Accuracy of Virtual Static Articulation: A Systematic Review

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Purpose: To evaluate the accuracy of virtual static articulation and to determine factors that affect its accuracy. ***Materials and Methods:*** An electronic search up to December 21, 2020 was carried out in the PubMed, Cochrane, and EMBASE databases, and further searching was performed in the references of the evaluated articles. Studies were included if they were published in a peer-reviewed journal in English, were a clinical or laboratory study assessing only static virtual articulation accuracy without making computer-aided manufacturing restorations, used intraoral scanner (IOS) or extraoral scanner (EOS) systems, and evaluated tooth or implant cases. ***Results:*** After applying the inclusion criteria, a total of 28 studies were analyzed. Nine were clinical, and 19 were laboratory. Most of the studies indicated that virtual static articulation had a comparable accuracy to conventional methods in the presence of completely dentate arches, stable occlusal contacts, a single prepared tooth, or arches involving a single missing posterior tooth. The factors that appeared to influence the accuracy were the articulation technique, number, dimension, and location of virtual interocclusal records (VIRs), the length of articulated scans, and the position and size of edentulous areas. ***Conclusion:*** Though conclusions were derived mainly from laboratory studies, static VIR had an acceptable accuracy in the presence of certain situations. *Int J Prosthodont 2022 March 29. doi: 10.11607/ijp.7407*

One of the keys for successful restorative treatment is accurately recording and transferring the patient intermaxillary relationship.[1] Planning orthognathic surgery,[2] orthodontic treatment,[3] and implant treatment[3] all require precise recording and transferring of the patient intermaxillary relationship. Registration and transferring the patient intermaxillary relationship can be accomplished through analog procedures or with recently introduced virtual articulation associated with CAD/CAM techniques.[4]

The analog method is well recognized, extensively used, relatively uncomplicated, and inexpensive. However, the analog conventional procedures might be associated with errors due to inherent inaccuracies of the various materials used[5] and due to human error, which cannot be disregarded during recording, transferring, and mounting on the articulator.[5] Several sources of conventional articulation inaccuracy exist,[3] including occlusal record material distortion, imprecise positioning of the records on the casts, errors during mounting of the casts on the articulator, dimensional distortion of the mounting plaster material, and inadequate stability of the articulator.[3]

The introduction of a complete digital workflow with CAD/CAM technology has made a striking change in the field of fixed prosthodontics, with the potential for making monolithic fixed prostheses digitally without the need for any physical cast.[6] This in turn improves the cost-effectiveness,[7] enhances the efficiency,[8] and increases patient acceptance.[9] Working in the digital world also reduces the need for storage space for physical casts.[10] With the help of a virtual articulator, planning dental implant treatment can be done in a precise manner by making a virtual wax-up of the future prosthesis in cooperation with CBCT data.[3] In addition, virtual articulation is a

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Submitted September 18, 2020;
accepted July 20, 2021.

beneficial step in planning orthodontic[3] and orthognathic treatments.[2,11,12]

Instead of the analog methods used to record and transfer the patient interocclusal relationship to a mechanical articulator, direct or indirect digitization can be used to transfer scans and records to the digital world.[13] With the direct digital technique, the intraoral scanner digitizes the maxillary arch, the mandibular arch, and the interocclusal relationship to complete the virtual articulation without the need for any physical cast.[13] However, the indirect digital scan includes all of the conventional steps until the casts are mounted in the articulator, then the maxillary and mandibular casts are scanned, and the interocclusal relationship is made with an extraoral scanner.[13]

Different techniques for virtual articulation in a static relationship have been reported in the literature. One of the earliest reported techniques is the manual alignment of virtual casts in which three occluding pairs are selected on the maxillary and mandibular casts, and, with a fitting algorithm, the virtual casts are brought close together by matching those pairs of contacts.[14] The concerns of this technique are the uncertainty of the results and the considerable amount of time needed for manual alignment.[15] A more common technique for alignment of virtual arches is by using a scanned interocclusal record.[14,16] The image of the scanned record is matched either with the virtual maxillary cast seated on the mandibular cast,[14] or the independently scanned record is matched to both the maxillary and the mandibular virtual casts to achieve the virtual articulation.[14,16] Another common method is the buccal occlusal scan record, which involves digitizing the maxillary and the mandibular casts or arches, then digitizing the buccal surfaces of the maxillary and mandibular teeth while they are in maximum intercuspation position (MIP).[17] Subsequently, a special fitting algorithm software aligns the virtual arches automatically.[17] The same can be applied intraorally.[18]

The accuracy of different steps of the digital workflow has been investigated. Trueness of digital impressions has been investigated by different studies[19,20] and several systematic reviews.[21–25] In addition, several studies have evaluated the virtual articulation accuracy of different scanner systems; however, to the knowledge of the present authors, there is no systematic review that concentrates on the accuracy of the virtual static articulation. The aims of this systematic review were to evaluate the accuracy of virtual static articulation and to determine the factors that could affect the accuracy. The accuracy of virtual facebow transfer and the virtual dynamic interocclusal records were not assessed in this review due to the paucity of studies focusing on those issues.

MATERIALS AND METHODS

This systematic review was prepared according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) criteria.[26] The PICO (population, intervention, comparison, outcome) question was: Is static virtual articulation more accurate than conventional articulation for complete dentate and/or partially edentulous arches?

Studies were included if they were published in a peer-reviewed journal in the English language, were a clinical or laboratory study assessing only virtual static articulation accuracy without constructing CAM restorations, used intraoral scanner (IOS) or extraoral scanner (EOS) systems, and evaluated tooth or implant cases. Case reports, abstracts, technique descriptions, studies that assessed restorations made by CAM, and studies that described dynamic virtual articulation were excluded.

The PubMed, Embase, and Cochrane databases were searched with English language restriction on December 21, 2020. The search strategy was:

- ((Complete dentate) OR (fully dentate) OR (full dentition) OR (completely dentulous) OR (partially edentulous) OR (dentate dentition) OR (partial edentulism) OR (partially dentate) OR (non-edentulous) OR (dental arch*) OR (jaw*) OR (dental cast*) OR (dental model*) OR (tooth) OR (teeth) OR (implant*)) AND ((Digital occlusion) OR (virtual interocclusal records (VIRs)) OR (VIRs) OR (optical bite registration) OR (digital bite registration) OR (digital static interocclusal registration) OR (virtual articulation) OR (digital buccal bite scan) OR (virtual 'bites') OR (virtual occlusion) OR (buccal scan registration) OR (buccal scan*) OR (virtual occlusal contacts)) AND ((Accuracy) OR (trueness) OR (precision) OR (predictive value*) OR (sensitivity) OR (specificity)).
- EMBASE search approach was: ((Digital occlusion) OR (virtual interocclusal records (VIRs)) OR (VIRs) OR (optical bite registration) OR (digital bite registration) OR (digital static interocclusal registration) OR (virtual articulation) OR (digital buccal bite scan) OR (virtual 'bites') OR (virtual occlusion) OR (buccal scan registration) OR (buccal scan*) OR (virtual occlusal contacts)).

