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The effects of salivas on occlusal forces

SUMMARY Contacting surfaces of opposing teeth produce friction that, when altered, changes the contact force direction and/or magnitude. Since friction can be influenced by several factors, including lubrication and the contacting materials, the aim of this study is to measure the occlusal load alterations experienced by teeth with the introduction of different salivas and dental restorative materials. Pairs of molar teeth were set into occlusion with a weighted maxillary tooth mounted onto a vertical sliding assembly and the mandibular tooth supported by a load cell. The load components on the mandibular tooth were measured with three opposing pairs of dental restorative materials (plastic denture, all-ceramic and stainless steel), four (human and 3 artificial) salivas, and 16 occlusal configurations. All lateral force component measurements were significantly different (P<0.0001) from the dry (control) surface regardless of the crown material or occlusal configuration, while the effects of the artificial salivas compared to each other and to human saliva depended on the crown material.

KEYWORDS: dental occlusion, friction, saliva, occlusal force, lubrication, permanent dental restoration

Introduction

When teeth occlude, friction forces are produced at the contact points. These forces depend on the materials in contact and their environment (1). For example, porcelain-on-porcelain friction has been estimated to be three times that of enamel-on-enamel (2). Altering the friction changes the contact force magnitude and/or direction, and if these forces become excessive and/or misdirected (3) and therefore exceed physiologic tolerance, pathologic changes (2, 4), occlusal trauma or temporomandibular joint disorders may result (5).

Friction between occluding teeth is influenced by the quantity or quality of saliva and the presence of restorative materials (6). Lubrication is the property of a substance that reduces the friction between contacting surfaces and saliva provides a lubricating film on the surfaces of teeth (6, 7). Studies have shown that some liquids reduce the friction between enamel surfaces, while others may increase it between enamel and restorative materials (8-11). Studies have confirmed that alterations in occlusion are multifactorial (12) and that friction and lubrication may play a role (13).

There is a gap in the literature about the effects of occlusal contact friction and its modification by liquids or the presence of restorative materials. Thus, the purpose of this study is to measure the occlusal load alterations experienced by teeth with different salivas and dental restorative materials.

Materials and methods

Brief Description

Two opposing molar teeth were mounted in a testing apparatus and set into occlusion (Fig. 1). As the maxillary tooth was lowered along a vertical slide onto the mandibular tooth (which was supported by a load cell), the 6 load components, Fig. 2, acting on the mandibular tooth were recorded by the load cell. The procedure was repeated with the teeth in various occlusal configurations, with or without (control) a saliva, and of three restorative materials.

Experimental materials and methods

Human saliva and three artificial substitutes currently on the market were used and compared to a control (dry) sample. The human saliva (IRB approved bio bank #1105005588) was kept refrigerated, but at room temperature during data collection. The salivary substitutes were kept at room temperature. They were Moi-Stir® (Kingswood Labs, Indianapolis, IN), Mouth Kote® (Parnell Pharmaceuticals, San Rafael, CA), and Oasis® (Oasis Consumer Healthcare, Cleveland, OH). These were chosen for their different active ingredients, namely carboxymethylcellulose (CMC) in Moi-Stir®, the Yerba Santa plant (a mucopolysaccharide) in Mouth Kote®, and glycerin (35%) in Oasis®. The three crown materials were plastic denture teeth (Dentsply Portrait IPN® 33 degrees), esthetic all-ceramic crowns (IPS Empress® CAD), and stainless steel crowns (3M™ ESPE™).

Instrument and measurement

The apparatus (Fig. 1) included a base shelf with a vertical support that were bolted onto an MTS Bionix 858 (MTS Corp., Minneapolis, MN) testing machine. The maxillary tooth was weighted down to 15 N, which is within the range of the average biting force in the molar region [9-180 N (14)] and within the limits of the load cell (Gamma Transducer, SI-65-5, ATI Industrial Automation, Apex, NC) that supported the mandibular tooth. A precision slide (Mini-Guide, Double Carriage, Model #SEBS 9BUU2-195, Nippon Bearing Co, Japan) on the vertical support guided the maxillary tooth, and a pivoting assembly allowed the slide to be tipped in all directions, Fig. 1A.

