OCCLUSAL CONTACTS OF MILLED POLYURETHANE CASTS MOUNTED IN A PROPRIETARY AND SEMI-ADJUSTABLE ARTICULATOR

A Thesis

by

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ABSTRACT

Digital impressions utilize digital images of the dentition from multiple intraoral scans that are stitched together. A digital bite scan records a static, MI occlusion of the patient and orients the digital casts into the indicated occlusal relationship. This information is transferred to a milling machine that carves casts from a solid polyurethane block using a subtractive process. The completed arches can be 'snap-mounted' in a proprietary articulator for restoration fabrication at a lab. Digital acquisition of the tooth preparation is comparable to traditional impression methods for many of the intraoral scanners on the market today. However, few studies have demonstrated the potential discrepancies of milled or rapid-prototyped casts from an occlusal aspect. The purpose of this study was to compare the actual occlusal contact (AC, 0-50um) and near occlusal contact (NC, 51-350um) areas of iTero® milled polyurethane casts articulated in a proprietary articulator, and a semi-adjustable articulator, by using trans-illumination of inter-occlusal records.

A statistically significant difference was found between the actual contact of milled casts in the proprietarily-mounted (PM) and semi-adjustable (SA) articulator groups, but not with near contact. PM casts' NC was significantly different from the control while the AC was not. The SA casts showed no statistical significant difference from the control patient in terms of AC or NC. Occlusal contact of milled casts from the same subject are not identical, and these differences may be compounded or minimized depending on the articulation method.

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I. INTRODUCTION

There is a trend in clinical dentistry to move from analog to digital process conversion. Nearly every dental supply company now offers digital impression technologies that are advertised as cheaper, faster, and hassle-free when compared to traditional impressions. Traditional methods of impression making, cast, die, and restoration fabrication are still the norm in the majority of dental offices, but these techniques have limitations. Custom trays of auto-polymerizing resin are superior to stock trays and control the thickness of impression material but stock trays permit variable thickness of impression material and can incorporate distortion and unwanted dimensional changes in the definitive cast.[1,2]Another source of potential error is the recording material. Vinylpolysiloxane (VPS) impression materials are reported to have excellent tear strength and minimal deformation upon removal from undercuts,[3]making them favorable for indirect restorative techniques. Interestingly, inaccuracies of the recording material are not necessarily immediately visible to the practitioner, which could cause misfit of the restoration. While disinfection procedures (spraying or immersion) of elastomeric impression materials have not been shown to affect the dimensional stability of VPS[4], the disinfection process itself takes time and may not provide complete disinfection.

Errors in the fabrication process may also be due to the gypsum cast. Significant differences have been recorded between brands of Type IV dental stone commonly used for master dies.[5] These improved dental stones have also shown delayed linear expansion up to 120 hours after initial set.[6] Gypsum casts may also wear, chip, and fracture. Not only is the structure of the definitive cast important for accuracy, but also the physical mounting of the casts in a suitable articulator. If errors exist from the first step of a procedure and throughout subsequent steps, the final error will be cumulative of all the previous errors.

Logically, the way to reduce these error sources is to remove the materials from the process and record the tooth preparation and occlusion digitally. Digital scans of the arch have been shown to be very accurate. However, comparison of landmarks on stone casts and digital scans show that cast measurements are more repeatable but consistently larger than the same measurements in a digital model.[7] With respect to occlusal contacts, trans-illumination from records on stone casts and the same digitally aligned casts provide similar contact areas that are not statistically different.[8]

The iTero ® scanning system (Cadent Articulator, Align Technology Inc., San Jose CA) is able to produce digital images of the dentition from multiple intraoral scans that are stitched together. A digital bite record also allows a static occlusion of the digital 'casts' and the occlusal relationship of the arches to be recorded three dimensionally. These scans are then transferred to a milling machine that mills a copy of the digital casts from a solid polyurethane block using burs similar to those used for crown and bridge preparation. They are milled in such an orientation that the arches can be 'snap-mounted' in a proprietary articulator and sent to the lab for prosthesis fabrication.

The precision of digital impressions has been evaluated by overlaying many different files or scans of the same subject,[9]but this is limited by the scanning software and resolution. The accuracy of creating a master cast that duplicates the subject depends on the method of converting a digital file to a physical model. Different systems of cast fabrication, currently with mill-able or printable materials, will make a difference in the accuracy despite the accuracy of a digital scan. First, it has been established that direct digital acquisition of the preparation is comparable to traditional impression methods[10] for many of the intraoral scanners on the market today. However, few studies have demonstrated the potential discrepancies of milled or rapid-prototyped casts from an occlusal aspect. Hwang et al[11] demonstrated the reproducibility of a virtual cast from an iTero® digital file, but when multiple polyurethane casts are milled using the same file, there is significantly less reproducibility among the casts. These casts also showed more variability than printed casts and traditional stone models of the same arch.

Visually, milled casts may present with a surface texture that is rougher that gypsum and lacking in occlusal detail. Sharp angles or grooves that are narrower than the milling burs cannot be fully reproduced as with a VPS impression and gypsum cast. The finish line of the preparation can be reproduced precisely in the polyurethane die because the same size/shape bur used to mill the die was likely used to prepare the tooth surface. It is worthy of evaluation how much contact area difference is present in milled casts as this affects the occlusal scheme, interferences, and proposed contacts of the crown.

