Effect of Margin Design, its Subgingival Depth and Installation Pressure on Subgingival Cement and Open Margins: an in vitro study

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Abstract: *Intra-oral cementation is a common process for attaching crowns and bridges to natural teeth and dental implants. While fixed prosthetics are cemented onto natural teeth, dental implants may also be restored by a screw-in prosthetic installation technique. Unfortunately, both the cement-in and screw-in installation systems have inherent problems that expose patients to mechanical complications and related dental diseases. The troubling prevalence of implant treatment complications related to both these installation systems appears to be similar and treatment for peri-implant diseases can be uncomfortable, unpredictable, and expensive. The Intra-oral cementation system can prevent several risk factors for complications related to the screw-in prosthesis installation system, like misfit parts and poor access to care. However, it has also been plagued by complications related to residual subgingival cement and open margins. While removal of excess cement may result in the resolution of related peri-implant disease, an intra-oral cementation system that could mitigate these risk factors for disease could be key to reducing treatment complications.*

This study compared the installation of single crowns with the common Chamfer Margin System (CMS) to a more recent Reverse Margin System (RMS). Both systems were tested in vitro with their abutment margins positioned at ½ to 1 mm subgingival, while their complementary crowns were cemented into place under varying pressure conditions. The RMS outperformed the CMS under all pressure and margin depth conditions, regarding the incidence and extension of submarginal cement. In general, reducing cementation pressure reduced the distance excess cement travelled beyond abutment margins. Unlike the CMS, the RMS was able to prevent submarginal cement when crowns were installed at lower pressure, 2 Kg or less. While RMS trials had no open margins, all CMS crowns had open margins under all conditions. Indeed, reduced installation pressure and deeper margins both resulted in larger open margins in the CMS trials.

Conclusions*: Unlike the CMS, the RMS was able to prevent the occurrence of submarginal cement and open margins under low pressure installation conditions. Identifying an installation system that can consistently prevent several risk factors for complications may have great clinical significance and thus forms the basis of a* ***New Gold Standard of Care****.*

Correspondence: drsvoboda@rogers.com. Dr. Svoboda is in private practice placing and restoring dental implants. He invented the Reverse Margin System (RMS) and holds patents through CSD Connection Systems for Dentistry Inc. on the unique design aspects of both the Reverse Margin crowns and complimentary custom abutments. Co-authors Drs. Sharma and Cheema have no financial interests in the RMS. Published in Spectrum Implants Mar/Apr 2022,V13,N2;50-64, and available for download at www.ReverseMargin.com.

Search Words: Dental implants, fixed prosthesis installation, crown installation, intra-oral cementation, chamfer margin system, open margins, subgingival cement, Reverse Margin System, passive prosthesis, misfit connections, peri-implant disease, treatment complications, risk factors for complications.

Intra-oral cementation is a common process for attaching crowns and bridges to natural teeth and dental implants. (1,2) While fixed prosthetics are cemented onto natural teeth, dental implants can also be restored by a screw-in technique. Unfortunately, this latter installation system has inherent problems that can make it difficult to impossible to optimize the fit of the implant-abutment and/or abutment-prosthesis connections. These problems can compromise the stability of the prosthesis and diminish its ability to prevent the movement of oral pathogens between the internal spaces of the implant and the peri-implant environment. Misfit joints are a risk factor for peri-implant disease. Worse yet, the screw-in installation system often uses cantilevers to hide screw access holes. These process-related cantilevers can amplify stress on misfit connections and block access for effective professional and personal maintenance. Plaque and calculus are known to accumulate under these cantilevers and are also risk factors for peri-implant disease. (3,4,5)

Intra-oral cementation provides the dentist with an opportunity to optimize the fit of implant parts and to avoid unnecessary screw-access-related cantilevers. However, this system of installation has been plagued by complications related to residual subgingival cement and open prosthesis margins. (6) Residual subgingival cement is a known risk factor for peri-implant disease. (7,8)

Both the screw-in and cement-in prostheses installation systems appear to expose the patient to similar troubling rates of peri-implant disease and implant loss. (9,10) Treatment for peri-implant disease can be uncomfortable, unpredictable, and expensive. (11) A system of installation that can reduce the risk factors for complications may also reduce the prevalence of related peri-implant disease and implant failure. (5)

