Investigation of PMMA Cement Penetration in Prepared Femoral Heads with a Longitudinal Slot for Hip Resurfacing Arthroplasty

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Abstract

Hip resurfacing arthroplasty is becoming increasingly popular in younger, active patients due to its preservation of natural biomechanics. Failure of these implants can be very traumatic and potentially life threatening. The role of cement penetration in early implant failure is not yet known, and must be investigated. This study specifically investigates the effects of a 5mm by 5mm longitudinal channel on cement penetration into the femoral head. High-density open-cell reticulated vitreous carbon foam cylinders and Huntsman Pro-cast® 20 implants based on the Birmingham Hip Resurfacing implant were used. It was determined cement penetration was increased in the area immediately surrounding the slot, and the slot caused increased penetration in the dome and chamfer areas, but did not significantly alter the penetration at the wall at the back of the implant. On either side of the slot (Faces 2A, 2B) cement penetration is again statistically increased in the dome and chamfer areas, but not statistically different at the wall.

Introduction

Hip Resurfacing History

Hip resurfacing arthroplasty was a popular alternative to total hip replacement in the mid 1970's; however it was later found to have a high loosening/failure rate due to polyethylene wear debris initiating a cascade that ends with osteolysis. This issue was resolved by the development of modern metal on metal bearings, which have proven to produce very low wear rates over several decades of use (Silva, 2004). In the past 10 years hip resurfacing arthroplasty has again become the choice for younger patients with arthritis of the hip for several reasons. When compared to total hip replacement, hip resurfacing arthroplasty is a more appealing treatment for patients with highly active lifestyles. This is because hip resurfacing arthroplasty preserves much more of the femur head, and restores natural joint biomechanics (Falez, 2010). Although these hip resurfacing implants have a relatively low failure rate of 3.6% (Carrothers, 2010) the role of cement in implant failure is not yet entirely clear (Falez, 2010). The methods and results from this study may help better characterize cement penetration into the femoral head with the use of Birmingham Hip Resurfacing Implants.

Cementing Background and Techniques

Although this study focuses on PMMA bone cement penetration as causes of failure, it is important to note femoral component failure is multifaceted (Carrothers, 2010). Excessive valgus/varus positioning, over/under sizing of the implant, as well as the structural integrity of the patient's femur all play very important roles in the success or failure of an implant. Additionally it has been shown that osteoporotic bone in women leads to a significantly higher failure rate in females (Treacy, 2010).

Generally, there are two schools of thought regarding femoral cement fixation: one is to minimize the amount of cement used and only produce a few millimeters of penetration; and the opposite is to apply copious amounts of cement and produce deep penetration into the femoral head (Campbell, 2009). Both of these techniques have advantages and disadvantages, and each one may be the best choice for different patients. Basically the goal is to have enough cement penetration to secure the implant for its intended life, without applying too much bone cement to cause thermal necrosis. Thermal necrosis can occur as the PMMA cement cures, and causes bone to be replaced with fibrous membranes which can lead to component failure (Sakagoshi, 2009).

The Birmingham Hip Resurfacing implant uses a tight fit with low viscosity PMMA applied to the interior of the implant, which is then manually seated on the prepared femoral head (Campbell, 2009). This technique falls under the copious cement and deep penetration category, because it produces penetration deeper than 3 mm. This study will investigate the characteristics of low viscosity PMMA penetration with a 5 mm deep x 5 mm wide channel along the longitudinal axis of the femoral head, when compared to a control implant. The purpose of the channel is to increase cement penetration in the channel, thus increasing resistance to a rotational torque. This could prove to be a valuable technique for surgeons currently searching for the perfect cementing technique. This channel will be successful because the implant will have a 5 mm x 5 mm protrusion which will fit into the foam like a key; thus increasing the rotational resistance of the implant. It is hypothesized the channel would reduce cement penetration into a prepared femoral head.

Methods

Hip Resurfacing Implants

The femoral component design was based on the dimensions taken from the Birmingham Hip Resurfacing System (Figure 1) by Smith & Nephew (Memphis, Tennessee). A Cal Poly graduate student (Mark Paulick) recreated the implants in Solidworks. These files were used to rapid prototype the femoral components using a Objet Eden 350V rapid prototyping system (Objet Geometries Inc., Billerica, Massachusetts). The Object machine uses a non-disclosed polymer called VeroWhite FullCure®, which uses UV light to harden resin and build the part. Once the FullCure® femoral components were cleaned, Mark then used them to create a mold from which a number of polymer components were produced. These polymer implants cast with Huntsman Pro-cast® 20 (Huntsman International, Hong Kong) were the actual femoral components used in this experiment. All femoral components had an inner diameter of 50mm.

Figure 1: Birmingham Hip Resurfacing System

Foam Cylinders

The goal of this experiment was to determine cement penetration characteristics into the femoral head. For this reason high-density open-cell reticulated vitreous carbon foam (Pacific Research Laboratories Inc, Vashon Washington) was chosen to model the trabecular bone (Bitsch, 2008). Next the cylinders were reamed with a Depuy Orthopaedics (Warsaw, Indiana) reamer consistent with the tool used during a real surgical procedure. After reaming the cylinders to an outer diameter of 50mm, a 5 mm deep x 5 mm wide slot was milled longitudinally along the shaft of the cylinders (Along red line in Figure 2 B). This slot was the experimental variable; the control cylinder was a normally prepared shaft with a complete cylindrical outer surface. It is also important to note that surgeons sometimes drill additional holes into the head of the prepared femur, as can be seen in Figure 2 A. These holes were not taken into account in this experiment, and could potentially change the penetration characteristics into the femoral head. In a future study it would be worthwhile to investigate just how much these additional holes would alter cement penetration.

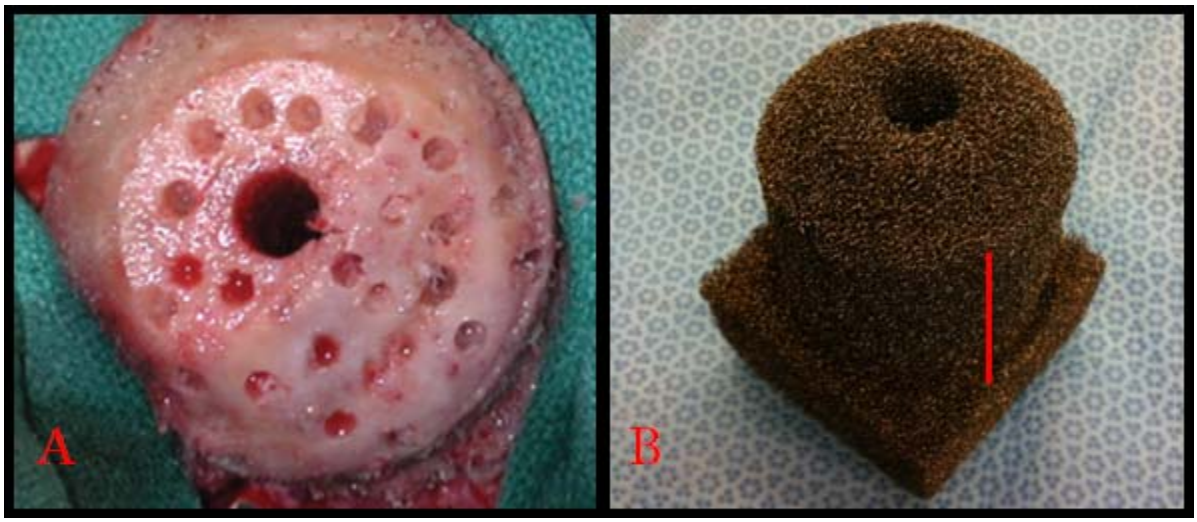


Figure 2: Prepared Femoral Head and Additional Holes (A). Reamed High Density Open Cell Reticulated Vitreous Carbon Foam Cylinder (B).

Implantation

Dr. Amir Jamali of UC Davis performed the implantation procedures, to better replicate surgical conditions. The PMMA bone cement was prepared under very specific conditions, which are detailed in Mark's thesis (Paulick, 2009). Instead of Dr. Jamali implanting the femoral components by hand, an Instron 8511 was used to insure reproducibility. The femoral components were applied with a 20 – 30 N load for two minutes, after which they were ready to be sectioned. However, it should be noted that during an actual surgery, the femoral component is seated manually by the surgeon. Also, in this experiment the implants acted as a cup filled with PMMA cement, while the cylinders were pushed down into the femoral component. In this scenario gravity is working in a different direction than in a real surgery. Although this was inconsistent with an actual surgery, it is a very reproducible and consistent way to seat the implants.

Cross Sections

Next the implants were sectioned with a 1/32" band saw, in order to analyze the cement penetration at different locations in the model. A jig was used to hold the implants during the cuts, which insured the sections were aligned and consistent. After sectioning the face of several implants were marred by cutting grease which is used to protect the band saw blade. This made it impossible to see where the cement penetrated, so these sections were cleaned by block sanding the faces with 120 grit sandpaper. The amount of material removed was minimized to maintain the original implant as much as possible (Figure 4).

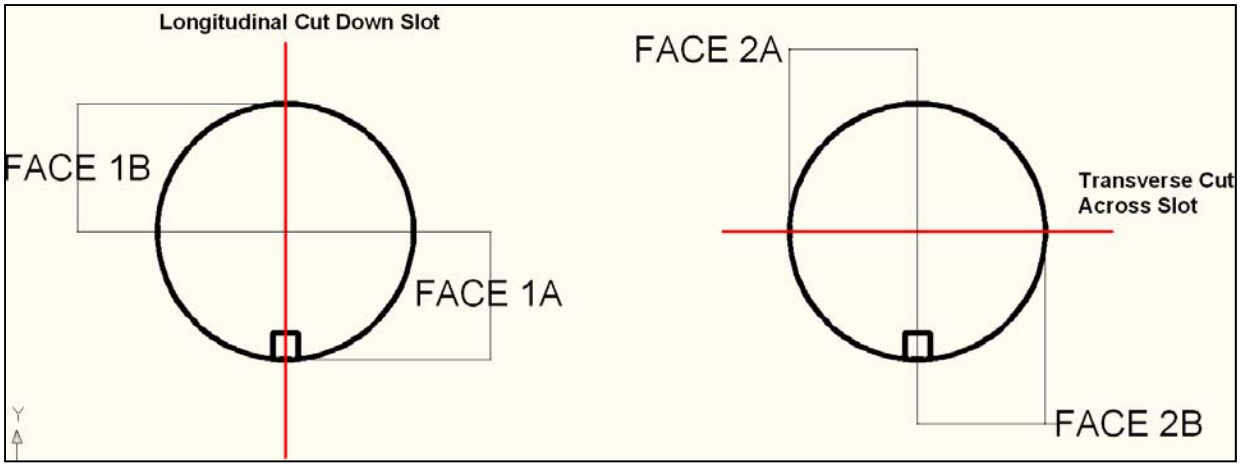


Figure 3: View Geometry of Faces and Cross Sections

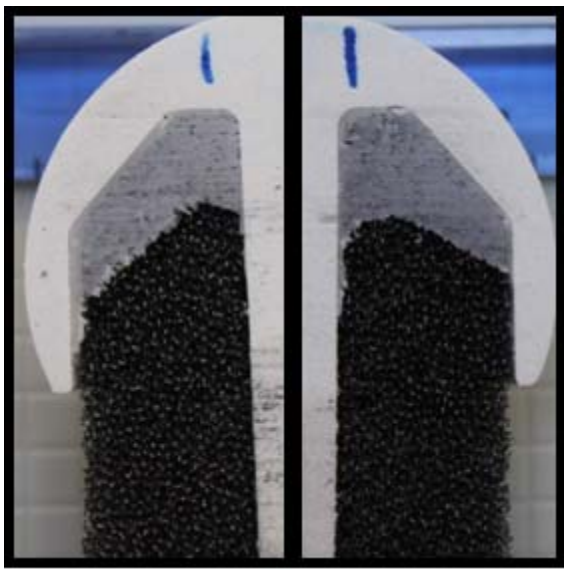
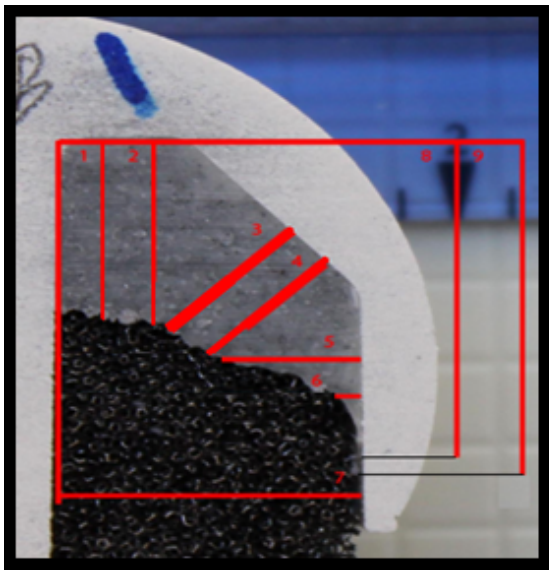


Figure 4: Implant Cross Sections after Cleaning

ImageJ Analysis

Pictures of each face were imported into ImageJ for ten measurements (all in mm) of each section. Each implant had four unique faces, labeled 1A, 1B, 2A and 2B (As Labeled in Figure 3). Faces 1A and 1B are seen when a longitudinal cut was made down the slot. 2A and 2B were the remaining two transverse faces. Measurements were similar to a previous study (Krause, 2009) to quantify bone cement penetration. These

measurements can be seen in Figure 5. The red lines in the pictures are a measurement overlay to make sure each measurement is observed correctly on each implant/face. All data collected can be seen in Appendix B.



