Journal of Oral Science, Vol. 59, No. 3, 431-438, 2017

Original

Geometrical effects of conventional and digital prosthodontic planning wax-ups on lateral occlusal contact number, contact area, and steepness

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(Received August 15, 2016; Accepted November 24, 2016)

Abstract: This study evaluated and compared the effect of conventional and digital wax-ups on three lateral occlusion variables: contact number, contact area, and steepness. Dental casts of 10 patients with Angle Class I relationship were included in the study. All patients required fixed prosthodontic treatment that would affect lateral occlusion. The casts of all patients received conventional and digital wax-ups. For pretreatment, conventional wax-up, and digital wax-up casts, contact number, contact area, and occlusion steepness were measured at four lateral positions, that is, at excursions of 0.5, 1.0, 2.0, and 3.0 mm from maximal intercuspation. Lateral occlusion scheme variables were affected by use of diagnostic wax-ups. For all types of casts, contact number decreased as excursion increased. The two types of wax-ups had similar contact number patterns, and contact number was significantly greater for these casts than for pretreatment casts in the earlier stages of excursion. Similarly, contact area gradually decreased with increasing excursion in the pretreatment and conventional and digital wax-up casts. There was only a minimal decrease in occlusion steepness as excursion increased. However, lateral occlusion was generally steeper for digital wax-up casts.

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Color figures can be viewed in the online issue at J-STAGE.
doi.org/10.2334/josnusd.16-0610
DN/JST.JSTAGE/josnusd/16-0610

Keywords: digital dentistry; wax-up; dental occlusion; contact number; contact area; steepness.

Introduction

For many patients, fixed prosthodontic treatment is indicated for improvement of esthetics, comfort, and function. However, fixed prosthodontic treatment usually affects the static and dynamic occlusal relationship. Occlusion scheme, contact number, contact area, and occlusion steepness may be altered by complex prosthodontic treatment (1,2). The lateral occlusion scheme has been extensively studied, as it is believed to control mandibular movement, chewing efficiency, restoration longevity, and patient comfort (2). The most recent studies indicate that occlusion should conform to an individual's masticatory physiology (3-5). The Glossary of Prosthodontic Terms defines physiological occlusion as any occlusion that is in harmony with the functions of the masticatory system (6). Thus, lateral occlusions not associated with mechanical, biological, or esthetic problems can be classified as physiological. From a research perspective, it is reasonable to relate the occlusion scheme after prosthodontic treatment to what has been observed in natural physiological occlusion.

Contact number, contact area, and steepness are the occlusal variables that define the lateral occlusion scheme. Contact number in different lateral positions reflects the number of contact points present during mastication and the manner in which lateral forces are dissipated on the occlusal surface (7-10). The extent of contact area is thought to be related to occlusion stability

(1,11). Occlusal steepness is part of mandibular border movement and may affect the design of prostheses, the smoothness of gliding movement, and patient comfort (12-14).

Complex prosthodontic treatment is associated with significant dental changes; therefore, several clinicians recommend use of a diagnostic wax-up (15,16), that is, simulated dental treatment on diagnostic casts. Treatments such as tooth removal, tooth movement, and morphological alteration can be done with a diagnostic wax-up. In addition, a good wax-up can be used to control tooth preparation and fabricate provisional and subsequent definitive restorations (15,16). Thus, a diagnostic wax-up provides a good indication of how a planned treatment will affect dental occlusion. Moreover, use of a diagnostic wax-up markedly enhances clinician-patient and clinician-technician communication. Traditionally, a diagnostic wax-up is created by altering the tooth surface with the addition of wax (15,16) and therefore largely depends on the artistic abilities of dental technicians. Recently, with the advancement of digital technologies, digital diagnostic wax-ups have been proposed as an alternative treatment (17). Digital diagnostic wax-ups involve virtual modifications of tooth morphology based on average tooth shape, a biogeneric library, or mirror imaging of ideal adjacent teeth (18,19). It is thought that digital wax-ups can reduce wax-up time and material manipulation (17). However, for digital wax-ups to be accepted as a viable tool they must be comparable to conventional wax-ups.

