For the digital recording of centric relation, the iTero software provided the occlusogram, an image of the casts with color-coded markings identifying the interocclusal space between the arches. According to

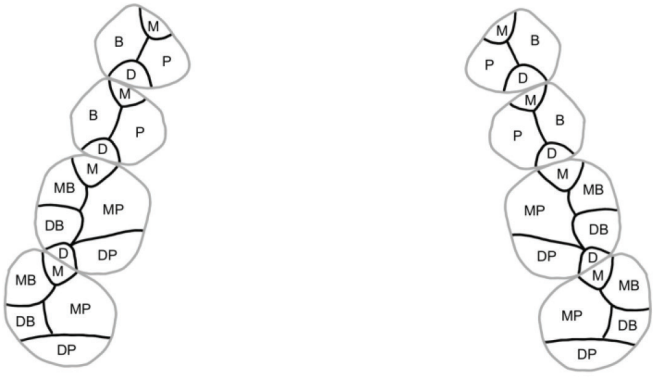

Figure 1 Anatomical landmarks based on the dental anatomy of the upper arch (B: Buccal, P: Palatal, M: Mesial, D: Distal, MB: Mesio-buccal, DB: Disto-buccal, MP: Mesio-palatal, DP: Disto-palatal)

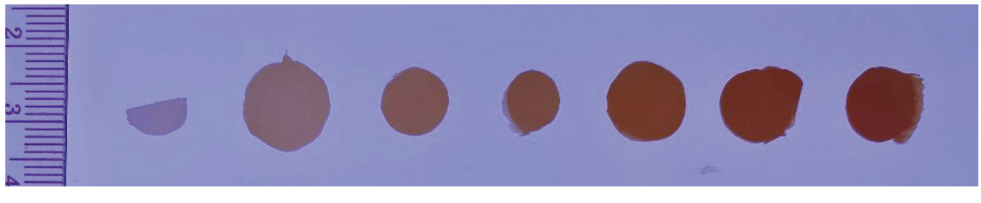

Figure 2 PVS material in known thickness placed together on a lightbox (50, 100, 150, 200, 250, 300, 350 µm)

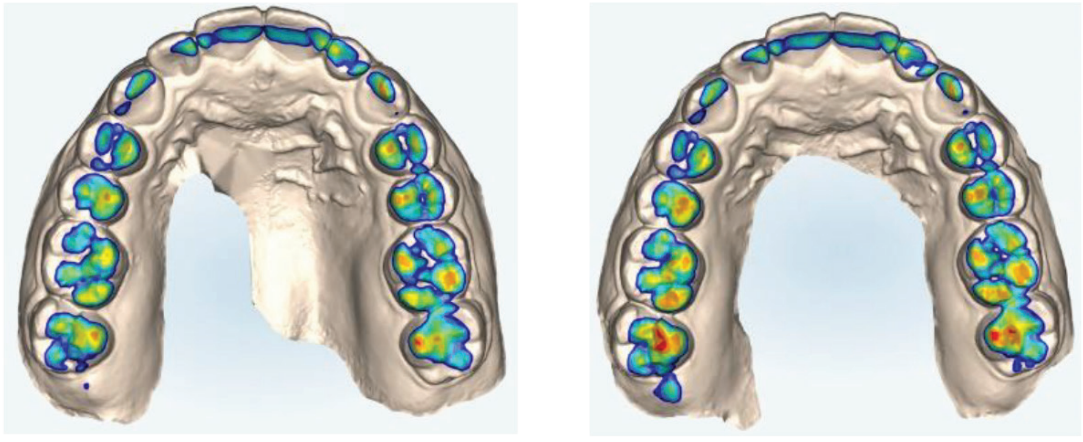

Figure 3 Occlusogram of two recordings generated by iTero software (Left: the first visit, Right: the second visit)