Measurement	Description
1	Cement penetration from dome (1)
2	Cement penetration from dome (2)
3	Cement penetration from chamfer (superior)
4	Cement penetration from chamfer (inferior)
5	Cement penetration from wall (superior)
6	Cement penetration from wall (inferior)
7	Actual offset at wall
8	Actual cement penetration height
9	Maximum cement penetration height
10	Cross-sectional area of penetrated cement

Figure 5: (L): Cross Section with Red Measurement Layer overlaid using Adobe Photoshop (R): Table of Measurements as seen on diagram

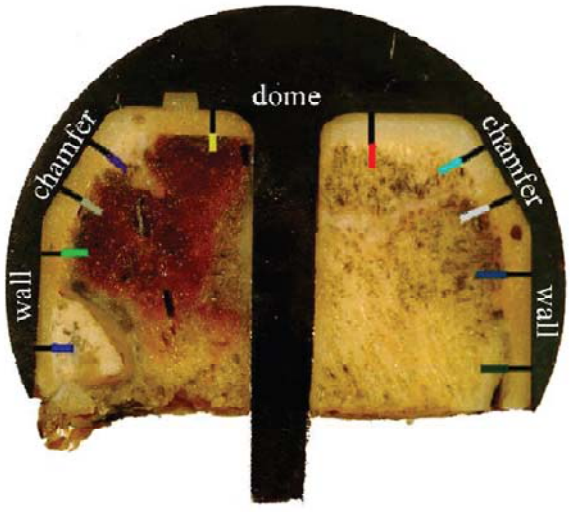


Figure 6: Labeling of Wall, Chamfer and Dome portions of a Femoral Component

Minitab Statistical Analysis

All data was analyzed in Minitab, specifically using two sample T tests. Next, all measurements from a particular face were then compared to the same measurement from all four faces of the control, because the control implants were non-directional. For example, all Measurement 1's taken from all eight Face 1A slot implants were then compared to the four Measurement 1's taken from the four faces of the control implant. Statistical significance was defined as a p-value less than 0.05. The results are summarized in the Table 2.

Next, the measurements of just the slot implants were compared to Face 1A and Face 1B of the slot implants. This determined if the distribution of cement was symmetrical within the slotted implants. The results from this analysis can be seen in Table 3 and Table 4.

Results

As demonstrated by the figure below, the longitudinal slot (Figure 7A) allows deeper penetration along the length of the slot. It also affected the penetration at the opposite side of the slot as described below. However, it was also noted in several implants that excess bone cement collected at the end of the slot, as noted by the red arrow. This would have been removed in a real surgery, and is merely noted in this study.

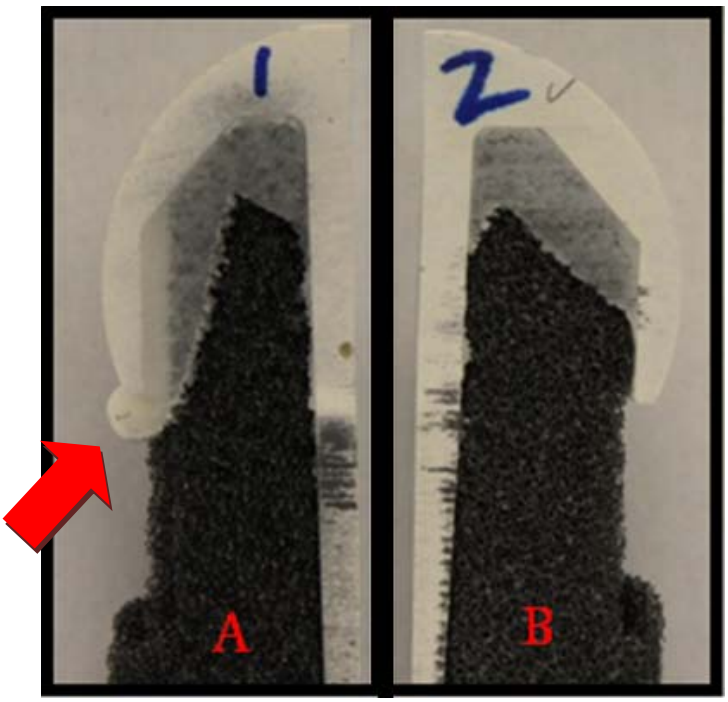


Figure 7: (A) Face 1A of slotted implant with excess PMMA .
(B) Face 2A of Control Implant

Table 1A: Average Measurements of 8 Experimental and one Control Implants

Averages	Slot 1A	Slot 1B	Slot 2A	Slot 2B	Control
1	12.604	11.909	12.023	11.793	10.580
2	12.443	12.628	12.306	12.218	10.56
3	8.898	9.080	8.944	8.806	7.305
4	8.501	8.201	8.149	7.503	6.968
5	7.320	4.311	5.135	3.979	3.843
5B	2.32	4.311	5.135	3.979	3.843
6	5.929	0.911	1.383	0.816	1.053
6B	0.929	0.911	1.383	0.816	1.053
7	4.186	0.000	0.124	0.000	0.410
8	29.489	18.421	19.849	18.393	21.308
10	259.726	191.423	197.559	184.751	187.19

Table 1B: Standard Deviations of 8 Experimental and one Control Implants

Standard Deviations	Slot 1A	Slot 1B	Slot 2A	Slot 2B	Control
1	1.393	1.085	1.576	1.215	0.790
2	1.900	0.853	1.703	1.284	0.369
3	1.841	0.989	1.378	1.243	0.191
4	1.253	1.016	0.878	1.086	0.56
5	1.363	2.737	2.195	2.789	1.903
5B	1.363				
6	0.881	0.888	1.181	1.146	0.503
6B	0.800				
7	0.657	***	0.234	***	0.473
8	2.106	2.401	2.653	2.359	2.151
10	22.985	10.306	16.729	15.206	4.319

Table 1: P-Values from Control Measurements vs. Slotted Measurements

Measurement	Face 1A	Face 1B	Face 2A	Face 2B
1	0.011	0.042	0.064	0.071
2	0.031	0.0	0.024	0.01
3	0.046	0.002	0.013	0.012
4	0.017	0.024	0.02	0.289
5	0.031	0.739	0.333	0.923
5B	0.227			
6	0.0	0.734	0.515	0.632
6B	0.852			
7	0.0	***	0.336	***
8	0.002	0.08	0.341	0.076
10	0.000	0.344	0.138	0.685

*** Indicates all values were identical for that test.

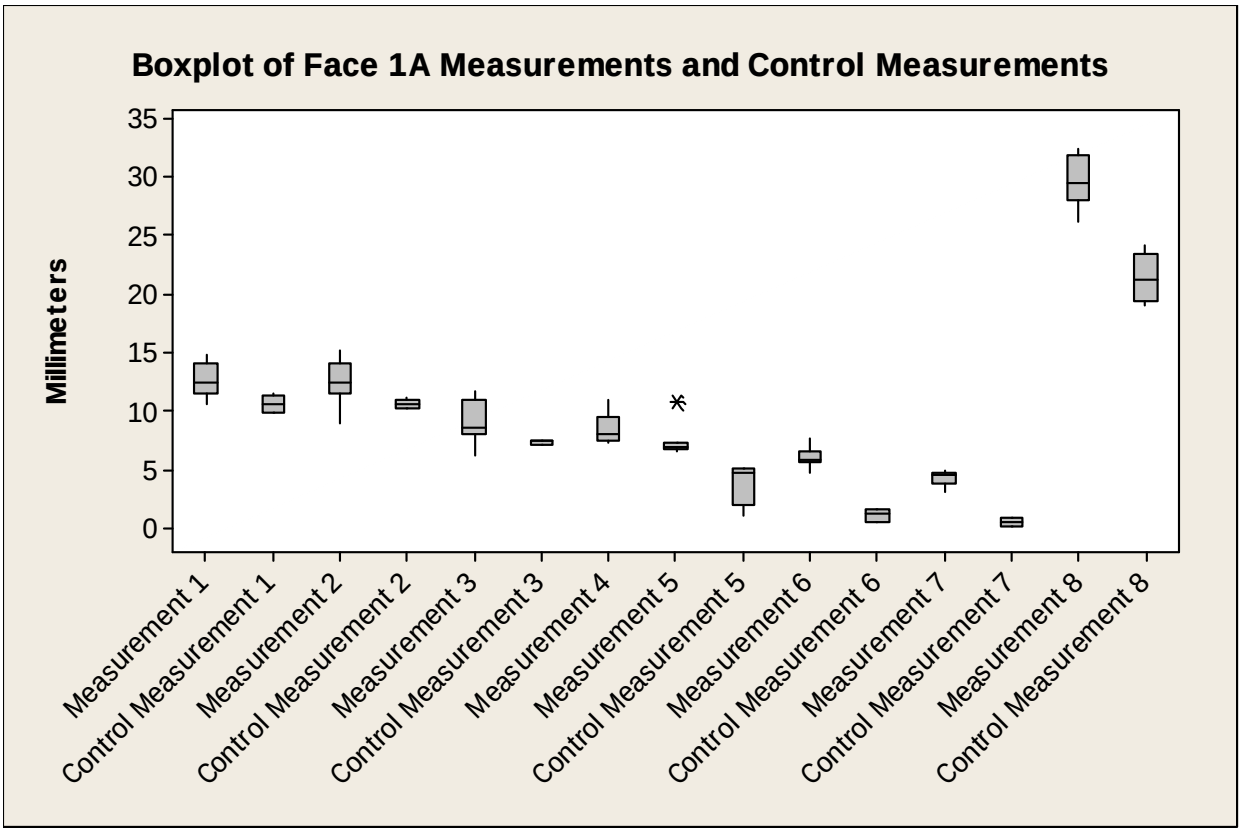
Table 2: P-Values from Slot Face 1B, 2A, 2B vs. Slot Face 1A

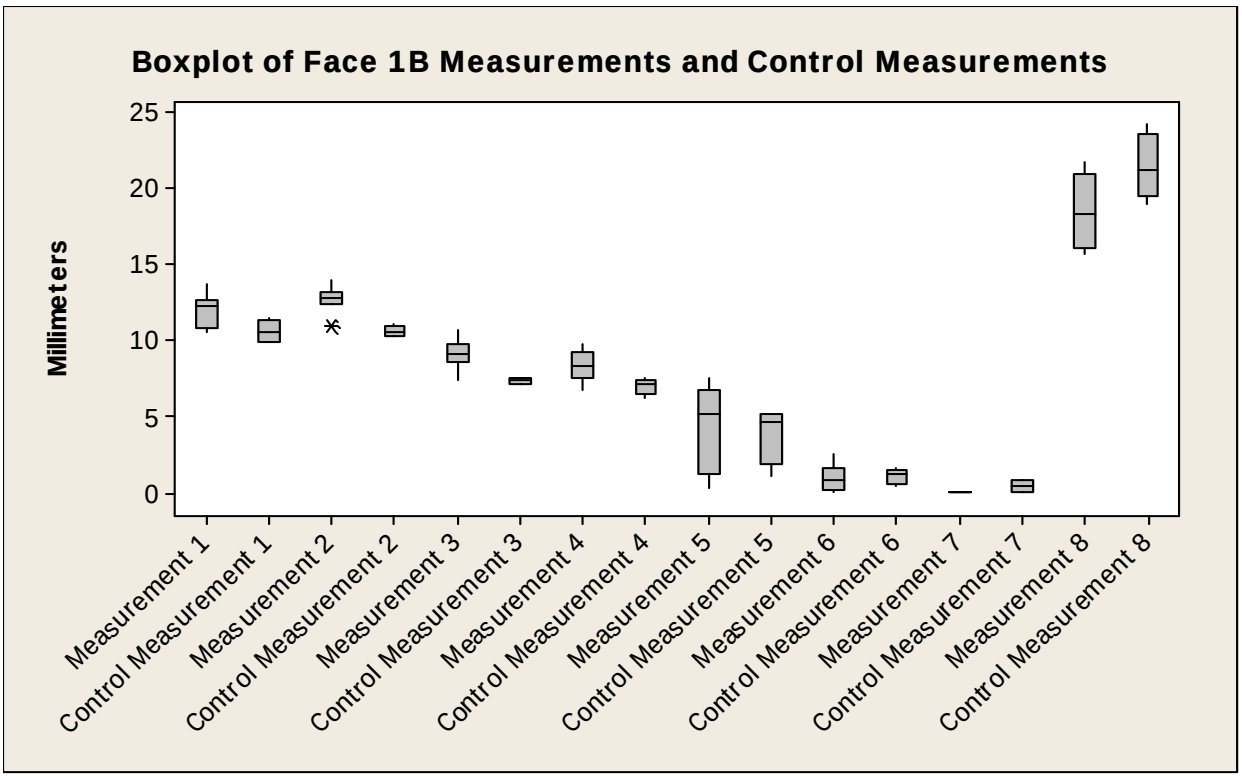
	Face 1B	Face 2A	Face 2B
1	0.286	0.448	0.236
2	0.807	0.882	0.786
3	0.810	0.956	0.909
4	0.608	0.527	0.112
5	0.019	0.036	0.012
6	0.000	0.000	0.000
7	0.000	0.000	0.000
8	0.000	0.000	0.000
10	0.000	0.000	0.000

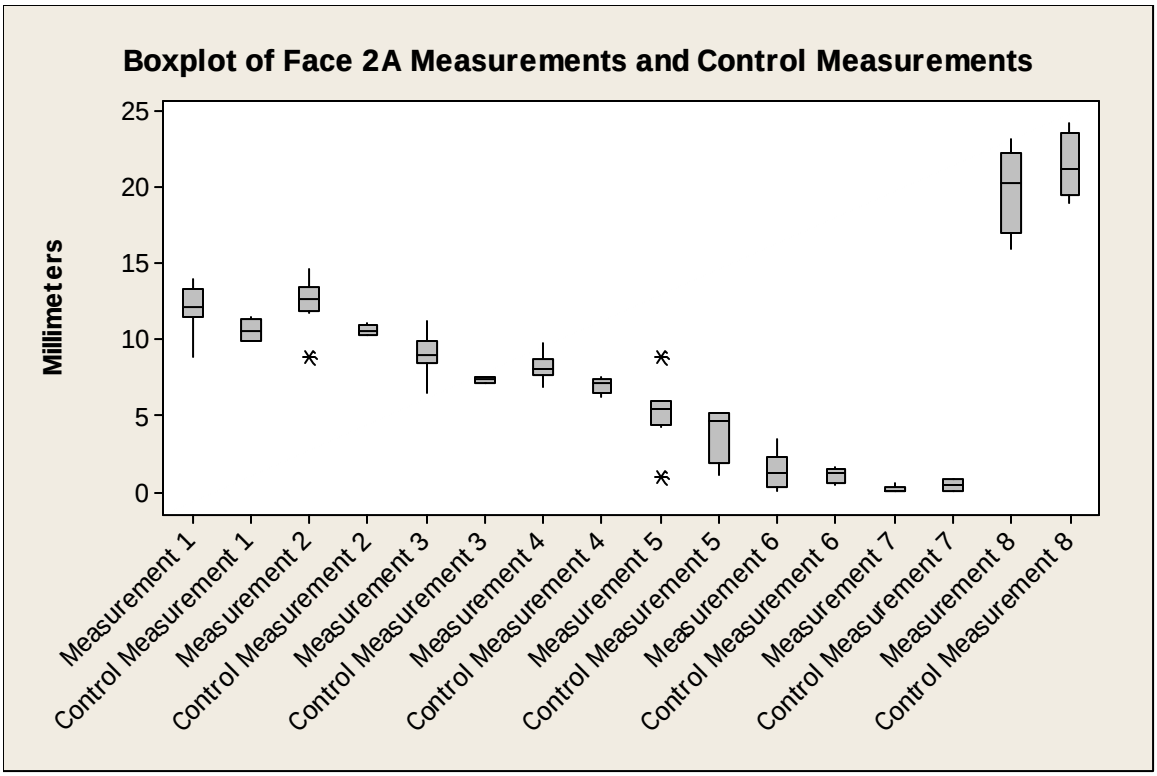
Table 3: P-Values from Slot Face 1A, 2A, 2B vs. Slot Face 1B