Purpose

This research compared the efficacy of the common Chamfer Margin based crown installation system (CMS) to a more recent system utilizing a Reverse Margin (RMS) design. Unlike the **Chamfer Margin System (CMS)**, the **Reverse Margin System (RMS)** utilizes an abutment with an inflected margin that redirects excess cement out of the tissue environment rather than into it, and a complimentary crown shape that facilitates that direction of cement flow. Unlike the CMS, the RMS has been specifically designed to mitigate the root causes of prosthesis installation-related complications, namely Prosthesis Dimensional Error (PDE) and the Tissue Effects (TE). (12) These root causes of mechanical and related biological complications have frustrated dentists' efforts to safely install prostheses over many years. An intra-oral cementation system that could provide the dentist with the means of optimizing the fit of implant parts and preventing the occurrence of residual subgingival cement and open margins could be key to making dental treatment better. (13)

Method

a) Design Features of Abutment-Crown Systems

Each crown and complimentary abutment group was designed with 3Shape software (www.3Shape.com) as described in a previous publication. (14) **Figures 1 & 2** are scaled renditions displaying the features of the two systems. The CMS and RMS groups had their crowns and complimentary abutment shapes milled from similar zirconia pucks (DWX-520Ci, www.dgshape.com) according to their respective design templates. The milled shapes were then sintered and refined manually. All abutment shapes were cemented to Titanium bases (Ti bases) and screwed to matching implant analogues. (www.BioHorizons.com) Identical acrylic models were printed (NextDent 5100, www.3dSystems.com) and a silicone gingiva (GI Mask, www.Coltene.com) template was created to simulate the replacement of a single mandibular first molar with adjacent soft tissue. **Gingiva was mastered to ensure contact with abutment retainers after installation.**

Figure 1 shows a CMS design with a 45-micron cement space that is designed to diminish to zero about 340 microns from the tissue-facing edge of its margin. **CMS crowns have a convex shape that emerges from the narrower abutment profile.** This common CMS design is made to simulate the emergence profile of a natural tooth. CMS crowns are thus designed to displace adjacent gingiva laterally during their installation. This type of design is common and expected from dental laboratories when abutment margins are placed into the subgingival environment. CMS crown margins are also designed to contact their complementary abutment margins when installed.

Figure 2 shows an RMS margin design with its wider 80-micron space between its crown and abutment. **In contrast to the CMS, the RMS abutment profile is wider than the tissue-facing base of their complementary RMS crowns.** In addition, RMS crowns are designed to have unique concave emergence profiles that further prevent direct interaction with adjacent gingiva during installation. This facilitates the flow of excess cement away from the adjacent tissues.

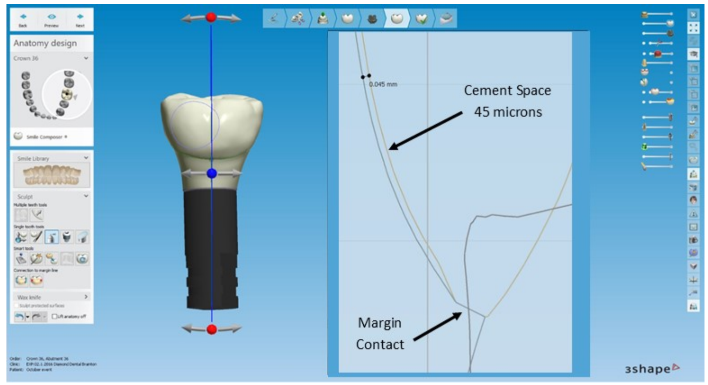

Figure 1: This is a computer-screen display showing a 3-D view of a CMS crown, abutment, and implant-analogue complex with a cross-sectional view on the right. The cement space was set to 45 microns and the crown was designed to sit directly onto the abutment margin. The emergence profile of the crown is convex and wider than the abutment.

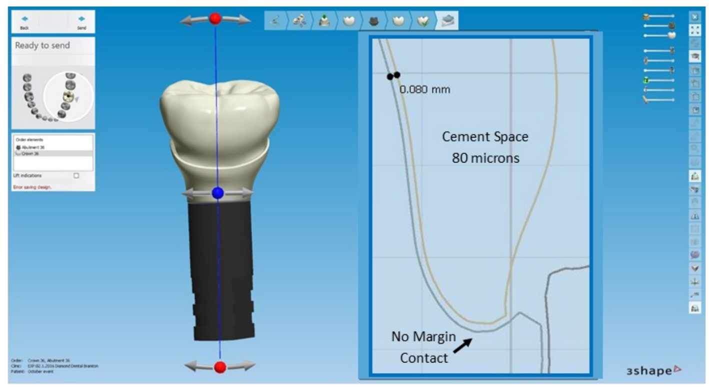

Figure 2: This is a screen display showing a 3-D view of a RMS crown, abutment, and implant-analogue complex with a cross-sectional view on the right. The cement space is 80 microns and the crown was designed to float within the abutment margin inflected trough. The emergence profile of the crown is concave and is narrower than the underlying abutment.