The MTS testing machine was used to lower (sinusoidal displacement control, 0.2 Hz and 4.0 mm amplitude) the maxillary tooth with a 17 inch #16 double-loop jack chain (generic). The load cell measured (at 100 Hz) the force F_x, F_y and F_z (0 - 65 ± 0.2 N) and moment M_x, M_y and M_z (0 - 5000 ± 0.9 N-mm) components acting on the mandibular tooth (Fig. 2) with the teeth in various occlusal configurations (Fig. 3), with or without (control) a saliva. Three pairs of crown materials (denture plastic, ceramic and stainless steel) were tested.

The maxillary and mandibular denture teeth were attached with orthodontic resin into an acrylic tube and an enlarged (drilled about ½ way down) hex coupling nut, respectively (Figs. 3A and B). 3M Unitek Multi-Cure Glass Ionomer Band Cement was used to attach the ceramic (Fig. 3C) and stainless steel (Fig. 3D) crowns onto ground-down screw head abutments.

Data sets and data acquisition

A data set (Table 1) consists of the 6 load components measured with opposing molars in one of the 4 occlusions (Class I, cross-bite, Class II or Class III; Fig. 3) and one of the maxillary angulations (Vertical, Mesial, Distal or Buccal).

The occlusal surfaces were cleaned with a 95.5% Ethanol (200-proof Ethyl Alcohol) dipped gauze pad and dried with oil-free compressed air. The 6 load components measured with this dry surface constituted the first control (C1). Then, Moi-Stir (MS) was placed on the mandibular tooth with a disposable pipette and on the maxillary tooth by dipping it into a shallow cap. The load components were measured, the occlusal surfaces were cleaned again, and the C2 readings were obtained, and so on. Thus, a full sequence consisted of C1→MS→C2→MK→C3→Oa→C4→HS→C5. By repositioning the plywood base (Fig. 1A), this sequence was performed with all four molar relationships (Class I, I crossbite, II and III).

All procedures described in the previous paragraph were conducted with 4 maxillary crown angulations (measured with the Clinometer + bubble app by Plaincode™) at 0° (upright), 2° mesial, 2° distal and 2° buccal, for a total of 16 data sets, each a different occlusal configuration (Table 1). All 16 data sets were obtained with three pairs (denture teeth, all-ceramic crowns and stainless steel crowns) of opposing restorative materials, or 48 sets of data.

Statistical methods

The difference from control regardless of direction, the absolute fold-change, AFC = $\left|\frac{\text{Product} - \text{Control}}{\text{Control}}\right|$, was calculated for each measurement. An AFC of zero indicates the same measurement as control, while an AFC of 1 indicates a 100% change (i.e., twice as high or twice as low) from control. Wilcoxon signed rank tests were used to test for the significance of AFC, which determined whether the saliva had a significant effect compared to the dry surface. A linear mixed-effects model was used to determine whether the salivas affected the loads, with fixed effects for saliva (human, Moi-Stir, Mouth Kote, and Oasis), restoration type (denture plastic, ceramic and stainless steel), and their interaction, and random effects to correlate data within occlusal configuration for each restoration type and across restoration types. For all analyses, pair-wise comparisons were performed when the overall F-test for any difference was significant, using Fisher's Protected Least Significant Differences to control the overall significance level at 5%. The ranks of the data were used in the analyses because of the non-normally distributed data.

Results

Analyses were conducted on lateral force components F_x and F_y that were linearly interpolated to the F_z = -13.0 N value. Moments (M_x, M_y, M_z) were not considered because the positions of the occlusal surfaces relative to the load cell (i.e., the moment arms) impact the moments, whereas the force components are unaffected by apparatus geometry (15).