	Face 1A	Face 2A	Face 2B
1	0.286	0.869	0.843
2	0.807	0.644	0.466
3	0.810	0.824	0.634
4	0.608	0.914	0.207
5	0.019	0.581	0.814
5B	0.095		
6	0.000	0.383	0.856
6B	0.873		
7	***	***	***
8	0.000	0.282	0.981
10	0.000	0.396	0.325

*** Indicates all values were identical for that test.


Boxplot of Face 1A Measurements and Control Measurements
Millimeters
35
30
25
20
15
10
5
0
Measurement 1
Control Measurement 1
Measurement 2
Control Measurement 2
Measurement 3
Control Measurement 3
Measurement 4
Measurement 5
Control Measurement 5
Measurement 6
Control Measurement 6
Measurement 7
Control Measurement 7
Measurement 8
Control Measurement 8


Boxplot of Face 1B Measurements and Control Measurements
Millimeters
25
20
15
10
5
0
Measurement 1
Control Measurement 1
Measurement 2
Control Measurement 2
Measurement 3
Control Measurement 3
Measurement 4
Control Measurement 4
Measurement 5
Control Measurement 5
Measurement 6
Control Measurement 6
Measurement 7
Control Measurement 7
Measurement 8
Control Measurement 8


Boxplot of Face 2A Measurements and Control Measurements
Millimeters
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Measurement 1
Control Measurement 1
Measurement 2
Control Measurement 2
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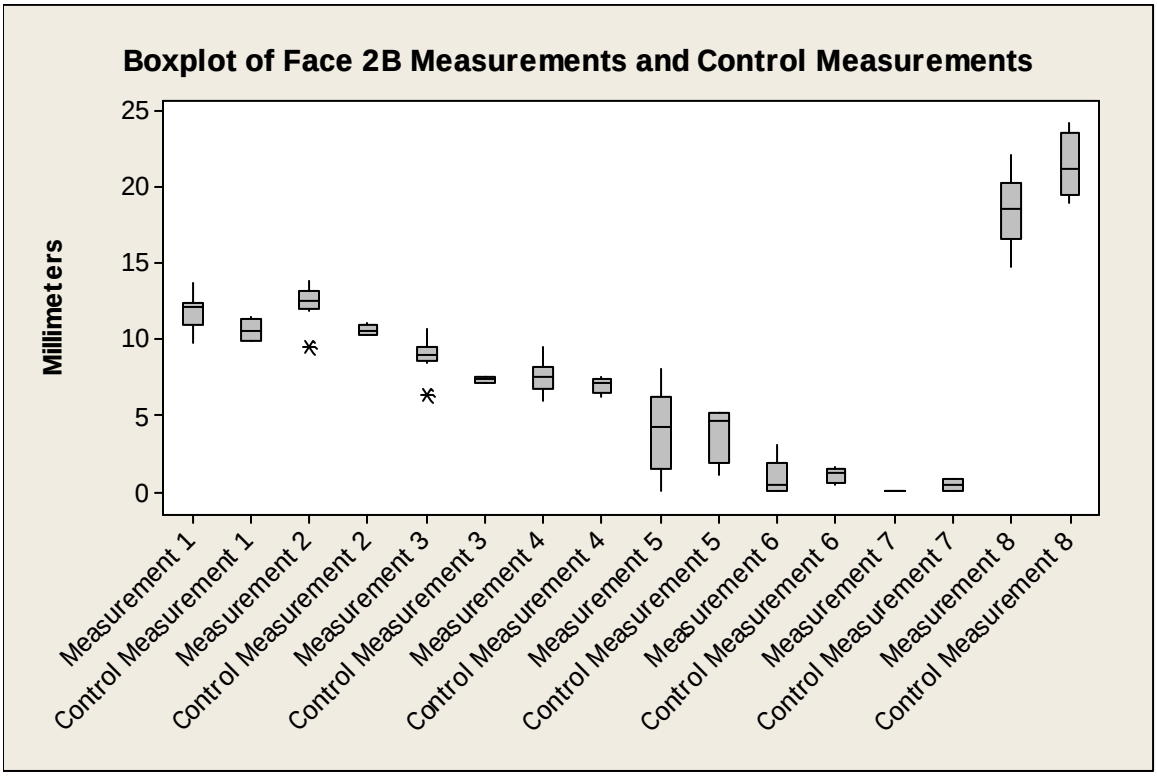
Boxplot of Face 2B Measurements and Control Measurements
Millimeters
25
20
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5
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Measurement 1
Control Measurement 1
Measurement 2
Control Measurement 2
Measurement 3
Control Measurement 3
Measurement 4
Control Measurement 4
Measurement 5
Control Measurement 5
Measurement 6
Control Measurement 6
Measurement 7
Control Measurement 7
Measurement 8
Control Measurement 8

Discussion

It would appear the addition of a longitudinal slot along the prepared femoral head will indeed alter the penetration profile of PMMA cement into trabecular bone. From Table 2 above we see that only 15 out of 32 measurements were not statistically different from the control. The remaining 17 measurements were different by a statistically significant amount, with p values less than 0.05.

The measurements from the control implant were compared to previous data in order to determine consistency (Paulick, 2009). However, it was found measurements 1 through 4 were statistically different from the previous data collected by Mr. Paulick. Measurements 5 through 8 were not statistically significant. This variability has been attributed to the implants being made in batches, which could lead to variability in the implantation procedures and amount of cement used. It is also worth noting that the previous study used six control implant models, whereas this study only had one.

Face 1A – Along Slot

From tables in the Results section, we can see all eight measurements were statistically different from controls for Face 1A. We can also see from the boxplot of Face 1A that all eight measurements were larger than the control implants. This suggests that cement penetration is increased in the area immediately surrounding the slot. Figure 7 shows the visible difference in cement penetration with the experimental slot (Fig. 7 A) when shown next to the control implant (Fig. 7 B). Measurement 5B was defined as Measurement 5 minus the 5mm channel depth. The difference of these two (Measurement 5B) is the actual penetration from the bottom of the channel. Measurement 6B was defined the same way. From Table 2 and Table 4 we can see

that Measurements 5B and 6B are not statistically significant. This would suggest that the actual cement penetration is not different, but the overall depth including the channel is statistically significant.

Face 1B – Opposite Side of Slot

If the slot is in the “front” then Face 1B is looking at the “back” of the implant, directly opposite from the slot. Looking at the tables in the Results section, we see measurements 1, 2, 3 and 4 are statistically significant but 5, 6, 7 and 8 are not. This shows that cement penetration from the dome and chamfer (Figure 6) are different from the control. Next, looking at the boxplot of Face 1B we can see that measurements 1, 2, 3 and 4 are higher than the control. Measurements 5, 6, 7 and 8 on the other hand were not statistically significant and from the boxplot we can see the distributions for the slot and control implants overlap quite a bit. So we can see that the slot causes increased penetration in the dome and chamfer areas, but does not significantly alter the penetration at the wall at the back of the implant.

Face 2A and 2B

These two Faces should be very similar and symmetric because they lie on either side of the slot. From the tables in the Results section we can see that the two faces are very similar. Face 2A had statistically significant measurements 2, 3 and 4 whereas Face 2B had statistically significant measurements 2 and 3. The difference in measurement 4 could be due to any number of experimental errors, and is not regarded as important. From the boxplots of Faces 2A and 2B we can see that the distributions mimic each other very closely, which is what we would expect. So in the transverse plane the cement penetration was higher in the dome and chamfer areas, but not different in the wall area.

Symmetry within the Slotted Implants

One important detail about the slotted implant cement penetration profile is whether or not it is symmetrical about the stem of the implant. Tables 3 and 4 are comparing the faces of the slotted implants to each other. Specifically Table 3 is the results from comparing faces 1B, 2A, and 2B to the face 1A (with the slot). We can see measurements 1 through 4 were not statistically different, but measurements 5 through 8 were. So it appears that cement penetration in the dome and chamfer area are not statistically different, but cement penetration from the wall is indeed statistically different.

In Table 4 the results from comparing faces 1A, 2A, 2B to face 1B are summarized. It appears that faces 2A and 2B are not statistically significant from 1B, however on Face 1A (with the slot) the cement penetration from the wall is statistically significant.

As with any scientific investigation, this study had several limitations which should be considered by readers. First, the implantation procedure was designed to be easily replicated; not to exactly mimic the actual surgical procedure. Gravity in the implantation procedure acted in a different direction than in the actual surgery. Additionally, the implants were seated onto the cylinders via an instron machine capable of reproducing the exact same load each time. This varies greatly from a surgeon manually seating the implants by feel. The extra holes drilled into the head of the femur were another limitation to this study. These holes have the possibility of producing an alternate cement penetration which would definitely be worth investigating. Finally, the measurements from ImageJ may not be as exact as possible. The measurement layer

added in Photoshop was not custom fit to each section, which could have lead to inexact measurements.

From the data and discussion above we can start to get an idea of how the cement penetration reacts to the presence of a longitudinal slot. Contrary to the hypothesis, it appears that cement penetration is statistically increased in the area directly surrounding the longitudinal slot (Face 1A), when compared to an implant with no slot. At the “back” (Face 1B) of the implant cement penetration is statistically increased in the dome and chamfer areas, but not statistically different at the wall. On either side of the slot (Faces 2A, 2B) cement penetration is again statistically increased in the dome and chamfer areas, but not statistically different at the wall. Although this study was not perfect, the data collected is definitely valuable and relevant to the search for the perfect cementing technique for hip resurfacing arthroplasty. Below are some suggestions to anyone who may be investigating this topic in greater detail.

Table 4: Suggestions for Future Investigations

Alter implantation procedure to more accurately replicate true surgical conditions
Increase the number of experimental and control models
Investigate effects of additional holes drilled into femoral head as shown in Figure 2.
Investigate effects of osteoporosis by using varying carbon foam porosities.
Investigate effects of transverse slot, as well as the effects of femoral component offset in combination with slots.

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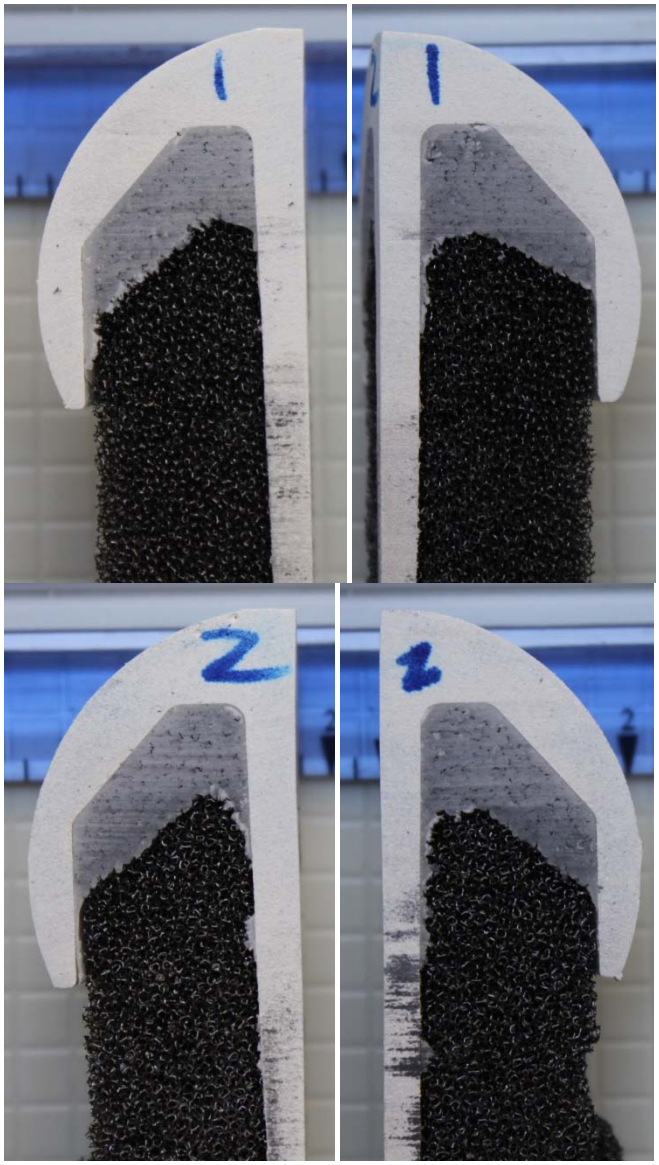
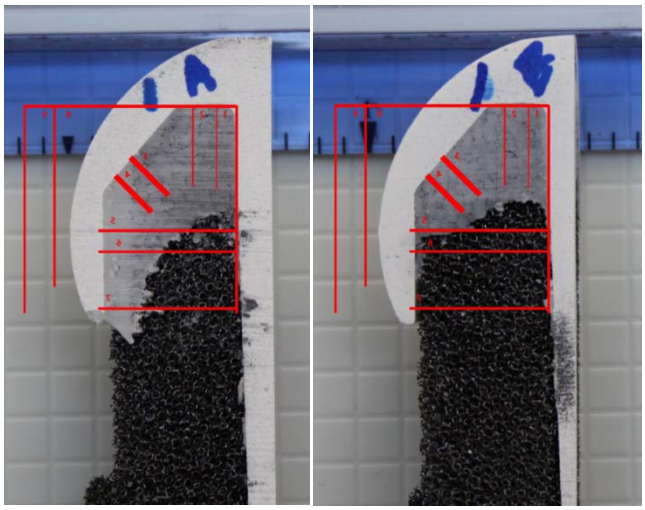
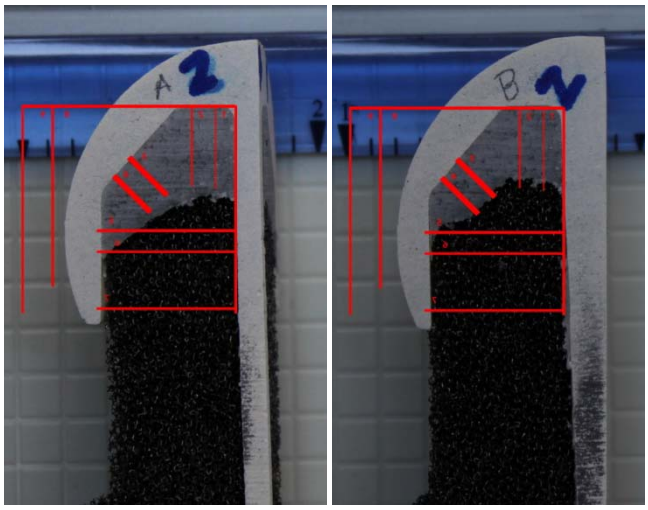
Appendix A: Hip Resurfacing Implant Analysis Pictures