Further searching was also performed in the references of all evaluated articles and on the webpages of some journals: *The International Journal of Prosthodontics*; *Journal of Prosthetic Dentistry*; *Journal of Prosthodontics*; *Journal of Dentistry*; *Odontology*; *Journal of Oral Rehabilitation*; *Operative Dentistry*; *Clinical Oral Investigations*; *American Journal of Orthodontics and Dentofacial Orthopedics;* and *Angle Orthodontist*.

Two reviewers (R.S. and N.S.) implemented the literature search independently to select titles and abstracts. If titles and abstracts did not provide adequate information, the full-text article was ordered. Both reviewers read the full texts of related articles, and any disparity regarding the inclusion of the studies was resolved by discussion. The following data were retrieved and tabulated for each included study (Table 1): author names and year of publication; study design; description of subjects; number of subjects; scanner system(s); virtual interocclusal method; compared methods; assessment method(s); assessed parameter(s); accuracy outcome(s); and conclusion(s). Due to the high degree of variability among the studies in relation to the design, assessment methods, reference groups, and scanners used, a meta-analysis was not performed, and rather a descriptive systematic review was offered.

Trueness, precision, sensitivity, specificity, and predictive value (PV) were the outcome parameters that were used in this review to assess the accuracy of the virtual interocclusal records (VIRs). Trueness measures how much the measurements of the virtual casts deviate from those of the analog reference casts,[27] while precision determines the degree of resemblance between the measurements of virtual casts produced by the same scanner.[27] Sensitivity is the capability of a VIR to recognize real occlusal contacts, while specificity is the capability of a VIR to recognize actual sites of clearance.[18] Positive predictive value (PV+) is the likelihood of the occlusal contact being actually present when the test is positive.[17] Negative predictive value (PV–) is the likelihood of the occlusal contact being nonexistent when the result is negative.[17] A predictive value that is nearer to 1 will be better.[17]

The risk of bias was individually assessed for each included study by the two reviewers (R.S. and N.S.) using the Critical Appraisal Skills Program (CASP).[28] Based on this approach, 12 questions, as stated in Table 2, were asked for each study, with "yes," "no," or "cannot tell" responses. The risk of bias was considered high if the number of "yes" responses was 1 to 4, medium if it was 5 to 8, and low if it was 9 to 12.

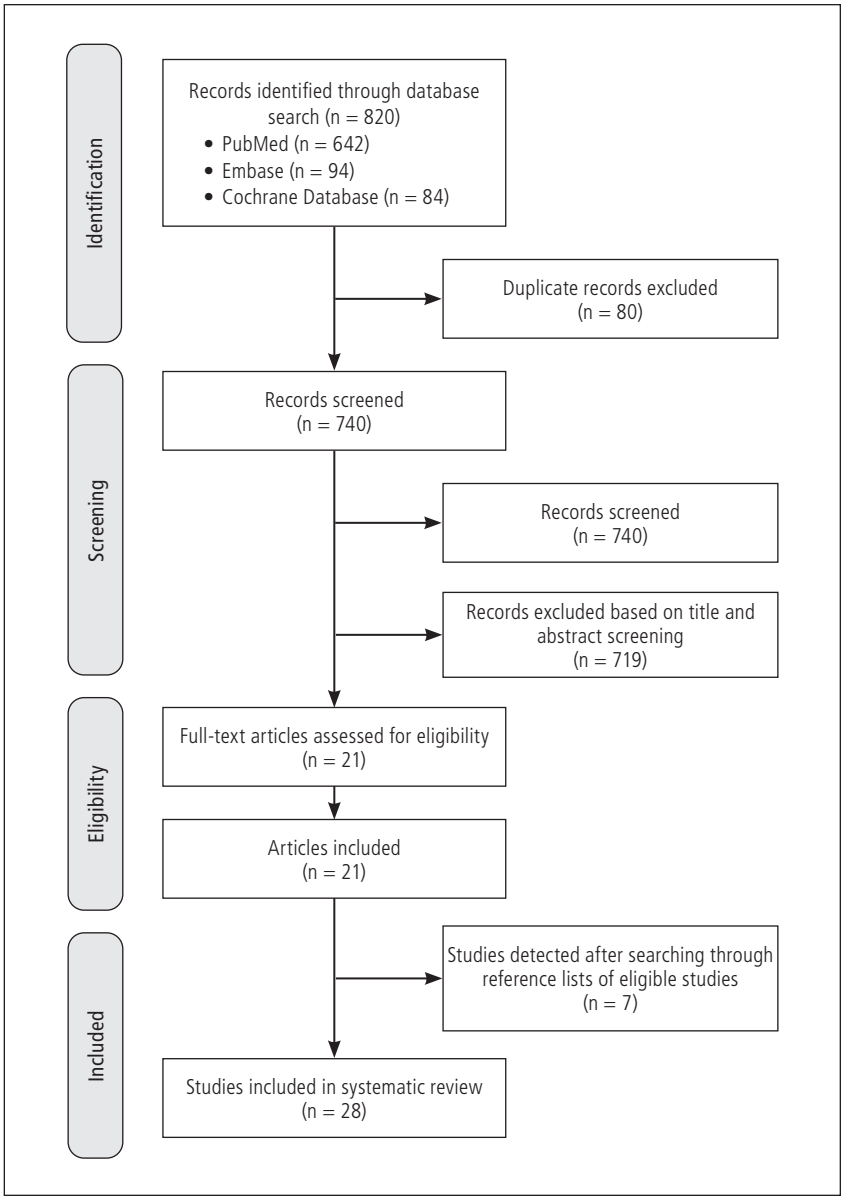

Fig 1 Flowchart showing study selection process.

RESULTS

As outlined in Fig 1, 21 studies[14,16–18,29–45] that remained after title and abstract screening were evaluated for eligibility. All proved eligible. Seven studies[13,15,46–50] were added after a hand-search and a search through the bibliographies of eligible studies. Therefore, a total of 28 studies[13–18,29–50] published up to December 21, 2020, were analyzed.