Figure 3: Printed model with silicone gingiva and installed RMS abutment. The screw access hole is filled with pink Teflon tape.

Figure 4: A RMS crown with a clear plastic covered screw-access hole is seated on its abutment. It sits passively, as it is not touching adjacent gingiva. Space is visible between the gingiva and crown.

Figure 3 shows an RMS abutment installed onto an implant analogue in the printed dental model. The silicone gingiva has been mastered to be displaced laterally by the abutment margin. All buccal (B) margins were measured to be 1.0 mm and lingual (L) margins 0.5 mm below the simulated gingiva margin. The distal (D) and mesial (M) aspects served as the transitional zones between the B and L margins and their margins thus ranged from 0.5 to 1.0 mm subgingival. **Figure 4 shows** an RMS crown sitting passively on its complementary abutment, as it is not in contact with the adjacent gingiva.

The top of the crown has a screw-access hole sealed with clear acrylic. This seal ensures that excess cement will be expelled from the crown margins during the installation procedure, rather than being allowed to exit through the screw-access hole. This plastic-covered screw access hole feature is available to dentists who wish it, but it was not used to separate the abutment-crown complex in this experiment. To collect data, the entire implant-analogue-abutment-crown complex was separated from the dental model by removing an implant-analogue fixation lug under its base.

All crowns were fabricated to be slightly out of contact with adjacent teeth to prevent any lateral forces by adjacent contacts from affecting their installation.

Figure 5 shows a black dot on the B surface of the crown and a black line on the B gingiva for crown orientation purposes during the cementation process.

b) The Cementation Process

The fit of multiple random abutments to crowns was sampled without gingiva, and with and without cement. **There were no visible gaps between their margins before the cementation process.**

The intaglio of each crown was ½ filled with RelyX™ Unicem 2 automix cement (3M Espe Neuss, Germany) expressed directly from the mixing tip into the deepest part of the intaglio of the crown. The crown buccal dot was aligned with the black line on the gingiva and seated into place on its abutment and dental model on a weight scale. (AccuWeight Digital Kitchen Scale, Item 3836-48, www.Amazon.com) **(Figure 5)**

Finger pressure on the crown was applied over 5 seconds to reach the desired seating pressure and then held for another 5 seconds before the cement was polymerized with a curing light. (Elipar™ Deepcure-S, 3M Neuss, Germany) **The RMS and CMS crown cementation trials were alternated to control for operator-induced variation.**

3) Collecting Data

The implant-analogue-abutment-crown complex was unscrewed from the base of the dental model and photographed using an iPhone 11 Pro Max (Apple Inc, www.apple.com) mounted on a stand. Photographs were taken of the B, M, L and D aspects of each abutment-crown surface while placed beside a millimetre grid. The submarginal cement was marked for illustration purposes in **Figure 6. Figure 7** shows the RMS without any submarginal cement. The images were copied into a Windows Publisher program (www.Windows.com) and enlarged to facilitate the measurement process. The maximum distance travelled by the cement beyond the abutment

Figure 5: The RMS crown is being cemented into place, guided by the black markings. This crown is being cemented at 2.174 Kg and the excess cement is visible above the gingival margin. There is an attempt to bring and keep the seating force at or about 2 Kg. during the installation process.

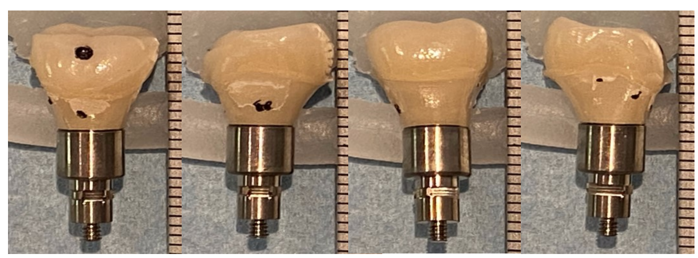

Figure 6: Photographs of CMS crowns positioned adjacent to ruler with mm markings to measure cement travel beyond their buccal (B), mesial (M), lingual (L) and distal (D) margins. Black markings highlight extent of cement travel.

