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ORIGINAL ARTICLE

Accuracy of different maxillomandibular relationship recording techniques in the edentulous maxillary arch

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Abstract

Purpose: This study investigated the effect of three digital bite registration techniques on the accuracy of intraoral scanning in maxillary edentulous and mandibular dentate arches.

Materials and Methods: Maxillary edentulous and mandible fully dentate models were created. Four dental implants were placed in the maxilla, fitted with scan bodies, and reference scans were obtained using a Nikon Altera 10.7.6 scanner. Digital impressions were acquired 10 times for each model using a Trios 4 intraoral scanner. Three different digital bite records were collected for each pair of mandible and maxilla scans. The first one was a bite record without additional material (WSB), the second utilized a silicone index between the models (WSB silicone), and the third followed a pre-preparation scanning protocol (Pre-PREP). The data was exported in standard tessellation language (STL) format, which was assessed for trueness and precision using statistical analysis.

Results: According to mean trueness values, WSB exhibited the lowest value, 173 µm, followed by WSB silicone 242 µm and Pre-PREP 620 µm. The differences were significant only when comparing Pre-PREP to WSB and Pre-PREP to WSB silicone ($p < 0.05$). Regarding precision, WSB demonstrated a mean value of 171.5 µm, followed by WSB silicone with 213.8 µm, and Pre-PREP with 222.2 µm with no significant difference between the groups.

Conclusion: The presence of interarch bite registration material adversely affected interocclusal record accuracy, while WSB silicone presented a suitable substitute for WSB.

KEYWORDS
accuracy, digital bite registration, edentulous, intraoral scanner

One of the most crucial elements of edentulous arch reconstruction using implants is the maxillomandibular relationship, which helps to create precise fixed prostheses.[1–3] The redetermination of the interocclusal relationship is essential to the outcome when the vertical component of the relationship is altered, and thus redetermination of the vertical dimension is required.[4] Capturing the vertical maxillomandibular relation is a challenging procedure, especially with no existing satisfactory natural or restored dentition. Patient-related variables such as soft tissue quality, tongue movement, and salivation are one group of variables that can influence the accuracy of both arch scanning and bite registration. Soft tissue type, amount of attached tissues, overall mobility, and flexibility may be the reasons for the above-mentioned errors[5–7] along with IOS-related variables such as scanning tip,[8] scanning strategy,[9] stitching algorithm,[10] and scanning environment.[11] Most of these potential sources of error are to some degree reviewed in the literature in the context of scanning accuracy for an individual arch, but there is little to no research exploring these factors in the context of bite scanning for edentulous patients.

In an analog workflow, the patient would typically need to come in for a few sessions in order to capture the maxillomandibular relationship in the edentulous jaw.[5] From wax or other materials, the dental technician can create the bite registration rim that the dentist will subsequently utilize in the patient's mouth.[12–14] Unfortunately, the physical characteristics of the impression materials, such as distortion, expansion, and shrinking, as well as human error, make this analog workflow time-consuming and prone to accuracy problems.[14,15]

In recent years, digital dentistry technology has made it possible for practitioners to register the required maxillomandibular relations more quickly and efficiently by using intraoral scanning.[16] Among the more widely used methods are scanning bite registration using scanbodies,[17] creating a chairside custom silicone bite rim, or using pre-preparation scanning of the existing dentures.[13,16–20] Although scanning just with scanbodies as a reference for bite registration or creating a silicone index before beginning a scanning procedure are quick and simple ways to record the maxillomandibular relationship, there are few reports in the literature regarding the accuracy of such techniques. Additionally, this technique is prone to stability issues similar to those encountered with the analog techniques.[1,18] Moreover, according to a recent study, the digital bite registration workflow was reported to be 60% faster than the analog bite registration workflow.[17]

There are benefits to recording maxillomandibular relationships using a pre-preparation method.[15] A pre-preparation scanning protocol (Pre-PREP) allows the clinician to take a few impressions for the same jaw. Following the completion of the pre-preparation digital impression, the software allows the clinician to delete necessary parts and scan the secondary impression. Both scans appear in the same coordinates. In this way, the interarch distance and other significant dental characteristics are among the numerous useful pieces of information that the pre-preparation scan provides to the dental technician. However, before scanning the mucosa and implant scan bodies, a significant amount of the scan must be removed, which could cause an error in the accuracy of bite registration.[21] It is necessary to mention the fact that traditional elastomeric materials are also prone to distortion in various conditions.[1]