Table 1 Data Extracted from Included Studies

Author (year)	Study design	Description of subjects	No. of subjects	Scanner system(s)	Virtual interocclusal method(s)
Buccal occlusal scan technique studies					
Iwaki et al (2013)[32]	Laboratory	First test: completely dentate, hand-articulated epoxy casts with right maxillary first molar prepared for crown Second test: the same casts, but with right maxillary first premolar and second molar prepared for onlays	1 pair (n = 2)	IOS: CB	Unilateral buccal occlusal scans
Wriedt et al (2013)[31]	Laboratory	Dentate, articulated plaster casts with acrylic adhesive representing diverse types of skeletal and dental malformation	10 pairs (n = 20)	EOS: A 102	Full-arch buccal occlusal scan
Jaschouz and Mehl (2014)[33]	Clinical	Completely dentate adults	15 participants	IOS: CB	Unilateral buccal occlusal scan
Ueda et al (2014)[47]	Clinical	Not mentioned	9 participants	IOS: CB	Unilateral buccal occlusal scan
Solaberrieta et al (2015)[17]	Laboratory	Completely dentate, hand-articulated gypsum casts	6 pairs (n = 12)	EOS: AS	Full-arch buccal occlusal scan
Solaberrieta et al (2016)[48]	Clinical	Not mentioned	4 participants	IOS: LC TS	LC: 3 VIRs (2 lateral and 1 frontal) TS: 2 VIRs in molar region bilaterally

IOS = intraoral scanner; EOS = extraoral scanner; MIP = maximum intercuspation position; C = central region; PVS = polyvinyl siloxane; PV = predictive value; CAM = computer-aided manufacturing; CMM = coordinate measuring machine; VIR = virtual interocclusal record; CR = centric relation; OCA = occlusal contact area; SCP = sites of close proximity; SC = sites of clearance; ISMDM = surface-based minimum-distance mapping algorithm. See Table 4 for scanner abbreviations.

Author (year)	Compared methods	Assessment method(s)	Assessed parameter(s)	Accuracy outcome(s)	Conclusions
Buccal occlusal scan technique studies					
Iwaki et al (2013)[32]	Buccal occlusal scan vs conventional PVS occlusal record	Measuring the interarch distance between reference sites and angles formed by the occlusal planes n physical casts and virtual casts.	Trueness	Single prepared tooth: Interarch distance discrepancy VIR: 243.2 µm PVS: 311.1 µm Mean horizontal deviation: VIR: 2 degrees PVS: 13 degrees Multiple prepared teeth: Distance discrepancy VIR: up to 833.2 µm at left molar site PVS: up to 116.8 µm at right molar site VIR > PVS in horizontal deviation	VIR was more accurate than physical PVS record for casts with single prepared posterior tooth, but not for multiple prepared teeth.
Wriedt et al (2013)[31]	Comparison between 3 repeated VIRs	Superimposition.	Precision	37 µm	Full-arch buccal scan revealed adequate precision for orthodontic use.
Jaschouz and Mehl (2014)[33]	VIRs in supine vs VIRs in upright position; VIRs in morning vs VIRs in afternoon	Superimposition.	Precision	42 µm	*The reproducibility of the habitual MIP can be attained by buccal occlusal scans. *Neither the time of day nor the position of the patient had any significant effect.
Ueda et al (2014)[47]	Comparison between 6 VIRs	Comparing areas of close occlusal contacts and areas of penetration between VIRs.	Precision	Penetration areas: 0.83 mm^2 Close contact areas: 0.98 mm^2	Changes in buccal occlusal scans had a significant effect on reproducibility of defining the occlusal contact areas, especially those of close contacts.
Solaberrieta et al (2015)[17]	VIR vs physical hand articulation	Comparing virtual occlusal contacts on the digital casts to the physical occlusal contacts identified with shimstock and articulating paper by superimposition.	Trueness	69 µm	Virtual occlusal contacts were more accurate than the physical contacts.
Solaberrieta et al (2016)[48]	Comparison between different combinations of VIR sections (2 lateral and 1 frontal vs 2 lateral). Comparing different sizes of VIR of each section (1 tooth vs 2 teeth vs 3 teeth wide).	Comparing virtual contacts to the analog occlusal contacts obtained with shimstock and articulating paper by superimposition.	Trueness	The highest mean PV (1.0) was for LC (2 lateral and 1 frontal VIRs)	*Intraoral buccal occlusal scan was an accurate interocclusal record. *No significant differences between LC and TS in accuracy. *The best combination of VIRs was the 2 lateral and 1 frontal section, the width of the section was of 2 teeth (24 mm × 15 mm).

Table 1 Data Extracted from Included Studies *(continued)*

Author (year)	Study design	Description of subjects	No. of subjects	Scanner system(s)	Virtual interocclusal method(s)
Solaberrieta et al (2016)[34]	Laboratory	Completely dentate, hand-articulated gypsum casts	6 pairs (n = 12)	EOS: AS	Full-arch buccal occlusal scan 2 lateral and 1 frontal VIRs 2 lateral VIRs
Arslan et al (2017)[35]	Laboratory	First test: completely dentate gypsum casts, but with left mandibular first molar removed Second test: the same casts, but with left mandibular second premolar and second molar prepared as FDP abutments	10 pairs (n = 20)	IOS: CO	Buccal occlusal scan
Yee et al (2018)[38]	Laboratory	Completely dentate maxillary stone cast simulating prepared right second molar articulated with partially edentulous mandibular cast simulating prepared right second premolar and right second molar	5 pairs (n = 10)	EOS: AG SIR ZKN	AG: full-arch buccal occlusal scan SIR: unilateral buccal occlusal scan ZKN: full-arch buccal occlusal scan
Lee et al (2018)[37]	Laboratory	Completely dentate mounted casts with class I or class II division 1 occlusal relationship	24 pairs (n = 48) of Class I and 20 pairs (n = 40) of Class II	IOS: 2nd generation TS	Full-arch buccal occlusal scan
Edher et al (2018)[40]	Laboratory	Completely dentate, hand-articulated zirconia casts but with right maxillary first premolar prepared for crown	1 pair (n = 2)	IOS: CO	Full-arch articulation: One anterior, right posterior, and left posterior buccal occlusal scans. Quadrant articulation: Right canine, right molar, and right quadrant buccal occlusal scans

IOS = intraoral scanner; EOS = extraoral scanner; MIP = maximum intercuspation position; C = central region; PVS = polyvinyl siloxane; PV = predictive value; CAM = computer-aided manufacturing; CMM = coordinate measuring machine; VIR = virtual interocclusal record; CR = centric relation; OCA = occlusal contact area; SCP = sites of close proximity; SC = sites of clearance; ISMDM = surface-based minimum-distance mapping algorithm. See Table 4 for scanner abbreviations.