Control



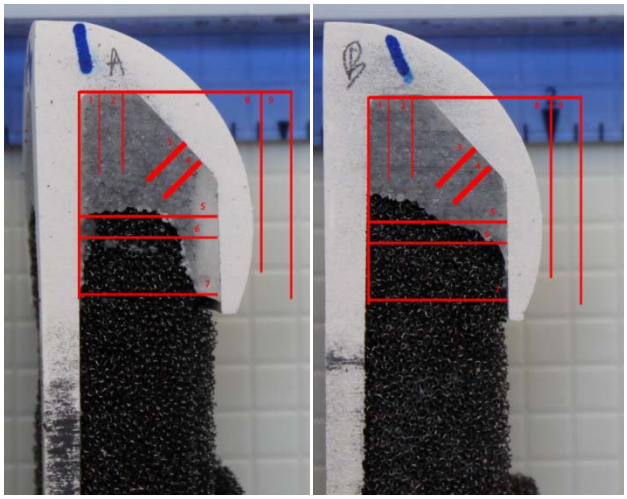
Slot #1

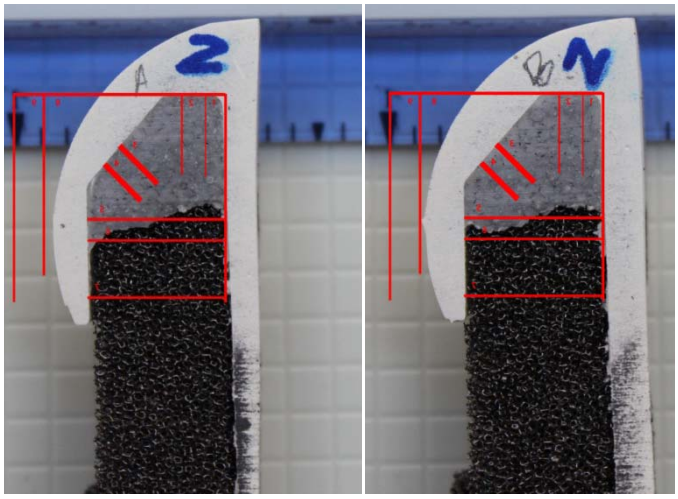




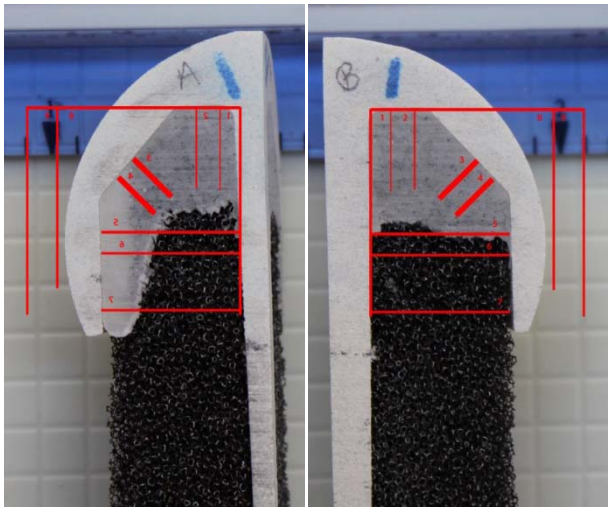
Excess PMMA spilling out of slot.