In terms of accuracy, our results are comparable to other studies. A bite registration technique using scanbodies was similarly utilized in an in vivo study by Nuytens et al.[17] and it was concluded that the overall deviation was around 1 mm, which according to the authors, can be considered clinically acceptable. The silicone index technique for edentulous maxillomandibular registration, was utilized in previous research.[22] This technique was used to record a maxillomandibular relation between the edentulous maxilla and mandible. Four different scanning systems were compared and, according to the findings, mean trueness deviations ranged from 74 to 513 μm and precision from 90 to 565 μm. To the best of the authors' knowledge, there are no studies regarding the accuracy of the full arch pre-preparation bite registration technique.

Therefore, this study aimed to investigate the effect of three different maxillomandibular relationship recording techniques on the accuracy of digital bite registration using an intraoral scanner. The null hypothesis was that there was no significant difference between the accuracy of bite records established by the three maxillomandibular relationship recording techniques.

MATERIALS AND METHODS

Using a 3D printer (Asiga Max UV, version 1.2.11, Sydney, Australia), one maxillary edentulous and one mandible fully dentate model were created in accordance with the Frasaco model (Frasaco GmbH, Tettnang, Germany) design. For 3D printing, Asiga DentaMODEL (Asiga, Sydney, Australia) dental model resin was used (at room temperature 23°C). Washing was done in two steps, pre-washing for 5 min in an ultrasonic bath and post-washing in an ultrasonic bath for 5 min in 98%+ pure isopropyl alcohol (IPA). Models were dried thoroughly after washing and before post-curing. Final polymerization was done in Asiga Flash Curing Unit for 20 min. Models were mounted in KaVo Protar evo 7 (KaVo Ker, Brea, California, United States). The articulating pin was set to a specific length and was never adjusted during data collection. During bite registration, a five-kilogram weight was attached to the top of the articulator to standardize the pressure of the upper part of the articulator.

Four dental implants (4.1 mm, BLT RC, Straumann, Basel, Switzerland) were freehand positioned symmetrically in the canine and first molar regions of the maxilla model. The implants were fitted with scan bodies (CARES RC Mono scan body, Straumann, Basel, Switzerland) using a cordless electric screwdriver (NSK iSD900, Tokyo, Japan) set to 15 Ncm torque.

Each model had five metrological spheres, 5 mm in diameter and a tolerance of 1 μm, (MIB-Messzeuge GmbH, Spangerberg, Germany) affixed to the vestibule area of the maxillary and mandibular dental arches for measuring of maxillomandibular distances after scanning. Nikon Altera 10.7.6 (Nikon Metrology, Shinagawa, Tokyo, Japan) was used to obtain reference scans ($n = 1$).

Using an intraoral scanner (Trios 4, 3Shape, version 19.2.2), a standard scanning protocol was utilized to obtain both maxillary and mandibular models. The scanning sequence employed was according to the manufacturer's recommendations. For the edentulous model, scanning started with the alveolar ridge, then palatal aspect, and finally the buccal aspect. For the dentate model, first the occlusal surface, then the buccal, and finally the lingual aspect was scanned. After scanning of alveolar part, scanning was extended to capture the border part of the model to capture metrological spheres. Three different maxillomandibular relationship recording techniques were implemented ($n = 10$). All experimental bite registration scans were performed without capturing metrological spheres to prevent the IOS software from using them to capture the bite. Using scan bodies attached to the upper model, the first group of maxillomandibular dimension registrations, scanning the buccal aspects of the models from side to side (WSB),