The milling process itself incorporates minor differences into each milled cast, which may be due to small movements of the milling machine, differences in the ‘blanks’ used for milling, dulling of the burs during milling, and distortion of the final model.[12] Since a milled cast is not completely accurate, discrepancies are magnified when the casts are articulated and occlusion is evaluated. Solid, milled polyurethane cast such as with iTero®, can be milled multiple times from the same file to compare the effect of milling or can be milled from multiple scans of the same subject to evaluate both the milling and scanning, though control of the variables is necessary for sensitivity. Differences in the physical master casts can be measured via additional scanning methods of the individual casts, but a more practical and clinically relevant comparison includes comparing contacts of the articulated casts. As Cadent recommends the use of the proprietary articulator for the iTero® models when restoring a limited number of teeth, an evaluation of this articulation method is warranted. The occlusal contacts achieved by mounted casts on the iTero® proprietary articulator have not been compared to traditional mounting in a semi-adjustable articulator. If there is a difference in occlusal contact area, is it a result of the intra-oral arch scans, the MI bite scans, milling, or articulation?

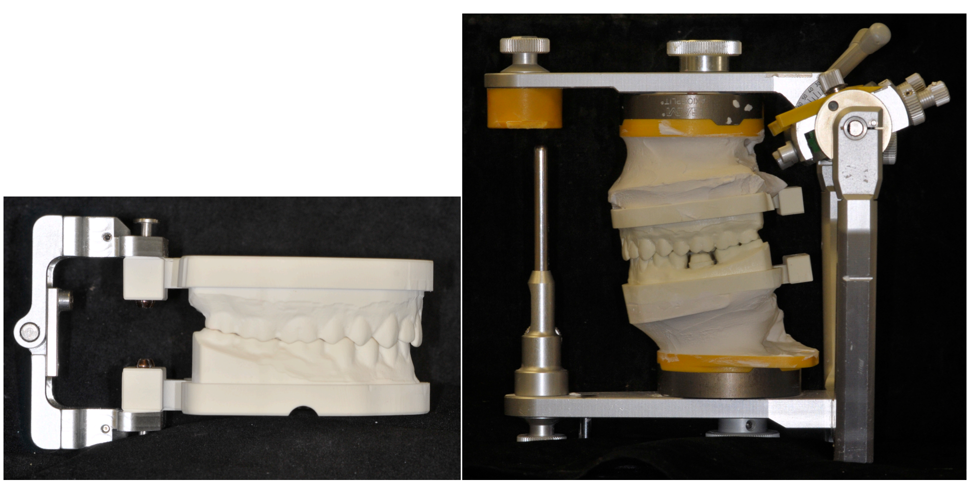
The clinical affect of proprietary models has previously been examined by fabrication of restorations on milled casts. A study by Arrowhead Laboratories, published in Aesthetic Dentistry 2007, indicates significantly reduced restoration remake factor (0.0015%) with crowns made on iTero casts.[13] This review, however, was limited to a single source of information (Arrowhead Dental Labs) and only practitioner feedback on completed restorations, such as how long it took to seat crown and if adjustments were necessary. This study was not selective of the type or number of restorations made for each case. A more scientific study was conducted at the University of Pacific in which single unit posterior restorations were fabricated using a traditional impression method or a digital impression, iTero. Feedback from the student practitioners was reported as well as amount of chair-side time necessary for adjustments. iTero-fabricated restorations required an average 22% less adjustment time prior to insertion, though the standard deviations of adjustment time required for the digital and traditional impression method did not seem statistically significant.[14] Practitioners were also asked to rate four aspects of the restorations: proximal contacts, internal fit, marginal adaptation, and occlusion. The digital impression method was rated slightly higher in all of these aspects with the exception of occlusion: conventional impression and cast fabrication methods produced superior occlusion.[14] This difference found in the study could be due to the articulation method of each technique.

The purpose of this study was to compare the actual occlusal contact (AC) and near occlusal contact (NC) areas of iTero® milled polyurethane casts articulated in a proprietary articulator, and a semi-adjustable articulator, by using trans-illumination of inter-occlusal records. The null hypothesis was there are no differences between actual contact and near contact between theses two articulation methods.

II. MATERIALS AND METHODS

A simulated patient in the form of a typodont with an equilibrated occlusion and single tooth preparation for #19 was mounted on a SAM® 3 articulator (SAM PRÄZISIONSTECHNIK GmbH, Germany). Even and simultaneous contact was confirmed with 12 µm shimstock (Almore International, Inc., Beaverton OR) and articulating paper prior to obtaining digital impressions and bite registrations. Two study groups were identified: maxillary and mandibular full-arch iTero® casts mounted on a proprietary articulator (Cadent Articulator, Align Technology Inc., San Jose CA), and the same cast sets re-mounted with mounting stone in a semi-adjustable SAM® 3 articulator. The proprietarily-mounted (PM) and semi-adjustable mounted (SA) groups each contained the same ten cast sets, which were compared to the simulated patient (control). Photos of both articulations, and the simulated patient, are shown in Figure 1.