This study evaluated and compared the effects of conventional and digital diagnostic wax-ups on three occlusal variables that dictate lateral occlusion, namely, contact number, contact area, and steepness. The hypotheses tested are that there is a difference between pretreatment and wax-up casts and there is no difference between the two wax-up casts.

Materials and Methods

Diagnostic wax-ups

Dental casts of 10 patients receiving fixed prosthodontics were collected for this study. The treatment indications were management of failed restorations, tooth wear, esthetic problems, and short-span bound edentulous areas equivalent to a single missing tooth. For all patients, the planned treatment had the potential to alter lateral occlusion. The inclusion criteria were 1) need for tooth-supported fixed prosthodontic treatment (crowns or fixed partial dentures), 2) need for diagnostic wax-up before treatment, 3) presence of natural canines and stable occlusal contacts on the posterior teeth, 4) presence of Angle Class I relationship, and 5) absence of masticatory or temporomandibular joint disorder. The patients were treated at the Oral Health Centre of Western Australia, and the experiment complied with human research ethics approval obtained from the University of Western Australia Human Research Ethics Committee (RA/44/1/5079).

For each patient, pretreatment casts were created by filling irreversible hydrocolloid impressions (Alginate, GC America, IL, USA) with type III dental stone (Buff Stone, Adelaide Moulding & Casting Supplies, South Australia, Australia). The centric relation was recorded for every patient by injecting intraoral vinyl polysiloxane registration material (GC Exabite, GC America). The centric relation position was used to ensure that the wax-up procedure was not influenced by existing occlusal contacts and was obtained by manipulating the mandible in the most retruded physiological position (6). For every cast, two duplicate casts were produced from hydrocolloid duplicating molds (Magafeel, MKM System, Haanova, Slovakia). The first duplicate cast represents the pretreatment situation and was used as a template for the digital wax-up. The other duplicate cast was used for the conventional wax-up (Fig. 1).

The first sets of casts—the pretreatment casts—were articulated according to maximal intercuspation on a semi-adjustable articulator (Whip Mix, Louisville, KY, USA). The maximal intercuspation position was used for articulation of pretreatment casts because it is the habitual position for the patient before any occlusal alteration. For the conventional wax-up, the casts were articulated on the semi-adjustable articulator, in accordance with the centric relation, by using clinically obtained intraoral records. This allowed reestablishment of occlusal contacts by the wax-up without interference from pretreatment occlusal contacts. The conventional wax-up was created by additive waxing technique to alter the tooth surface. This step was performed by an experienced fixed prosthodontics technician. The purpose of the wax-up was to restore natural tooth morphology, dental esthetics, and bilateral occlusal contacts. For the initial excursions, a group function lateral occlusion scheme was planned. The articulated pretreatment and conventional wax-up casts were indexed by adapting silicone material putty (Dental Speedex Putty, Coltene/Whaledent AG, Altstatten, Switzerland) on the facial aspects of the posterior teeth.

The pretreatment and conventional wax-up casts were separated from the articulating bases and scanned with a micro-CT scanner (SkyScan, Bruker microCT, Kontich, Belgium). All silicone indices were scanned with the micro-CT scanner. The scanning process yielded a

