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Global Dental Science Phase IV Report

In Vitro Wear of AvaDent FM

February 16, 2014

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Purpose: Compare the wear of the experimental AvaDent FM denture tooth material to the wear of Ivoclar DCL denture tooth material in a simulated oral environment.

Executive Summary:
There were no significant differences in the wear of the Ivoclar DCL and AvaDent denture teeth for any of the wear parameters ($p > 0.05$); however, the volume loss of the AvaDent teeth was consistently lower than that of the Ivoclar DCL teeth. There were no significant differences in the wear rates of the Ivoclar DCL and AvaDent denture teeth; however, the wear rate for the AvaDent teeth (0.056 mm^3/Year) was less than that of the Ivoclar DCL teeth (0.079 mm^3/Year). There were no significant differences in the wear between the upper and lower teeth of the same material ($p > 0.05$). The wear in this study was greater than that in the previous study because the lateral excursion was increased from 1 mm to 2 mm, which effectively increased the contact sliding distance by nearly a factor of three.

Method and Materials

Materials:
- Two different plastic materials were used: AvaDent FM and Ivoclar DCL.
- The AvaDent FM material was milled to tooth shapes using CAD/CAM.
- The Ivoclar DCL teeth were standard plastic denture teeth currently available.

Test Samples:
- Each test sample consisted of a second premolar and first molar in clinical alignment.
- Upper and lower samples were made using maxillary and mandibular teeth, respectively.
- The upper and lower teeth were aligned to produce the correct occlusion.
- Test samples were opposed by samples of the same material.

Wear Simulation:
Material wear was done using the University of Minnesota ART 1 wear simulator (DeLong R, Douglas WH. An artificial oral environment for testing dental materials. *IEEE Trans Biomed Eng*. 1991 Apr; 38(4):339-45), Figure 1. The simulator reproduces the motion and forces of human chewing using servo-hydraulic actuators. The closing velocity, tooth contact time, and occlusal force profile are designed to match those of human chewing. A vertical force is applied to the sample by the vertical actuator following a force profile that resembles half a sine wave, Figure 2. The applied force, which is measured by a load cell, is compared to the programmed force, and any deviations from the program are corrected through closed-loop control.

Lateral forces are normally, not monitored in the simulation. It is quite possible that the horizontal force is significantly larger than the vertical force; how large depends on cusp angles and friction. To minimize effects related to lateral forces, samples with similar anatomy and similar contact locations are recommended.

A previous study measuring friction between opposing natural teeth using several different lubricants, which included deionized water, spun saliva, and artificial saliva, found no significant differences between lubricants (Douglas WH, Sakaguchi RL, DeLong R. Frictional effects between natural teeth in an artificial mouth. *Dent Mater*. 1985 Jun;1(3):115-9). As a result of this study, 37 °C deionized water is used as the lubricant because it is readily available in our laboratory.

Calibration of the chewing system by correlating clinical and simulated wear of a dental composite found that 300,000 simulated cycles was approximately equal to one year of clinical wear (DeLong R, Pintado MR, Douglas WH, Fok AS, Wilder AD Jr, Swift EJ Jr, Bayne SC. Wear of a dental composite in an artificial oral environment: A clinical correlation. J Bomed Mater Res B Appl Biomater 2012 Nov; 100(8):2297-306. Epub 2012 Sep 21). At one cycle per second, it would take nearly three and a half days to complete one year's equivalent wear. To reduce machine time, the chewing path was truncated by removing that portion of the path where the teeth were not in contact, Figure 2. This enabled a chewing rate of four cycles per second, or one day to complete one year's equivalent wear. Tooth contact parameters (force, velocity, and contact time) were not altered.

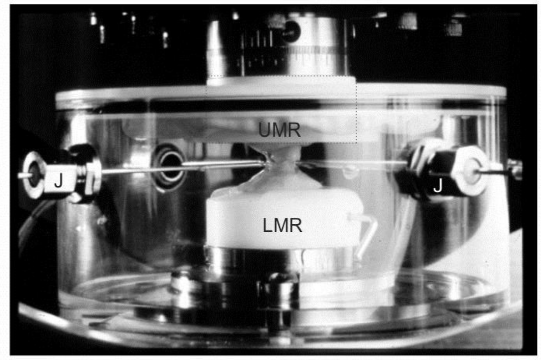


Figure 1: ART 1 Environmental Chamber. LMR – lower mounting ring. UMR – upper mounting ring (ring is outlined by the dashed line). The UMR is fixed to the load cell, which is just visible at the top of the image, and does not move. The LMR moves laterally and vertically to produce the chewing motion. J – Lubricating jets. Four adjustable jets spaced uniformly around the sample direct the lubricating media onto the samples.

- No preconditioning of the samples was done; samples were used as delivered.
- Each molar, premolar sample was placed in a mounting block for positioning in the oral simulator, Figure 3a.
- A test couple, which consisted of upper and lower sets of teeth, was mounted in ART 1, Figure 3b.
    - When mounted in the test system there could be one or two contact points.
    - No occlusal adjustment was done to increase the number of contact points. Attempts were made to keep contacts in similar locations.

ART 1 Chewing Parameters:

- Force profile: half a sine wave
- Maximum force: 30N
- Cycle rate: 4 Hz
- Lateral slide: 2 mm
- Lubricant: Deionized water
- Temperature: 37 °C

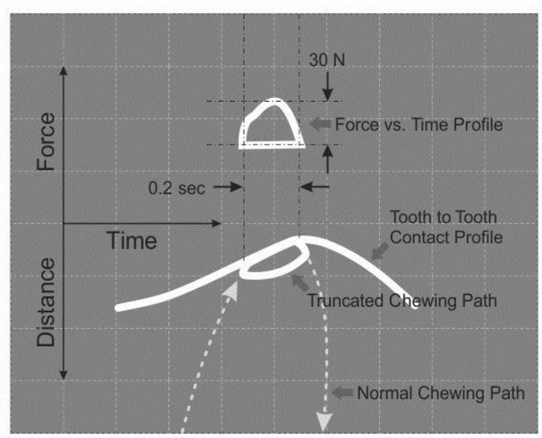


Figure 2: Cathode Ray Display of ART 1. Two profiles are displayed: force vs. time (upper profile) and distance vs. time (lower profile). The contact curve is generated by moving the lower tooth laterally against the upper tooth under a constant force.