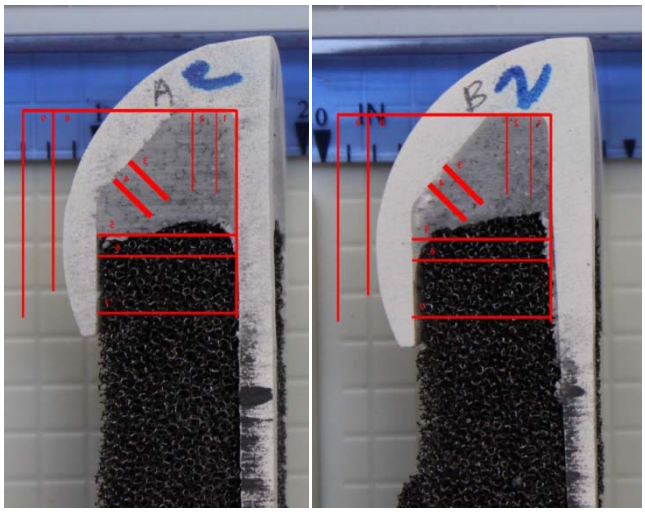
Slot #2



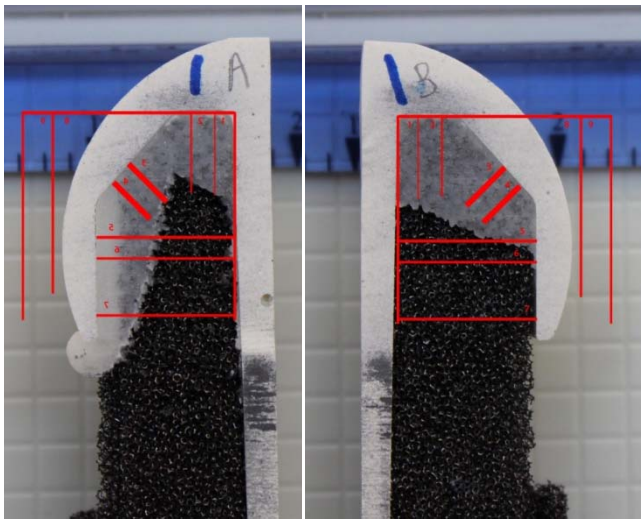


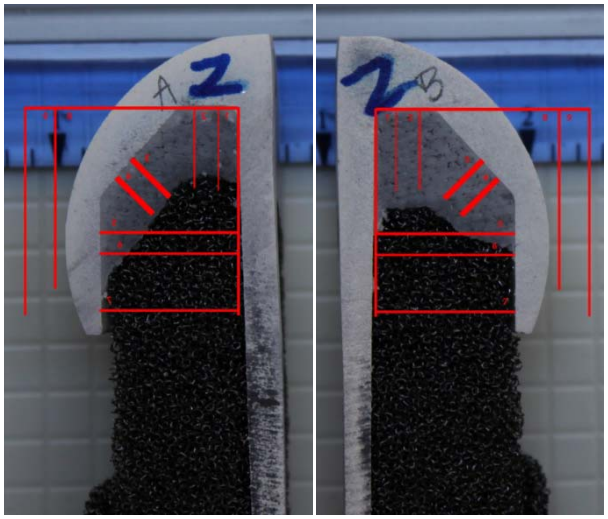
Slot #3





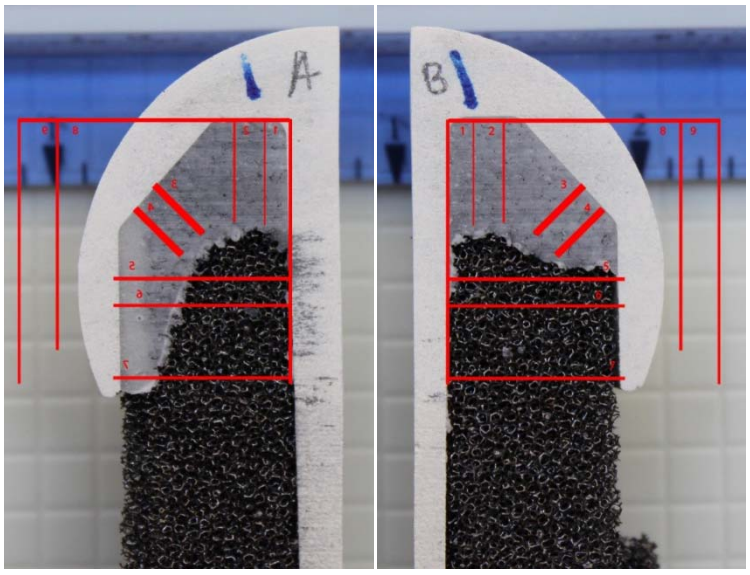
Slot #4

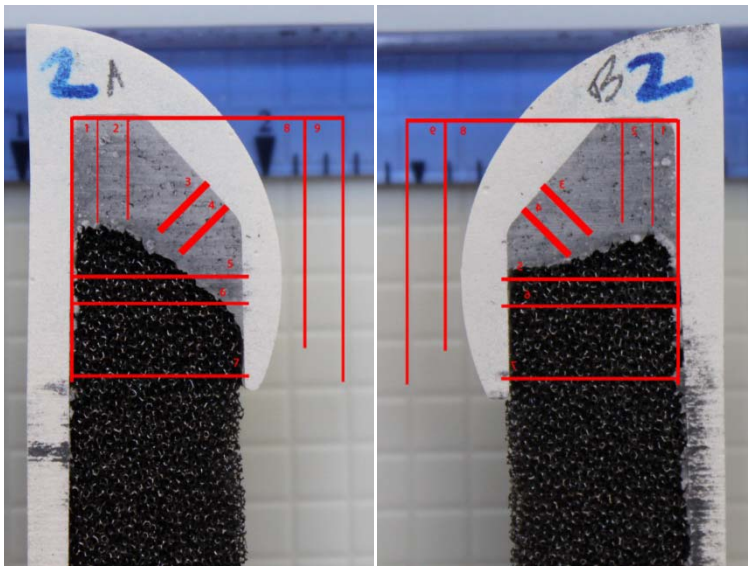




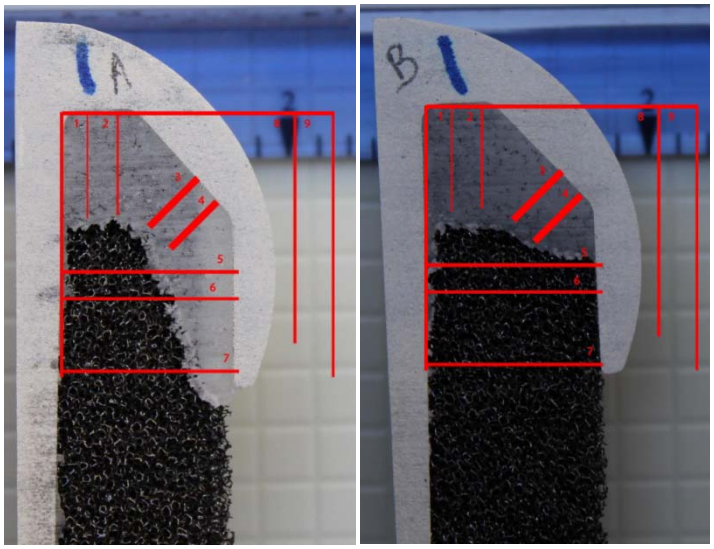
Slot #4 with excess PMMA

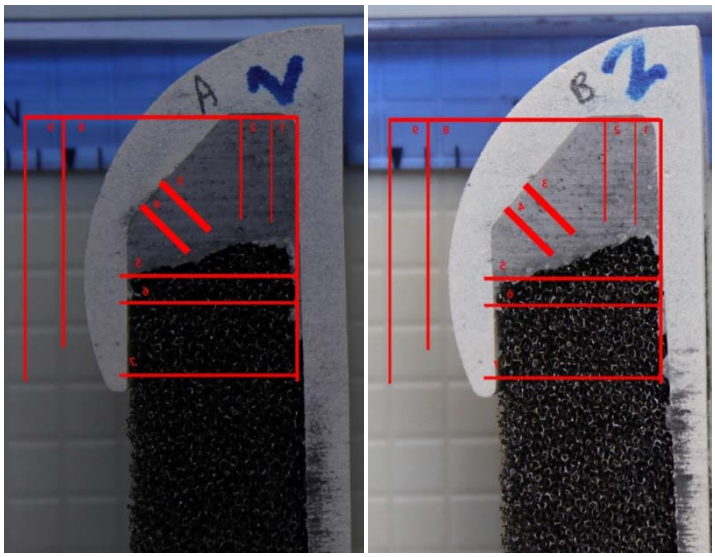
Slot #5



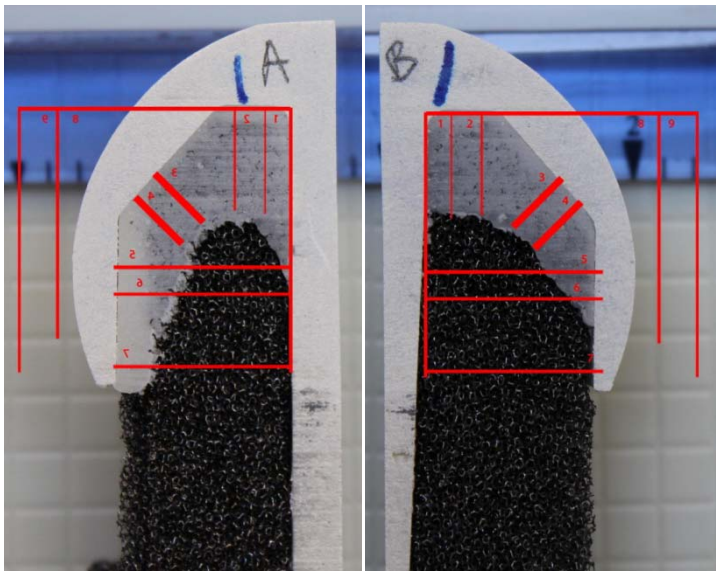


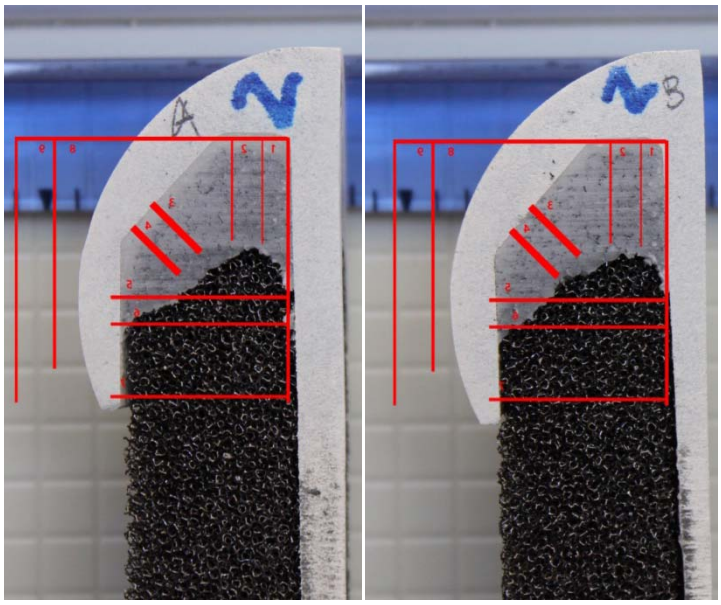
Slot #6



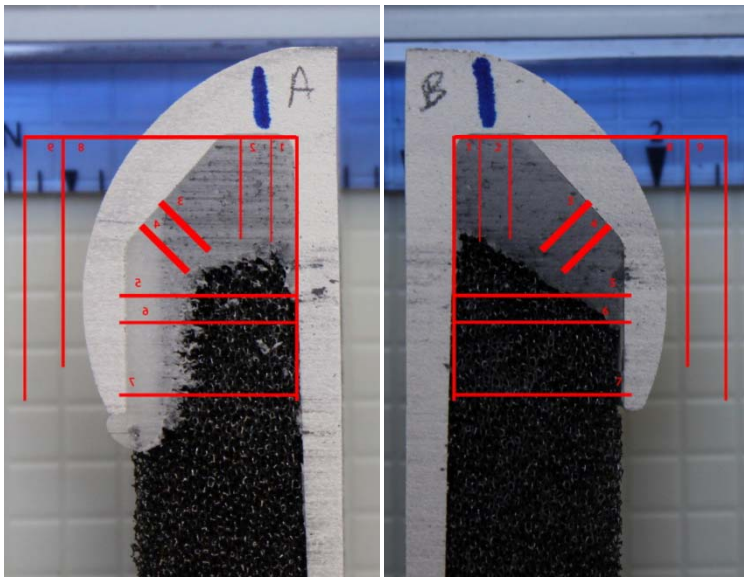


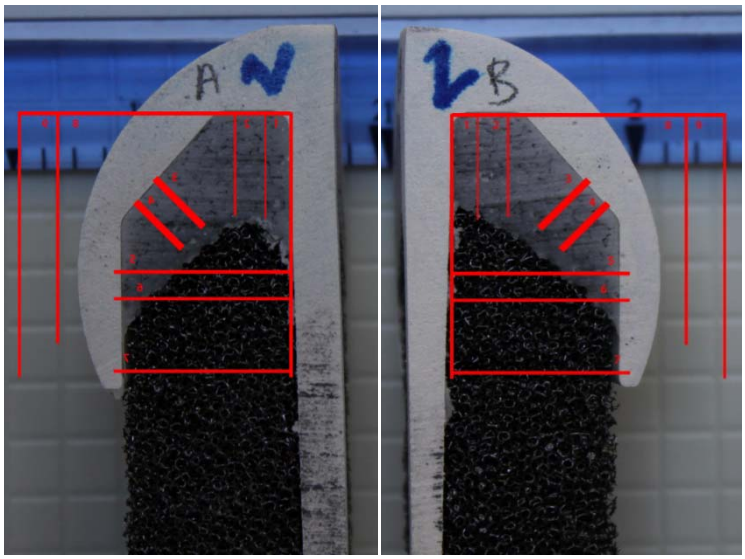
Slot #7



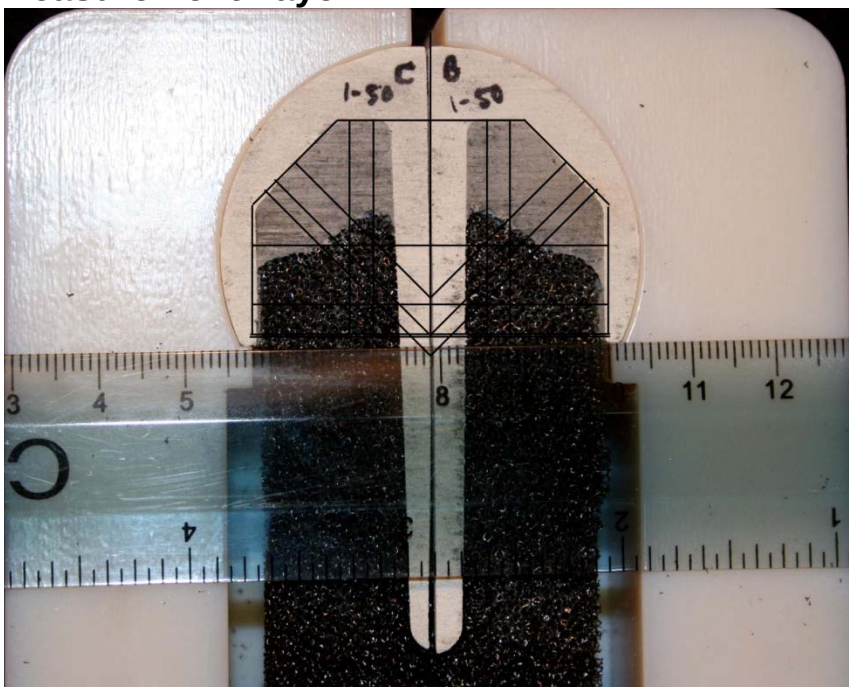


Slot #8





Measurement Layer



The red measurement layers seen on the pictures above was essentially pulled from this photo and then overlaid onto the control and slot implants for this study.

Appendix B: ImageJ Measurements

All Measurements are in mm or mm^2

Slot 1	1	2	3	4	5	6	7	8	9	10
1A	14.12	15.16	11.51	10.94	10.64	7.63	4.49	29.59	28.5	292.98
1B	12.57	12.77	9.08	8.45	5.24	1.09	0	19.91	28.5	190.54
2A	11.64	12.26	8.35	7.46	4.66	1.03	0.58	19.42	28.5	188.57
2B	9.67	9.42	6.27	5.94	1.18	0.39	0	19.28	28.5	155.27

Slot 2	1	2	3	4	5	6	7	8	9	10
1A	14.68	14.42	11.57	8.73	6.58	4.59	2.99	26.14	28.5	240.55
1B	12.43	13.21	9.89	9.34	7.48	1.48	0	21.12	28.5	197.66
2A	13.26	14.51	11.21	9.68	8.75	1.44	0	19.82	28.5	218.79
2B	13.69	13.72	10.69	9.4	8.06	0	0	16.26	28.5	192.54

Slot 3	1	2	3	4	5	6	7	8	9	10
1A	12.69	12.66	8.89	7.35	6.91	5.82	4.57	28.36	28.5	257.53
1B	13.65	13.91	10.67	9.75	7.13	0.35	0	16.82	28.5	209.46
2A	13.87	13.48	10.15	8.67	4.23	0	0	15.91	28.5	194.98
2B	12.23	12.42	8.81	6.64	2.19	0.69	0	19.3	28.5	185.61

Slot 4	1	2	3	4	5	6	7	8	9	10
1A	10.62	8.93	6.15	7.32	7.07	6.54	4.81	32.27	28.5	229.194
1B	11.18	12.89	9.39	8.06	3.9	0.35	0	17.06	28.5	183.68
2A	8.78	8.74	6.48	6.76	5.68	3.45	0	23.03	28.5	168.24
2B	11.96	11.96	8.55	8.11	6.37	0.26	0	17.4	28.5	184.07

Slot 5	1	2	3	4	5	6	7	8	9	10
1A	11.37	11.97	8.04	8.08	6.66	5.52	3.68	27.82	28.5	241.95
1B	11.95	12.27	9.04	7.45	0.35	0	0	15.59	28.5	185.78
2A	11.3	11.88	8.66	7.94	5.19	1.77	0	21.63	28.5	194.4
2B	11.93	12.76	9.1	7.05	0	0	0	14.74	28.5	176.82

Slot 6	1	2	3	4	5	6	7	8	9	10
1A	11.81	11.38	8.22	9.71	7.21	6.01	4.35	30.22	28.5	259.35
1B	12.4	12.62	8.42	7.51	0.24	0	0	15.76	28.5	192.69
2A	13.06	13.02	9.1	7.91	0.86	0	0	16.14	28.5	189.33
2B	12.29	13.16	9.49	7.85	3.14	0	0	17.63	28.5	181.77

Slot 7	1	2	3	4	5	6	7	8	9	10
1A	13.41	12.17	7.89	7.94	6.96	5.51	3.73	29.29	28.5	265.99
1B	10.61	10.94	7.33	6.66	5.09	2.49	0	21.61	28.5	175.26
2A	12.41	12.85	9.06	8.67	5.84	0.91	0	20.53	28.5	212.13
2B	12.07	12.43	9.09	6.89	5.13	2.17	0	20.43	28.5	207.67

Slot 8	1	2	3	4	5	6	7	8	9	10

1A	12.13	12.85	8.91	7.94	6.53	5.81	4.87	32.22	28.5	290.26
1B	10.48	12.41	8.82	8.39	5.06	1.53	0	19.5	28.5	196.31
2A	11.86	11.71	8.54	8.1	5.87	2.46	0.41	22.31	28.5	214.03
2B	10.5	11.87	8.45	8.14	5.76	3.02	0	22.1	28.5	194.26

Control	1	2	3	4	5	6	7	8	9	10
1A	9.97	10.24	7.38	7.07	4.28	1.3	0.83	24.14	28.5	181.97
1B	11.4	11	7.02	6.16	1.04	0.36	0	18.94	28.5	185.42
2A	9.84	10.27	7.42	7.44	5.12	1.52	0.81	21.34	28.5	189.93
2B	11.11	10.73	7.4	7.2	4.93	1.03	0	20.81	28.5	191.44

Averages	1	2	3	4	5	6	7	8	9	10
1A	12.604	12.443	8.898	8.501	7.320	5.929	4.186	29.489	28.500	259.726
1B	11.909	12.628	9.080	8.201	4.311	0.911	0.000	18.421	28.500	191.423
2A	12.023	12.306	8.944	8.149	5.135	1.383	0.124	19.849	28.500	197.559
2B	11.793	12.218	8.806	7.503	3.979	0.816	0.000	18.393	28.500	184.751
Control	10.580	10.560	7.305	6.968	3.843	1.053	0.410	21.308	28.500	187.190

Standard Deviations	**Slot 1A**	**Slot 1B**	**Slot 2A**	**Slot 2B**	**Control**
1	1.393	1.085	1.576	1.215	0.790
2	1.900	0.853	1.703	1.284	0.369
3	1.841	0.989	1.378	1.243	0.191
4	1.253	1.016	0.878	1.086	0.56
5	1.363	2.737	2.195	2.789	1.903
6	0.881	0.888	1.181	1.146	0.503
7	0.657	***	0.234	***	0.473
8	2.106	2.401	2.653	2.359	2.151
10	22.985	10.306	16.729	15.206	4.319

Appendix C: Statistical Data Analysis

SLOT MEASUREMENTS vs. CONTROL Measurements

Two-Sample T-Test and CI: Face 1A - 1, Control 1A

```
Two-sample T for face 1 - 1A vs. Control 1A

              N    Mean  StDev  SE Mean
face 1A - 1   8   12.60   1.39     0.49
Control 1A    4  10.580  0.790     0.40
Difference = mu (face 1 - 1A) - mu (Control 1A)
Estimate for difference:  2.024
95% CI for difference:  (0.596, 3.452)
T-Test of difference = 0 (vs. not =): T-Value = 3.21  P-Value = 0.011  DF = 9
```

Two-Sample T-Test and CI: Face 1A - 2, Control 2

```
Two-sample T for Face 1A - 2 vs. Control 2

              N    Mean  StDev  SE Mean
Face 1A - 2   8   12.44   1.90     0.67
Control 2     4  10.560  0.369     0.18
Difference = mu (Face 1A - 2) - mu (Control 2)
Estimate for difference:  1.882
95% CI for difference:  (0.235, 3.530)
T-Test of difference = 0 (vs. not =): T-Value = 2.70  P-Value = 0.031  DF = 7
```

Two-Sample T-Test and CI: Face 1A - 3, Control 3

```
Two-sample T for Face 1A - 3 vs. Control 3

              N   Mean  StDev  SE Mean
Face 1A - 3   8   8.90   1.84     0.65
Control 3     4  7.305  0.191    0.095
Difference = mu (Face 1A - 3) - mu (Control 3)
Estimate for difference:  1.592
95% CI for difference:  (0.037, 3.148)
T-Test of difference = 0 (vs. not =): T-Value = 2.42  P-Value = 0.046  DF = 7
```

Two-Sample T-Test and CI: Face 1A - 4, Control 4

```
Two-sample T for Face 1A - 4 vs. Control 4

              N   Mean  StDev  SE Mean
Face 1A - 4   8   8.50   1.25     0.44
Control 4     4  6.968  0.560     0.28
Difference = mu (Face 1A - 4) - mu (Control 4)
Estimate for difference:  1.534
95% CI for difference:  (0.348, 2.719)
T-Test of difference = 0 (vs. not =): T-Value = 2.93  P-Value = 0.017  DF = 9
```

Two-Sample T-Test and CI: Face 1A - 5, Control 5

```
Two-sample T for Face 1A - 5 vs. Control 5

             N  Mean  StDev  SE Mean
Face 1A - 5  8  7.32   1.36     0.48
Control 5    4  3.84   1.90     0.95
Difference = mu (Face 1A - 5) - mu (Control 5)
Estimate for difference:  3.48
95% CI for difference:  (0.52, 6.44)
T-Test of difference = 0 (vs. not =): T-Value = 3.26  P-Value = 0.031  DF = 4
```

Two-Sample T-Test and CI: Face 1A - 6, Control 6

```
Two-sample T for Face 1A - 6 vs. Control 6

             N   Mean  StDev  SE Mean
Face 1A - 6  8  5.929  0.881     0.31
Control 6    4  1.053  0.503     0.25
Difference = mu (Face 1A - 6) - mu (Control 6)
Estimate for difference:  4.876
95% CI for difference:  (3.970, 5.782)
T-Test of difference = 0 (vs. not =): T-Value = 12.18  P-Value = 0.000  DF = 9
```

Two-Sample T-Test and CI: Face 1A - 7, Control 7

```
Two-sample T for Face 1A - 7 vs. Control 7

             N   Mean  StDev  SE Mean
Face 1A - 7  8  4.186  0.657     0.23
Control 7    4  0.410  0.473     0.24
Difference = mu (Face 1A - 7) - mu (Control 7)
Estimate for difference:  3.776
95% CI for difference:  (3.012, 4.541)
T-Test of difference = 0 (vs. not =): T-Value = 11.39  P-Value = 0.000  DF = 8
```