Author (year)	Compared methods	Assessment method(s)	Assessed parameter(s)	Accuracy outcome(s)	Conclusions
Solaberrieta et al (2016)[34]	Comparison between combination of 2 lateral and 1 frontal VIRs and 2 lateral VIRs with full-arch buccal scan as reference	Comparing virtual contacts with the analog occlusal contacts identified with shimstock and articulating paper by superimposition.	Trueness	Mean PV: 2 lateral and 1 frontal VIRs with minimum 10 × 15 mm: (1.0) 2 lateral VIRs with 12 × 15 mm: (0.925)	The most accurate VIRs were the combination of two lateral and one frontal with minimum 10 × 15 mm dimension or by making two lateral VIRs as far apart as possible with a dimension to be at least 12 × 15 mm.
Arslan et al (2017)[35]	*VIR of complete-arch scan of nonprepared teeth vs VIR of complete-arch scan of prepared teeth; *VIR of complete-arch scans of prepared teeth vs VIR of half-arch scans of prepared teeth; *VIR from prepared side vs VIR from contralateral side These were compared with conventional mounting of casts, where occlusal contacts were recognized with articulating paper.	Superimposition.	Trueness	The highest mean% of virtual contacts identical to physical contacts: VIR of nonprepared complete-arch scans: 23%. The lowest mean%: VIR of prepared half-arch scans: 3%.	*The highest trueness was found with complete-arch scans of nonprepared teeth. *After tooth preparation, complete-arch virtual articulation was more accurate than half-arch articulation. *No significant difference in virtual articulation accuracy was detected of Complete-arch scans made before and after tooth preparation; even the buccal occlusal scan was made from the same side or contralateral side.
Yee et al (2018)[38]	VIRs obtained with AG, SIR, ZKN compared to conventional articulation	Measuring and comparing interarch and interocclusal virtual distances with reference values. Precision: superimposition.	Trueness Precision	Overall interarch global distortion for all 3 EOS systems did not surpass 0.6%. Precision (interarch): AG: 37.7 µm ZKN: 23.8 µm SIR: 82.1 µm	*Acceptable trueness for all three EOS systems with low interarch distortion. *SIR was less precise than AG and ZKN.
Lee et al (2018)[37]	Virtual occlusal record compared to Presacle method	Calculating the percentage of the total occlusal contact area obtained from the virtual record and comparing them to occlusal contacts measured by Prescale.	Trueness	Difference (Prescale–VIR) in OCA (%) Molar: 1.59 Premolar: 1.84 Anterior: 3.43	For VIR and Prescale, comparable occlusal contacts were found in the molar and premolar portions, while exaggerated occlusal contacts were found in the anterior region when using the VIR
Edher et al (2018)[40]	VIRs made in different sections compared totransilluminated PVS records and physical contacts held with shimstock	Comparing SCPs and SCs obtained from VIR tothose obtained from PVS by CO software and CloudCompare software.	Sensitivity Specificity	CO software analysis: Full-arch articulation sensitivity: 88.89%, specificity: 48.15% Quadrant articulation sensitivity 100%, specificity 25% CloudCompare analysis: Full-arch articulation sensitivity: 59.26%, specificity: 85.19% Quadrant articulation sensitivity: 86.67%, specificity: 66.67%	Quadrant scan articulation revealed a greater sensitivity to identify contacts than complete virtual arch articulation. Multiple VIRs were more accurate than single VIR for complete-arch articulation. Single anterior VIR was more accurate than single right or left VIR.

Table 1 Data Extracted from Included Studies *(continued)*

Author (year)	Study design	Description of subjects	No. of subjects	Scanner system(s)	Virtual interocclusal method(s)
Wong et al (2018)[41]	Laboratory	Completely dentate, hand-articulated stereolithographic (SLA) casts with left maxillary and mandibular first molars simulating crown-prepared teeth	1 pair (n = 2)	IOS: TDS TRC CER	Buccal occlusal scan
Zimmermann et al (2018)[36]	Clinical	Completely dentate participants were subjected to 5 different MIP records: 1. CI, buccal scan of poured casts with SIR; 2. Intraoral quadrant impression and buccal scan with CB; 3. Intraoral quadrant impression and buccal scan with CO version 4.2; 4. Intraoral quadrant impression and buccal scan with CO version 4.5β; 5. Intraoral quadrant impression and buccal scan with TS	10 participants	IOSs: CB 4.2, CO 4.2, CO 4.5β, TS EOS: SIR	Unilateral buccal occlusal scan
Botsford et al (2019)[43]	Clinical	Dentate adults having all canines, first molars, and second molars in occlusion	20 participants	IOS: CS 3600	VIR: One anterior and two bilateral buccal occlusal scans

IOS = intraoral scanner; EOS = extraoral scanner; MIP = maximum intercuspation position; C = central region; PVS = polyvinyl siloxane; PV = predictive value; CAM = computer-aided manufacturing; CMM = coordinate measuring machine; VIR = virtual interocclusal record; CR = centric relation; OCA = occlusal contact area; SCP = sites of close proximity; SC = sites of clearance; ISMDM = surface-based minimum-distance mapping algorithm. See Table 4 for scanner abbreviations.

Author (year)	Compared methods	Assessment method(s)	Assessed parameter(s)	Accuracy outcome(s)	Conclusions
Wong et al (2018)[41]	VIRs obtained from 3 IOS systemscompared to conventionally mounted physical casts	Measuring interarch and interocclusal distortion between the reference sites on physical and virtual casts.	Trueness Precision	Interarch distance discrepancy: TRC: R: 31.7 µm C: –110.8 µm L: 69.4 µm TDS: R: –471.9 µm C: –579.0 µm L: –381.5 µm Precision (interocclusal): TRC the most accurate (–23.1 µm) TDS the least accurate (–184.9 µm)	*There were significant differences between the 3 evaluated IOS systems in virtual articulation accuracy. *For interarch distortions, TRC performed overall the best, and TDS was the worst. *Negative interocclusal distortions were found for TDS and CER, but not for TRC.
Zimmermann et al (2018)[36]	Intraoral buccal occlusal scans obtained with the tested IOS systems compared to buccal scan of hand-articulated poured casts	Analysis of translation and rotation in mandibular position in relation to maxillary arch.	Trueness	Translation and rotation: CI: Trans: 98.74 µm Rot: 0.23 degrees CB: Trans: 84.12 µm Rot: 0.73 degrees CO 4.2: Trans: 60.70 µm Rot: 0.45 degrees CO 4.5β: Trans: 68.36 µm Rot: 0.50 degrees TS: Trans: 66.60 µm Rot: 0.47 degrees	*Comparable accuracy was achieved between intraoral VIR and VIR of poured casts. *No significant differences were found between the tested IOS systems in terms of static virtual articulation accuracy.
Botsford et al (2019)[43]	Comparison between 2 repeated VIRs	Analyzing contact locations, size, and intensity.	Precision	Nonsignificant difference in contact locations and mean size (–250 µm) Significant difference in contact intensity	Satisfactory precision in contact size and location, but not in contact intensity, of VIR was demonstrated.