Figure 1. Proprietarily-mounted (PM) and semi-adjustable (SA) articulator mounted casts, lateral views



For the control, a single left and right side inter-occlusal VPS registration was made with Blu-mousse® (VPS Bite Registration material, Parkell Inc., Edgewood NY) under a 2.2kg weight resting on the upper member of the semi-adjustable articulator. These bilateral VPS records would later be trans-illuminated and photographed to determine VPS thickness and occlusal contact areas of the specimens. These records used for occlusion evaluation and data collection will be referred to as the trans-illumination records (TIRs). Because the typodont lacked physiological variables of periodontal ligaments and tooth movements, a single TIR was deemed acceptable for the control. The maxillary and mandibular arches of the control were scanned ten times, each with it's own MI bite scan for arch orientation during milling, thus producing ten specimens. This data was sent to the milling facility (Align Technology Inc., San Jose CA) and casts were returned shortly thereafter. For the PM group, each milled cast set was first articulated in the proprietary iTero® articulator and bilateral TIRs were made from first bicuspid to third molar. For ease of removal from the polyurethane cast, a lubricant (Super-Sep™, Kerr, Orange CA) was sprayed onto the surface and allowed to dry for twenty-four hours before the VPS material was applied to the cast. For the SA group, a stone facebow preservation record was made of the simulated patient, and the 10 maxillary iTero® casts were re-mounted in the SAM® 3 articulator with a low-expansion stone (Mounting Stone, ISO Type 3, Low Expansion, Fast Setting; Whip Mix, Louisville KY). The mandibular iTero® casts were mounted by hand articulation in MI, and bilateral TIRs were obtained. Both PM and SA trans-illumination records were trimmed to 2.0mm around the edges of the occlusal tables to be able to lay the records flat on the light source.

Trans-illumination was achieved by laying a set of VPS registrations on the light box (Viewer – DE 100, 110 V AC, Star X-Ray, Amityville NY) with a novel calibration tool described below (Figure 2). The light box was placed on a level surface below a camera tripod surrounded by an opaque, light-obscuring tent. A Nikon™ D300S (Nikon DSLR, Manual setting, f32, 1/60 s, ISO 200; Tokyo Japan) was positioned 0.5 meters from the light box, perpendicular to its surface. Photographic images were taken of the calibration tool with each set of TIRs (one control, ten PM, ten SA) during one session under identical lighting conditions. Photos were uploaded to a personal computer for cropping and image processing (Apple® MacBook Pro, Cupertino CA; Adobe® Photoshop Elements 9, San Jose CA). The right and left TIRs for each specimen were isolated/cropped to include only occlusal contact areas from second bicuspid to second molar (Figure 3). These teeth were chosen based on previous studies[15] and the number of occluding units usually present in dentate patients.

Figure 2. Raw photographic image of trans-illuminated calibration tool and control TIRs, right and left sides.

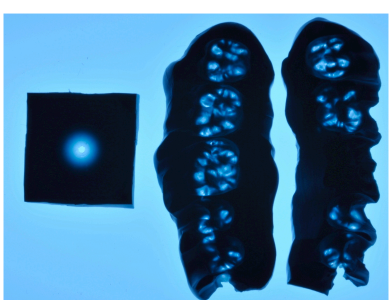
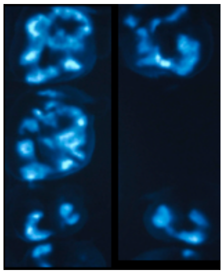
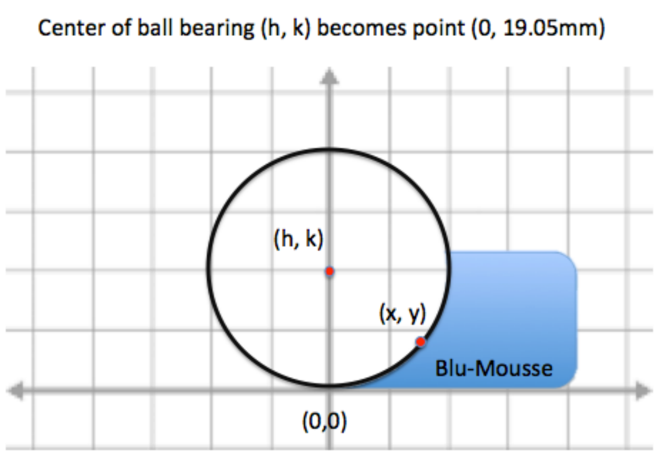


Figure 3. Example of cropped photographic image of TIRs, right and left sides, second bicuspid to second molar.



For evaluation of the contact areas, a pre-determined thickness of the same VPS material was created, adapted from the technique used by Delong[8], to produce a standardized calibration tool to which all TIRs were compared. This calibration tool was fabricated using a fixed-diameter chrome steel ball bearing with a radius of 19.05 mm (1-1/2" Inch Chrome Steel Bearing Balls G25, BC Precision Balls, BC Trade LLC, Los Angeles, CA). The spherical bearing was placed in the unset VPS on a level surface to create an indention, the center of which was absolute contact with the surface. This tool was trimmed 10.00 mm from this central point, as measured with a digital caliper (Neiko 01407A 6-Inch Digital Caliper). Diameter of the bearing was chosen to ensure enough variation in thickness to produce trans-illumination data for comparison to the bite records. Arbitrary trimming of the record to 10.00mm, measured from the center of absolute contact to the edge, was done for ease of measurement conversion. The calibration tool thickness was calculated using the equation of a circle: $(x-h)^2 + (y-k)^2 = r^2$. By overlaying the cross section of the tool on a Cartesian coordinate system, absolute contact of the bearing with the surface is labeled as coordinates (0,0) and the center of the bearing is (0,19.05) (Figure 4). Once uploaded to Photoshop Elements 9, the trans-illuminated calibration tool was cropped to the predetermined 10.00mm length, and this cropped photo (Figure 5) was imported into the statistical program Mathematica® (Wolfram Mathematica® 9 Student Edition, Wolfram Research, Champaign IL) for processing. First, all photos were converted to gray scale. Gray scale conversion changes the RGB color scale to a 256-level gray image valued in "bytes", whose levels may be compared with other gray scale images. The known millimeter length of the calibration tool (10.00) was converted to pixels (421) and a formula was derived to determine the pixel location, and corresponding byte level, of any registration thickness (Figure 4).