Note: The lateral slide is twice that used in the previous tests. This equates to a sliding contact distance nearly three times that used in the previous work, which explains the increase wear for the same number of cycles in this work.

Scanning of Test Samples:
Digital models of all samples were created at baseline, 300K, 600K, 900K, 1200K and 1500K cycles. All samples were digitized using a custom contact profiling system, Figure 4.

Profiler Parameters:

- Accuracy: <0.010 mm for surface angles < 55 degrees to the horizontal plane.
- Precision: <0.002 mm for surface angles < 55 degrees to the horizontal plane.
- Step Size: X: 0.100 mm; Y: 0.050 mm
  - X is the distance between profiles
  - Y is the horizontal distance between points in a surface profile

Figure 3a: Test samples with mounting rings AvaDent FM samples have a white base; Ivoclar DCL samples have a pink base.

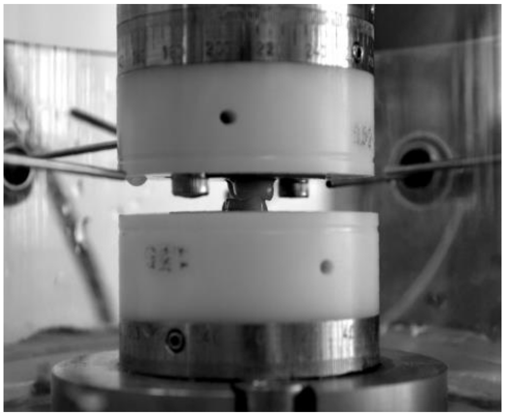
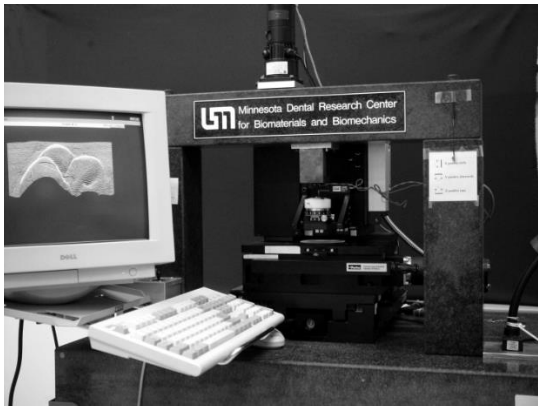


Figure 3b: Example of denture teeth mounted in ART 1



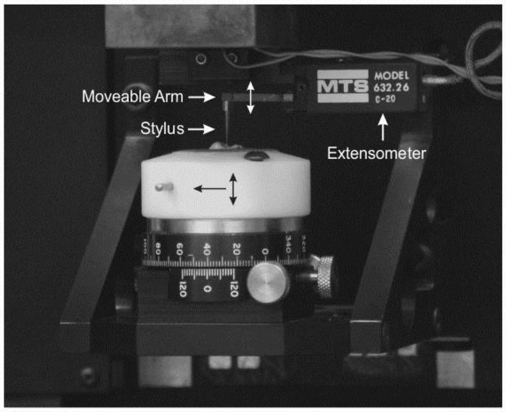


Figure 4: MDRCBB Contact Profiling System. This system uses a unique method to profile surfaces. The stylus is mounted on an extensometer, which is very sensitive to vertical movement. The stylus is brought into contact with the surface and deflected upwards a fixed amount. As the surface moves under the stylus horizontally, the stylus wants to move up or down depending on the anatomy of the surface. Closed loop circuitry moves the surface in the direction opposite to the deflection of the stylus; thus, keeping the stylus tip at the fixed offset. The vertical movement of the stylus and the surface are combined to determine the height of the surface. The final shape of the surface is corrected for the shape of the stylus tip.

Analysis:
Wear was measured using Cumulus Alpha Build V 0.8 64-20150130. Cumulus is a custom software program developed in the Minnesota Dental Research Center for Biomaterials and Biomechanics. The program aligns two or more digital models using an optimization algorithm to minimize the absolute distances between the points in the digital models. Regions where the models differ significantly are excluded from the alignment process. Surface changes are characterized using volume loss, maximum depth, and mean depth.

- Volume Loss: Calculated as the volumetric difference between the two aligned surfaces over a defined region. The region is normally defined as the area where the differences between the two surfaces are greater than the mean of the absolute differences for the aligned surfaces; see Quality of Digital Model Alignment. Cumulus uses two different methods to calculate the volume. Both methods give similar but not always identical results; therefore the final reported volume is the average of the two methods.

  Volume is the preferred parameter for comparisons because it is independent of the shape of the wear facet (DeLong R. Intra-oral Restorative Materials Wear: Rethinking the Current Approaches: How to Measure Wear. Dent Mater. 2006 22(8): 702-11). Dentistry has historically used depth to measure wear because it was the only parameter that they could measure, and it relates to vertical dimension. The problem with depth is that for the same volume of material removed you can have an infinite number of depths. Depth also depends on the direction it is measured: vertically or normal to the surface. Finally, theoretically, volume loss is linear with time whereas depth is not. Depth shows an initial rapid increase, which decreases with time.

- Maximum Depth: This is the maximum difference between the two surfaces within the defined wear region. It is measured normal to the unworn surface.
- Mean Depth: Calculated as the average of all depths within the defined region. It can also be calculated as the volume divided by the projected area.

Statistics:
The two materials were compared using t-tests (Microsoft Excel 2010).

Results and Discussion

Quality of the alignments
The quality of the alignment was determined using two methods: Absolute Mean Difference and the Two Sigma (2σ) value of the absolute distances between the aligned images. For more detail, see **Appendix: Quality of Digital Model Alignment**

For all alignments, the average absolute distance was 0.005±0.0004 mm. The 2σ values ranged from 0.012 mm to 0.017 mm; thus, all alignments fell in the very good category. The quality of the alignments allowed difference plots to be done with a range of ±0.050 mm, with intervals of 0.010 mm, Figure 5.