The intraclass correlation coefficients (ICCs) for the controls were 0.98 or higher for all measurements, confirming that each control (taken as a measurement alternating with each liquid) was consistent, thus verifying that the occlusal surface cleaning between salivas was effective. An absolute fold change (AFC) was used to detect differences regardless of the direction (positive or negative). The

AFCs for F_x and F_y for all salivas and all occlusions were significantly different ($P<0.0001$) than the dry-surface control, Table 2. The salivas are compared with each other in Table 3.

Discussion

Clinically, all force and moment components must be considered, but, as noted above, focusing on the former is appropriate for the purposes of this study. All wet F_x and F_y were significantly different ($P<0.0001$) from those with dry (control) surfaces (Table 2), regardless of crown material or occlusion. With denture teeth, Oasis® produced F_x and F_y changes greater than Moi-Stir® and Mouth-Kote® (Table 3). In contrast, with ceramic, F_x and F_y changed more with human saliva, Moi-Stir® and Mouth-Kote® than with Oasis®. With stainless steel, F_y changed more with Oasis® than with Mouth-Kote®.

There is no evidence to suggest that good lubrication is clinically preferable to poor lubrication, so it is useful to compare the artificial salivas with human saliva, Table 3. With denture teeth, Oasis® was the most similar to human saliva, while Moi-Stir® and Mouth-Kote® produced significantly different force values. With ceramic, it was the opposite, and there were no significant differences with stainless steel crowns. It has been stated that mucin-based substitutes (e.g., Mouth Kote®) possess lubricating qualities comparable to human saliva (16). Our results indicate that that may be true with ceramic and stainless steel, but not with denture teeth. Thus, these results have potential clinical implications particularly for patients with xerostomia, various restorations and those using salivary substitutes.

Thus the salivas cause significant contact force differences that depend on the restorative materials. (There were no significant differences in the effects of the salivas with the Class I, II and III molar relationships and with the tipped maxillary tooth configurations.) Although the modifications in contact forces are attributable to dissimilar lubrication by the salivas, the results cannot be used to deduce if a specific saliva is a better, or worse, lubricant than another. Conversely, the lubricative ability of a saliva is not predictive of the associated contact force alterations. Although contact forces and lubrication are intimately related, the relationship is entirely unpredictable. (This unpredictability, is due to the nature of statically indeterminate systems.) Therefore, comparisons with salivary lubrication literature would be useless.

This study did not consider combinations of occluding surfaces (e.g, plastic/ceramic, plastic/stainless-steel, and ceramic/stainless-steel). And, typically, there can be more than one type of contact surface on the same tooth, for example, with amalgam restorations. Lubrication by foods and drinks also has a role.

Quantitatively, the measurements depend on the unique stiffness of the testing apparatus. However, given the purposes of this study, that should not be considered as a shortcoming because, clinically, there is a huge range of flexibilities associated with healthy periodontia, periodontally compromised teeth, ankylosed teeth, implants, dentures, and so on.

It can be concluded that these findings have clinical implications whenever occlusal forces are involved. After all, the magnitudes of the lateral force components on the crown (F_x and F_y), which are generally considered to be destructive, were measured to be as high as ~80% that of the occlusal (F_z) force (Moi-Stir® on ceramic crowns, Table 2). Our data demonstrate that saliva is one of the critical determinants of those lateral force magnitudes. Consider also the clinically desired axial alignment of occlusal forces. If attained, it would likely be ruined by any change in saliva. Another example is the relationship between athletic endurance training and oral health problems (17). Although changes in saliva are cited as contributing factors, the effect of those changes on friction is overlooked as a possible etiology (13).

This study clearly illustrates the complexity of occlusal contact force dependence on the interactions between occlusion, tooth materials and salivas. It is impossible to quantitatively define those relationships, however, the data demonstrate that changes in saliva have the potential to adversely, or beneficially, alter the mechanical environment in the masticatory system.