Two-Sample T-Test and CI: Face 1A - 8, Control 8

```
Two-sample T for Face 1A - 8 vs. Control 8

             N   Mean  StDev  SE Mean
Face 1A - 8  8  29.49   2.11     0.74
Control 8    4  21.31   2.15      1.1
Difference = mu (Face 1A - 8) - mu (Control 8)
Estimate for difference:  8.18
95% CI for difference:  (4.82, 11.54)
T-Test of difference = 0 (vs. not =): T-Value = 6.25  P-Value = 0.002  DF = 5
```

Two-Sample T-Test and CI: Face 1B - 1, Control 1

```
Two-sample T for Face 1B - 1 vs. Control 1

             N    Mean  StDev  SE Mean
```

```
Face 1B - 1  8   11.91   1.09     0.38
Control 1    4  10.580  0.790     0.40
Difference = mu (Face 1B - 1) - mu (Control 1)
Estimate for difference:  1.329
95% CI for difference:  (0.059, 2.599)
T-Test of difference = 0 (vs. not =): T-Value = 2.41  P-Value = 0.042  DF = 8
```

Two-Sample T-Test and CI: Face 1B - 2, Control 2

```
Two-sample T for Face 1B - 2 vs. Control 2
             N    Mean  StDev  SE Mean
Face 1B - 2  8  12.628  0.853     0.30
Control 2    4  10.560  0.369     0.18
Difference = mu (Face 1B - 2) - mu (Control 2)
Estimate for difference:  2.067
95% CI for difference:  (1.267, 2.868)
T-Test of difference = 0 (vs. not =): T-Value = 5.85  P-Value = 0.000  DF = 9
```

Two-Sample T-Test and CI: Face 1B - 3, Control 3

```
Two-sample T for Face 1B - 3 vs. Control 3
             N   Mean  StDev  SE Mean
Face 1B - 3  8  9.080  0.989     0.35
Control 3    4  7.305  0.191    0.095
Difference = mu (Face 1B - 3) - mu (Control 3)
Estimate for difference:  1.775
95% CI for difference:  (0.918, 2.632)
T-Test of difference = 0 (vs. not =): T-Value = 4.90  P-Value = 0.002  DF = 7
```

Two-Sample T-Test and CI: Face 1B - 4, Control 4

```
Two-sample T for Face 1B - 4 vs. Control 4
             N   Mean  StDev  SE Mean
Face 1B - 4  8   8.20   1.02     0.36
Control 4    4  6.968  0.560     0.28
Difference = mu (Face 1B - 4) - mu (Control 4)
Estimate for difference:  1.234
95% CI for difference:  (0.203, 2.264)
T-Test of difference = 0 (vs. not =): T-Value = 2.71  P-Value = 0.024  DF = 9
```

Two-Sample T-Test and CI: Face 1B - 5, Control 5

```
Two-sample T for Face 1B - 5 vs. Control 5
             N  Mean  StDev  SE Mean
Face 1B - 5  8  4.31   2.74     0.97
Control 5    4  3.84   1.90     0.95
Difference = mu (Face 1B - 5) - mu (Control 5)
```

Estimate for difference: 0.47

95% CI for difference: (-2.66, 3.60)

T-Test of difference = 0 (vs. not =): T-Value = 0.35 P-Value = 0.739 DF = 8

Two-Sample T-Test and CI: Face 1B - 6, Control 6

Two-sample T for Face 1B - 6 vs. Control 6

	N	Mean	StDev	SE Mean
Face 1B - 6	8	0.911	0.888	0.31
Control 6	4	1.053	0.503	0.25

Difference = mu (Face 1B - 6) - mu (Control 6)

Estimate for difference: -0.141

95% CI for difference: (-1.052, 0.769)

T-Test of difference = 0 (vs. not =): T-Value = -0.35 P-Value = 0.734 DF = 9

Two-Sample T-Test and CI: Face 1B - 7, Control 7

* ERROR * All values in column are identical.

All zeros

Two-Sample T-Test and CI: Face 1B - 8, Control 8

Two-sample T for Face 1B - 8 vs. Control 8

	N	Mean	StDev	SE Mean
Face 1B - 8	8	18.42	2.40	0.85
Control 8	4	21.31	2.15	1.1

Difference = mu (Face 1B - 8) - mu (Control 8)

Estimate for difference: -2.89

95% CI for difference: (-6.24, 0.47)

T-Test of difference = 0 (vs. not =): T-Value = -2.11 P-Value = 0.080 DF = 6

Two-Sample T-Test and CI: Face 2A - 1, Control 1

Two-sample T for Face 2A - 1 vs. Control 1

	N	Mean	StDev	SE Mean
Face 2A - 1	8	12.02	1.58	0.56
Control 1	4	10.580	0.790	0.40

Difference = mu (Face 2A - 1) - mu (Control 1)

Estimate for difference: 1.442

95% CI for difference: (-0.102, 2.987)

T-Test of difference = 0 (vs. not =): T-Value = 2.11 P-Value = 0.064 DF = 9

Two-Sample T-Test and CI: Face 2A - 2, Control 2

Two-sample T for Face 2A - 2 vs. Control 2

	N	Mean	StDev	SE Mean
Face 2A - 2	8	12.31	1.70	0.60
Control 2	4	10.560	0.369	0.18

Difference = mu (Face 2A - 2) - mu (Control 2)

Estimate for difference: 1.746

95% CI for difference: (0.294, 3.198)

T-Test of difference = 0 (vs. not =): T-Value = 2.77 P-Value = 0.024 DF = 8

Two-Sample T-Test and CI: Face 2A - 3, Control 3

Two-sample T for Face 2A - 3 vs. Control 3

	N	Mean	StDev	SE Mean
Face 2A - 3	8	8.94	1.38	0.49
Control 3	4	7.305	0.191	0.095

Difference = mu (Face 2A - 3) - mu (Control 3)

Estimate for difference: 1.639

95% CI for difference: (0.465, 2.813)

T-Test of difference = 0 (vs. not =): T-Value = 3.30 P-Value = 0.013 DF = 7

Two-Sample T-Test and CI: Face 2A - 4, Control 4

Two-sample T for Face 2A - 4 vs. Control 4

	N	Mean	StDev	SE Mean
Face 2A - 4	8	8.149	0.878	0.31
Control 4	4	6.968	0.560	0.28

Difference = mu (Face 2A - 4) - mu (Control 4)

Estimate for difference: 1.181

95% CI for difference: (0.236, 2.127)

T-Test of difference = 0 (vs. not =): T-Value = 2.83 P-Value = 0.020 DF = 9

Two-Sample T-Test and CI: Face 2A - 5, Control 5

Two-sample T for Face 2A - 5 vs. Control 5

	N	Mean	StDev	SE Mean
Face 2A - 5	8	5.13	2.19	0.78
Control 5	4	3.84	1.90	0.95

Difference = mu (Face 2A - 5) - mu (Control 5)

Estimate for difference: 1.29

95% CI for difference: (-1.71, 4.30)

T-Test of difference = 0 (vs. not =): T-Value = 1.05 P-Value = 0.333 DF = 6

Two-Sample T-Test and CI: Face 2A - 6, Control 6

Two-sample T for Face 2A - 6 vs. Control 6

	N	Mean	StDev	SE Mean
Face 2A - 6	8	1.38	1.18	0.42
Control 6	4	1.053	0.503	0.25

Difference = mu (Face 2A - 6) - mu (Control 6)

Estimate for difference: 0.330

95% CI for difference: (-0.773, 1.433)

T-Test of difference = 0 (vs. not =): T-Value = 0.68 P-Value = 0.515 DF = 9

Two-Sample T-Test and CI: Face 2A - 7, Control 7

Two-sample T for Face 2A - 7 vs. Control 7

	N	Mean	StDev	SE Mean
Face 2A - 7	8	0.124	0.234	0.083
Control 7	4	0.410	0.473	0.24

Difference = mu (Face 2A - 7) - mu (Control 7)

Estimate for difference: -0.286

95% CI for difference: (-1.084, 0.512)

T-Test of difference = 0 (vs. not =): T-Value = -1.14 P-Value = 0.336 DF = 3

Two-Sample T-Test and CI: Face 2A - 8, Control 8

Two-sample T for Face 2A - 8 vs. Control 8

	N	Mean	StDev	SE Mean
Face 2A - 8	8	19.85	2.65	0.94
Control 8	4	21.31	2.15	1.1

Difference = mu (Face 2A - 8) - mu (Control 8)

Estimate for difference: -1.46

95% CI for difference: (-4.83, 1.92)

T-Test of difference = 0 (vs. not =): T-Value = -1.02 P-Value = 0.341 DF = 7

Two-Sample T-Test and CI: Face 2B - 1, Control 1

Two-sample T for Face 2B - 1 vs. Control 1

	N	Mean	StDev	SE Mean
Face 2B - 1	8	11.79	1.22	0.43
Control 1	4	10.580	0.790	0.40

Difference = mu (Face 2B - 1) - mu (Control 1)

Estimate for difference: 1.213

95% CI for difference: (-0.134, 2.559)

T-Test of difference = 0 (vs. not =): T-Value = 2.08 P-Value = 0.071 DF = 8

Two-Sample T-Test and CI: Face 2B - 2, Control 2

Two-sample T for Face 2B - 2 vs. Control 2

	N	Mean	StDev	SE Mean
Face 2B - 2	8	12.22	1.28	0.45
Control 2	4	10.560	0.369	0.18

Difference = mu (Face 2B - 2) - mu (Control 2)

Estimate for difference: 1.658

95% CI for difference: (0.527, 2.788)

T-Test of difference = 0 (vs. not =): T-Value = 3.38 P-Value = 0.010 DF = 8

Two-Sample T-Test and CI: Face 2B - 3, Control 3

```
Two-sample T for Face 2B - 3 vs. Control 3
             N   Mean  StDev  SE Mean
Face 2B - 3  8   8.81   1.24     0.44
Control 3    4  7.305  0.191    0.095
Difference = mu (Face 2B - 3) - mu (Control 3)
Estimate for difference:  1.501
95% CI for difference:  (0.438, 2.564)
T-Test of difference = 0 (vs. not =): T-Value = 3.34  P-Value = 0.012  DF = 7
```

Two-Sample T-Test and CI: Face 2B - 4, Control 4

```
Two-sample T for Face 2B - 4 vs. Control 4
             N   Mean  StDev  SE Mean
Face 2B - 4  8   7.50   1.09     0.38
Control 4    4  6.968  0.560     0.28
Difference = mu (Face 2B - 4) - mu (Control 4)
Estimate for difference:  0.535
95% CI for difference:  (-0.540, 1.610)
T-Test of difference = 0 (vs. not =): T-Value = 1.13  P-Value = 0.289  DF = 9
```

Two-Sample T-Test and CI: Face 2B - 5, Control 5

```
Two-sample T for Face 2B - 5 vs. Control 5
             N  Mean  StDev  SE Mean
Face 2B - 5  8  3.98   2.79     0.99
Control 5    4  3.84   1.90     0.95
Difference = mu (Face 2B - 5) - mu (Control 5)
Estimate for difference:  0.14
95% CI for difference:  (-3.02, 3.30)
T-Test of difference = 0 (vs. not =): T-Value = 0.10  P-Value = 0.923  DF = 8
```

Two-Sample T-Test and CI: Face 2B - 6, Control 6

```
Two-sample T for Face 2B - 6 vs. Control 6
             N   Mean  StDev  SE Mean
Face 2B - 6  8   0.82   1.15     0.41
Control 6    4  1.053  0.503     0.25
Difference = mu (Face 2B - 6) - mu (Control 6)
Estimate for difference:  -0.236
95% CI for difference:  (-1.315, 0.843)
T-Test of difference = 0 (vs. not =): T-Value = -0.50  P-Value = 0.632  DF = 9
```

Two-Sample T-Test and CI: Face 2B - 7, Control 7

```
* ERROR * All values in column are identical.
```

All zero’s

Two-Sample T-Test and CI: Face 2B - 8, Control 8

```
Two-sample T for Face 2B - 8 vs. Control 8

             N   Mean  StDev  SE Mean
Face 2B - 8  8  18.39   2.36     0.83
Control 8    4  21.31   2.15      1.1
Difference = mu (Face 2B - 8) - mu (Control 8)
Estimate for difference:  -2.92
95% CI for difference:  (-6.25, 0.42)
T-Test of difference = 0 (vs. not =): T-Value = -2.14  P-Value = 0.076  DF = 6
```

SLOTS: Face 1A vs. 1B

Two-Sample T-Test and CI: Face 1A - 1, Face 1B -1

```
Two-sample T for Face 1A - 1 vs. Face 1B -1

             N   Mean  StDev  SE Mean
Face 1A - 1  8  12.60   1.39     0.49
Face 1B -1   8  11.91   1.09     0.38
Difference = mu (Face 1A - 1) - mu (Face 1B -1)
Estimate for difference:  0.695
95% CI for difference:  (-0.654, 2.044)
T-Test of difference = 0 (vs. not =): T-Value = 1.11  P-Value = 0.286  DF = 13
```

Two-Sample T-Test and CI: Face 1A - 2, Face 1B - 2

```
Two-sample T for Face 1A - 2 vs. Face 1B - 2

             N    Mean  StDev  SE Mean
Face 1A - 2  8   12.44   1.90     0.67
Face 1B - 2  8  12.628  0.853     0.30
Difference = mu (Face 1A - 2) - mu (Face 1B - 2)
Estimate for difference:  -0.185
95% CI for difference:  (-1.851, 1.481)
T-Test of difference = 0 (vs. not =): T-Value = -0.25  P-Value = 0.807  DF = 9
```

Two-Sample T-Test and CI: Face 1A - 3, Face 1B - 3

```
Two-sample T for Face 1A - 3 vs. Face 1B - 3

             N   Mean  StDev  SE Mean
Face 1A - 3  8   8.90   1.84     0.65
Face 1B - 3  8  9.080  0.989     0.35
Difference = mu (Face 1A - 3) - mu (Face 1B - 3)
Estimate for difference:  -0.183
95% CI for difference:  (-1.829, 1.464)
T-Test of difference = 0 (vs. not =): T-Value = -0.25  P-Value = 0.810  DF = 10
```

Two-Sample T-Test and CI: Face 1A - 4, Face 1B - 4

Two-sample T for Face 1A - 4 vs. Face 1B - 4

	N	Mean	StDev	SE Mean
Face 1A - 4	8	8.50	1.25	0.44
Face 1B - 4	8	8.20	1.02	0.36

Difference = mu (Face 1A - 4) - mu (Face 1B - 4)

Estimate for difference: 0.300

95% CI for difference: (-0.932, 1.532)

T-Test of difference = 0 (vs. not =): T-Value = 0.53 P-Value = 0.608 DF = 13

Two-Sample T-Test and CI: Face 1A - 5, Face 1B - 5

Two-sample T for Face 1A - 5 vs. Face 1B - 5

	N	Mean	StDev	SE Mean
Face 1A - 5	8	7.32	1.36	0.48
Face 1B - 5	8	4.31	2.74	0.97

Difference = mu (Face 1A - 5) - mu (Face 1B - 5)

Estimate for difference: 3.01

95% CI for difference: (0.60, 5.42)

T-Test of difference = 0 (vs. not =): T-Value = 2.78 P-Value = 0.019 DF = 10

Two-Sample T-Test and CI: Face 1A - 6, Face 1B - 6

Two-sample T for Face 1A - 6 vs. Face 1B - 6

	N	Mean	StDev	SE Mean
Face 1A - 6	8	5.929	0.881	0.31
Face 1B - 6	8	0.911	0.888	0.31

Difference = mu (Face 1A - 6) - mu (Face 1B - 6)

Estimate for difference: 5.018

95% CI for difference: (4.062, 5.973)

T-Test of difference = 0 (vs. not =): T-Value = 11.34 P-Value = 0.000 DF = 13

Two-Sample T-Test and CI: Face 1A - 7, Face 1B - 7

* ERROR * All values in column are identical.