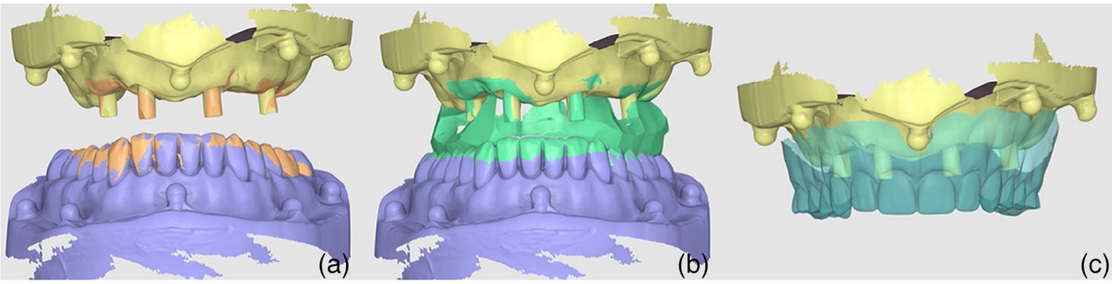

FIGURE 1 The representative image of three groups investigated in the study utilizing different bite registration strategies: (a) with scan bodies (WSB group) attached to the implants; (b) silicone index added to the maxillary model and buccal aspect of the scan bodies exposed (WSB silicone group); (c) pre-preparation scan of the maxillary removable denture, followed by bite registration and then deletion of denture image and registering scan bodies' images with IOS (Pre-PREP group).

involved capturing bite records between the maxilla and mandible in a static maxillomandibular position. The second group underwent the same maxillomandibular relationship recording technique but with the inclusion of a polyvinyl siloxane interocclusal index between the two models (WSB silicone). A mandibular occlusal and maxillary edentulous ridge impression with silicone putty (Variotime Easy putty, Kulzer GmbH, Germany) was fabricated, cut, and reduced through the alveolar ridge crest to reveal the buccal region of the edentulous maxilla to facilitate scanning the buccal surface of the scan body and alveolar ridge. In accordance with the Pre-PREP, the third group of intermaxillary connection registration was completed.[15] A digital impression of a prefabricated maxillary removable denture fitted onto the maxillary model was obtained. The removable denture was manufactured covering two-thirds of the palate to represent the clinical situation of a patient with an existing removable denture. After the mandibular model scan was conducted, the digital bite registration was done with a removable denture seated on the maxillary model in maximal intercuspal position. The implant position was acquired after the maxillomandibular relationship was established (Figure 1). Scanning was carried out from the remaining part of the palate after deletion of the removable denture, by moving the scanner outward from the palatal area to the alveolar ridge, capturing implant positions and attached soft tissue area.

The scanning sequences were implemented in accordance with IOS documentation and manufacturer recommendations. The scanning data were exported in standard tessellation language (STL) format. The maxillomandibular relation was represented by measuring distances between the pairs of corresponding metrological spheres (Figure 2). The distances between spheres measured on the scan acquired using a metrological scanner were regarded as a reference using metrology software (Geomagic Control X version 2022.1.0, 3D Systems, USA). The identical measurements were implemented on each maxillomandibular relationship record obtained using three different strategies. Trueness and precision were calculated, and pairwise comparisons were made between three maxillomandibular relationship records groups.

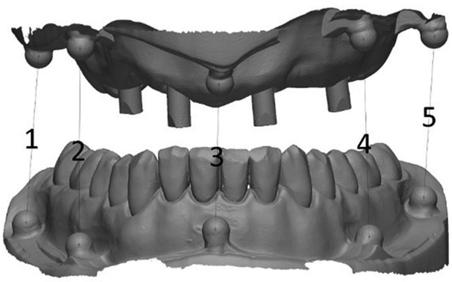

FIGURE 2 The representative image of metrological spheres and their corresponding pairs in the opposite arch with five different distances measured for trueness and precision evaluation among the groups.

The statistical analysis of the data was conducted using MATLAB 2020a (The MathWorks Inc., Santa Clara, USA). The normality of the data was computed using the Shapiro–Wilks test. The homogeneity of variances was tested using Levene's test. A one-way ANOVA was conducted to analyze variance across groups in trueness data, followed by the Games-Howell post hoc test for multiple comparisons between groups. The precision data were non-normally distributed across groups and were further analyzed using the Kruskal–Wallis test for group comparisons ($\alpha = .05$). If needed, the Conover post hoc test with Bonferroni correction was used.