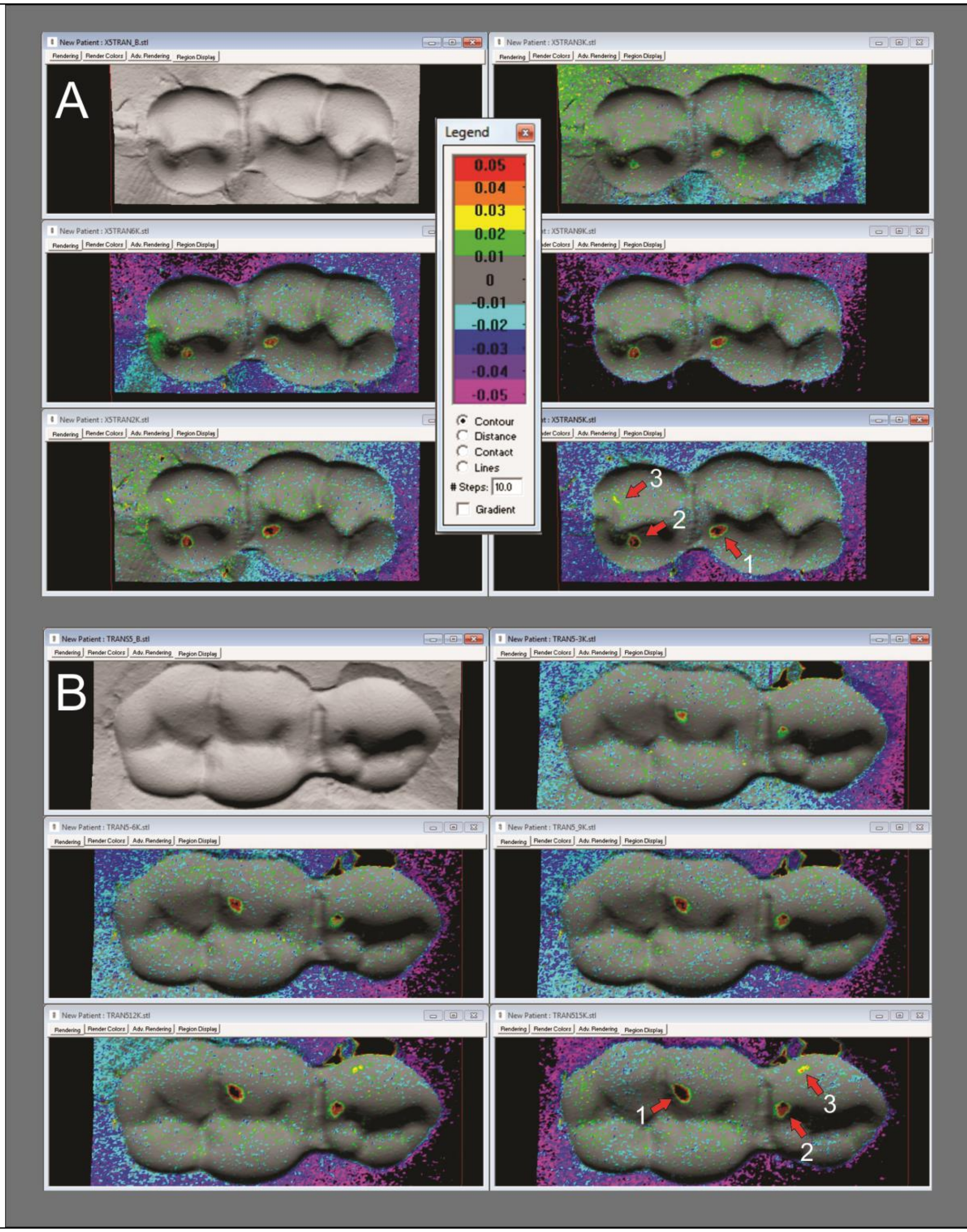


Figure 5: AvaDent Sample 5 Difference Plot. A color plot of the differences between the baseline and the 300 to 1500 Kcycle images. The scale is provided in A. Differences less than ±0.010 mm are shown as the gray scaled image. Regions in black have differences greater than ±0.050 mm. The red arrows indicate the regions of wear. The upper arch is A and the lower arch is B. Progression of the wear is easily monitored with increasing cycles. .

Accuracy of Measurements (calculated from test measurements):

- **Volume:** ±0.005 mm^3 per cubic millimeter of material loss – calculated as the average absolute distance of all alignments times 1 mm^2 projected area. Volume loss values less than this may not be meaningful.
- **Maximum Depth** and **Mean Depth**: 0.005 ± 0.0004 mm – calculated as the average absolute mean distance for all alignments.

With the exception of AvaDent sample 1, all of the samples had multiple wear regions at the end of the 1500K cycles, Figure 6. For samples with multiple wear facets, the volumes of the wear facets were summed to get the total volume removed for the sample. The maximum depth is the largest maximum depth of the wear facets in the sample. The mean depth is the weighted average of the mean depths for the multiple wear facets on the selected sample. Area was used as the weighting factor. Mean depth can also be calculated as the volume divided by the projected area. For all tables, volumes are in cubic millimeters, depths are in millimeters, and areas are in square millimeters. Area is the projected area onto the horizontal plane. Values for the individual samples are provided in Tables 1 through 4. Average values are shown in Table 5 and displayed in Figures 7, 9 and 11.

Upper and lower wear values were combined for the different parameters. This is a better representation of the wear. Volume loss was combined by adding the upper and lower volumes. The maximum depths for the upper and lower wear areas were added as were those for the mean depths. Values are provided in Table 6 and displayed in Figures 8, 10 and 12.