Two-Sample T-Test and CI: Face 1A - 8, Face 1B - 8

Two-sample T for Face 1A - 8 vs. Face 1B - 8

	N	Mean	StDev	SE Mean
Face 1A - 8	8	29.49	2.11	0.74
Face 1B - 8	8	18.42	2.40	0.85

Difference = mu (Face 1A - 8) - mu (Face 1B - 8)

Estimate for difference: 11.07

95% CI for difference: (8.63, 13.51)

T-Test of difference = 0 (vs. not =): T-Value = 9.80 P-Value = 0.000 DF = 13

SLOTS: Face 1A vs. 2A

Two-Sample T-Test and CI: Face 1A - 1, Face 2A - 1

```
Two-sample T for Face 1A - 1 vs. Face 2A - 1

             N   Mean  StDev  SE Mean
Face 1A - 1  8  12.60   1.39     0.49
Face 2A - 1  8  12.02   1.58     0.56
Difference = mu (Face 1A - 1) - mu (Face 2A - 1)
Estimate for difference:  0.581
95% CI for difference:  (-1.025, 2.188)
T-Test of difference = 0 (vs. not =): T-Value = 0.78  P-Value = 0.448  DF = 13
```

Two-Sample T-Test and CI: Face 1A - 2, Face 2A - 2

```
Two-sample T for Face 1A - 2 vs. Face 2A - 2

             N   Mean  StDev  SE Mean
Face 1A - 2  8  12.44   1.90     0.67
Face 2A - 2  8  12.31   1.70     0.60
Difference = mu (Face 1A - 2) - mu (Face 2A - 2)
Estimate for difference:  0.136
95% CI for difference:  (-1.813, 2.085)
T-Test of difference = 0 (vs. not =): T-Value = 0.15  P-Value = 0.882  DF = 13
```

Two-Sample T-Test and CI: Face 1A - 3, Face 2A - 3

```
Two-sample T for Face 1A - 3 vs. Face 2A - 3

             N  Mean  StDev  SE Mean
Face 1A - 3  8  8.90   1.84     0.65
Face 2A - 3  8  8.94   1.38     0.49
Difference = mu (Face 1A - 3) - mu (Face 2A - 3)
Estimate for difference:  -0.046
95% CI for difference:  (-1.818, 1.725)
T-Test of difference = 0 (vs. not =): T-Value = -0.06  P-Value = 0.956  DF = 12
```

Two-Sample T-Test and CI: Face 1A - 4, Face 2A - 4

```
Two-sample T for Face 1A - 4 vs. Face 2A - 4

             N   Mean  StDev  SE Mean
Face 1A - 4  8   8.50   1.25     0.44
Face 2A - 4  8  8.149  0.878     0.31
Difference = mu (Face 1A - 4) - mu (Face 2A - 4)
Estimate for difference:  0.353
95% CI for difference:  (-0.826, 1.531)
T-Test of difference = 0 (vs. not =): T-Value = 0.65  P-Value = 0.527  DF = 12
```

Two-Sample T-Test and CI: Face 1A - 5, Face 2A - 5

```
Two-sample T for Face 1A - 5 vs. Face 2A - 5

             N  Mean  StDev  SE Mean
```

```
Face 1A - 5  8  7.32   1.36     0.48
Face 2A - 5  8  5.13   2.19     0.78
Difference = mu (Face 1A - 5) - mu (Face 2A - 5)
Estimate for difference:  2.185
95% CI for difference:  (0.174, 4.196)
T-Test of difference = 0 (vs. not =): T-Value = 2.39  P-Value = 0.036  DF = 11
```

Two-Sample T-Test and CI: Face 1A - 6, Face 2A - 6

```
Two-sample T for Face 1A - 6 vs. Face 2A - 6
             N   Mean  StDev  SE Mean
Face 1A - 6  8  5.929  0.881     0.31
Face 2A - 6  8   1.38   1.18     0.42
Difference = mu (Face 1A - 6) - mu (Face 2A - 6)
Estimate for difference:  4.546
95% CI for difference:  (3.411, 5.681)
T-Test of difference = 0 (vs. not =): T-Value = 8.73  P-Value = 0.000  DF = 12
```

Two-Sample T-Test and CI: Face 1A - 7, Face 2A - 7

```
Two-sample T for Face 1A - 7 vs. Face 2A - 7
             N   Mean  StDev  SE Mean
Face 1A - 7  8  4.186  0.657     0.23
Face 2A - 7  8  0.124  0.234    0.083
Difference = mu (Face 1A - 7) - mu (Face 2A - 7)
Estimate for difference:  4.063
95% CI for difference:  (3.494, 4.631)
T-Test of difference = 0 (vs. not =): T-Value = 16.49  P-Value = 0.000  DF = 8
```

Two-Sample T-Test and CI: Face 1A - 8, Face 2A - 8

```
Two-sample T for Face 1A - 8 vs. Face 2A - 8
             N   Mean  StDev  SE Mean
Face 1A - 8  8  29.49   2.11     0.74
Face 2A - 8  8  19.85   2.65     0.94
Difference = mu (Face 1A - 8) - mu (Face 2A - 8)
Estimate for difference:  9.64
95% CI for difference:  (7.05, 12.23)
T-Test of difference = 0 (vs. not =): T-Value = 8.05  P-Value = 0.000  DF = 13
```

SLOTS: 1A vs. 2B

Two-Sample T-Test and CI: Face 1A - 1, Face 2B -1

```
Two-sample T for Face 1A - 1 vs. Face 2B -1
             N   Mean  StDev  SE Mean
Face 1A - 1  8  12.60   1.39     0.49
```

```
Face 2B -1   8  11.79   1.22     0.43
Difference = mu (Face 1A - 1) - mu (Face 2B -1)
Estimate for difference:  0.811
95% CI for difference:  (-0.601, 2.223)
T-Test of difference = 0 (vs. not =): T-Value = 1.24  P-Value = 0.236  DF = 13
```

Two-Sample T-Test and CI: Face 1A - 2, Face 2B - 2

```
Two-sample T for Face 1A - 2 vs. Face 2B - 2
             N   Mean  StDev  SE Mean
Face 1A - 2  8  12.44   1.90     0.67
Face 2B - 2  8  12.22   1.28     0.45
Difference = mu (Face 1A - 2) - mu (Face 2B - 2)
Estimate for difference:  0.225
95% CI for difference:  (-1.542, 1.992)
T-Test of difference = 0 (vs. not =): T-Value = 0.28  P-Value = 0.786  DF = 12
```

Two-Sample T-Test and CI: Face 1A - 3, Face 2B - 3

```
Two-sample T for Face 1A - 3 vs. Face 2B - 3
             N  Mean  StDev  SE Mean
Face 1A - 3  8  8.90   1.84     0.65
Face 2B - 3  8  8.81   1.24     0.44
Difference = mu (Face 1A - 3) - mu (Face 2B - 3)
Estimate for difference:  0.091
95% CI for difference:  (-1.620, 1.802)
T-Test of difference = 0 (vs. not =): T-Value = 0.12  P-Value = 0.909  DF = 12
```

Two-Sample T-Test and CI: Face 1A - 4, Face 2B - 4

```
Two-sample T for Face 1A - 4 vs. Face 2B - 4
             N  Mean  StDev  SE Mean
Face 1A - 4  8  8.50   1.25     0.44
Face 2B - 4  8  7.50   1.09     0.38
Difference = mu (Face 1A - 4) - mu (Face 2B - 4)
Estimate for difference:  0.999
95% CI for difference:  (-0.268, 2.265)
T-Test of difference = 0 (vs. not =): T-Value = 1.70  P-Value = 0.112  DF = 13
```

Two-Sample T-Test and CI: Face 1A - 5, Face 2B - 5

```
Two-sample T for Face 1A - 5 vs. Face 2B - 5
             N  Mean  StDev  SE Mean
Face 1A - 5  8  7.32   1.36     0.48
Face 2B - 5  8  3.98   2.79     0.99
Difference = mu (Face 1A - 5) - mu (Face 2B - 5)
Estimate for difference:  3.34
```

95% CI for difference: (0.90, 5.79)

T-Test of difference = 0 (vs. not =): T-Value = 3.04 P-Value = 0.012 DF = 10

Two-Sample T-Test and CI: Face 1A - 6, Face 2B - 6

Two-sample T for Face 1A - 6 vs. Face 2B - 6

	N	Mean	StDev	SE Mean
Face 1A - 6	8	5.929	0.881	0.31
Face 2B - 6	8	0.82	1.15	0.41

Difference = mu (Face 1A - 6) - mu (Face 2B - 6)

Estimate for difference: 5.112

95% CI for difference: (4.008, 6.217)

T-Test of difference = 0 (vs. not =): T-Value = 10.00 P-Value = 0.000 DF = 13

Two-Sample T-Test and CI: Face 1A - 7, Face 2B - 7

* ERROR * All values in column are identical.

Two-Sample T-Test and CI: Face 1A - 8, Face 2B - 8

Two-sample T for Face 1A - 8 vs. Face 2B - 8

	N	Mean	StDev	SE Mean
Face 1A - 8	8	29.49	2.11	0.74
Face 2B - 8	8	18.39	2.36	0.83

Difference = mu (Face 1A - 8) - mu (Face 2B - 8)

Estimate for difference: 11.10

95% CI for difference: (8.68, 13.51)

T-Test of difference = 0 (vs. not =): T-Value = 9.92 P-Value = 0.000 DF = 13

SLOTS: 1B vs. 1A

Two-Sample T-Test and CI: Face 1B - 1, Face 1A - 1

Two-sample T for Face 1B - 1 vs. Face 1A - 1

	N	Mean	StDev	SE Mean
Face 1B - 1	8	11.91	1.09	0.38
Face 1A - 1	8	12.60	1.39	0.49

Difference = mu (Face 1B - 1) - mu (Face 1A - 1)

Estimate for difference: -0.695

95% CI for difference: (-2.044, 0.654)

T-Test of difference = 0 (vs. not =): T-Value = -1.11 P-Value = 0.286 DF = 13

Two-Sample T-Test and CI: Face 1B - 2, Face 1A -2

Two-sample T for Face 1B - 2 vs. Face 1A -2

	N	Mean	StDev	SE Mean
Face 1B - 2	8	12.628	0.853	0.30
Face 1A -2	8	12.44	1.90	0.67

Difference = mu (Face 1B - 2) - mu (Face 1A -2)

Estimate for difference: 0.185

95% CI for difference: (-1.481, 1.851)

T-Test of difference = 0 (vs. not =): T-Value = 0.25 P-Value = 0.807 DF = 9

Two-Sample T-Test and CI: Face 1B - 3, Face 1A -3

Two-sample T for Face 1B - 3 vs. Face 1A -3

	N	Mean	StDev	SE Mean
Face 1B - 3	8	9.080	0.989	0.35
Face 1A -3	8	8.90	1.84	0.65

Difference = mu (Face 1B - 3) - mu (Face 1A -3)

Estimate for difference: 0.183

95% CI for difference: (-1.464, 1.829)

T-Test of difference = 0 (vs. not =): T-Value = 0.25 P-Value = 0.810 DF = 10

Two-Sample T-Test and CI: Face 1B - 4, Face 1A -4

Two-sample T for Face 1B - 4 vs. Face 1A -4

	N	Mean	StDev	SE Mean
Face 1B - 4	8	8.20	1.02	0.36
Face 1A -4	8	8.50	1.25	0.44

Difference = mu (Face 1B - 4) - mu (Face 1A -4)

Estimate for difference: -0.300

95% CI for difference: (-1.532, 0.932)

T-Test of difference = 0 (vs. not =): T-Value = -0.53 P-Value = 0.608 DF = 13

Two-Sample T-Test and CI: Face 1B - 5, Face 1A -5

Two-sample T for Face 1B - 5 vs. Face 1A -5

	N	Mean	StDev	SE Mean
Face 1B - 5	8	4.31	2.74	0.97
Face 1A -5	8	7.32	1.36	0.48

Difference = mu (Face 1B - 5) - mu (Face 1A -5)

Estimate for difference: -3.01

95% CI for difference: (-5.42, -0.60)

T-Test of difference = 0 (vs. not =): T-Value = -2.78 P-Value = 0.019 DF = 10

Two-Sample T-Test and CI: Face 1B - 6, Face 1A -6

Two-sample T for Face 1B - 6 vs. Face 1A -6

	N	Mean	StDev	SE Mean
Face 1B - 6	8	0.911	0.888	0.31
Face 1A -6	8	5.929	0.881	0.31

Difference = mu (Face 1B - 6) - mu (Face 1A -6)

Estimate for difference: -5.018

95% CI for difference: (-5.973, -4.062)

T-Test of difference = 0 (vs. not =): T-Value = -11.34 P-Value = 0.000 DF = 13

Two-Sample T-Test and CI: Face 1B - 7, Face 1A -7

* ERROR * All values in column are identical.