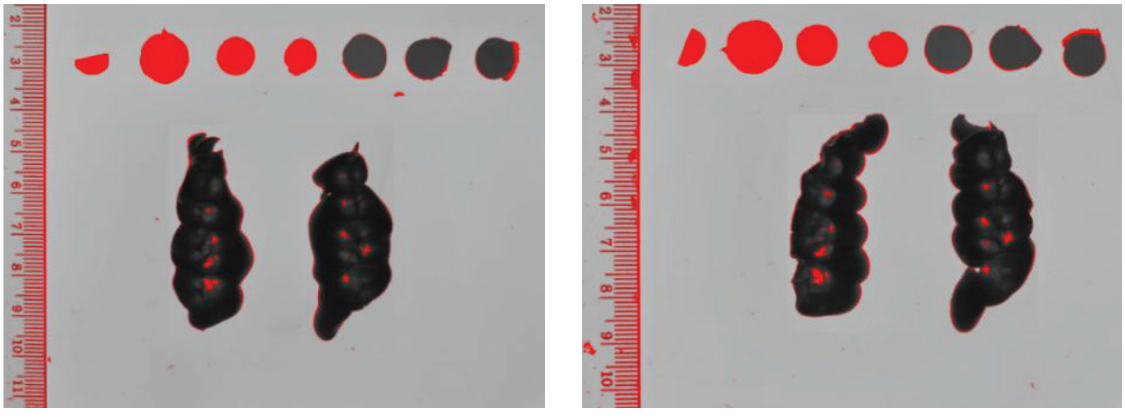

Figure 4 Trans-illuminated PVS bite records (analyzed at 200 μm)

the manufacturer, red represented no interocclusal space, orange represented 0 to 200 μm of interocclusal space, and yellow and other colors represented greater than 200 μm. In this way, the occlusogram showed the presence or absence of SCP at similar anatomical sites on the virtual casts as those on the bite records. The occlusogram was then captured for further analysis.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics 28 (IBM Corp, United States) at a 5 % significance level. The difference in CR first contact between the two groups was determined using McNemar's test. The trueness of the intraoral scans was analyzed by comparing the measurements with the control. Repeatability was tested through the measurements of repeated scans using Cohen's Kappa Statistic.

Results

A total of 30 subjects were recruited for this study. One of them was withdrawn from the experiment due to inability to complete the second visit in time. So, there were 29 subjects for the analysis. An example of recorded CR first contact and site of close proximity in each subject was shown in Figure 3 and Figure 4. The results were summarized in Table 1 and 2.

Table 1 McNemar's test was used to evaluate trueness in identifying CR first contact and SCP.

Trueness (McNemar's Test)		*P* value
CR first contact	First Conventional Recording vs. First Digital Scan	< 0.001
	Second Conventional Recording vs. Second Digital Scan	< 0.001
Site of close proximity	First Conventional Recording vs. First Digital Scan	< 0.001
	Second Conventional Recording vs. Second Digital Scan	0.027

Table 2 Cohen's kappa statistic was used to assess the repeatability.

Repeatability		Kappa value
CR first contact	conventional bite registration	0.860
	iTero digital recordings	0.707
Site of close proximity	conventional bite registration	0.880
	iTero digital recordings	0.865

The trueness of identifying centric relation (CR) first contact was evaluated using McNemar's test. The comparison between the two conventional recordings of CR obtained by the operator on different visits showed no significant difference ($P = 0.118$), indicating consistency in identifying CR first contact between the two conventional recordings. However, significant discrepancies were observed when comparing the first conventional bite registration with the first scan (iTero) ($P < 0.001$) and the second conventional bite registration with the second scan (iTero) ($P < 0.001$). This suggests that the digital recordings obtained with the iTero scanner were significantly different from the conventional method in identifying CR first contact.

For identifying sites of close proximity (SCP), McNemar's test also showed significant differences. The comparison between the first conventional recording and the first scan (iTero) yielded a *P* value of < 0.001, indicating a significant discrepancy in SCP detection between the two methods. The comparison between the second conventional recording and the second scan (iTero) showed a smaller but still statistically significant difference ($P = 0.027$).

In terms of repeatability, the Cohen's kappa statistic was used to assess the consistency of those methods. For the conventional bite registration, the kappa value for identifying CR first contact was 0.860, indicating strong agreement, while the kappa for identifying SCP was higher at 0.880, reflecting strong agreement. For the iTero digital recordings, the repeatability was similar. The kappa value for CR first contact was 0.707, indicating moderate agreement. The repeatability for identifying SCP with the iTero scanner was also higher, with a kappa value of 0.865, reflecting strong agreement.[26]

Discussion

This study aimed to assess the accuracy of digital recordings of centric relation obtained from an intraoral scanner by quantitatively comparing occlusal contacts in terms of both trueness and repeatability. Based

on the results obtained in this study, the hypothesis stating that multiple digital recordings of centric relation obtained from an intraoral scanner can identify the same CR first contact consistently can be accepted. However, discrepancies in trueness were observed, particularly when compared to conventional methods.