RESULTS

The WSB group presented the most accurate results, followed by WSB silicone and Pre-PREP, respectively, in both the trueness and precision of bite records. Although the difference in trueness values between the groups was statistically significant ($F(2;90.75) = 29.68$, $p = 4.78 \times 10^{-11}$), the difference in precision values between the groups was statistically insignificant ($\chi^2(2) = 2.37$, $p = 0.3$).

In terms of trueness, WSB presented values between 65 ± 47 µm and 212 ± 132 µm with a mean value of 173 µm. WSB silicone values were between 86 ± 106 µm and 443 ± 241 µm with a mean value of 242 µm while the values of Pre-PREP ranged between 196 ± 177 µm and 991 ± 122

TABLE 1 Mean, standard deviation, and median between the spheres among the groups in terms of trueness values with the summary of ANOVA results for group comparison ($\alpha = 0.05$).

Bite registration techniques	Distance (µm)												
	1		2		3		4		5				
	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean distance	Median distance	Statistics
WSB	396 (200)	332	118 (103)	86	65 (47)	52	107 (68)	107	177 (140)	158	173	130	F(2;90.75) = 29.68, $p \leq 0.05$
WSB silicone	443 (241)	429	115 (139)	42	86 (106)	50	191 (169)	124	374 (242)	337	242	141	
Pre-PREP	196 (177)	195	302 (90)	299	818 (137)	854	991 (122)	997	794 (378)	751	620	171	

Abbreviations: Pre-PREP, pre-preparation scanning protocol; WSB, without additional material.

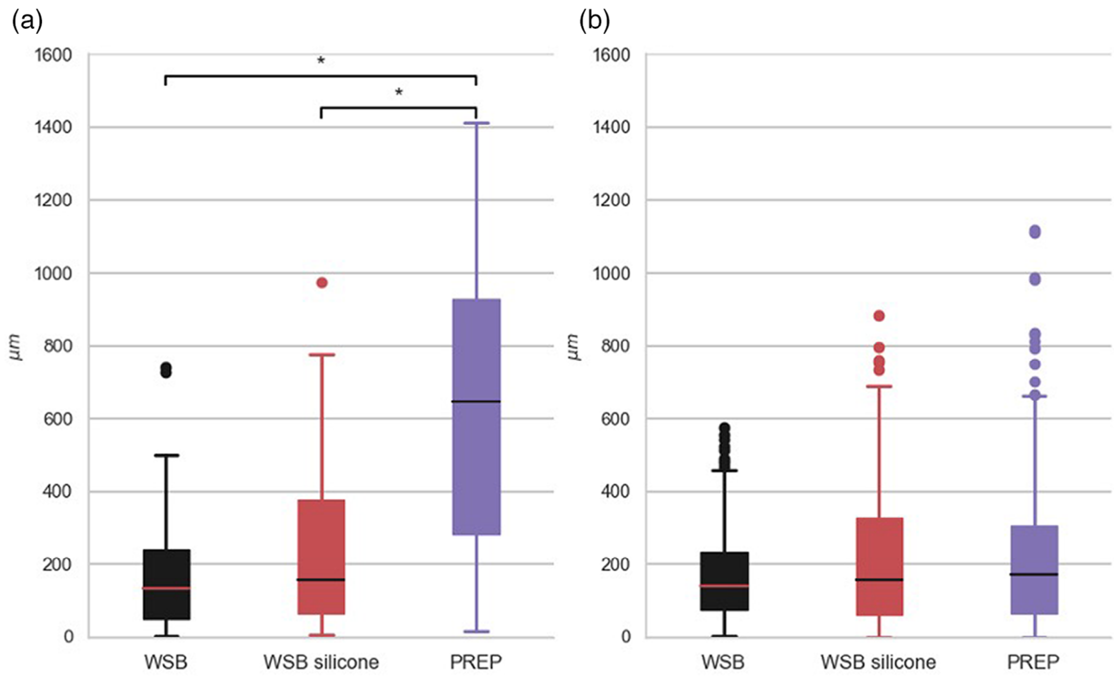

FIGURE 3 Trueness (a) and precision (b) data. Asterixis and lines connecting the data imply a significant difference ($p < 0.05$) between them.