Table 1 Data Extracted from Included Studies *(continued)*

Author (year)	Study design	Description of subjects	No. of subjects	Scanner system(s)	Virtual interocclusal method(s)
Gintaute et al (2020)[45]	Laboratory	Completely dentate mounted resin models: Group A: Eichner Class A1 Partially edentulous: Group B: Eichner Class A2 Group C: Eichner Class A3 Group D: Eichner Class B1 Group E: Eichner Class B2 Group F: Eichner Class B4	6 pairs (n = 12)	IOS: CO TS PE	Bilateral buccal occlusal scans
Úry et al (2020)[13]	Clinical	Articulated gypsum casts with CR record of nonedentulous patients	18 pairs (n = 36)	EOS: A 885	Buccal occlusal scan
Ren et al (2020)[44]	Laboratory	Completely dentate and partially edentulous articulated stone casts: *Group Dent: completely dentate *Group 1-Post: 1 missing posterior tooth *Group 3-Post: 3 missing posterior teeth *Group 6-Ant: 6 missing anterior teeth *Group Bil-Post: bilateral missing posterior teeth	5 pairs (n = 10)	IOS: DW	Bilateral buccal occlusal scans
Ayuso-Montero et al (2020)[50]	Clinical	Dentate adults having at least 24 natural teeth were subjected to 3 occlusal analysis methods to measure OCA. 1. T-scan at maximum occlusal pressure and at half of the maximum pressure. VIR with IOS 3. PVS record at moderate and maximum biting force	31 participants	IOS: TS	One anterior scan and two bilateral buccal occlusal scans

IOS = intraoral scanner; EOS = extraoral scanner; MIP = maximum intercuspation position; C = central region; PVS = polyvinyl siloxane; PV = predictive value; CAM = computer-aided manufacturing; CMM = coordinate measuring machine; VIR = virtual interocclusal record; CR = centric relation; OCA = occlusal contact area; SCP = sites of close proximity; SC = sites of clearance; ISMDM = surface-based minimum-distance mapping algorithm. See Table 4 for scanner abbreviations.

Author (year)	Compared methods	Assessment method(s)	Assessed parameter(s)	Accuracy outcome(s)	Conclusions
Gintaute et al (2019)[45]	Comparison between 5 repeated VIRs obtained with 3 IOS systems for all groups (A–F)	Measuring OCA obtained with 3 IOS systems for all groups. Measuring interarch distances between reference sites.	Precision	OCA range (mm^2): CO: 5.7–25.3 (smallest) PE: 22.2–60.2 (largest) Precision for posterior interarch distances across IOS systems: 100–900 µm Precision for anterior interarch distances (groups A–C): 40–420 µm Precision for anterior interarch distances (groups D–F): maximum 310 µm Worst precision: Left molar PE group C: Highest precision, right canine CO group: A and R canine TS group: D	*Significant differences of OCA among scanners across all groups. *Anterior occlusion recording once surrounded by enough posterior teeth produced higher precision than posterior occlusion. *TS was the most precise. *PE was the least precise. *CO was associated with false posterior open bite.
Úry et al (2020)[13]	VIR compared to conventional mounting of casts using CR record	Comparing number and location of occlusal contacts between virtual and physical contacts recorded by articulating paper by superimposition	Trueness Precision	Trueness location: 550 µm. Number: 93% of physical contacts matched virtual ones Precision: 23 µm.	*Virtual contacts compared favorably with the physical ones. *High precision for both physical and virtual measurements.
Ren et al (2020)[44]	VIRs for groups Dent, 1-Post, 3-Post, 6-Ant, and Bil-Post compared to physical articulation	Measuring and comparing interarch distances on virtual casts and physical casts	Trueness	Dent: 50 µm 1-Post: 100 µm 3-Post: 280 µm 6-Ant: 190 µm Bil-Post: 280 µm	*The accuracy of virtual articulation of completely dentate and a single missing posterior tooth cases was as good as conventionally mounted casts. *Virtual articulation of extended partially edentulous cases, whether anterior or posterior regions, significantly reduced the accuracy of VIRs.
Ayuso-Montero et al (2020)[50]	VIR and T-scan compared to transilluminated PVS record	Evaluating and comparing OCA gained with the 3 techniques	Trueness	OCA: The highest was for T-scan with maximum force, the lowest: VIR High correlation between T-scan and PVS, and low correlation between VIR and PVS.	*VIR was not a reliable technique for assessing the OCA. *T-scan and conventional PVS record swere more reliable methods.

Table 1 Data Extracted from Included Studies *(continued)*

Author (year)	Study design	Description of subjects	No. of subjects	Scanner system(s)	Virtual interocclusal method(s)
Abdulateef et al (2020)[18]	Clinical	Dentate adults having at least 24 natural teeth	10 participants	IOS: CO	Right and left buccal occlusal scans
Scanned interocclusal record technique studies					
Delong et al (2002)[14]	Laboratory	Completely dentate, hand-articulated stone casts	10 pairs (n = 20)	IOS: C	Manual alignment of virtual casts Scanned interocclusal record
Delong et al (2007)[29]	Clinical	Completely dentate patients	12 participants	IOS: C	Scanned interocclusal record
Sweeney et al (2015)[16]	Laboratory	Completely dentate, articulated typodont	1 pair (n = 2)	EOS: OI	Scanned interocclusal record
Buccal occlusal scan vs scanned interocclusal record					
Yee et al (2018)[39]	Laboratory	Completely dentate maxillary stone cast simulating prepared right second molar articulated with partially edentulous mandibular cast simulating prepared right second premolar and right second molar. Two virtual articulation methods for each scanner: mounted casts with acrylic resin bite record (MO) and IR technique	5 pairs (n = 10)	EOS: AG SIR ZKN	AG-MO: full- arch buccal scan AG-IR: scanning imprints of the maxillary teeth while PVS seated onto mandibular cast. SIR-MO: unilateral buccal scan SIR-IR: buccal scan while the 2 casts were articulated and held together with PVS positioned between them. ZKN-MO: full- arch buccal scan ZKN-IR: buccal scan while the 2 casts were articulated and stabilized with sticky wax with PVS positioned between them.