The accuracy for full arch dentate scans and virtual interocclusal records has been previously evaluated.[20] A systematic review by Shadid R. provided information about the accuracy of static virtual articulation. However, it presented some limitations due to the small number of clinical studies. Most of them used three-dimensional laboratory scanners to digitize the casts rather than an intraoral scanner.[21] The use of intraoral scanning for recording CR is a new technique and few studies have investigated the reliability or validity of CR bite registration using an intraoral scanner.[15,22] One of them only purposed a technique for direct digital recording of CR using an intraoral scanner without accuracy comparison.[15,22] Though another one[22] provided statistical comparison of accuracy with model superimposition and concluded that the iTero produced the best trueness and precision compared with other scanners, it included only a single dentate participant, and only one CR recording technique was measured without reliability test.

The accuracy of identifying CR first contact revealed significant differences between the iTero digital scans and conventional methods, with McNemar's test showing *P* values of less than 0.001 for both comparisons. These results suggest that the CR first contact identified by the iTero scanner differs significantly from those obtained using conventional methods. Previous studies have also reported similar challenges when comparing digital scanners with conventional methods, suggesting that while digital methods offer consistency, their accuracy in replicating conventional CR may vary due to factors such as scanner algorithms and operator technique.[24]

The repeatability of the methods was analyzed using Cohen's kappa statistic.[26] Conventional bite registration showed strong agreement for identifying CR first contact (kappa = 0.860) and for identifying sites of close proximity (SCP) (kappa = 0.880). In comparison, iTero recordings demonstrated slightly lower repeatability. The Kappa value for CR first contact was 0.707, indicating moderate agreement, but not as strong as the conventional bite registration. For SCP, the iTero scanner showed a Kappa value of 0.865, which was comparable to the conventional method. While the precision for SCP detection was high and nearly matched the performance of the conventional approach, the slightly lower Kappa value for CR first contact suggests that digital scans might have more variability in capturing this specific aspect of the centric relation.

According to the present results, factors such as digital scanning technology, algorithms, operator skill, scanning protocols, data collection, and patient-related variables may contribute the reduced repeatability of the intraoral scanner. In bite registrations, intraoral scanners have demonstrated repeatability in capturing the location and size of occlusal contacts. However, challenges arise in accurately measuring occlusal contact intensities. Wong et al. identified interocclusal distortions, with positive values potentially leading to hyper-occluded CAD-CAM restorations and negative values indicating distortions.[13] In that study, the authors credited these differences to potential flaws in the scanner software algorithm, which serves to match the maxillary and mandibular arches together. Furthermore, the researchers pointed out that the observed interocclusal distortion could be attributed to inaccuracies within the software, encompassing the entire sequence of image capturing, stitching, and postprocessing capabilities. This dependence on software-based processes may also provide insight into the diminished level of agreement observed in the study.[13]

The potential variation in bite force among participants could be a confounding factor for occlusal contact intensity readings during the study. The

strategic decision to undertake an in vivo study with participants not only increased the clinical relevance of the findings but also presented a greater challenge in achieving thorough standardization of participant bite force.[27] Out of all the clinical studies within the dentate group, only a single study instructed patients to sustain the intercuspal jaw position while applying a consistently light occlusal force, achieved through the utilization of electromyographic feedback.[28]

As the intraoral scanner gathers data by navigating a relatively small camera through the curved arch, it undergoes a process of repeated analysis and stitching of scanned surface fragments to construct the overall shape, inevitably resulting in distortion. Flugge conducted a comparative analysis of digital impressions captured with the iTero intraoral scanner and desktop scanners, revealing that extraoral scan data exhibited greater accuracy than intraoral data. Challenges arising from the presence of saliva, reflections from teeth and surrounding tissues, and movements of both patients and operators' hands during scanning contribute to uncertainties, deformations, and ultimately introduce errors into the final dataset.[29]