Figure 7: RMS crowns are cemented onto their abutments and attached to their implant analogues. Excess cement is above the abutment margins, unlike CMS.

margin on each surface was measured from the image on the

5 Kg	CM				Totals	RM				Totals
Trial #	B	D	L	M	mm	B	D	L	M	mm
1	4.0	2.0	0.2	3.2	9.4	0.0	0.0	0.0	0.0	0.0
2	4.8	3.6	0.0	0.2	8.6	0.0	0.0	0.0	0.0	0.0
3	6.0	2.2	0.8	1.8	10.8	1.0	0.0	0.0	0.0	1.0
4	8.2	2.8	1.8	6.2	19.0	1.0	0.0	0.0	0.0	1.0
5	8.2	2.8	7.0	6.1	24.1	0.0	0.0	0.0	0.0	0.0
6	4.2	1.5	0.0	2.0	7.7	0.4	0.2	0.0	0.0	0.6
7	0.5	8.0	6.8	9.2	24.5	0.8	0.0	0.0	0.0	0.8
8	4.8	1.4	5.5	0.0	11.7	0.0	0.0	0.0	0.0	0.0
9	8.6	2.2	0.2	6.0	17.0	0.0	0.0	0.0	0.0	0.0
10	8.6	10.8	4.5	7.8	31.7	7.6	0.0	0.0	4.0	11.6
Totals	57.9	37.3	26.8	42.5	164.5	10.8	0.2	0.0	4.0	15.0

4 Kg	CM				Totals	RM				Totals
Trial #	B	D	L	M	mm	B	D	L	M	mm
1	4.2	1.8	0.0	0.2	6.2	0.8	0.0	0.0	0.0	0.8
2	2.8	0.0	0.0	0.0	2.8	0.5	0.0	0.0	0.0	0.5
3	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
4	4.0	0.0	0.0	0.0	4.0	0.5	0.0	0.0	0.0	0.5
5	7.8	11.0	11.5	8.6	38.9	1.0	0.0	0.0	0.0	1.0
6	2.9	4.0	0.0	4.0	10.9	0.5	0.0	0.0	0.0	0.5
7	8.2	9.0	4.6	9.8	31.6	0.5	0.0	0.0	0.0	0.5
8	8.0	9.4	8.2	9.6	35.2	0.5	0.0	0.0	0.0	0.5
9	8.0	3.0	1.4	8.9	21.3	1.0	0.1	0.0	0.0	1.1
10	3.9	3.3	0.0	2.0	9.2	0.5	0.0	0.0	0.0	0.5
Totals	50.8	41.5	25.7	43.1	161.1	5.8	0.1	0.0	0.0	5.9

2 Kg	CM				Totals	RM				Totals
Trial #	B	D	L	M	mm	B	D	L	M	mm
1	1.9	3.1	0.0	2.1	7.1	0.0	0.0	0.0	0.0	0.0
2	4.0	3.8	2.0	3.1	12.9	0.0	0.0	0.0	0.0	0.0
3	1.3	2.7	0.0	2.8	6.8	0.0	0.0	0.0	0.0	0.0
4	2.7	3.0	1.1	1.8	8.6	0.0	0.0	0.0	0.0	0.0
5	4.0	3.7	0.0	4.0	11.7	0.0	0.0	0.0	0.0	0.0
6	0.1	3.8	0.0	1.5	5.4	0.0	0.0	0.0	0.0	0.0
7	2.1	3.8	0.0	1.6	7.5	0.0	0.0	0.0	0.0	0.0
8	3.4	4.1	0.6	2.6	10.7	0.0	0.0	0.0	0.0	0.0
9	1.9	3.2	0.0	1.0	6.1	0.0	0.0	0.0	0.0	0.0
10	0.6	4.2	0.2	1.0	6.0	0.0	0.0	0.0	0.0	0.0
Totals	22	35.4	3.9	21.5	82.8	0.0	0.0	0.0	0.0	0.0

1 Kg	CM				Totals	RM				Totals
Trial #	B	D	L	M	mm	B	D	L	M	mm
1	1.8	1.7	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0
2	1.0	1.3	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0
3	1.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	2.8	0.0	0.0	1.2	4.0	0.0	0.0	0.0	0.0	0.0
7	0.4	2.1	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
8	3.0	0.2	0.0	1.0	4.2	0.0	0.0	0.0	0.0	0.0
9	3.3	2.2	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0
10	2.3	1.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0
Totals	16.5	8.5	0.0	2.2	27.2	0.0	0.0	0.0	0.0	0.0

0.5 Kg	CM				Totals	RM				Totals
Trial #	B	D	L	M	mm	B	D	L	M	mm
1	0.2	0.8	0.0	0.5	1.5	0.0	0.0	0.0	0.0	0.0
2	0.2	1.8	0.0	0.1	2.1	0.0	0.0	0.0	0.0	0.0
3	1.4	1.4	1.0	1.2	5.0	0.0	0.0	0.0	0.0	0.0
4	1.4	3.8	0.0	0.4	5.6	0.0	0.0	0.0	0.0	0.0
5	0.0	2.0	1.2	0.0	3.2	0.0	0.0	0.0	0.0	0.0
6	0.2	0.2	0.0	0.6	1.0	0.0	0.0	0.0	0.0	0.0
7	1.2	2.5	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0
8	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
9	1.2	1.8	0.0	1.0	4.0	0.0	0.0	0.0	0.0	0.0
10	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
Totals	5.8	17.3	2.2	3.8	29.1	0.0	0.0	0.0	0.0	0.0