Figure 4. Equation of a circle and calculations for calibration tool thickness



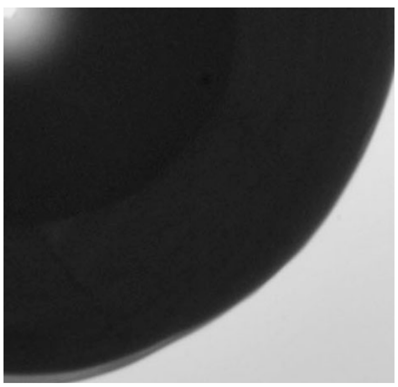
$(x-h)^2 + (y-k)^2 = r^2$

- $(x-0)^2 + (y-19.05mm)^2 = 19.05^2$
- $X^2 + (0.05mm - 19.05mm)^2 = 362.9025$ mm
- $X^2 + (-19)2 = 362.9025$
- $X^2 + 361 = 362.9025$

- $X^2 = 1.9025$
- X = 1.379 mm from center is 50 microns thick

- $(x-0)^2 + (0.35mm – 19.05mm)^2 = 362.9025$ mm
- $X^2 + 349.69mm = 362.9025$ mm
- $X^2 = 13.2125$ mm
- X = 3.635 mm from center is 350 microns thick

Figure 5. Cropped photographic image of calibration tool used for pixel correlation, superior view.



Sakaguchi[16] determined that pixel density of low viscosity VPS was not significantly different in 50um increments, beginning with 40um. Owens[17] then used this same threshold for an actual contact (AC) near contact (NC) scale in 50um increments, outlining ≤ 50um as AC and 50-350um as NC. Using the Owens guidelines of AC and NC, AC corresponds to 1.379 mm from center and NC is seen 1.38mm to 3.635 mm from the center of the calibration tool. In terms of pixels, pixel numbers 1-58 from the center (top left of trans-illuminated calibration tool in Figure 4) in the first line of pixels are AC and pixel numbers 59-153 are NC. Any pixels past the 153^{rd} constitute no contact. The byte value of any pixel in a grayscale photo can be determined using a Mathematica function code. The 58^{th} and 153^{rd} pixels was obtained using *Mathematica* function code PixelValue[photo,{x,1},"Byte"], and coordinates to 168 and 39, respectively. AC would then be 168-255 bytes (light gray to pure white) and NC is 39-167 bytes (mid-grays) on the gray scale. The total number of pixels of each byte channel 0-256 were extracted for the control record, the PM records, and the SA records were obtained using Mathematica code ImageLevels[photo,"Byte"]. Total number of pixels for AC and NC were summed manually and recorded in Microsoft Excel for each pair of models, right and left sides on either the iTero articulator or the SAM 3. For our calculations, one pixel corresponds to 0.0238mm x 0.0238mm, and the actual area of each pixel is 0.00056644 mm^2. Pixel numerical data was converted to actual area with the formula (total number pixels) x 0.00056644.

Statistical comparisons of the groups were then completed with SPSS (IBM SPSS Statistics, Version 20.0, IBM Corp, Armonk NY). The raw data gathered was the number of pixel units corresponding to both actual contact and near contact (Table 1).

Table 1. Actual contact (AC) and near contact (NC) in amount of pixels, right and left sides

Specimen	R AC	R NC	L AC	L NC
Control	7425	248659	2654	91710
1 PM	0	196937	718	89101
1 SA	14125	225260	99	65743
2 PM	0	24957	0	5921
2 SA	24608	248388	7881	76898
3 PM	18257	246561	0	58554
3 SA	26896	259147	19001	111788
4 PM	1597	169983	0	29922
4 SA	2613	236937	4008	78954
5 PM	368	115563	486	79367
5 SA	1344	174114	5409	107361
6 PM	0	40913	0	62453
6 SA	2155	168316	829	72250
7 PM	5828	267720	0	70910
7 SA	19448	245760	94	59707
8 PM	0	82120	0	2553
8 SA	5553	226682	690	76260
9 PM	12318	243187	7043	103858
9 SA	24996	252793	9402	93570
10 PM	17489	272161	2627	98406
10 SA	29334	248066	6088	90778

Control = simulated patient
PM = proprietary articulator
SA = semi-adjustable articulator
Numbers with PM or SA indicate cast set articulation specimen

The total area in mm^2 was calculated for each pixel to derive a total area of contact for each sample (Table 2). Independent sample t-Tests were used to compare differences between the PM and SA groups in terms of total AC and NC and of each side, and then to compare the test groups to the control. All cropped, trans-illuminated images can be seen in the appendix.