TABLE 2 Multiple comparisons of mean difference (Games-Howell test results) of the trueness values among the groups.

Pair					
A	B	Mean (A)	Mean (B)	Difference	*p*-values
Pre-PREP	**WSB**	620	173	447	9.84×10^{-11}
Pre-PREP	**WSB silicone**	620	242	378	2.59×10^{-8}
WSB	**WSB silicone**	173	242	⁻69	0.2

Abbreviations: Pre-PREP, pre-preparation scanning protocol; WSB, without additional material.

µm with a mean value of 620 µm (Table 1, Figure 3a). The differences between Pre-PREP and WSB ($p = 9.84 \times 10^{-11}$) as well as Pre-PREP and WSB silicone were statistically significant ($p = 2.59 \times 10^{-8}$), while the difference between WSB and WSB silicone was statistically insignificant ($p = 0.2$) (Table 2, Figure 3a).

In terms of precision, WSB presented values between 95 ± 59 µm, and 228 ± 169 µm with a mean value of 171.5 µm. WSB silicone values were between 137 ± 125 µm and 297 ± 187.9 µm with a mean value of 213.8 µm while the values of Pre-PREP ranged between 102 ± 185 µm and 440 ± 303 µm with a mean value of 222.2 µm. No significant

TABLE 3 Mean, standard deviation, and median between the spheres among the groups in terms of precision values with the summary of Kruskal–Wallis for group comparison.

Bite registration techniques	Distance (μm) 1 Mean (SD)	1 Median	2 Mean (SD)	2 Median	3 Mean (SD)	3 Median	4 Mean (SD)	4 Median	5 Mean (SD)	5 Median	Mean distance	Median distance	Statistics
WSB	228 (169)	190	167 (109)	143	95 (59)	81	156 (101)	147	212 (132)	181	172	140	$\chi^2(2) = 2.37$, $p = 0.3$
WSB silicone	268 (210)	199	144 (139)	101	137 (125)	92	223 (198)	183	297 (187.9)	266	214	156	
Pre-PREP	266 (185)	231	102 (77)	80	161 (106)	138	142 (99)	130	440 (303)	420	222	170	

Abbreviations: Pre-PREP, pre-preparation scanning protocol; WSB, without additional material.

difference was observed in pairwise comparisons among the groups (Table 3, Figure 3b).

DISCUSSION

In this in vitro study, three different maxillomandibular relationship recording techniques were compared in terms of the accuracy of bite records. According to the results of this study, the difference between the adopted strategies was statistically significant in terms of trueness and statistically insignificant in terms of precision. Therefore, the null hypothesis was rejected.

Digital impressions have been shown to be just as precise as traditional impressions for both tooth-supported and implant-supported fixed partial prostheses. However, manufacturing full-arch implant-supported reconstructions using a digitalized approach continues to present difficulties.[17] The absence of reference points brought on by ridge resorption and missing teeth are the two most important obstacles to achieving optimal precision with the digital scanning process.[23] The accuracy of digital scanning can be impacted by various factors, including IOS device-related factors,[14–26] intraoral factors,[27–29] and operator-related factors.[30,31] Although recent studies have shown that full-arch digital implant impressions can be produced accurately enough to produce a passive fit,[21,32–34] a bite rim or tooth guide are examples of tangible auxiliary items that are still needed for maxillomandibular relationship recording. The technique used for the acquisition of the digital impression of the arches and bite records is reported to have a significant impact on the accuracy of the final digital product.[14,15,24] In the present study, a single IOS was used in an in vitro environment by a single operator to minimize the affecting factors to gather homogenous results with a purpose to compare the three different maxillomandibular relationship recording techniques which presented different results in terms of accuracy and precision. In all measurements, the technique with no bite registration rim, WSB, presented the best accuracy, followed by WSB silicone with similar results. This might be due to the exposure of actual arch surfaces to the digital scanning process, thus creating more accurate digital scanning process compared to the pre-preparation technique. Because a significant portion of the scanned data must frequently be removed, including information that is essential for IOS to stitch data, the pre-preparation scanning workflow in edentulous arches may be a source of error.[35] Even though this procedure takes less time than the silicone index technique,[14] errors may arise in the end if more data has been deleted before the final scan. Therefore, the significant amount of erased data may be the cause of the increased disparities in trueness and precision regarding the pre-preparation technique.[15,35,36]