IOS = intraoral scanner; EOS = extraoral scanner; MIP = maximum intercuspation position; C = central region; PVS = polyvinyl siloxane; PV = predictive value; CAM = computer-aided manufacturing; CMM = coordinate measuring machine; VIR = virtual interocclusal record; CR = centric relation; OCA = occlusal contact area; SCP = sites of close proximity; SC = sites of clearance; ISMDM = surface-based minimum-distance mapping algorithm. See Table 4 for scanner abbreviations.

Author (year)	Compared methods	Assessment method(s)	Assessed parameter(s)	Accuracy outcome(s)	Conclusions
Abdulateef et al (2020)[18]	Right and left buccal occlusal scans compared to right and left PVS interocclusal records	Comparing SCP and SCs between VIRs and transilluminated PVS	Sensitivity Specificity Precision	VIR sensitivity: 87%. VIR specificity: 95%. Precision: 74% of SCP and 92% of SCs were recognized truly.	*VIR showed satisfactory accuracy in recognizing occlusal contacts, but had a tendency to miss some actual occlusal contacts. *Fair precision of VIR was obtained.
Scanned interocclusal record technique studies					
Delong et al (2002)[14]	Virtual casts aligned manually (CM) vs virtual casts articulated with scanned interocclusal records while adapted on the mandibular models (C1) or digitized independently (C2) vs directly from scanned IR vs physical contacts held with shimstock	Comparing virtual occlusal contacts to physical contacts	Sensitivity Specificity	Sensitivity, %: C2: 89 CM: 86 IR: 80 C1: 76 Specificity, %: C1: 98 CM: 96 C2: 95 IR: 89	Virtual occlusal contacts obtained with all virtual articulation methods compared favorably to physical contacts.
Delong et al (2007)[29]	Virtual casts articulated with independently scanned interocclusal record vs directly from scanned interocclusal record vs PVS transilluminated record vs shimstock	Comparing virtual occlusal contacts to analog contacts recognized clinically using shimstock and PVS transillumination	Trueness	Accuracy of scanned interocclusal record of recognizing tooth contacts compared to transillumination: 95%. Aligned virtual arches compared to transillumination: 95%. Scanned interocclusal record compared to shimstock: 85%. Aligned virtual arches compared to shimstock: 84%.	The scanned interocclusal record technique and the aligned virtual arches produced virtual contacts as accurate as clinically determined contacts by VPS transillumination, but not compared to shimstock method.
Sweeney et al (2015)[16]	Comparison of 5 materials of scanned IR (Regisil Rigid PVS, Futar Scan PVS, Byte Right thermoplastic bite registration material, Aluwax aluminum-based wax, and Beauty Pink hydrocarbon wax)	Measuring the interarch distances between specific points on the digital casts and comparing to those on typodont.	Trueness	Significant interarch distance discrepancy from the reference for all tested materials. Regisil Rigid PVS > Futar Scan PVS > Byte Right > Aluwax > Beauty Pink wax.	*This method presented with significant interarch distance discrepancy irrespective of the material used. *PVS was the most accurate for virtual articulation.
Buccal occlusal scan vs scanned interocclusal record					
Yee et al (2018)[39]	Comparison between MO and IR digital articulation techniques using the 3 scanners	Measuring and comparing interarch and interocclusal virtual distances with reference values	Trueness	Interarch distortion of all groups except AG-IR did not surpass 0.7%. AG-IR group at the prepared tooth sites presented with the most interarch and interocclusal superior-inferior distortions.	*Articulation method did not have a significant effect on accuracy in the nonprepared tooth sites in all groups. *In the prepared tooth sites, the AG-IR group presented with the least accurate results.

Table 1 Data Extracted from Included Studies *(continued)*

Author (year)	Study design	Description of subjects	No. of subjects	Scanner system(s)	Virtual interocclusal method(s)
Porter et al (2018)[42]	Laboratory	Completely dentate, hand-articulated plaster casts made from articulated typodont	25 pairs (n = 50)	EOS: OI IOS: iTero 2.9 iTE TDS	IOSs: Buccal occlusal scan EOSPVS: Scanned interocclusal record (PVS Regisil) EOSWAX: Scanned interocclusal record (Coprwax)
Virtual articulation with collision resolution					
Chang et al (2010)[46]	Laboratory	Completely dentate, hand-articulated stone casts except for 4 partially edentulous pairs	12 pairs (n = 48)	EOS: GH	2 stages. First stage was to approximate the maxillary and mandibular virtual curves using point matching software. Second stage was finalizing the articulation by using (ISMDM) with collision constraints.
Xia et al (2010)[15]	Laboratory	Completely dentate, hand-articulated stone casts except for 4 partially edentulous sets	12 pairs (n = 48)	EOS: GH	2 stages. First stage was to approximate the maxillary and mandibular virtual curves using point matching software. Second stage was finalizing the articulation by using (ISMDM) with collision constraints.
Chang et al (2012)[30]	Laboratory	Dentate, hand-articulated stone casts for patients with dentofacial deformities and stable occlusion	12 pairs (n = 48)	EOS: GH	2 stages. First stage was to approximate the maxillary and mandibular virtual curves using point matching software. Second stage was finalizing the articulation by using (ISMDM) with collision constraints.
Stavness et al (2016)[49]	Laboratory	Completely dentate prefabricated hand-articulated models	1 pair (n = 2)	EOS: XC	Full-arch buccal occlusal scan combined with collision correction.

IOS = intraoral scanner; EOS = extraoral scanner; MIP = maximum intercuspation position; C = central region; PVS = polyvinyl siloxane; PV = predictive value; CAM = computer-aided manufacturing; CMM = coordinate measuring machine; VIR = virtual interocclusal record; CR = centric relation; OCA = occlusal contact area; SCP = sites of close proximity; SC = sites of clearance; ISMDM = surface-based minimum-distance mapping algorithm. See Table 4 for scanner abbreviations.