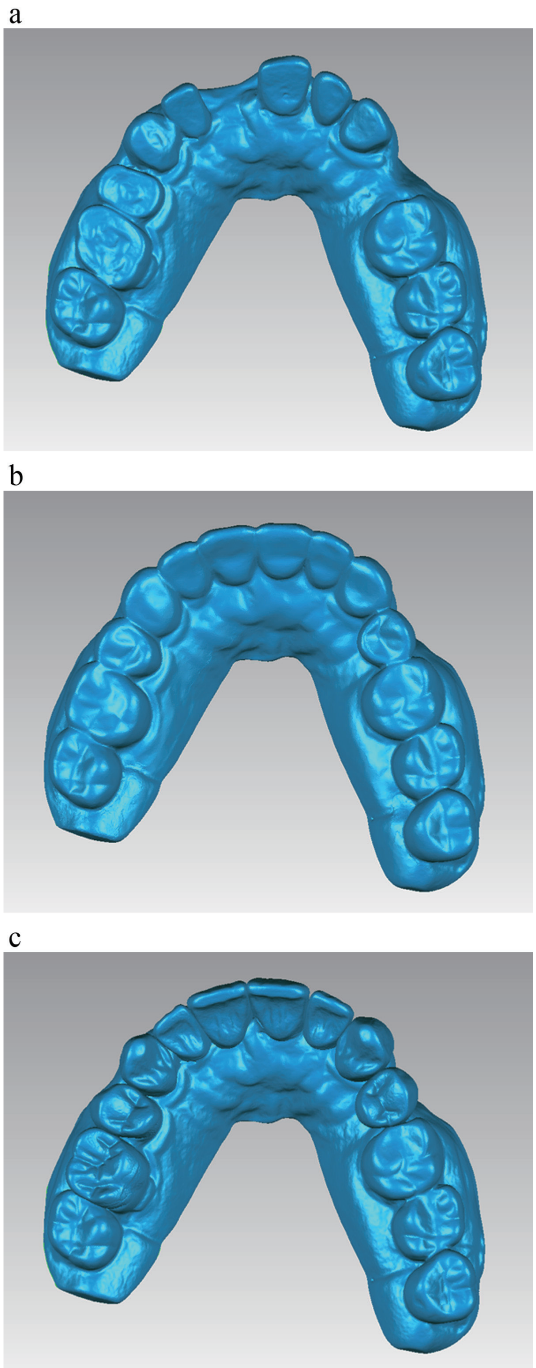

Fig. 1 Representative diagnostic wax-ups. (a) Pretreatment virtual cast. (b) Conventional wax-up virtual cast. (c) Digital wax-up virtual cast.

series of stacked Digital Imaging and Communication Medicine (DICOM) images, which were converted to virtual 3D stereolithography (STL) casts with DICOM viewing software (CTvox, Bruker microCT). Industrial 3D rendering software (Geomagic Studio, Raindrop Geomagic Inc., Research Triangle Park, NC, USA) was used to view and virtually articulate the digital casts. To establish the spatial articulation of casts, the common surfaces between maxillary and mandibular casts and the associated silicone indices were matched virtually. This was followed by elimination of the silicone indices.

As described previously (17), digital wax-ups were created on virtual pretreatment casts. Copies of virtual pretreatment casts were articulated by superimposing them on conventional wax-up casts. The unaltered surfaces were used to control superimposition. Therefore, the casts were articulated in accordance with the centric relation before digital wax-up. A database of virtual natural teeth molds (Phonares Teeth, Ivoclar Vivadent AG, Schaan, Liechtenstein) was used as a template to modify tooth morphology with 3D rendering software (Geomagic Studio). The virtual size of teeth was modified to ensure optimal fit against existing teeth. In addition, each virtual tooth was rotated and translated to ensure a natural emergence profile, esthetics, and symmetry. Ultimately, the virtual cast and teeth were fused to produce a single cast (Fig. 1c), which enhanced subsequent manipulation and mathematical analysis.

Simulation of virtual lateral movement

Four horizontal excursive positions from maximal intercuspation were considered: 0.5, 1.0, 2.0, and 3.0 mm. Excursive motion was simulated by fixing the maxillary cast and horizontally displacing the mandibular cast toward the working side to each excursive position. This step was followed by gradual vertical (perpendicular) displacement of the mandibular cast, away from the maxillary cast, by 0.05-mm increments. After disappearance of all contacts on the working side, the mandibular cast was shifted vertically toward the maxillary cast by 0.05 mm. This process could be used to detect the existing working-side contacts that control lateral occlusion (20). In this experiment, all lateral occlusion variables were evaluated for each working side. Because virtual simulation of condylar movement is unreliable, non-working side contacts were not considered (20). To ensure standardization, the virtual casts of all patients were subjected to a similar pattern of virtual movement.

Analysis

In each lateral position, three occlusal variables were measured: 1) number of contacts, 2) contact area, and 3) steepness. Number of contacts was measured by counting the number of contacting teeth in each excursive position (Fig. 2). The virtual casts were imported to mesh quantifying software (Meshlab Software, Visual Computing Lab, University of Pisa, Italy) to evaluate occlusal contact number and area. A threshold of 200 μm was used to analyze the contacting surfaces (21,22).