There were no significant differences between wear parameters for the Ivoclar DCL and AvaDent denture teeth; however, the volume loss for AvaDent teeth was consistently lower than that for the Ivoclar DCL teeth. P-values ranged from 0.09 to 0.41 for the different cycle values. The lack of any significant differences is due to the large standard deviations and the small number of samples. Wear is a statistical phenomenon; therefore, one expects variation. Wear also depends on the anatomy of the samples. Small variations in anatomy can cause large variations in wear. This amount of variation is seen in all of our tests, and is not unusual. Even using flat discs with opposing spherical abraders we see a lot of variation, although the variation with flat samples is significantly less than when anatomical forms are used.

There were no significant differences between the wear on the upper and lower teeth for both the Ivoclar DCL and AvaDent teeth. P-values ranged from 0.11 to 0.65, Figures 7, 9 and 11.

Using the combined wear data, which is the better representation of wear, the Ivoclar DCL wear rate for volume loss (0.079 mm^3/year) was slightly greater than that of AvaDent (0.056 mm^3/year)), Table 6. Wear rates for the maximum depth and mean depths were similar for both materials. Wear rates were calculated from the slope of the linear regression lines equating 300K cycles to one year of simulated clinical wear.

Conclusions:

Under the conditions of this work:

1. There were no significant differences in the wear of the Ivoclar DCL and AvaDent denture teeth for any of the wear parameters; however, the volume loss of the AvaDent teeth was consistently lower than that of the Ivoclar DCL teeth.
2. There were no significant differences in the wear rates of the Ivoclar DCL and AvaDent denture teeth; however, the wear rate for the AvaDent teeth was less than that of the Ivoclar DCL teeth.
3. There were no significant differences in the wear between the upper and lower teeth of the same material.

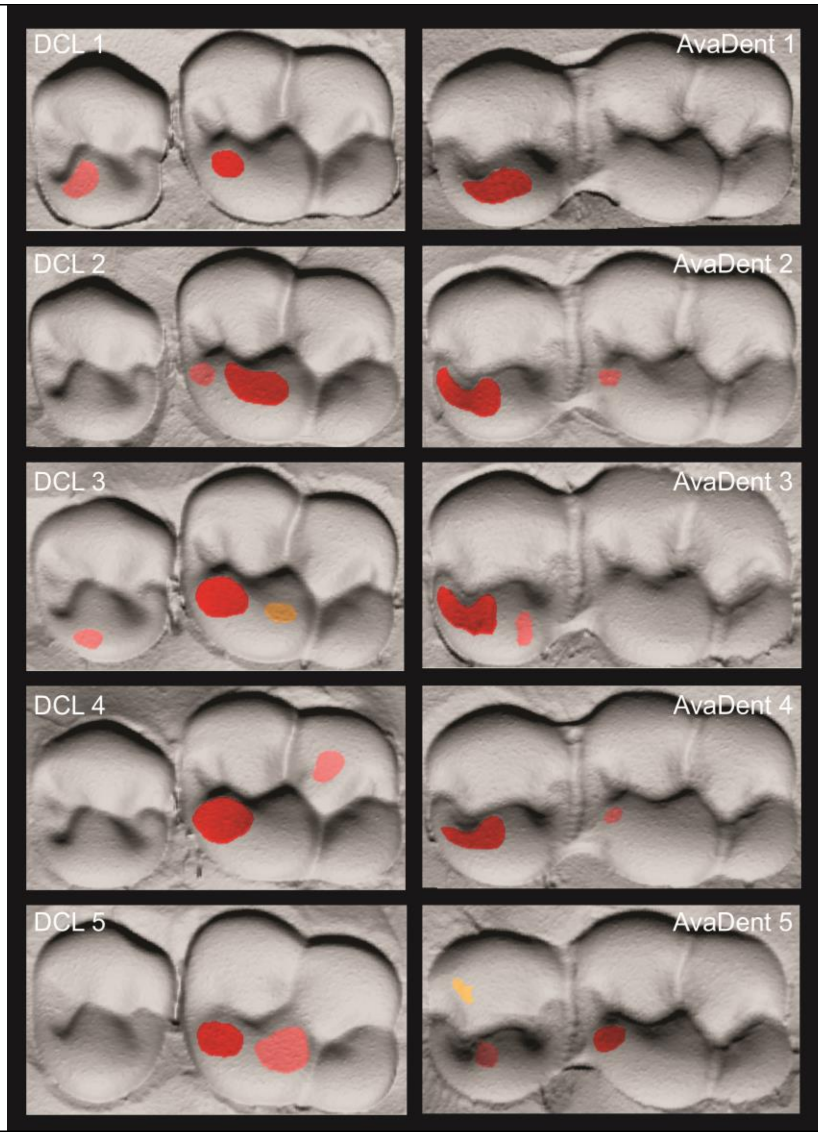


Figure 6: Wear regions of the upper teeth. The colored regions indicate the wear regions after 1500K cycles. The wear regions on the lower teeth correspond to those of the upper.

Table 1: Ivoclar DCL Lower Teeth					
			Depth (mm)		
Sample	KCycles	Volume (mm^3)	Maximum	Mean	Area (mm^2)
1	300	0.038	0.070	0.028	1.338
1	600	0.048	0.072	0.030	1.558
1	900	0.072	0.084	0.036	1.947
1	1200	0.085	0.089	0.039	2.137
1	1500	0.128	0.110	0.045	2.723
2	300	0.073	0.081	0.036	1.953
2	600	0.093	0.087	0.039	2.346
2	900	0.111	0.092	0.041	2.597
2	1200	0.180	0.104	0.050	3.481
2	1500	0.246	0.125	0.060	3.938
3	300	0.089	0.116	0.051	1.714
3	600	0.130	0.137	0.056	2.242
3	900	0.165	0.149	0.061	2.598
3	1200	0.192	0.161	0.056	3.366
3	1500	0.243	0.176	0.061	3.891
4	300	0.128	0.132	0.064	1.957
4	600	0.172	0.147	0.072	2.339
4	900	0.212	0.164	0.072	2.838
4	1200	0.258	0.179	0.073	3.415
4	1500	0.304	0.193	0.077	3.824
5	300	0.054	0.067	0.029	1.810
5	600	0.088	0.082	0.036	2.421
5	900	0.140	0.099	0.045	3.070
5	1200	0.181	0.113	0.052	3.455
5	1500	0.234	0.130	0.056	4.043