Acknowledgements

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Conflicts of interest

No conflicts of interest declared.

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Table 1. Experimental groups. These groups were used with each of the 3 crown materials (denture, ceramic and stainless steel).

Occlusion:	I				C-B				II				III			
Tip (2°):	V	M	D	B	V	M	D	B	V	M	D	B	V	M	D	B
	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1
	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2
	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK
	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3
	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa	Oa
	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4
	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS
	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5

Tip: V = Vertical (0°) M = Mesial D = Distal B = Buccal

C1-5: Controls 1 through 5

Salivas: MS = Moi-Stir MK = Mouth Kote Oa = Oasis HS = Human Saliva

Table 2. Absolute Fold Change (AFC) for wet versus dry surface ("All" refers to denture + ceramic + SS.)

Saliva	Tooth	n	AFC for F_x Mean (SE)	AFC for F_y Mean (SE)
Human	All	48	0.17 (0.03)	0.09 (0.03)
	Denture	16	0.09 (0.02)	0.03 (0.01)
	Ceramic	16	0.31 (0.09)	0.19 (0.08)
	SS	16	0.10 (0.03)	0.04 (0.02)
Moi-Stir	All	48	0.37 (0.19)	0.12 (0.04)
	Denture	16	0.03 (0.01)	0.12 (0.10)
	Ceramic	16	0.79 (0.52)	0.15 (0.08)
	SS	16	0.29 (0.21)	0.09 (0.04)
Mouth-Kote	All	48	0.15 (0.04)	0.25 (0.17)
	Denture	16	0.04 (0.01)	0.53 (0.51)
	Ceramic	16	0.30 (0.11)	0.19 (0.10)
	SS	16	0.11 (0.04)	0.04 (0.02)
Oasis	All	48	0.13 (0.02)	0.14 (0.08)
	Denture	16	0.13 (0.04)	0.27 (0.22)
	Ceramic	16	0.14 (0.05)	0.09 (0.04)
	SS	16	0.12 (0.04)	0.06 (0.01)

All $P < 0.0001$

Table 3. Comparisons of saliva pairs for each restorative material

Tooth	AFC for F_x	P-Value	AFC for F_y	P-Value
Denture	Human > Moi-Stir	0.0011*	Human & Moi-Stir	0.3571
	Human > Mouth-Kote	0.0300*	Human & Mouth-Kote	0.4365
	Human & Oasis	0.1773	Human & Oasis	0.0617
	Moi-Stir & Mouth-Kote	0.2571	Moi-Stir & Mouth-Kote	0.8859
	Moi-Stir < Oasis	0.0000*	Moi-Stir < Oasis	0.0057*
	Mouth-Kote < Oasis	0.0005*	Mouth-Kote < Oasis	0.0086*
Ceramic	Human & Moi-Stir	0.4310	Human & Moi-Stir	0.2585
	Human & Mouth-Kote	0.4043	Human & Mouth-Kote	0.4246
	Human > Oasis	0.0005*	Human > Oasis	0.0002*
	Moi-Stir & Mouth-Kote	0.9628	Moi-Stir & Mouth-Kote	0.7891
	Moi-Stir > Oasis	0.0058*	Moi-Stir > Oasis	0.0085*
	Mouth-Kote > Oasis	0.0067*	Mouth-Kote > Oasis	0.0032*
SS	Human & Moi-Stir	0.7715	Human & Moi-Stir	0.9428
	Human & Mouth-Kote	0.8114	Human & Mouth-Kote	0.1271
	Human & Oasis	0.6042	Human & Oasis	0.4735
	Moi-Stir & Mouth-Kote	0.5970	Moi-Stir & Mouth-Kote	0.1104
	Moi-Stir & Oasis	0.4190	Moi-Stir & Oasis	0.5188
	Mouth-Kote & Oasis	0.7794	Mouth-Kote < Oasis	0.0258*

* $P < 0.05$

FIGURE LEGENDS

Fig. 1. Testing apparatus. (A) Maxillary tipping is exaggerated for illustrative purposes. (B) The load cell.