Author (year)	Compared methods	Assessment method(s)	Assessed parameter(s)	Accuracy outcome(s)	Conclusions
Porter et al (2018)[42]	Buccal occlusal scan obtained with 3 IOS systems vs scanned PVS interocclusal record (EOSPVS) vs scanned wax record (EOSWAX) with articulated typodont as gold standard	Measuring the interarch distances between specific points on the digital casts and comparing them to those on typodont	Trueness	iTero 2.9 and iTE: ± 500 µm discrepancy in all 6 interarch distances. TDS and (EOSPVS): ± 500 µm discrepancy in 4 of 6 interarch distances. EOSWAX: ± 500 µm discrepancy in 3 of 6 interarch distances.	*Only the buccal occlusal scan obtained with (iTero 2.9 and iTE) IOSs yielded the required accuracy for orthodontic digital cast articulation. *Scanned PVS interocclusal record was more accurate than scanned wax record.
Virtual articulation with collision resolution					
Chang et al (2010)[46]	Virtual articulation using the two steps compared to complete buccal occlusal scan	Analysis of rotation, translation, and surface deviations in the mandibular arch position in relation to the maxillary arch		The largest translational deviation was within 200 µm. The largest angular deviation was within 0.2 degrees.	This technique was efficient and accurate for virtual static articulation.
Xia et al (2010)[15]	Virtual articulation using the two steps compared to complete buccal occlusal scan	Analysis of rotation, translation, and surface deviations in the mandibular arch position in relation to the maxillary arch		The largest translational deviation was within 200 µm. The largest rotational difference was within 0.08 degrees.	This technique was efficient and accurate for virtual static articulation.
Chang et al (2012)[30]	Virtual articulation using the two steps compared to complete buccal occlusal scan	Analysis of rotation, translation, and surface deviations in the mandibular arch position in relation to the maxillary arch		The largest translational difference was within 200 µm. The largest rotational difference was within 0.1 degrees. The average surface deviation was 80 µm.	This technique was efficient and accurate for virtual static articulation.
Stavness et al (2016)[49]	VIR compared to transillumiated PVS record	Comparison of no. of SCPs obtained from VIR to those obtained from PVS interocclusal record		Congruence coefficient between the SCPs of VIR and PVS was 0.91 after collision resolution.	Virtual contacts closely matched those identified by transilluminated PVS record.

Table 2 CASP Questions

No.	CASP questions
Q1	Was there a clear question for the study to address?
Q2	Was there a comparison with an appropriate reference standard?
Q3	Did all patients get the diagnostic test and reference standard?
Q4	Were the results of the test interpreted independently without knowing the results of the reference standard (ie, was there blinding)?
Q5	Is the disease status of the tested population clearly described?
Q6	Were the methods for performing the test described in sufficient detail?
Q7	The results are clear (ie, what are the results?).
Q8	The results are credible (ie, how sure are we about the results?).
Q9	Can the results be applied to your patients/the population of interest?
Q10	Can the test be applied to your patient or population of interest?
Q11	Were all outcomes important to the individual or population considered?
Q12	There are important clinical implications.

The parameters recorded for all included studies are described in Table 1. Upon assessing the quality of the included studies, a medium risk of bias was allocated to all studies except for one, which had a high risk of bias (Table 3). The evaluated IOS and EOS systems are summarized in Table 4.

The results of all included studies are summarized in Table 1, and the studies were categorized according to the following: buccal occlusal scan technique; scanned interocclusal record technique; buccal occlusal scan vs scanned interocclusal record; and virtual articulation with collision resolution.

DISCUSSION

The objectives of this systematic review were to investigate the accuracy of static virtual articulation and to determine the factors that could affect the accuracy. Nine clinical and 19 laboratory studies were included. The outcomes of this systematic review indicated that static virtual articulation had a comparable accuracy to conventional methods in the presence of completely dentate arches, stable occlusal contacts, a single prepared tooth, or arches with a single missing posterior tooth.

Although there is no universal consensus on the minimal clinically acceptable level of accuracy required for VIR,[39] Delong et al[29] demonstrated that mean predictive values greater than 0.9 are deemed to be of sufficient accuracy. Sensitivity of 70% and specificity of 95% are considered the minimum requirements of virtual occlusal contacts to be clinically accurate.[14,50] In addition, translational differences in the mandibular position of < 500 µm in all axes and less than 1-degree rotational deviation are considered clinically acceptable.[15] For orthodontic use, a VIR of 500-µm trueness is regarded to be clinically acceptable based on the American Board of Orthodontics objective grading system.[51] Further, Wriedt et al[31] stated that if VIR precision value is within the resolution of a caliper gauge (100 µm), it is adequately precise for orthodontic practice.

Fourteen studies,[13,17,18,32,34–38,40,41,44,48,50] both clinical and laboratory, investigated the accuracy (trueness) of buccal occlusal scan VIRs. Generally, these studies tended to endorse the idea that static VIR had an accuracy comparable to that of conventional methods. However, this outcome was in the presence of completely dentate arches, stable occlusal contacts, a single prepared tooth, or partially edentulous scenarios involving only a single missing posterior tooth.[13,17,18,32,34–38,44,48] Although Abdulateef et al[18] came to the same conclusion, they reported that VIR had a tendency to miss some actual occlusal contacts due to collision between the arches.[18] Furthermore, a laboratory study[37] reported that VIR had a comparable accuracy to the Prescale method in the molar and premolar portions, while exaggerated occlusal contacts were found in the anterior region.[37] In contrast to previous studies, a clinical study[50] reported that VIR was not a valid technique for assessing the occlusal contact area.

Regarding the precision of VIR, four studies[13,31,33,43] reported that buccal occlusal scan VIR could reproduce a uniform occlusion. In addition, a laboratory study revealed a higher precision for anterior virtual occlusion that was surrounded by a sufficient number of posterior teeth in comparison with posterior occlusion.[45] Conversely, a clinical study[47] revealed that changes in buccal occlusal scans had a significant effect on the reproducibility of identifying the occlusal contact areas,

Table 3 Quality Assessment by CASP

Sutdy (year)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Score (0–12)
Delong et al (2002)[14]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Delong et al (2007)[29]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Chang et al (2010)[46]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	No	6
Xia et al (2010)[15]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	5
Chang et al (2012)[30]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	No	6
Iwaki et al (2013)[32]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Wriedt et al (2013)[31]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Jaschouz and Mehl (2014)[33]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Ueda et al (2014)[47]	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	5
Sweeney et al (2015)[46]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Solaberrieta et al (2015)[16]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Solaberrieta et al (2016)[48]	No	Yes	Yes	No	No	No	Yes	No	No	Yes	No	No	4
Solaberrieta et al (2016)[34]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Stavness et al (2016)[49]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	5
Arslan et al (2017)[35]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Yee et al (2018)[38]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Yee et al (2018)[39]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Wong et al (2018)[41]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Lee et al (2018)[37]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Zimmermann et al (2018)[36]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Edher et al (2018)[40]	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	6
Porter et al (2018)[42]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	8
Ury et al (2020)[13]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Ren et al (2020)[44]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	8
Ayuso-Montero et al (2020)[50]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7
Botsford et al (2019)[43]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	8
Gintaute et al (2020)[45]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	8
Abdulateef et al (2020)[18]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	7

especially those of close contacts. Another clinical study also revealed a fair precision of buccal occlusal scans.[18]