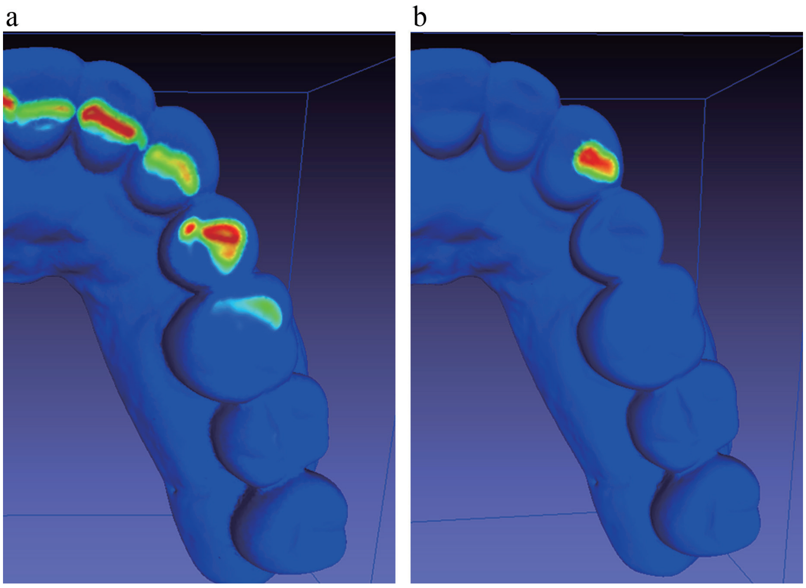

Fig. 2 Changes in occlusal contact number and area with increasing excursion. (a) 0.5-mm excursion. (b) 3.0-mm excursion.

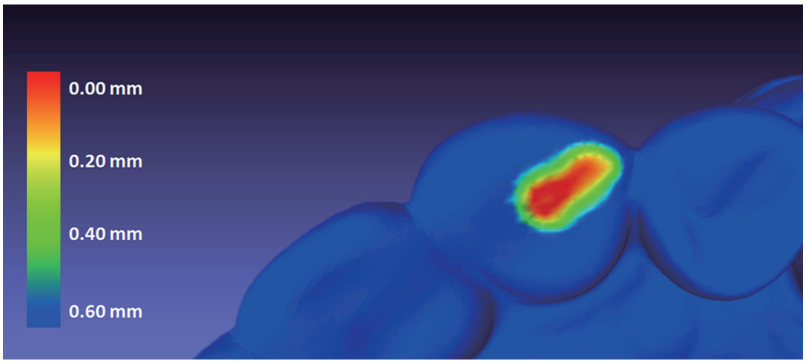

Fig. 3 A color-labeled map showing contact number and area. Occlusal contact number was determined by counting areas with yellow peripheries. To quantify occlusal area, areas with yellow peripheries were extracted and measured.

To visualize the occlusal relationship of the opposing occlusal surfaces, Meshlab was used to color-label the occlusal surfaces on a 3D map. The color yellow represents a distance of 200 µm, and red denotes a distance of 0 µm (Fig. 3). Thus, the number of occlusal contacts was calculated after counting the yellow spots on the occlusal surface. Occlusal regions with yellow peripheries were quantified, and the value obtained represented contact area. Occlusion steepness was measured in each position by relating the vertical mandibular displacement to horizontal excursive movement. The following equation was used to measure the angle of steepness (θ), in degrees:

$$\theta = \tan^{-1} \frac{Horizontal\ excursion}{Vertical\ displacement}$$

Statistical analysis

For all variables, the Kruskal-Wallis test was used to evaluate differences between data for different positions ($P = 0.05$). When a significant difference was observed, the Mann-Whitney test was used for post-hoc analysis. In addition, differences between pretreatment, conventional wax-up casts, and digital wax-up casts were investigated for all variables.

Results

The mean (SD) values for contact number, contact area, and steepness are presented in Table 1. For all evaluated variables, the patterns of change during excursion were similar for the cast groups (Fig. 4).