Table 2: Ivoclar DCL Upper Teeth					
			Depth (mm)		
Sample	KCycles	Volume (mm^3)	Maximum	Mean	Area (mm^2)
1	300	0.037	0.063	0.026	1.407
1	600	0.038	0.067	0.026	1.438
1	900	0.064	0.074	0.032	1.887
1	1200	0.077	0.084	0.036	2.102
1	1500	0.110	0.091	0.042	2.537
2	300	0.088	0.107	0.053	1.609
2	600	0.091	0.104	0.045	1.975
2	900		No Data		
2	1200	0.203	0.155	0.061	3.232
2	1500	0.255	0.173	0.068	3.640
3	300	0.105	0.125	0.054	1.902
3	600	0.137	0.141	0.059	2.255
3	900	0.182	0.157	0.055	3.188
3	1200	0.219	0.170	0.060	3.525
3	1500	0.270	0.186	0.066	3.953
4	300	0.126	0.129	0.057	2.147
4	600	0.169	0.149	0.065	2.537
4	900	0.215	0.162	0.070	3.000
4	1200	0.262	0.178	0.074	3.441
4	1500	0.325	0.195	0.072	4.369
5	300	0.052	0.052	0.021	2.469
5	600	0.097	0.065	0.030	3.136
5	900	0.136	0.077	0.037	3.639
5	1200	0.217	0.099	0.046	4.555
5	1500	0.250	0.108	0.050	4.872

Table 3: AvaDent Lower Teeth					
			Depth (mm)		
Sample	KCycles	Volume (mm^3)	Maximum	Mean	Area (mm^2)
1	300	0.053	0.088	0.035	1.432
1	600	0.066	0.104	0.040	1.591
1	900	0.077	0.106	0.043	1.773
1	1200		No Data		
1	1500	0.105	0.114	0.047	2.181
2	300	0.051	0.097	0.034	1.457
2	600	0.089	0.113	0.046	1.872
2	900	0.167	0.146	0.054	2.971
2	1200	0.193	0.149	0.057	3.216
2	1500	0.209	0.157	0.059	3.415
3	300	0.054	0.105	0.037	1.414
3	600	0.083	0.120	0.042	1.897
3	900	0.105	0.131	0.041	2.459
3	1200	0.131	0.141	0.042	3.007
3	1500	0.150	0.156	0.043	3.401
4	300	0.043	0.069	0.030	1.396
4	600	0.098	0.100	0.048	1.970
4	900	0.120	0.113	0.056	2.099
4	1200	0.179	0.137	0.060	2.892
4	1500	0.221	0.153	0.067	3.178
5	300	0.016	0.052	0.020	0.765
5	600	0.033	0.062	0.026	1.188
5	900	0.038	0.065	0.030	1.260
5	1200	0.055	0.079	0.030	1.768
5	1500	0.064	0.080	0.032	1.894

Table 4: AvaDent Upper Teeth					
			Depth (mm)		
Sample	KCycles	Volume (mm^3)	Maximum	Mean	Area (mm^2)
1	300	0.062	0.089	0.039	1.526
1	600	0.085	0.103	0.043	1.912
1	900	0.105	0.117	0.049	2.060
1	1200	0.134	0.128	0.059	2.220
1	1500	0.148	0.129	0.060	2.394
2	300	0.056	0.089	0.040	1.343
2	600	0.116	0.124	0.053	2.073
2	900	0.177	0.148	0.061	2.738
2	1200	0.205	0.156	0.063	3.125
2	1500	0.219	0.159	0.063	3.280
3	300	0.050	0.090	0.035	1.353
3	600	0.110	0.131	0.056	1.887
3	900	0.165	0.162	0.060	2.625
3	1200	0.211	0.184	0.066	3.035
3	1500	0.257	0.208	0.073	3.376
4	300	0.048	0.094	0.041	1.121
4	600	0.069	0.101	0.042	1.579
4	900	0.074	0.103	0.044	1.633
4	1200	0.091	0.102	0.042	2.081
4	1500	0.111	0.107	0.046	2.353
5	300	0.016	0.037	0.019	0.782
5	600	0.033	0.055	0.027	1.160
5	900	0.044	0.061	0.029	1.435
5	1200	0.055	0.068	0.029	1.833
5	1500	0.063	0.070	0.029	2.056

Table 5: Average of five samples (Mean ± Standard Deviation)							
		Mean Volume (mm3)		Maximum Depth (mm)		Mean Depth (mm)	
Material	Cycles	Lower	Upper	Lower	Upper	Lower	Upper
Ivoclar DCL	300	0.076 ± 0.035	0.081 ± 0.037	0.093 ± 0.029	0.095 ± 0.036	0.041 ± 0.015	0.042 ± 0.017
	600	0.106 ± 0.047	0.106 ± 0.049	0.105 ± 0.035	0.105 ± 0.039	0.046 ± 0.017	0.045 ± 0.017
	900	0.140 ± 0.053	0.149 ± 0.066	0.117 ± 0.036	0.117 ± 0.049	0.051 ± 0.015	0.048 ± 0.018
	1200	0.179 ± 0.062	0.195 ± 0.070	0.129 ± 0.039	0.137 ± 0.043	0.054 ± 0.013	0.055 ± 0.015
	1500	0.230 ± 0.064	0.242 ± 0.080	0.147 ± 0.036	0.150 ± 0.048	0.060 ± 0.012	0.060 ± 0.013
Avadent	300	0.043 ± 0.016	0.046 ± 0.018	0.082 ± 0.022	0.080 ± 0.024	0.031 ± 0.006	0.035 ± 0.009
	600	0.074 ± 0.026	0.082 ± 0.033	0.100 ± 0.023	0.103 ± 0.030	0.040 ± 0.008	0.044 ± 0.011
	900	0.102 ± 0.048	0.113 ± 0.057	0.112 ± 0.031	0.118 ± 0.040	0.045 ± 0.011	0.049 ± 0.013
	1200	0.139 ± 0.062	0.139 ± 0.069	0.126 ± 0.032	0.127 ± 0.045	0.047 ± 0.014	0.052 ± 0.016
	1500	0.150 ± 0.067	0.159 ± 0.079	0.132 ± 0.034	0.134 ± 0.052	0.049 ± 0.014	0.054 ± 0.017