Two-Sample T-Test and CI: Face 1B - 8, Face 1A -8

Two-sample T for Face 1B - 8 vs. Face 1A -8

	N	Mean	StDev	SE Mean
Face 1B - 8	8	18.42	2.40	0.85
Face 1A -8	8	29.49	2.11	0.74

Difference = mu (Face 1B - 8) - mu (Face 1A -8)

Estimate for difference: -11.07

95% CI for difference: (-13.51, -8.63)

T-Test of difference = 0 (vs not =): T-Value = -9.80 P-Value = 0.000 DF = 13

SLOTS: 1B vs. 2A

Two-Sample T-Test and CI: Face 1B - 1, Face 2A - 1

Two-sample T for Face 1B - 1 vs Face 2A - 1

	N	Mean	StDev	SE Mean
Face 1B - 1	8	11.91	1.09	0.38
Face 2A - 1	8	12.02	1.58	0.56

Difference = mu (Face 1B - 1) - mu (Face 2A - 1)

Estimate for difference: -0.114

95% CI for difference: (-1.588, 1.360)

T-Test of difference = 0 (vs not =): T-Value = -0.17 P-Value = 0.869 DF = 12

Two-Sample T-Test and CI: Face 1B - 2, Face 2A - 2

Two-sample T for Face 1B - 2 vs Face 2A - 2

	N	Mean	StDev	SE Mean
Face 1B - 2	8	12.628	0.853	0.30
Face 2A - 2	8	12.31	1.70	0.60

Difference = mu (Face 1B - 2) - mu (Face 2A - 2)

Estimate for difference: 0.321

95% CI for difference: (-1.179, 1.822)

T-Test of difference = 0 (vs not =): T-Value = 0.48 P-Value = 0.644 DF = 10

Two-Sample T-Test and CI: Face 1B - 3, Face 2A - 3

Two-sample T for Face 1B - 3 vs Face 2A - 3

	N	Mean	StDev	SE Mean
Face 1B - 3	8	9.080	0.989	0.35
Face 2A - 3	8	8.94	1.38	0.49

Difference = mu (Face 1B - 3) - mu (Face 2A - 3)

```
Estimate for difference:  0.136
95% CI for difference:  (-1.170, 1.443)
T-Test of difference = 0 (vs not =): T-Value = 0.23  P-Value = 0.824  DF = 1
```

Two-Sample T-Test and CI: Face 1B - 4, Face 2A - 4

```
Two-sample T for Face 1B - 4 vs Face 2A - 4

             N   Mean  StDev  SE Mean
Face 1B - 4  8   8.20   1.02     0.36
Face 2A - 4  8  8.149  0.878     0.31
Difference = mu (Face 1B - 4) - mu (Face 2A - 4)
Estimate for difference:  0.053
95% CI for difference:  (-0.973, 1.078)
T-Test of difference = 0 (vs not =): T-Value = 0.11  P-Value = 0.914  DF = 13
```

Two-Sample T-Test and CI: Face 1B - 5, Face 2A - 5

```
Two-sample T for Face 1B - 5 vs Face 2A - 5

             N  Mean  StDev  SE Mean
Face 1B - 5  8  4.31   2.74     0.97
Face 2A - 5  8  5.13   2.19     0.78
Difference = mu (Face 1B - 5) - mu (Face 2A - 5)
Estimate for difference:  -0.82
95% CI for difference:  (-3.50, 1.86)
T-Test of difference = 0 (vs not =): T-Value = -0.66  P-Value = 0.518  DF = 13
```

Two-Sample T-Test and CI: Face 1B - 6, Face 2A - 6

```
Two-sample T for Face 1B -  6 vs Face 2A - 6

              N   Mean  StDev  SE Mean
Face 1B -  6  8  0.911  0.888     0.31
Face 2A - 6   8   1.38   1.18     0.42
Difference = mu (Face 1B -  6) - mu (Face 2A - 6)
Estimate for difference:  -0.471
95% CI for difference:  (-1.600, 0.657)
T-Test of difference = 0 (vs not =): T-Value = -0.90  P-Value = 0.383  DF = 13
```

Two-Sample T-Test and CI: Face 1B - 7, Face 2A - 7

```
* ERROR * All values in column are identical.
```

Two-Sample T-Test and CI: Face 1B - 8, Face 2A - 8

```
Two-sample T for Face 1B - 8 vs Face 2A - 8

             N   Mean  StDev  SE Mean
Face 1B - 8  8  18.42   2.40     0.85
Face 2A - 8  8  19.85   2.65     0.94
Difference = mu (Face 1B - 8) - mu (Face 2A - 8)
Estimate for difference:  -1.43
```

95% CI for difference: (-4.16, 1.31)

T-Test of difference = 0 (vs not =): T-Value = -1.13 P-Value = 0.280 DF = 13

SLOTS: 1B vs. 2B

Two-Sample T-Test and CI: Face 1B - 1, Face 2B - 1

Two-sample T for Face 1B - 1 vs Face 2B - 1

	N	Mean	StDev	SE Mean
Face 1B - 1	8	11.91	1.09	0.38
Face 2B - 1	8	11.79	1.22	0.43

Difference = mu (Face 1B - 1) - mu (Face 2B - 1)

Estimate for difference: 0.116

95% CI for difference: (-1.128, 1.361)

T-Test of difference = 0 (vs not =): T-Value = 0.20 P-Value = 0.843 DF = 13

Two-Sample T-Test and CI: Face 1B - 2, Face 2B - 2

Two-sample T for Face 1B - 2 vs Face 2B - 2

	N	Mean	StDev	SE Mean
Face 1B - 2	8	12.628	0.853	0.30
Face 2B - 2	8	12.22	1.28	0.45

Difference = mu (Face 1B - 2) - mu (Face 2B - 2)

Estimate for difference: 0.410

95% CI for difference: (-0.778, 1.598)

T-Test of difference = 0 (vs not =): T-Value = 0.75 P-Value = 0.466 DF = 12

Two-Sample T-Test and CI: Face 1B - 3, Face 2B - 3

Two-sample T for Face 1B - 3 vs Face 2B - 3

	N	Mean	StDev	SE Mean
Face 1B - 3	8	9.080	0.989	0.35
Face 2B - 3	8	8.81	1.24	0.44

Difference = mu (Face 1B - 3) - mu (Face 2B - 3)

Estimate for difference: 0.274

95% CI for difference: (-0.939, 1.487)

T-Test of difference = 0 (vs not =): T-Value = 0.49 P-Value = 0.634 DF = 13

Two-Sample T-Test and CI: Face 1B - 4, Face 2B - 4

Two-sample T for Face 1B - 4 vs Face 2B - 4

	N	Mean	StDev	SE Mean
Face 1B - 4	8	8.20	1.02	0.36
Face 2B - 4	8	7.50	1.09	0.38

Difference = mu (Face 1B - 4) - mu (Face 2B - 4)

Estimate for difference: 0.699

95% CI for difference: (-0.438, 1.835)

T-Test of difference = 0 (vs not =): T-Value = 1.33 P-Value = 0.207 DF = 13

Two-Sample T-Test and CI: Face 1B - 5, Face 2B - 5

Two-sample T for Face 1B - 5 vs Face 2B - 5

	N	Mean	StDev	SE Mean
Face 1B - 5	8	4.31	2.74	0.97
Face 2B - 5	8	3.98	2.79	0.99

Difference = mu (Face 1B - 5) - mu (Face 2B - 5)

Estimate for difference: 0.33

95% CI for difference: (-2.65, 3.32)

T-Test of difference = 0 (vs not =): T-Value = 0.24 P-Value = 0.814 DF = 13

Two-Sample T-Test and CI: Face 1B - 6, Face 2B - 6

Two-sample T for Face 1B - 6 vs Face 2B - 6

	N	Mean	StDev	SE Mean
Face 1B - 6	8	0.911	0.888	0.31
Face 2B - 6	8	0.82	1.15	0.41

Difference = mu (Face 1B - 6) - mu (Face 2B - 6)

Estimate for difference: 0.095

95% CI for difference: (-1.012, 1.202)

T-Test of difference = 0 (vs not =): T-Value = 0.19 P-Value = 0.856 DF = 13

Two-Sample T-Test and CI: Face 1B - 7, Face 2B - 7

* ERROR * All values in column are identical.

Two-Sample T-Test and CI: Face 1B - 8, Face 2B - 8

Two-sample T for Face 1B - 8 vs Face 2B - 8

	N	Mean	StDev	SE Mean
Face 1B - 8	8	18.42	2.40	0.85
Face 2B - 8	8	18.39	2.36	0.83

Difference = mu (Face 1B - 8) - mu (Face 2B - 8)

Estimate for difference: 0.03

95% CI for difference: (-2.54, 2.60)

T-Test of difference = 0 (vs not =): T-Value = 0.02 P-Value = 0.981 DF = 13

Measurement 10 Statistical Analysis

Two-Sample T-Test and CI: Face 1A - 10, Control - 10

Two-sample T for Face 1A - 10 vs Control - 10

	N	Mean	StDev	SE Mean
Face 1A - 10	8	259.7	23.0	8.1
Control - 10	4	187.19	4.32	2.2

Difference = mu (Face 1A - 10) - mu (Control - 10)

```
Estimate for difference:  72.54
95% CI for difference:  (52.65, 92.42)
T-Test of difference = 0 (vs not =): T-Value = 8.63  P-Value = 0.000  DF = 7
```

Two-Sample T-Test and CI: Face 1B - 10, Control - 10

```
Two-sample T for Face 1B - 10 vs Control - 10

               N    Mean  StDev  SE Mean
Face 1B - 10   8   191.4   10.3      3.6
Control - 10   4  187.19   4.32      2.2


Difference = mu (Face 1B - 10) - mu (Control - 10)
Estimate for difference:  4.23
95% CI for difference:  (-5.35, 13.81)
T-Test of difference = 0 (vs not =): T-Value = 1.00  P-Value = 0.344  DF = 9
```

Two-Sample T-Test and CI: Face 2A - 10, Control - 10

```
Two-sample T for Face 2A - 10 vs Control - 10

               N    Mean  StDev  SE Mean
Face 2A - 10   8   197.6   16.7      5.9
Control - 10   4  187.19   4.32      2.2


Difference = mu (Face 2A - 10) - mu (Control - 10)
Estimate for difference:  10.37
95% CI for difference:  (-4.15, 24.89)
T-Test of difference = 0 (vs not =): T-Value = 1.65  P-Value = 0.138  DF = 8
```

Two-Sample T-Test and CI: Face 2B - 10, Control - 10

```
Two-sample T for Face 2B - 10 vs Control - 10

               N    Mean  StDev  SE Mean
Face 2B - 10   8   184.8   15.2      5.4
Control - 10   4  187.19   4.32      2.2


Difference = mu (Face 2B - 10) - mu (Control - 10)
Estimate for difference:  -2.44
95% CI for difference:  (-15.80, 10.92)
T-Test of difference = 0 (vs not =): T-Value = -0.42  P-Value = 0.685  DF = 8
```

Two-Sample T-Test and CI: Slot Face 1A - 10, Slot Face 1B -10

```
Two-sample T for Slot Face 1A - 10 vs Slot Face 1B -10

                   N   Mean  StDev  SE Mean
Slot Face 1A - 10  8  259.7   23.0      8.1
Slot Face 1B -10   8  191.4   10.3      3.6


Difference = mu (Slot Face 1A - 10) - mu (Slot Face 1B -10)
Estimate for difference:  68.30
95% CI for difference:  (48.16, 88.45)
```

```
T-Test of difference = 0 (vs not =): T-Value = 7.67  P-Value = 0.000  DF = 9
```

Two-Sample T-Test and CI: Slot Face 1A - 10, Slot Face 2A - 10

```
Two-sample T for Slot Face 1A - 10 vs Slot Face 2A - 10

                    N   Mean  StDev  SE Mean
Slot Face 1A - 10   8  259.7   23.0      8.1
Slot Face 2A - 10   8  197.6   16.7      5.9


Difference = mu (Slot Face 1A - 10) - mu (Slot Face 2A - 10)
Estimate for difference:  62.2
95% CI for difference:  (40.3, 84.1)
T-Test of difference = 0 (vs not =): T-Value = 6.19  P-Value = 0.000  DF = 12
```

Two-Sample T-Test and CI: Slot Face 1A - 10, Slot Face 2B - 10

```
Two-sample T for Slot Face 1A - 10 vs Slot Face 2B - 10

                    N   Mean  StDev  SE Mean
Slot Face 1A - 10   8  259.7   23.0      8.1
Slot Face 2B - 10   8  184.8   15.2      5.4


Difference = mu (Slot Face 1A - 10) - mu (Slot Face 2B - 10)
Estimate for difference:  74.97
95% CI for difference:  (53.74, 96.20)
T-Test of difference = 0 (vs not =): T-Value = 7.69  P-Value = 0.000  DF = 12
```

Two-Sample T-Test and CI: Slot Face 1B -10, Slot Face 1A - 10

```
Two-sample T for Slot Face 1B -10 vs Slot Face 1A - 10

                    N   Mean  StDev  SE Mean
Slot Face 1B -10    8  191.4   10.3      3.6
Slot Face 1A - 10   8  259.7   23.0      8.1


Difference = mu (Slot Face 1B -10) - mu (Slot Face 1A - 10)
Estimate for difference:  -68.30
95% CI for difference:  (-88.45, -48.16)
T-Test of difference = 0 (vs not =): T-Value = -7.67  P-Value = 0.000  DF = 9
```

Two-Sample T-Test and CI: Slot Face 1B -10, Slot Face 2A - 10

```
Two-sample T for Slot Face 1B -10 vs Slot Face 2A - 10

                    N   Mean  StDev  SE Mean
Slot Face 1B -10    8  191.4   10.3      3.6
Slot Face 2A - 10   8  197.6   16.7      5.9


Difference = mu (Slot Face 1B -10) - mu (Slot Face 2A - 10)
Estimate for difference:  -6.14
95% CI for difference:  (-21.43, 9.15)
T-Test of difference = 0 (vs not =): T-Value = -0.88  P-Value = 0.396  DF = 11
```

Two-Sample T-Test and CI: Slot Face 1B -10, Slot Face 2B - 10

```
Two-sample T for Slot Face 1B -10 vs Slot Face 2B - 10

                    N   Mean  StDev  SE Mean
Slot Face 1B -10    8  191.4   10.3      3.6
Slot Face 2B - 10   8  184.8   15.2      5.4


Difference = mu (Slot Face 1B -10) - mu (Slot Face 2B - 10)
Estimate for difference:  6.67
95% CI for difference:  (-7.48, 20.82)
T-Test of difference = 0 (vs not =): T-Value = 1.03  P-Value = 0.325  DF = 12
```