Table 2. Actual contact (AC) and near contact (NC) in mm^2, right and left sides

Specimen	R AC	R NC	L AC	L NC
Control	4.206	140.850	1.503	51.948
1 PM	0	111.552	0.407	50.470
1 SA	8.001	127.596	0.056	37.239
2 PM	0	14.137	0	3.354
2 SA	13.939	140.697	4.464	43.558
3 PM	10.341	139.662	0	33.167
3 SA	15.235	146.791	10.763	63.321
4 PM	0.905	96.285	0	16.950
4 SA	1.480	134.211	2.270	44.723
5 PM	0.208	65.460	0.275	44.957
5 SA	0.761	98.625	3.064	60.814
6 PM	0	23.175	0	35.376
6 SA	1.221	95.341	0.470	40.925
7 PM	3.301	151.647	0	40.166
7 SA	11.016	139.208	0.053	33.820
8 PM	0	46.516	0	1.446
8 SA	3.145	128.402	0.391	43.197
9 PM	6.977	137.751	3.989	58.829
9 SA	14.159	143.192	5.326	53.002
10 PM	9.906	154.163	1.488	55.741
10 SA	16.616	140.515	3.448	51.420

Control = simulated patient
PM = proprietary articulator
SA = semi-adjustable articulator
Numbers with PM or SA indicate cast set articulation specimen

Through a power analysis, it was determined there were enough samples (10N each group) to detect a moderate effect size with a significance level of $p \leq 0.28$, but at least 100 samples in each group (200N total) would be necessary to achieve a $p \leq 0.05$.

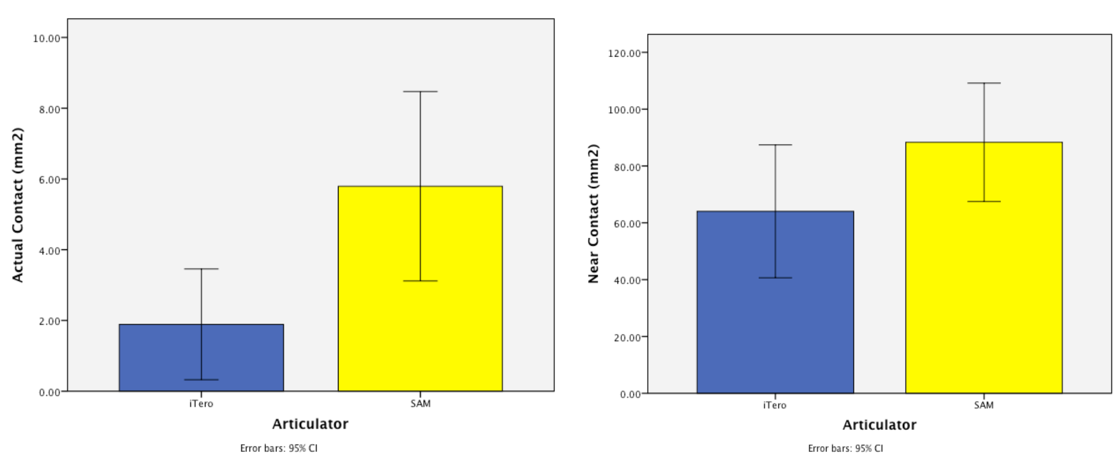
III. RESULTS

The mean total actual contact (AC) and near contact (NC) for casts mounted in the semi-adjustable (SA) articulator (5.794 mm^2, 88.33 mm^2 respectively) was larger than the proprietary (PM) articulator (1.89 mm^2, 64.04 mm^2) and can be seen in Table 3 and Figure 6.

Table 3. Mean actual contact and near contact in mm^2 for the different mounting methods

Articulator		N	Mean	Std. Deviation
Actual Contact	proprietary	20	1.89	3.345
	semi-adjustable	20	5.79	5.721
Near Contact	proprietary	20	64.04	50.012
	semi-adjustable	20	88.33	44.517

Figure 6. Graphical representation of mean actual contact and near contact in mm^2



An independent samples t-Test indicated a statistically significant difference between the AC of the PM and SA groups (sig. 0.003), but not the NC (sig. 0.965) (Table 4). When using a one-sample t-Test, the PM casts' NC was significantly different from the control patient (sig 0.022) while the AC was not (Table 5). An independent samples t-Test reflected the same statistical difference for the right side NC (sig 0.001) and left side NC (sig. 0.049). The SA casts showed no statistically significant difference from the control patient in terms of AC or NC (Table 6).