Contact number

In all cast groups, the number of occlusal contacts

Table 1 Mean (SD) values for contact number, area, and steepness for pretreatment and conventional and digital wax-up casts

Position (mm)	Pretreatment		Conventional wax-up		Digital wax-up	
			Contact number			
	Mean	SD	Mean	SD	Mean	SD
0.5	3.6	1.05	4.9	1.41	5.1	1.17
1.0	3.1	0.55	3.9	1.07	3.9	1.17
2.0	2.7	0.80	2.6	0.68	2.5	0.51
3.0	2.2	0.41	2.1	0.31	2.5	0.69
			Contact area			
	Mean (mm^2)	SD (mm^2)	Mean (mm^2)	SD (mm^2)	Mean (mm^2)	SD (mm^2)
0.5	2.13	1.27	2.30	1.57	2.23	1.30
1.0	0.91	0.54	1.45	1.15	1.40	1.06
2.0	0.62	0.36	0.79	0.82	0.72	0.53
3.0	0.26	0.14	0.35	0.26	0.43	0.44
			Occlusion steepness			
	Mean (°)	SD (°)	Mean (°)	SD (°)	Mean (°)	SD (°)
0.5	38.62	18.18	48.80	18.25	60.00	13.04
1.0	36.63	14.18	43.34	14.02	52.48	11.55
2.0	32.70	14.07	37.71	10.65	45.58	11.25
3.0	30.98	13.53	34.30	8.89	41.40	10.18

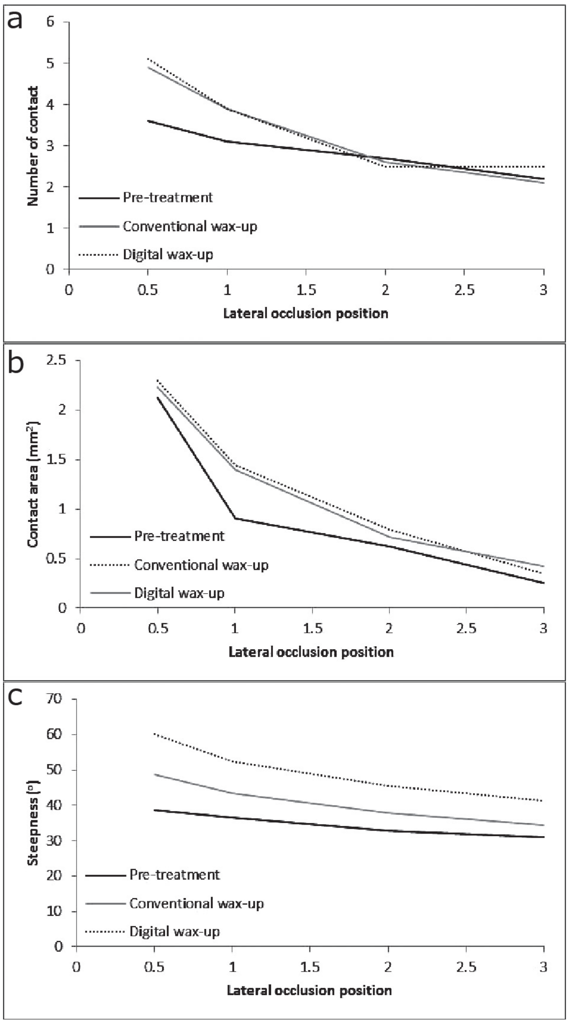

Fig. 4 Effect of increasing excursion on lateral occlusion variables. (a) Occlusal contact number. (b) Occlusal contact area. (c) Occlusion steepness.

gradually decreased as excursion increased (Fig. 4a). The decrease in contact number was less obvious for pretreatment casts, but there was a significant difference in contact number between the 0.5-mm and 2.0-mm positions ($P = 0.007$) and between the 0.5-mm and 3.0-mm positions ($P < 0.001$). For conventional wax-ups, there were significant differences in all comparisons ($P < 0.001$). For digital wax-ups, there were significant differences in all comparisons ($P < 0.001$), except for the comparison between the 2.0-mm and 3.0-mm positions.