Limitations of the present study include the variability associated with clinical studies, making it challenging to standardize occlusal force among participants. Additionally, the sample size of 29 healthy participants may not fully represent the diversity of anatomical variations and clinical conditions encountered in broader dental practice. A more extensive and diverse participant pool would enhance the generalizability of the study's findings. Also, the study's emphasis on a single intraoral scanner model (iTero) might limit the generalizability of the findings to other scanner brands with potentially distinct performance characteristics. A comparative analysis involving multiple scanner models would contribute to a more comprehensive evaluation of intraoral scanner reliability. In addition, the accuracy using in this study compared the appearance of anatomical landmark which cannot reflect the overall clinical maxilla-mandibular accuracy. Overall model superimposition with bite registration analyzing by the discrepancy at each dimension should be performed in the future.

Only one investigator is involved in identifying the contact areas in this study. It would be beneficial if the data is analyzed by two or more independent investigators from diverse specialties to investigate the variability between clinicians in terms of interpreting occlusal contacts and clearances in further study. Furthermore, the study investigates static occlusal relationships with no simulation of excursive movements. Therefore, it is advised that further research explore virtual articulators and inter-occlusal records in protrusive and laterotrusive positions.

These results suggest that, while digital methods may offer practical benefits, clinicians should be aware of the discrepancies in CR identification when transitioning from conventional to digital techniques. However, the digital dental field is rapidly evolving, with continuous advancements in software and hardware for intraoral scanners. Regular upgrades may be necessary to keep up with improvements in accuracy and efficiency, as well as to leverage new features that enhance functionality. Furthermore, the incorporation of dimensionally stable bite registration materials, such as ideal self-cured acrylic that exhibits no dimensional changes during polymerization, in conjunction with digital methods may enhance treatment outcomes.

As dentistry progresses into the digital era, understanding the capabilities and limitations of intraoral scanners becomes crucial. The results of this study may inform practitioners about the efficacy of this technology, potentially influencing its integration into routine dental procedures. Ultimately, the successful incorporation of intraoral scanners in centric relation recording could lead to improved efficiency, reduced chair time, and enhanced overall patient experience.

Conclusion

While the repeatability of both methods showed similar acceptable agreement, the trueness of identifying CR first contact and SCP was better in conventional bite registration method.

Author contributions

RL: Methodology, Data collection, Software analysis, Writing-Original Draft; NN: Conceptualization, Methodology, Writing-Review & Editing, Resource, Supervision, Project administration, Funding acquisition.

Ethical statement

This research protocol was approved by the Human Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (Ethical Approval Number: HREC-DCU 2023-015).

Disclosure statement

The authors have no conflicts of interest.

Funding

This study was supported by Faculty of Dentistry, Chulalongkorn University. The Scholarship from the Graduated School, Chulalongkorn University to commemorate the 72nd anniversary of his Majesty King Bhumibol Aduladej is gratefully acknowledged.