Table 6: Averaged Combined Upper and Lower Data					
			Depth (mm)		Wear Rate*
Material	Cycles	Volume (mm3)	Maximum	Mean	(mm/Year)
Ivoclar DCL	300	0.158 ± 0.071	0.188 ± 0.063	0.083 ± 0.031	0.079
	600	0.213 ± 0.096	0.210 ± 0.073	0.091 ± 0.034	
	900	0.296 ± 0.124	0.241 ± 0.087	0.102 ± 0.034	
	1200	0.375 ± 0.131	0.266 ± 0.078	0.109 ± 0.026	
	1500	0.473 ± 0.143	0.297 ± 0.079	0.120 ± 0.024	
AvaDent	300	0.089 ± 0.033	0.162 ± 0.042	0.066 ± 0.015	0.056
	600	0.156 ± 0.055	0.202 ± 0.052	0.084 ± 0.019	
	900	0.214 ± 0.098	0.230 ± 0.069	0.093 ± 0.021	
	1200	0.280 ± 0.125	0.254 ± 0.080	0.097 ± 0.027	
	1500	0.309 ± 0.123	0.266 ± 0.081	0.103 ± 0.024	

* Calculated as the slope of the regression line through the five cycle periods. Estimate that one year is equivalent to 300K cycles

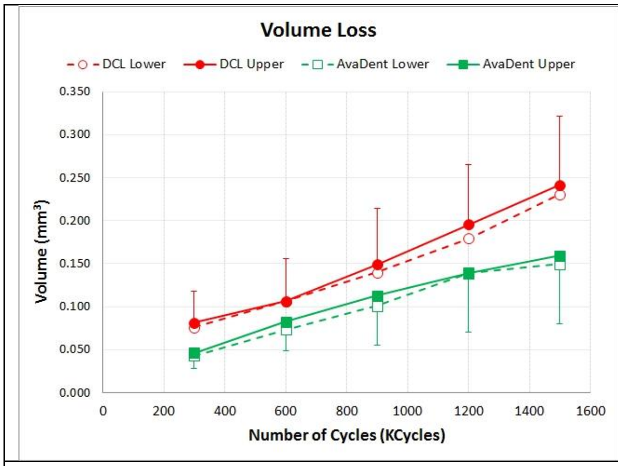


Figure 7: Upper and Lower Volume Loss Error bars represent one standard deviation

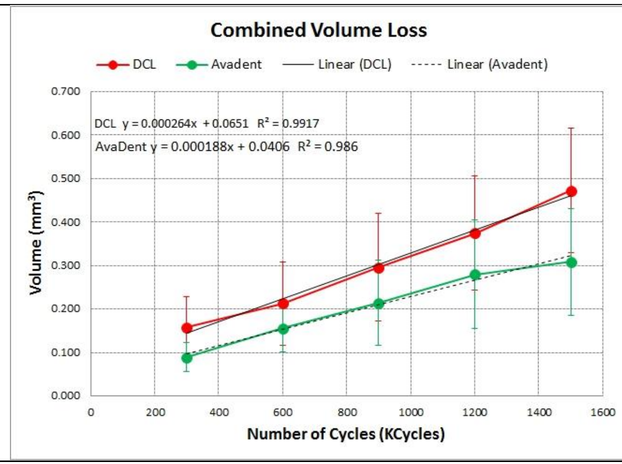


Figure 8: Combined Upper and Lower Volume Loss Error bars represent one standard deviation. Black lines are linear regression lines

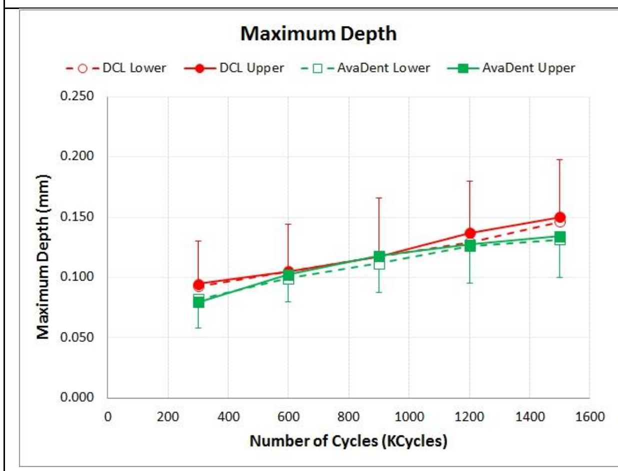


Figure 9: Upper and Lower Maximum Depth Error bars represent one standard deviation

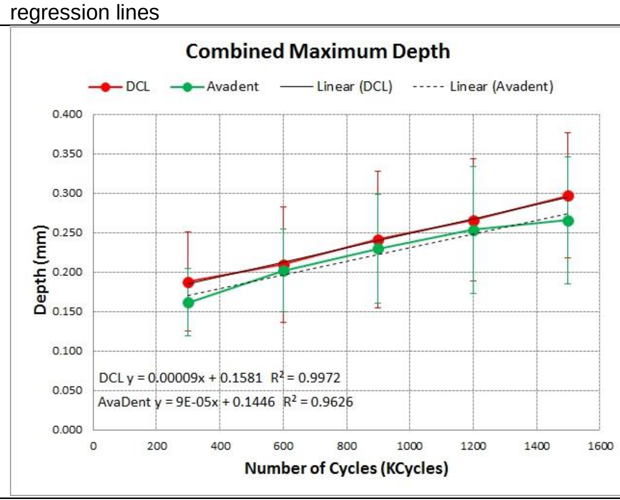


Figure 10: Combined Upper and Lower Maximum Depth Error bars represent one standard deviation. Black lines are linear regression lines