Fig. 2. Diagram of forces and moments measured by the load cell. (Moment directions are defined by the right-hand-rule.)

Fig. 3. The 4 molar relationships. (A) Class I, (B) Class I crossbite, (C) Class II and (D) Class III. A & B are illustrated with the denture teeth, while C and D show the ceramic and the stainless steel crowns, respectively.

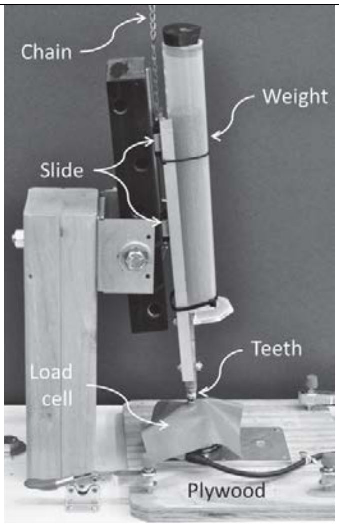

Fig. 1a

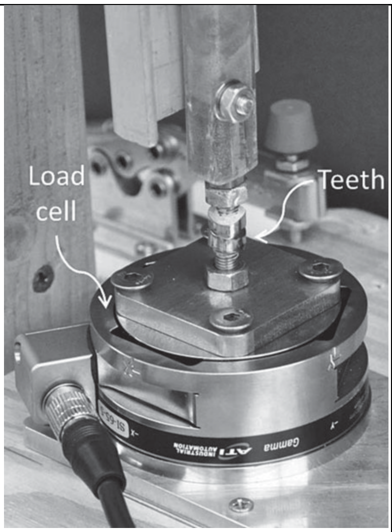

Fig. 1b

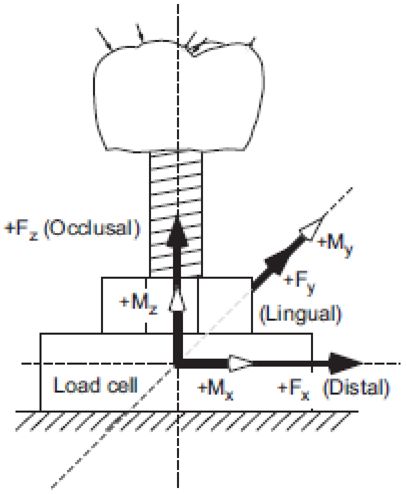

Fig. 2

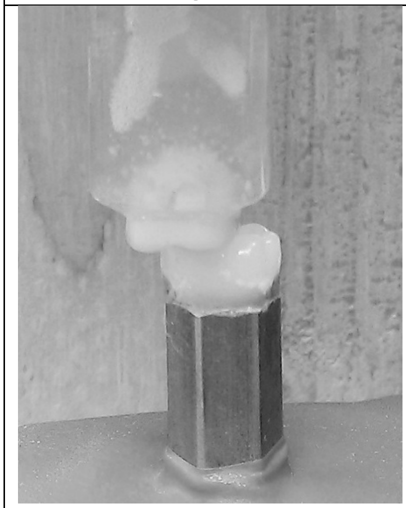

Fig. 3a

Fig. 3b

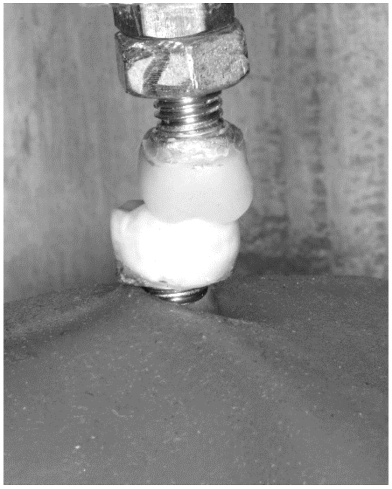

Fig. 3c

Fig. 3d