Concerning the use of a scanned interocclusal record to articulate digital casts, one laboratory study[14] and one clinical study[29] reported that the scanned interocclusal record technique was as accurate as conventional techniques in identifying the occlusal contacts. Conversely, a more recent laboratory study[16] demonstrated that this technique presented with significant interarch distance discrepancy.[16]

When comparing between the buccal occlusal scan and the scanned interocclusal record technique in terms of static articulation accuracy, a laboratory study[39] found that buccal occlusal scans of the mounted casts were more accurate than the scanned interocclusal record, especially in prepared teeth sites.[39] The authors attributed this outcome to imprecise matching between the maxillary virtual cast, and the scanned record might be due to some movement of the record during the digitizing process.[39] This is also supported by another laboratory study.[42]

It appears that the number and location of VIRs around the arch affected the accuracy of static virtual articulation.[34,40,48] Bilateral and one frontal or two lateral VIRs showed more accurate articulation than a single restricted VIR.[34,48] However, in situations in which multiple VIRs are not applicable, it is recommended to make a single VIR as adjacent as possible to the region of concern.[40]

Regarding the effect of the length of articulated scans on the accuracy of virtual static articulation, one study showed that quadrant scans' articulation yielded greater

Table 4 Scanner Systems Evaluated in Included Studies

Scanner name	Scanner manufacturer
Intraoral scanners (IOS)	
CEREC Omnicam (CO)	Dentsply Sirona
CEREC Bluecam (CB)	Dentsply Sirona
Dental Wings (DW)	Dental Wings
True Definition Scanner (TDS)	3M ESPE
TRIOS Color (TRC)	3Shape
TRIOS 3 Shape (TS)	3Shape
CEREC AC with CEREC Omnicam (CER)	Dentsply Sirona
Carestream 3500 (CS 3500)	Carestream Dental
Lava Chairside Oral Scanner (LC)	3M ESPE
Comet 100 optical scanner (C)	Steinbichler Optical Technologies,
iTero 2.9 (iT 2.9)	Align Technology
iTero Element (iTE)	Align Technology
PLANMECA Emerald (PE)	Software Romexis 5.0.0.R.
Extraoral scanners (EOS)	
Activity 102 (A 102)	Smart Optics, SensortechnikBochum, Germany
Activity 885 (A 885)	Smart Optics, Sensortechnik
Ortho Insight 3D laser surface scanner (OI)	Motion View Software
Ceramill Map 400 (AG)	Amann Girrbach
inEos X5 (SIR)	Dentsply Sirona
Scanner Arti S600 (ZKN)	Zirkonzahn
ATOS (AS)	ATOS Compact Scan 5M
5-axis XC65D digital cross-scanner (XC)	Nikon Metrology
3-dimensional laser scanner (GH)	GeoDigm

sensitivity for identifying occlusal contacts than complete arch scans' articulation for completely dentate cases due to a reduced tilting effect.[40] In contrast, complete arch scans produced more accurate articulation than quadrant scans in situations where posterior teeth lost occlusal contact after fixed dental prosthesis preparation.[35]

The effect of the position and extent of edentulous areas on the accuracy of virtual static articulation was evaluated by two laboratory studies.[44,45] One study showed that extended partially edentulous scenarios significantly reduced the accuracy of VIR, while single missing posterior tooth cases achieved an excellent degree of accuracy.[44] Another study[45] that assessed VIR precision of different combinations of articulated models showed higher precision for anterior occlusion when the area was surrounded by multiple posterior teeth. However, this precision decreased with a decreasing number of posterior occluding pairs.[45]

It appears from the limited evidence that virtual articulation of sound teeth that maintained opposing occlusal contacts was more predictable than articulation of prepared teeth that lost occlusal stops.[35,39] Further, virtual articulation for arches involving a single prepared tooth was more accurate than those involving multiple preparations.[32]

The effect of the scanner system on virtual articulation accuracy was assessed by four laboratory[39,41,42,45] and two clinical studies.[36,48] Concerning intraoral scanners, two clinical studies found no significant differences between the different IOS systems evaluated.[36,48] In contrast, a laboratory study[41] found significant differences between three IOS systems (True Definition Scanner [3Shape], Trios Color [3Shape], and CEREC AC with CEREC Omnicam [Dentsply Sirona]), with True Definition producing the least accurate results. The authors attributed this outcome to variations in scanning strategies and algorithm software between the three IOS systems and to the use of powder with True Definition, which might negatively affect the scanning accuracy.[41] In addition, another laboratory study[42] demonstrated that iTero 2.9 and iTero Element IOS systems produced more accurate articulation than the True Definition Scanner.

Further, a laboratory study reported a significant difference in VIR precision among CEREC Omnicam, Trios 3, and Planmeca Emeral IOS systems, with Trios 3 achieving the highest precision.[45] Regarding EOS systems, Yee et al[38] found significant differences in virtual articulation accuracy between three evaluated systems (Ceramill Map 400 [Amann Girrbach], inEos X5 [Dentsply Sirona], and Scanner Arti S600 [Zirkonzahn]), with SIR revealing the least precision.[38] Due to variations in the results reported from this inadequate number of studies, no conclusions could be drawn as to the most recommended scanner systems.

The phenomenon of collision between virtual arches was addressed in this review by four laboratory studies.[15,30,46,49] They demonstrated that collision could be managed by incorporating the potential of collision detection and correction in the matching algorithm software,[15,30,46,49] thus avoiding the results of restorations without occlusal contacts.[49]

Although this systematic review provides introductory key information about the accuracy of static virtual articulation, it presents with some limitations. The small number of clinical studies is one of the main limitations. In addition, several studies used IOS systems in vitro that could not replicate the clinical situation,[44] and some studies used EOS systems. Finally, a medium risk of bias was allocated to all studies, except for one, which had a high risk of bias. Future clinical studies should evaluate the accuracy of VIRs in both static and dynamic articulation.

CONCLUSIONS

From the limited evidence available, this systematic review concluded:

1. Most studies showed that buccal occlusal scan VIR had a comparable accuracy to conventional articulation methods in the presence of complete dentate arches, stable occlusal contacts, one prepared tooth, or arches involving a single missing posterior tooth. However, some studies reported that VIR tended to miss some actual occlusal contacts due to collision between the virtual arches, and the VIR precision was reported to be fair by some investigations.
2. It appears that the articulation technique, whether it was a buccal occlusal scan or scanned interocclusal record, the length of the articulated scans, the number and location of VIRs, single restricted or multiple VIRs around the arch, the position and extent of edentulous areas, and whether they were single missing posterior tooth cases or extended partially edentulous scenarios all might affect the accuracy of virtual articulation. However, no conclusions as to whether these factors are main influencers could be drawn.

ACKNOWLEDGMENTS

The authors report no conflicts of interest.

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