References

1. The glossary of prosthodontic terms 2023:10th ed. J Prosthet Dent 2023;130(4 Suppl 1):e1-3.
2. Goldstein GR. Centric relation: a needed reference position. J Prosthodont 2023;32(6):482-8.
3. Becker CM, Kaiser DA, Schwalm C. Mandibular centricity: centric relation. J Prosthet Dent 2000;83(2):158-60.
4. Galeković NH, Fugošić V, Braut V, Ćelić R. Reproducibility of centric relation techniques by means of condyle position analysis. Acta Stomatol Croat 2017;51(1):13-21.
5. The glossary of prosthodontic terms: 9th ed. J Prosthet Dent 2017;117(5s):e1-105.
6. Wasinwasukul P, Thongudomporn U, Promsawat M. Comparison of masticatory muscle effort when chewing on an anterior bite plane fabricated from hard and soft materials. Thai J Orthod 2024;14(2):17-27.
7. Kattadiyil MT, Alzaid AA, Campbell SD. What materials and reproducible techniques may be used in recording centric relation? best evidence consensus statement. J Prosthodont 2021;30(S1):34-42.
8. Anup G, Ahila SC, VasanthaKumar M. Evaluation of dimensional stability, accuracy and surface hardness of interocclusal recording materials at various time intervals: an in vitro study. J Indian Prosthodont Soc 2011;11(1): 26-31.
9. Keshvad A, Winstanley RB. Comparison of the replicability of routinely used centric relation registration techniques. J Prosthodont 2003;12(2):90-101.
10. Kantor ME, Silverman SI, Garfinkel L. Centric-relation recording techniques—a comparative investigation. J Prosthet Dent 1972;28(6):593-600.
11. de Moraes Melo Neto CL, Dos Santos DM, de Magalhães Bertoz AP, Moreno ALM, Goiato MC. Comparison of techniques for obtaining centric relation based on the reproducibility of the condylar positions in centric relation-a systematic review. Eur J Dent 2022;16(2):251-7.
12. Tejo SK, Kumar AG, Kattimani VS, Desai PD, Nalla S, Chaitanya KK. A comparative evaluation of dimensional stability of three types of interocclusal recording materials-an in-vitro multi-centre study. Head Face Med 2012;8:27.
13. Wong KY, Esguerra RJ, Chia VAP, Tan YH, Tan KBC. Three-dimensional accuracy of digital static interocclusal registration by three intraoral scanner systems. J Prosthodont 2018;27(2):120-8.
14. Dwivedi A, Maru K, Sharma A. A comparative evaluation of three dimensional accuracy of different types of interocclusal recording materials - an in vitro study. Med Pharm Rep 2020;93(3):280-6.
15. Radu M, Radu D, Abboud M. Digital recording of a conventionally determined centric relation: a technique using an intraoral scanner. J Prosthet Dent 2020;123(2):228-31.
16. Camcı H, Salmanpour F. A new technique for testing accuracy and sensitivity of digital bite registration: a prospective comparative study. Int Orthod 2021;19(3): 425-32.

17. Fraile C, Ferreiroa A, Romeo Rubio M, Alonso R, Pradíes Ramiro G. Clinical study comparing the accuracy of interocclusal records, digitally obtained by three different devices. Clin Oral Investig 2022;26(6):4663-8.
18. Jeamkatanyoo L, Suntornlohanakul S, Tianviwat S. Factors influencing orthodontic patient compliance with removable retainers. Thai J Orthod 2024;14(2):36-44.
19. Ruankaeo K, Suntornlohanakul S. Factors affecting patient satisfaction in orthodontic treatment. Thai J Orthod 2023;13(1):44-51.
20. DeLong R, Knorr S, Anderson GC, Hodges J, Pintado MR. Accuracy of contacts calculated from 3D images of occlusal surfaces. J Dent 2007;35(6):528-34.
21. Shadid R, Sadaqah N. Accuracy of virtual static articulation: a systematic review. Int J Prosthodont 2022;35(5):627–46.
22. Revilla-León M, Agustín-Panadero R, Zeitler JM, Barmak AB, Yilmaz B, Kois JC, et al. Differences in maxillomandibular relationship recorded at centric relation when using a conventional method, four intraoral scanners, and a jaw tracking system: a clinical study. J Prosthet Dent 2023.
23. Ngamjarus C, Chongsuvivatwong V, McNeil E. n4Studies: Sample size calculation for an epidemiological study on a smart device. Siriraj Med J 2016;68:160-70.
24. Abdulateef S, Edher F, Hannam AG, Tobias DL, Wyatt CCL. Clinical accuracy and reproducibility of virtual interocclusal records. J Prosthet Dent 2020;124(6):667-73.
25. Nalamliang N, Sumonsiri P, Thongudomporn U. Are occlusal contact area asymmetry and masticatory muscle activity asymmetry related in adults with normal dentition? CRANIO® 2022;40(5):409-17.
26. McHugh ML. Interrater reliability: the kappa statistic. Biochem Med (Zagreb) 2012;22(3):276-82.
27. Botsford KP, Frazier MC, Ghoneima AAM, Utreja A, Bhamidipalli SS, Stewart KT. Precision of the virtual occlusal record. Angle Orthod 2019;89(5):751-7.
28. Iwauchi Y, Tanaka S, Kamimura-Sugimura E, Baba K. Clinical evaluation of the precision of interocclusal registration by using digital and conventional techniques. J Prosthet Dent 2022;128(4):611-7.
29. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop 2013;144(3):471-8.