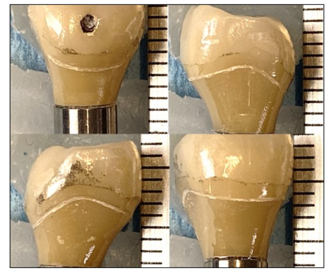

Figure 8: Excess cement was removed to display the CMS abutment to crown interface. The vertical height of the opening was measured on the computer display in reference to the adjacent mm ruler grid.

computer screen and recorded on a Windows Excel sheet.

To measure the space between the abutment and crown margins, excess cement was first removed with a scalpel and/or rotating instrument before taking photographs. Gaps, with and without cement between margins, were measured in the centre of each image. **(Figure 8)**

All differences between groups were tested for significance using the Mann-Whitney U test.

Tables 1-5: Show mm of cement extension beyond the B, D, L, M abutment margins for all crowns cemented at 5 to 0.5 Kg of pressure. The sums of cement extensions are listed under total for each trial and each surface. These data values are the basis of all calculations regarding design and cement travel distance beyond margins.

		Totals	
Pressure	Margin	Average	Range
5 Kg	CM	4.1	0 - 10.8
	RM	0.4	0 - 11.6
4 Kg	CM	4.0	0 - 11.5
	RM	0.1	0 - 1.0
2 Kg	CM	2.1	0.1 - 4.2
	RM	0	0
1 Kg	CM	0.7	0 - 3.3
	RM	0	0
0.5 Kg	CM	0.7	0 - 3.8
	RM	0	0

Table 6: Shows average distance and range of cement travel past margins for both the CMS and RMS.

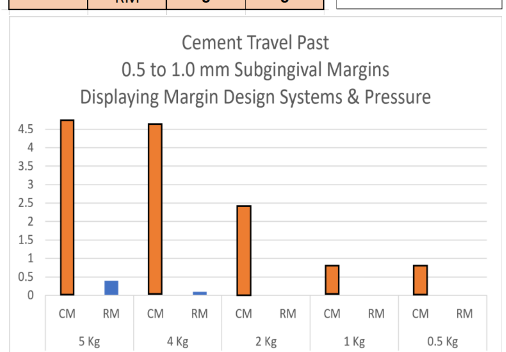

Figure 9: Graph displaying the effect of margin design and pressure per Table 6.

CM 5Kg					Totals
Trial #	B	D	L	M	mm
1	0.2	0.1	0.1	0.2	0.6
2	0.2	0.2	0.1	0.1	0.6
3	0.1	0.1	0.0	0.1	0.3
4	0.1	0.1	0.1	0.0	0.2
5	0.1	0.0	0.0	0.0	0.1
6	0.1	0.1	0.1	0.0	0.3
7	0.2	0.1	0.0	0.1	0.4
8	0.3	0.0	0.2	0.3	0.9
9	0.1	0.1	0.0	0.2	0.4
10	0.2	0.1	0.0	0.1	0.4
Totals	1.6	0.9	0.6	1.1	4.2

CM 4Kg					Totals
Trial #	B	D	L	M	mm
1	0.5	0.4	0.1	0.3	1.3
2	0.2	0.4	0.3	0.1	1.0
3	0.6	0.4	0.1	0.3	1.4
4	0.3	0.3	0.1	0.1	0.8
5	0.0	0.1	0.1	0.1	0.3
6	0.1	0.1	0.1	0.2	0.6
7	0.1	0.1	0.1	0.3	0.5
8	0.1	0.3	0.0	0.1	0.5
9	0.1	0.1	0.0	0.1	0.2
10	0.1	0.2	0.0	0.1	0.3
Totals	2.2	2.2	0.8	1.7	6.9

CM 2Kg					Totals
Trial #	B	D	L	M	mm
1	0.3	0.2	0.1	0.3	0.9
2	0.0	0.0	0.1	0.0	0.1
3	0.1	0.0	0.1	0.1	0.3
4	0.2	0.1	0.0	0.1	0.4
5	0.0	0.1	0.0	0.0	0.1
6	0.2	0.2	0.1	0.2	0.7
7	0.2	0.2	0.1	0.2	0.7
8	0.2	0.1	0.0	0.1	0.4
9	0.1	0.0	0.0	0.1	0.2
10	0.1	0.0	0.0	0.1	0.2
Totals	1.4	0.9	0.5	1.2	4.0