Table 4. Independent sample T-test comparing actual contact and near contact among PM and SA groups

Independent Sample T-test		F	Sig.	t	df	Sig. (2-tailed)
Actual contact	Equal variances assumed	9.801	0.003	-2.634	38	0.012
Near contact	Equal variances assumed	0.002	0.965	-1.622	38	0.113

Table 5. One-sample T-test results of PM versus control, comparing right and left side AC and NC

One-sample Test	t	df	Sig. (2-tailed)	Mean Difference
Difference R side AC from control	-0.768	9	0.462	-1.042
Difference R side NC from control	-2.769	9	0.022	-46.816
Difference L side AC from control	-2.205	9	0.055	-0.887
Difference L side NC from control	-2.751	9	0.022	-17.903

Table 6. One-sample T-test results of SA versus control, comparing right and left side AC and NC

One-sample Test	t	df	Sig. (2-tailed)	Mean Difference
Difference R side AC from control	2.146	9	0.060	4.351
Difference R side NC from control	-1.982	9	0.079	-11.393
Difference L side AC from control	1.455	9	0.180	1.527
Difference L side NC from control	-1.545	9	0.157	-4.746

IV. DISCUSSION

One of the secondary goals of the digital workflow is to decrease patient discomfort and dentist chair-side time for procedures, thereby increasing productivity with no less precision. Adding a physical component such as a cast or articulator mounting, however, may negate these advantages of digitization. Ideally, a completely digital workflow-optical impression, definitive virtual cast, dies, and restoration pattern-should include minimal error sources except the physical limitations of the milling or printing process that fabricates the restoration. The results of this study indicate a statistically significant difference among contact areas of the milled casts in regards to type of articulation method, which may also be clinically significant.

This study demonstrated that when ten digital files of a simulated patient with ten digital occlusal bite registrations were compared, the occlusal contacts were not identical when mounted in the proprietary articulator. When the same casts were remounted by hand in MIP in a semi-adjustable articulator, less deviation in amount of occlusal contact area was noted, but variation was still present. Digital scans of the dental models themselves have shown little variability when multiple scans from the same master model were made[9], and the simulated patient in this study lacked other in vivo variables such as centric interferences, periodontal ligaments, and inconsistent bite forces. With this design, contact variables are thought to result from the milling process and articulation method. The extent of which either influenced the results is unknown. The stable polyurethane material used for iTero definitive casts is proprietary, and little information about its specific structure and properties can be found. It is also unknown to what precision the milling process is capable as this information is also proprietary.

When precision between samples is assessed, the SA group presented a smaller standard deviation of NC than the PM group, but a larger standard deviation in terms of AC. This may be due to the consistency of hand articulation and that discrepancies recorded in the MI bite scan were corrected by re-articulation into a better occlusion. However, the samples with less contact area noted in the PM group also showed less contact area after subsequent hand articulation in the SAM articulator. This supports the conclusion that the milled casts from the same control do contain minor differences, the extent of which may not be clinically significant. This could be due to the inability of the milling apparatus and bur to recreate the anatomy of the simulated patient, and the inability of the MI bite scan to properly orient the arches to each other. Naturally-occurring grooves and ridges can be recreated by a bur of fixed diameter if the milling precision is small enough, which was unknown for this study. The differences found in occlusal contact support the statement that milling apparatuses may not be able to copy a patient's dental anatomy.

The AC and NC recorded for the SA group was not significantly different from the control because the articulation method in a semi-adjustable articulator more correctly approximated the simulated patient's occlusion, despite the minor differences in the casts already noted. The AC of the casts mounted in the proprietary articulator did not differ significantly from the control while the NC did, indicating a semi-correct orientation as recorded by the digital MI bite during scanning. Critical appraisal of the data collected indicates a statistical significance that may not actually be clinically significant. Clinical significance could be evaluated by fabrication of restorations in vitro or in vivo with strict control of the mounting variable.

There is a paucity of research about the occlusal effects caused by the subtractive technology of cast production and its subsequent articulation method. Most studies are outcome-based clinical studies on completed restorations and not the casts themselves and their inherent issues. The University of Pacific study[13] did receive feedback that the occlusion was adjusted more often on crowns made on the iTero® casts than stone models. Because the gypsum casts were mounted differently than the iTero® casts in the University of Pacific study, the articulation method may be responsible for the superior occlusion that resulted with traditional means. The difference is likely caused by the more precise mounting technique, as shown by the results of our study.

For restorations fabricated on proprietarily-mounted milled cast, only the static occlusion recorded with the MI bite scan can be used for designing the occlusal surface. Excursive movements and the appropriate arc of closure cannot be executed on the aluminum hinge articulator. These movements are important in restoring the type of occlusal scheme (canine-guidance, group function, etc.) as well as cusp height, fossa depth, and ridge/groove directions. Single units may not require such elaborate occlusal planning, and the differences noted in contact on a PM cast may not be clinically significant. But when anterior guidance and change in vertical dimension are involved in the rehabilitation, the dynamic occlusion and excursive movements are necessary for restoration design. These can be best evaluated on a semi-adjustable articulator. For the milled casts, differences in the AC and NC will undoubtedly affect both the static and dynamic occlusion, the extent of which warrants further research.

A dynamic occlusion occurs during the chewing strokes when the teeth come close to contacting but do not touch. It is here, in the near contact areas, where the food bolus is crushed during mastication. Functional design of restorations not only depends on proper location of AC areas but also the surrounding NC. In our study, the NC constituted more of the contact area than the AC on every sample (approximately 50 to 1), and four of the ten PM specimens had no measurable AC on either the left or right sides. Three samples had no measurable AC bilaterally. This lack of contact measured is likely the result of the MI bite scan which oriented the base for milling of that particular cast set, combined with the variables associated with the hinge articulator. More contact was achieved after 'correcting' with hand articulation and mounting with gypsum. A restoration fabricated to contact on the cast in the proprietary articulator would be in supra-occlusion in the actual patient, requiring occlusal adjustment before delivery. This indicates that the digital articulation method for determining the physical articulation in the PM groups is questionable, and further evaluation of digital bite registrations is warranted.