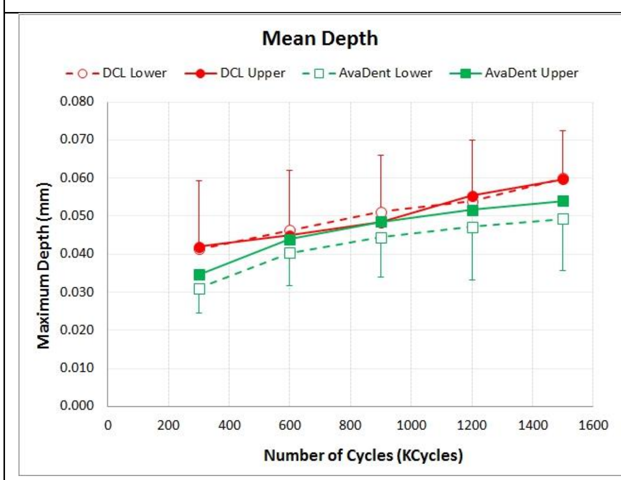


Figure 11: Upper and Lower Mean Depth Error bars represent one standard deviation

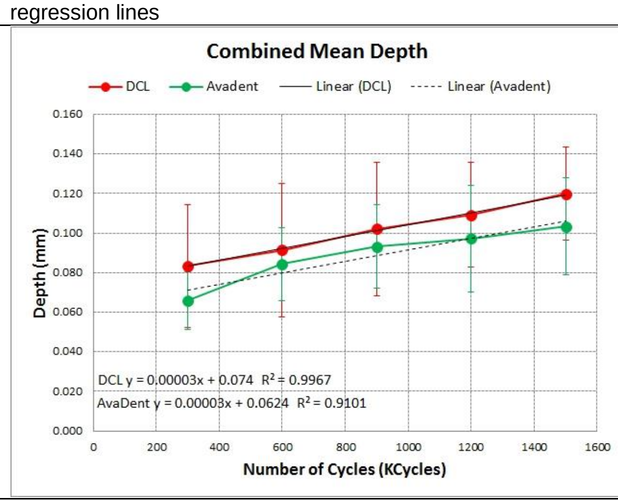


Figure 12: Combined Upper and Lower Volume Loss Error bars represent one standard deviation. Black lines are linear regression lines

Appendix: Quality of Digital Model Alignment

The quality of the alignment is determined using two methods: Absolute Mean Difference and the Two Sigma (2σ) value of the absolute distances between the aligned images. Both methods use the absolute distances between the two aligned images. Distances are calculated for all points used to align the two images. Points related to surface defects or wear are excluded from the calculation.

- Mean Absolute Difference: The average of the absolute values of the shortest distances from baseline to the second surface. Only points used in the alignment process are considered.
- Two Sigma: The smallest absolute distance that is larger than 95% of the absolute distances calculated for the points used to align the two images.

  The two sigma data is often presented as a graph of absolute distances verses the percent of points. This provides a visual image of the quality of the alignment. Ideally, the graph should be a straight line with an absolute distance equal to, or less than, the accuracy of the measuring device. Normally, however, there is a gradual increase in the absolute distance until 95% of the points are included, after which, the absolute distances increase exponentially. This rapid rise represents the inclusion of artifacts, Figure 13.

  Assuming system accuracy (accuracy of the measured points) of ±0.005 mm, then the quality of the alignments as measured by Two Sigma (2σ) is:

  - 2σ ≤ 0.010 mm is excellent
  - 2σ ≤ 0.020 mm is very good
  - 2σ ≤ 0.030 mm is good
  - 2σ > 0.050 mm is poor

  Note: these values are somewhat arbitrary because the points used to align the two images can be altered to remove “bad” point. Therefore, it is important to include as many points in the alignment as possible to avoid “fudging” the quality of fit.

The following alignments were done: Baseline to 300K, 600K, 900K, 1200K, and 1500K. For all alignments, the mean absolute distance was 0.005±0.0004 mm. The average number of points used in the alignment was 207795; range: 154728 to 228828. The 2σ values ranged from 0.012 mm to 0.017 mm; thus, all alignments fell in the very good category. The average absolute minimum distances are given in Table 7. The “Average” row in Table 7 is the average of the five samples for each category (Ivoclar DCL, AvaDent, Upper, Lower). The “Best” row is the minimum value for the absolute distance at each percentage, and the “Worst” row is the maximum absolute distance at each percentage.

Figure 14 shows plots of all the absolute distances between the points in the first model to the second model after the alignment. Points were ordered from smallest to largest. The percentage of points at or below a defined distance is shown. For a perfect alignment, the graph would be a straight line with an absolute mean distance of zero. Normally, however, the graph has a gradual slope with a sharply rising tail approaching 100% of the points. The tail represents outlier points in the digital models.

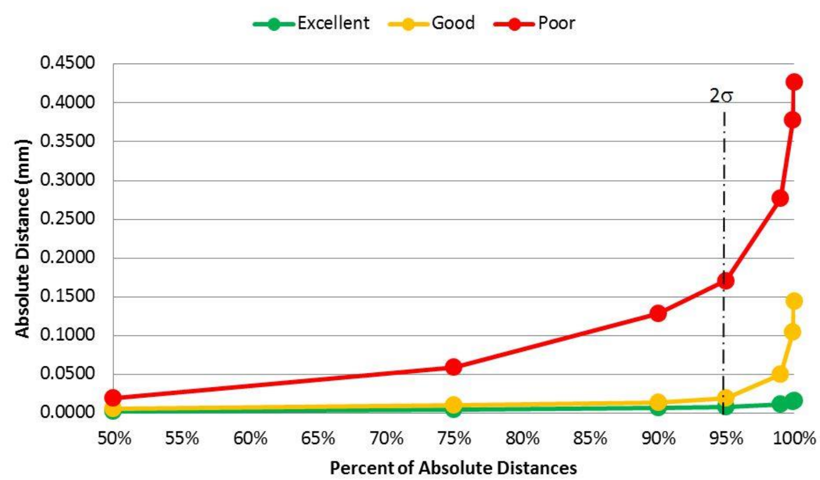


Figure 13: Quality of the alignment of two data sets. The minimum absolute distances between all the points used to align the two data sets are ordered from smallest to largest. The more horizontal the slope of the curve, the higher the quality of the fit. The exponential increase above 95% is caused by the inclusion of points that represent artifacts.