CM 1Kg					Totals
Trial #	B	D	L	M	mm
1	0.3	0.2	0.1	0	0.6
2	0.1	0.2	0.2	0.2	0.7
3	0.6	0.3	0	0.4	1.3
4	1.0	0.8	0.2	0.5	2.5
5	0.9	0.5	0.5	0.7	2.6
6	0.8	0.3	0.2	0.5	1.8
7	0.2	0	0.1	0.2	0.5
8	0.2	0.2	0.1	0.1	0.6
9	0.1	0	0	0.1	0.2
10	0.5	0.3	0.3	0.4	1.5
Totals	4.7	2.8	1.7	3.1	12.3

CM 0.5Kg					Totals
Trial #	B	D	L	M	mm
1	0.4	0.2	0.1	0.2	0.9
2	0.2	0.2	0.2	0.1	0.7
3	0.5	0.3	0.3	0.2	1.3
4	0.3	0.3	0.2	0.3	1.1
5	0.7	0.6	0.2	0.3	1.8
6	0.5	0.2	0.4	0.5	1.6
7	0.4	0.4	0.4	0.6	1.8
8	0.6	0.4	0.3	0.4	1.7
9	0.1	0.1	0.1	0.1	0.4
10	0.3	0.1	0.2	0.3	0.9
Totals	4.0	2.8	2.4	3.0	12.2

Results

1) Pressure and Submarginal Cement

CMS Conditions: The combined (B+M+L+D) 5 Kg pressure condition had excess cement travel an average of 4.1 mm (range 0-10.8mm) below their abutment margins. Under the 4,2,1 and 0.5 Kg conditions the cement travel averaged 4.1 mm (0-11.5), 2.1 mm (0-4.0), 0.7 mm (0-3.3) and 0.7 mm (0 to 1.8) respectively. All the CMS pressure conditions were found to be different from each other, except the 4 and 2Kg, and 1 and 0.5 Kg conditions. **Higher installation pressure resulted in excess cement travelling further beyond the CMS abutment margins.**

RMS Conditions: The combined 5 Kg pressure condition had excess cement travel an average of 0.4 mm (range 0-11.6 mm) beyond their abutment margins and the cement travel under the 4 Kg averaged 0.1mm (range 0-1.0mm). No cement breached any abutment margins when crowns were cemented under the 2,1 and 0.5 KG conditions. The 5 and 2Kg, 5 and 1 Kg, 5 and 0.5 Kg, 4 and 2 Kg, 4 and 1 Kg, 4 and 0.5 Kg, 2 and 1 Kg and 2 and 0.5 Kg conditions were different at the p=0.05.

There was a significant difference (p=0.05) between all the combined CM conditions and their corresponding combined RM conditions. All the CM trials demonstrated greater cement extensions beyond their margins than any of the combined RM conditions (p=0.01). **(Tables 1-6, Figure 9)**

Summary 1: Unlike the CMS, the RMS consistently prevented submarginal cement flow when installation pressures were 2 Kg or less. Under all pressure conditions, the RMS prevented the occurrence of subgingival cement much better than the CMS. ($p \leq 0.05$)

Tables 7-11: Display separation between the abutment–crown margins in the central part of the images of each of its surfaces. There are totals for each trial and margin surface under various installation pressures.

CM	Total	
Pressure	Average	Range
5 Kg	0.1	0-0.3
4 Kg	0.2	0-0.6
2 Kg	0.1	0-0.3
1 Kg	0.3	0-1.0
0.5 Kg	0.3	0-0.7

Table 12: This shows the average and range of open margins for the CMS under various pressure conditions. Margins ranged from 0.5 to 1.0 mm subgingival.

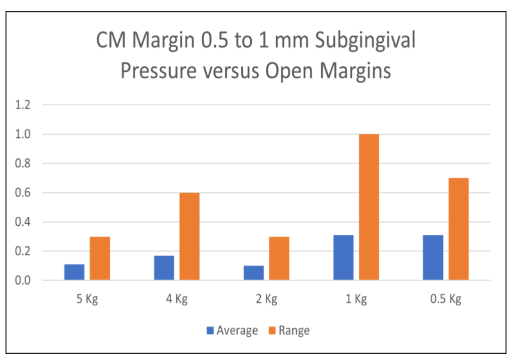

Figure 10: Shows CMS with increasing open margins with decreasing pressure.