Contact number was significantly greater for the wax-up cast groups than for the pretreatment casts at excursions of 0.5 mm ($P < 0.001$) and 1.0 mm ($P = 0.011$). However, there was no difference between the pretreatment casts and the two wax-up casts at excursions of 2.0 mm and 3.0 mm. The two wax-up casts had similar contact numbers at all positions.

Contact area

For all cast groups, contact area progressively decreased with increasing excursion (Fig. 4b). In addition, variation in the recorded contact area decreased as excursion increased. For pretreatment casts, there was a significant difference in all comparisons of positions ($P < 0.001$), except for the comparison between the 1.0-mm and 2.0-mm positions. For the conventional wax-up, there was a significant difference in all comparisons ($P < 0.001$), except for the comparison between the 0.5-mm and 1.0-mm positions. For digital wax-ups, all comparisons of positions yielded significant differences ($P < 0.001$).

For all comparisons of excursive positions, there was no significant difference in contact area in any cast group.

Occlusion steepness

Steepness slightly decreased with increasing excursion (Fig. 4c). Further, variation in steepness was obvious, especially for the pretreatment and conventional wax-up cast groups. For pretreatment casts, the decrease in steepness did not significantly differ in relation to excursive position. For conventional wax-ups, there was a significant difference between the 0.5-mm and 2.0-mm positions ($P = 0.020$), between the 0.5-mm and 3.0-mm positions ($P = 0.004$), and between the 1.0-mm and 3.0-mm positions ($P = 0.014$). For digital wax-ups, there was a significant difference in all comparisons ($P < 0.001$), except for the comparison between the 2.0-mm and 3.0-mm positions.

For all excursion positions, steepness was significantly greater for the digital wax-up casts than for the pretreatment ($P < 0.01$) and conventional wax-up ($P < 0.05$) casts. The pretreatment and conventional wax-up casts had similar values for steepness.

Discussion

This study indicates that lateral occlusion is related to the type of wax-up used before prosthodontic treatment. Further, the studied lateral occlusion variables were affected by excursion position. The variables most affected were contact number and area, which clearly decreased as excursion increased. This finding supports the hypothesis the lateral excursion within functional boundaries is complex and should be evaluated along the excursive path rather than at a specific location (5,8,23).

The inverse relationship between contact number and magnitude of excursion accords with several earlier reports (8,23-25). At earlier stages of excursion, many teeth will still be in contact because of the "freedom in centric occlusion" that is naturally present (5,26). As the magnitude of excursion increases (beyond 1 mm), interference within guiding surfaces will disclude the mandibular arch (10,27). Thus, at the position of maximal excursion (3.0 mm), the least number of teeth will be in contact. This was confirmed in several earlier studies, which found a higher prevalence of group function occlusion during earlier stages of excursion and a greater prevalence of canine-guided occlusion at maximal excursion (8,24,25).

After wax-up modifications, the contact numbers at early stages of excursion increased, which caused a steeper reduction in occlusal contacts during excursion. This is most likely related to the restoration of occlusal morphology and replacement of missing teeth. When a diagnostic wax-up is created, the operator aims to incorporate cuspal inclinations and occlusal anatomy that conform to the opposing arch, which will eventually increase the number of occlusal contacts. Because natural dentition or minimally restored dentition has more contacts during the initial stages of excursion (5), wax-up procedures might cause lateral occlusal contacts to be closer to the natural state. Since digital wax-ups had outcomes similar to those of conventional wax-ups, it is likely that restoration of occlusal contacts with a digital wax-up was at least as efficient as the conventional wax-up in restoring mastication. Some cross-sectional studies found that an increase in the number of contacts during the early stages of lateral excursion was associated with shorter duration of mastication (28,29) and less condylar displacement (30). This might increase mastication efficiency and lessen temporomandibular strain (28-30).