What sets this study apart from other trans-illumination and occlusion studies is the semi-novel method of assessing contact. The use of a ball-bearing as the gauge for VPS thickness instead of a hand-made step-wedge eliminates human error because precise thickness can be calculated without the need of a regression equation, as with previous trans-illumination studies, but with the equation of a circle. Samples must be photographed with the same light source at the same distance, which could be performed on many flatbed scanners on the market that can also directly upload trans-illuminated images to a computer for processing.

While the trans-illumination method of the records relied on a light box instead of newer flatbed scanners, the method for assessing contact was updated using newer software (Mathematica). This allowed for image processing and calibration in a single program. Previous studies relied on the total area of images and the cumulative gray composition to calculate the percentage of AC and NC for inter-occlusal registrations using a regression equation. Single pixels and precise location in the image could be identified as either AC or NC with this software. This study was not concerned with this type of occlusal detail, but further studies could use this as a way of mapping the AC and NC of occlusion. The 8-bit depth of the study design follows previous ones as this produces enough data with 256 grayscale levels to compare AC and NC as described by Sakaguchi's thresholds of 0-50um and 51-350um. A 16-bit depth evaluation of the scans would produce much more data due to the grayscale levels increasing to 32,769. This means there is greater detail in the tones of an image that can be assessed, and a much more precise evaluation of contact can be performed. The contact thresholds set by Sakaguchi may need reassessing as to what really constitutes actual and near contact by using newer technologies to redefine the numbers and new assessment methods with greater resolution.

A possible limitation of the study is distortion of the milled casts and articulation from the force necessary to ensure full, standardized closure. Full-arch models possess milled bilateral distal extensions of unsupported polyurethane that were easily bent on a sample cast not included in our bite study. The 2.2kg weight used to maintain pressure on the articulator during the TIR registration was chosen arbitrarily to stabilize the inter-occlusal recording and to imitate closing forces. Excessive pressure during the inter-occlusal registration may produce contact areas not actually present under normal biting forces, or during the initial MI bite scan. Furthermore, it may also distort the aluminum hinge articulator, though the pressure was placed only on the polyurethane casts and not on the articulator itself. The closing force on the semi-adjustable articulator was placed on the upper member, and not directly on the casts as with the proprietarily-mounted group. This may produce differences in the way the contacts were recorded in the TIRs for each test group.

In summary, polyurethane casts milled from a singular specimen do contain minor differences between one another that could be due to any step in the sequence. At which point the error is introduced in the scanning and milling process that significantly affects the occlusal contact areas is difficult to determine: the intra-oral arch scans, the MI bite scans, milling, or articulation. Evidence-based research supports that the intraoral digital scans are very accurate, while the MI bite scans are also accurate until the digital file is used to produce a physical model through milling. The milling process is met with many mechanical issues that have not yet been thoroughly evaluated but may be of greater interest in the engineering field. When the variable effects of scanning are minimized, it is the articulation method that stands out as the most aggravating factor for occlusal differences. The error noted in occlusal contact when casts are mounted onto the proprietary hinge articulator may be avoided by remounting in a semi-adjustable articulator, improving the actual and near contact of the articulation. Whether this significantly affects the restoration fabricated on such a cast, the answer is restoration and practitioner specific.

V. CONCLUSION

Within the limits of this study, we can state the following:

1. Occlusal contact area of milled casts articulated in a semi-adjustable articulator closely approximates the control specimen with little variation.
2. Occlusal contact area of milled casts articulated in a proprietary hinge articulator possess significant amount of variability and are significantly different from the control specimen.
3. Near contact area outnumber actual contact areas in specimens at a ratio of approximately 50:1.