2) Installation Pressure and Open Margins

CMS Conditions: The CMS 5 Kg trials had an average of 0.1 mm of separation between the crown margins and the abutment margins (Range 0-0.3mm). The 4,2,1 and 0.5 Kg conditions averaged 0.2 mm (0-0.6), 0.1 mm (0-0.3), 0.3 mm (0-1.0) and 0.3 mm (0 to 0.7) respectively. There was a difference between the 5 Kg and both the 1 Kg and 0.5 Kg conditions (p=0.05) and the 2Kg and 0.5 Kg conditions (p=0.01).
RMS Conditions: None of the RMS had any open margins under any of the pressure conditions. (Tables 7-12, Figure 10)

Summary 2: There was a difference (p=0.01) in open margins between all the combined CMS conditions and their corresponding combined RMS conditions. While all the CMS trials demonstrated open margins that increased in size with decreasing installation pressure, the RMS margins had no open margins under any pressure conditions.

3) Margin Depth and Submarginal Cement

CMS Conditions: All the abutments in the **1mm subgingival margin trials** had submarginal cement. The 5,4,2,1 and 0.5 Kg conditions had an average of 5.8 mm (range 0.5-8.6 mm), 5.1 (1-8.2), 2.2 (0.1-4.0),1.7 (0-3.3) and 0.6 (0-1.4) mm of excess cement travelling beyond the abutment margins respectively. The **0.5 mm subgingival margin trials** under the 5,4,2 and 0.5 Kg pressure conditions had an average cement travel beyond the margins of 2.7 mm (0-7.0), 2.6 mm (0-11), 0.4 mm (0-2) and 0.2 mm (0-1.2) mm, respectively. The 1 Kg condition had no cement past its 0.5 mm subgingival margins.
CMS 0.5 mm subgingival margins had smaller extensions of excess cement going past their margins than the 1 mm subgingival margins under different pressure conditions. (Tables 1-6 B vs L) (Table 13) and (Figures 11,12)

RMS Conditions: The 1 mm subgingival trials under the high -pressure conditions, 5 Kg and 4 Kg respectively, had some submarginal cement travel that averaged 1.1 mm (0-7.6) and 0.6mm (0-1.0) respectively. **The low-pressure trials, 2 Kg, 1 Kg and 0.5 KG had no submarginal cement.** None of the 0.5 mm subgingival trials had any submarginal cement under any of the pressure conditions tested.

		1.0 mm		0.5 mm	
Pressure	Margin	Average	Range	Average	Range
5 Kg	CM	5.8	0.5 - 8.6	2.7	0 - 7.0
	RM	1.1	0 - 7.6	0	0
4 Kg	CM	5.1	1 - 8.2	2.6	0 - 11.5
	RM	0.6	0 - 1.0	0	0
2 Kg	CM	2.2	0.1 - 4.0	0.4	0 - 2.0
	RM	0	0	0	0
1 Kg	CM	1.7	0 - 3.3	0.0	0
	RM	0	0	0	0
0.5 Kg	CM	0.6	0 - 1.4	0.2	0 - 1.2
	RM	0	0	0	0

Table 13: Displays average and range of submarginal cement travel according to cementation system and subgingival margin depth.

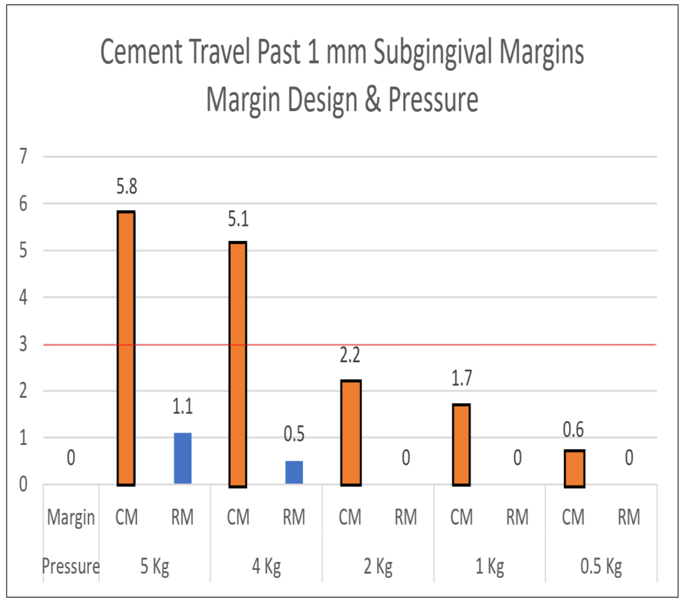

Figure 11: Compares submarginal cement (mm) according to systems and 1 mm margin depth under decreasing installation pressures. Red line aligns with Figure 12.