However, since the procedure requires fewer visits and involves fewer materials and steps, the pre-preparation technique is highly appreciated by both the laboratories and the patients.[5,15,35] Moreover, the technique enables the simultaneous scanning and alignment of intraoral scans of dental arches and discards the extraoral scanning and aligning process. Therefore, the pre-preparation technique is an essential component of the digital workflow in daily clinical practice, simplifying the communication between dentists and dental technicians.[15,35]

However, according to the results of this study, this technique should be further improved to increase accuracy in comparison to WSB and WSB silicone techniques. Because of the specific nature of this study, it is hard to compare these results to other studies. A study by Cha et al. utilized a similar methodology to measure the deviation after bite registrations.[37] The biggest difference between study protocols was that the replica models employed in this study represent scenarios where only a single upper molar is missing as opposed to our fully edentulous scenario. Mean deviations for full arch scans and bilateral scanning strategy were up to 87 μm. Similarly in this in vivo study maxillomandibular relation for both dentate arches were measured. Mean discrepancies were 31 ± 19 μm, but in some areas, deviations were up to 700 μm.[38] In vivo study by Ren et al. indicated, that for long-span defects a mean deviation of 0.8 ± 0.52 mm was observed, which is comparable to results from our study.

In the present study, data suggests that bite scans performed in situations without the presence of additional objects produced the most reliable results. It might be because bite alignment for these scan types was done only based on scan body position, making them the clearest scan types.[14,17] The stability of both models was ensured by the articulator. However, it would be virtually impossible to ensure the stability of the mandible in the clinical environment without any additional bite registration and stabilization device. Within other categories, such as scan bodies plus silicone index, the scan body shape has a partial silicone covering that is not detected.[39] In clinical situations with edentulous patients, the stability of the mandible and additional objects used to aid maxillomandibular relationship recording is crucial.[17,39] Moreover, in an in vivo context, the tongue would partially obscure the scan body surface, making it more challenging to scan the maxillomandibular relationship between the maxilla and mandible without the use of an auxiliary device.[40]

However, creating these interarch bite indexes is not standardized, and the visibility of scan bodies during the digitalized maxillomandibular relationship records is a prerequisite for better-established interocclusal records.[21,41,42]

The in vitro study design is one of the primary drawbacks of the present study. The instability of the mandible without any additional bite stabilization device could significantly compromise the accuracy. The maxillary denture from the pre-preparation group covered a large area of the palate without additional reference objects, thus compromising the accuracy during the stitching of the images. It can be speculated that if a fixed temporary implant-supported full-arch denture and additional reference object attached to the palate were used, the results would be better. Considering other clinical conditions that are not simulated in the in vitro study, it should be mentioned that the saliva-covered smooth, mobile mucosa are the biggest obstacles to accurate image-stitching with IOS when scanning a fully edentulous arch.[43] The vestibule area's precise depth may be obstructed by the IOS device tip's design, which prevents it from circumnavigating the maxilla's tuberosity.[44] Furthermore, soft tissue mobility triggered during the scanning process might cause the accuracy of the digital impression to decrease further; as a result, the final digital implant location becomes distorted due to the defective stitching process of the digital images.[40] Therefore, the performance of the evaluated maxillomandibular relationship recording strategies should be further assessed in future clinical studies.

CONCLUSIONS

The accuracy of interocclusal records was negatively impacted by the use of the pre-preparation technique when a denture covering a large part of the palate was used. The suggested method (WSB silicone) exposed scan bodies and the buccal vestibule section of the arches to the scanning process, provided similar results as in the group without any interarch material (WSB) and could help to stabilize the mandible in clinical situations.

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CONFLICT OF INTEREST STATEMENT

The authors did not have any commercial interest in any of the materials used in this study.

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