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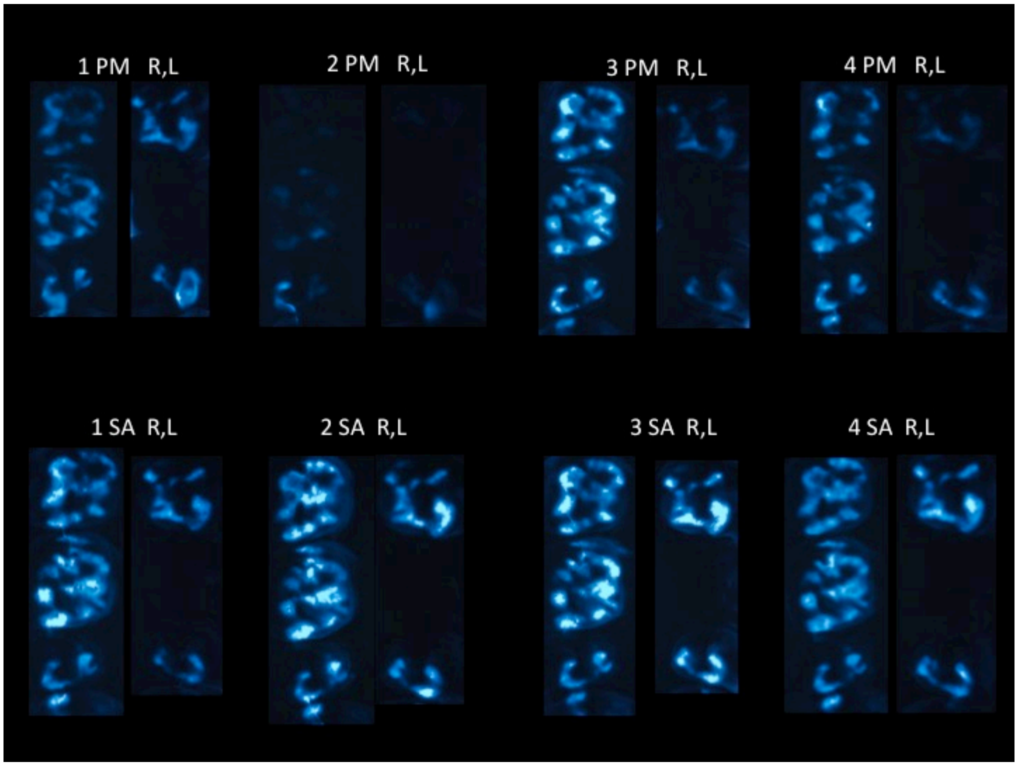
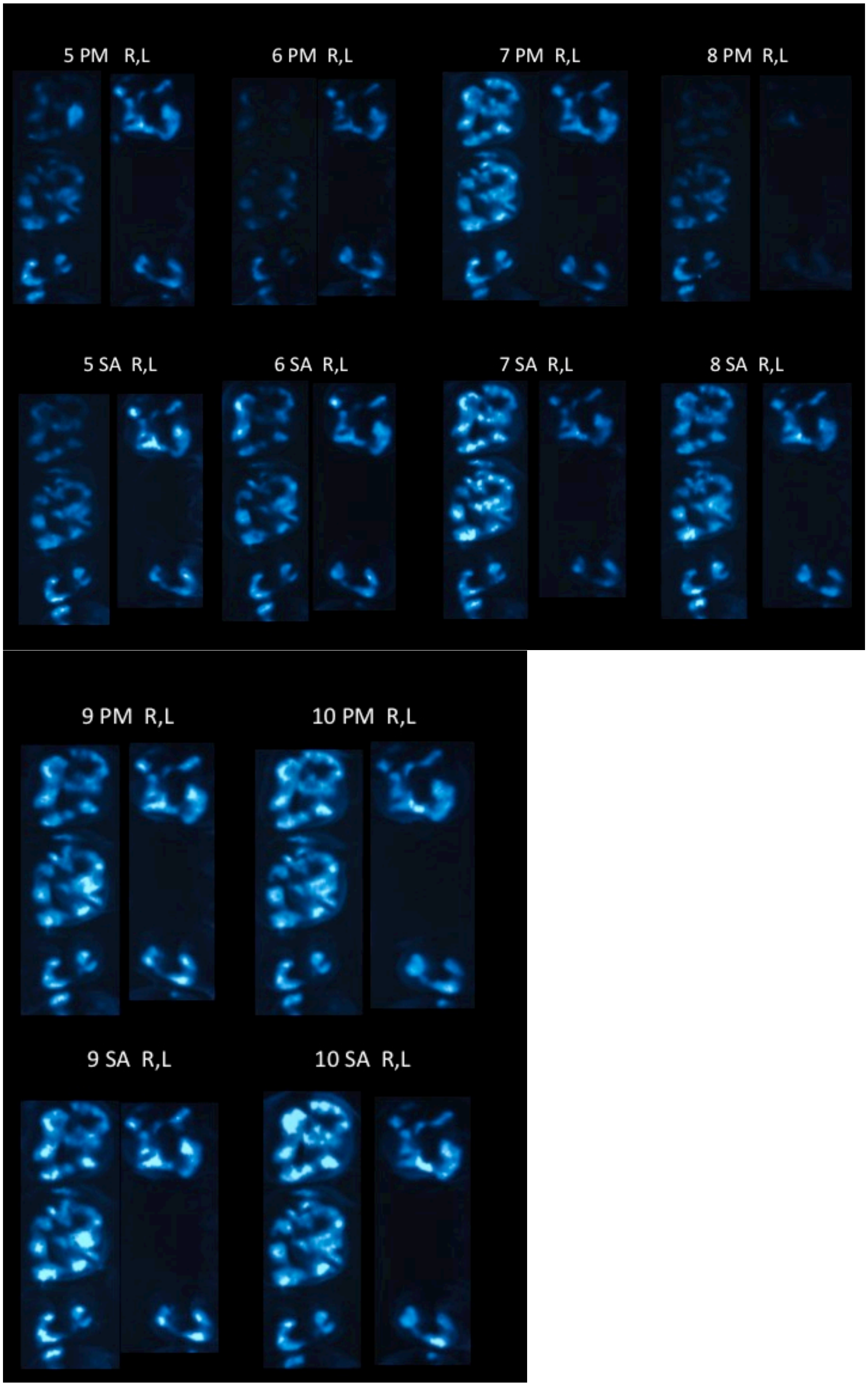
APPENDIX

All TIRs by number and articulator, right and left sides




5 PM R,L
6 PM R,L
7 PM R,L
8 PM R,L
5 SA R,L
6 SA R,L
7 SA R,L
8 SA R,L
9 PM R,L
10 PM R,L
9 SA R,L
10 SA R,L