Table 7: Quality of Sample Alignments in Cumulus

			Absolute Distance at Percent of Points						
Material	**Arch**	**Quality**	**50%**	**75%**	**90%**	**95%**	**99%**	**99.90%**	**100%**
Ivoclar DCL	Lower	Average	0.004	0.007	0.011	0.015	0.022	0.031	0.052
		Best	0.004	0.007	0.010	0.013	0.020	0.028	0.046
		Worst	0.005	0.008	0.013	0.016	0.024	0.035	0.061
	Upper	Average	0.004	0.007	0.012	0.015	0.022	0.032	0.060
		Best	0.004	0.007	0.011	0.014	0.021	0.030	0.043
		Worst	0.005	0.009	0.014	0.017	0.025	0.035	0.136
AvaDent	Lower	Average	0.004	0.007	0.011	0.014	0.021	0.030	0.050
		Best	0.003	0.006	0.009	0.012	0.018	0.026	0.039
		Worst	0.005	0.008	0.012	0.015	0.023	0.033	0.062
	Upper	Average	0.004	0.007	0.011	0.014	0.021	0.030	0.052
		Best	0.003	0.006	0.010	0.013	0.019	0.026	0.043
		Worst	0.005	0.008	0.012	0.015	0.022	0.032	0.065
All		Average	0.004	0.007	0.011	0.014	0.021	0.031	0.054
		Best	0.003	0.006	0.009	0.012	0.018	0.026	0.039
		Worst	0.005	0.009	0.014	0.017	0.025	0.035	0.136

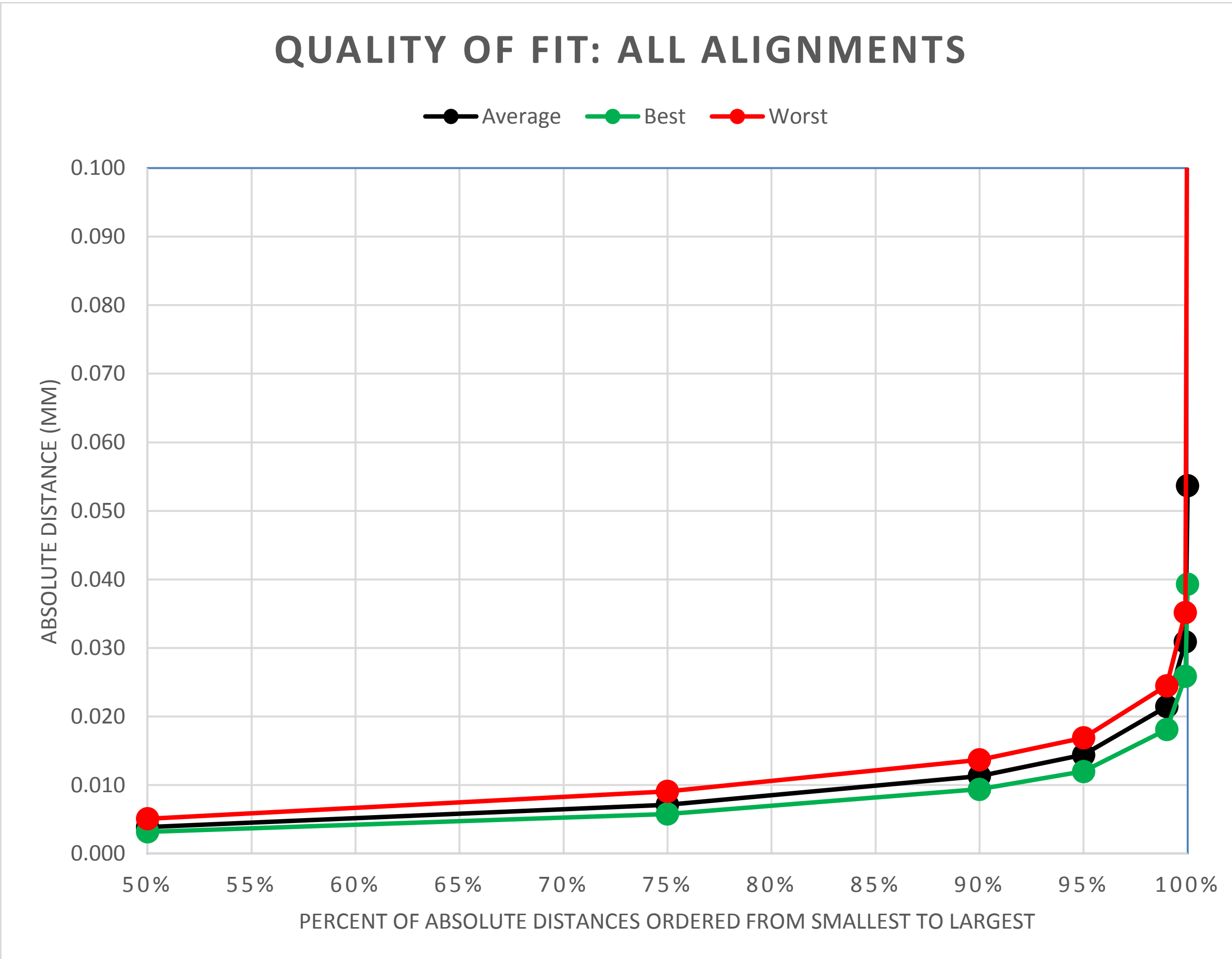


Figure 14: Quality of alignment of digital model. All alignments are to the baseline model. Results are the average of all samples (Ivoclar DCL Lower, Ivoclar DCL Upper, AvaDent Lower, Avadent Upper). The black line is the average, the red line is the upper limit, and the green line is the lower limit.