Few studies have examined contact area. Past research of the occlusal area used articulating paper (27), occlusal registration strips (23), impression material (31-33), wax, (34) and the Dental Prescale system (11). More recent research has used digital methods of quantifying the occlusal contact area (10,22,35). Digital methods have several advantages: they allow simultaneous evaluation of multiple occlusal variables and precise calculation of quantified areas (35,36). However, the measured area was related to the quantification method, as slight vertical displacement will result in significant underestimation of contact area. Therefore, the values for area in this study should be interpreted with caution. Nevertheless, the present finding of a decrease in contact area with increasing excursion is likely to be clinically relevant. This observation confirms the outcome of a study by Hayasaki et al., which showed a significant reduction in contact area with an increase in excursion from 1.0 to 3.0 mm. As in this study, they found a greater than 50% reduction in the area on the working side when excursion increased from 1.0 to 3.0 mm. The progressive and rapid reduction of contact area with increasing excursion confirms the observed changes in contact number. A larger contact area in the initial stages of excursion reflects greater jaw stability, as broader contact areas during chewing cycles may aid in evenly distributing occlusal forces (1,11).

Although the contact number for pretreatment casts differed from the values for the two wax-up casts, the total areas of the groups were similar. This finding is attributable to wear in pretreatment teeth. Thus, although the contact number is lower, the total area of occlusion is the same. However, because the contact number is greater for the two wax-up cast groups than for the pretreatment casts, the contact area is distributed on more teeth in the wax-up cast groups. This may be advantageous as it could reduce overloading of fewer teeth by spreading occlusal force on additional occluding units (5).

In relation to steepness, as excursion increased, the guidance angle decreased for all the casts. This observation accords with the cuspal morphology of the guiding teeth (1), as it is steeper closer to the fossae than at the cusp tips (14). This parabolic morphology was observed by Nishigawa et al. in their evaluation of mandibular border movement of healthy dentition (12). Similarly, Ekfeldt and Karlsson found that, after restoring worn dentition, the mandibular closing angle near the functional occlusal contact area became steeper (13). An earlier study of the occlusal steepness of posterior teeth in natural dentition found that steepness ranged from 6 to 47° (14). The present data show that the final steepness of evaluated casts, particularly pretreatment and conventional wax-up casts, is within this range.

The similarity in steepness between pretreatment and conventional wax-up casts might be due to a tendency of the technician to maintain the articulator set-up and existing teeth guidance when establishing new guidance. Thus, initial occlusion steepness will dictate post-treatment steepness. However, the digital wax-up casts had greater steepness because of the use of an anatomic teeth template to create the wax-up. Dental morphologies that can be achieved digitally by software tend to be pronounced (37). Because digital wax-ups utilize average tooth forms, the final tooth morphology tends to exhibit more-defined and steeper anatomic features (38). Physiologically, more-restricted occlusion was associated with greater chewing duration (28,29). However, these cross-sectional studies did not yield data on long-term characteristics (2).

Digital wax-ups are the most likely to have limitations in occlusion that are related to lack of a dynamic movement simulator (39). For example, this study did not consider non-working side contacts, which could affect the observed lateral occlusion scheme and introduce deflective occlusal interferences. The absence of data on non-working side contacts was unavoidable, as virtual modelling of condylar movement was reported to be imprecise (40). Several reports acknowledged that a limitation of available CAD/CAM systems is lack of a reliable virtual articulation system that can simulate dynamic motion (41-43). The authors therefore concluded that the accuracy of the virtual articulator in simulating dynamic motion might be acceptable for orthodontic treatment but not for prosthodontic treatment (39).

Therefore, in view of the limitations of this study, the following can be concluded: 1. Contact number, contact area, and steepness are affected by the two wax-up procedures and the extent of excursion. The observed changes are attributable to changes in occlusal anatomy; 2. Contact number tends to be higher for conventional and digital wax-ups, especially in the earlier stages of excursion. However, contact area is minimally affected by wax-up procedures. The digital wax-up cast group had the steepest occlusion guidance; 3. Contact number, contact area, and steepness decreased as excursion increased in all cast groups.

Acknowledgments

This research was funded by a Research Development Award from the University of Western Australia, and by the Australian Prosthodontic Society. The author thanks the staff at the technical facility of the Oral Health Centre of Western Australia.

Conflict of interest

The author has no conflict of interest to declare.

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