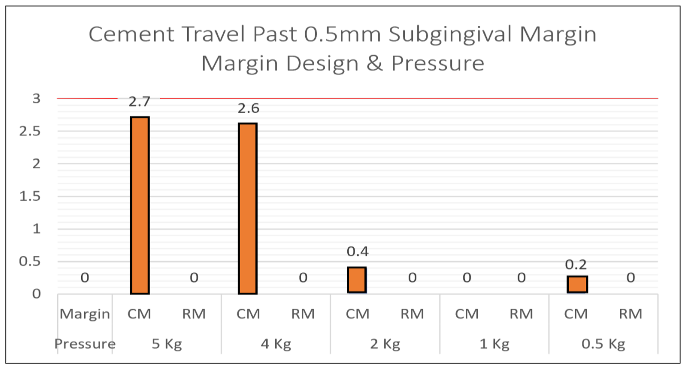

Figure 12: Compares submarginal cement (mm) according to systems and 1 mm margin depth under decreasing installation pressures. Red line aligns with Figure 11.

Summary 3: For both the CMS and RMS, reducing margin depth reduced the incidence and extent of excess cement breaching their abutment margins. Unlike the CMS, even the RMS 1 mm subgingival margins were free of submarginal cement when low-pressure cementation 2 Kg or less was used to seat their crowns.

4) Margin Depth and Open Margins

CMS Conditions: The 5,4,2,1 and 0.5 Kg **1 mm subgingival margin conditions** had open margins that averaged 0.2 mm (0.1-0.3), 0.2 mm (0-0.6), 0.1 mm (0-0.3), 0.5 mm (0-1.0) and 0.4 mm (0.1-0.7). The 5,4,2,1 and 0.5 Kg. The **0.5 mm subgingival margin conditions** had open margins that averaged 0.1 mm (0-03), 0.1 mm (0-0.3), 0.1 mm (0-0.1), 0.2 mm (0-0.5) and 0.2 mm (0-0.4) respectively. **(Tables 7-12 B vs L, Table 14, Figure 13)**

There were differences (p=0.05) between the 1 mm submarginal trials. 5 Kg was different from 1 Kg and 0.5 KG. 4 Kg was different from 0.5 KG and 2 Kg was different from 1 Kg and 0.5 Kg. In the 0.5 mm submarginal margin groups, 5,4

	1mm		0.5mm	
Pressure	Average	Range	Average	Range
5 Kg	0.2	0.1-0.3	0.1	0 - 0.3
4 Kg	0.2	0-0.6	0.1	0 - 0.3
2 Kg	0.1	0-0.3	0.1	0 - 0.1
1 Kg	0.5	0-1.0	0.2	0 - 0.5
0.5 Kg	0.4	0.1-0.7	0.2	0 - 0.4

Table 14: Displays average and range of open margins according to subgingival margin depth.

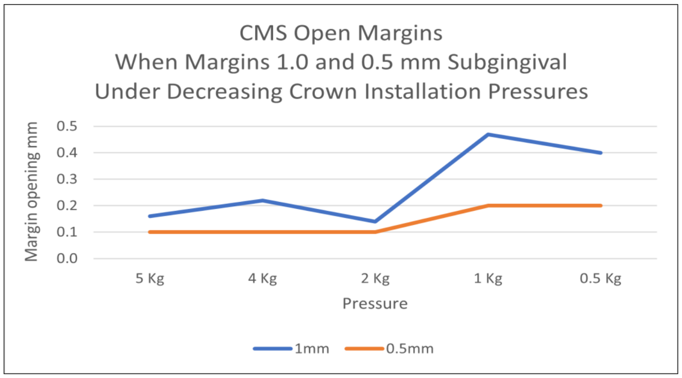

Figure 13: Compares open margins according to subgingival margin depth under decreasing installation pressures.

and 2 Kg groups were different from 0.5 Kg groups. 2 Kg was different from 1 Kg. The CMS demonstrated a trend to larger open margins with deeper subgingival margins and lower installation pressure.

Summary 4: The CMS had larger open margins when margins were deeper under all pressure conditions. The RMS had no open margins under any pressure conditions.

Discussion

There appears to be much in the literature noting the common non-ideal results of prosthesis installation, like misfit implant-abutment and abutment-prosthetic connector connections, poor access to maintenance, residual subgingival cement and open prosthesis margins. (1,8,14,15) However, there is little or no discussion about the possible root causes of these problems nor any effective solutions.

The literature appears to offer little more than a choice between two flawed installation systems that are known to expose patients to risk factors for complications. (5) **"Will that be the screw-in system with its misfit parts, cantilevered prostheses and poor access to care, or will that be the cement-in system with its subgingival cement and open margins?"**

There are attempts to rationalize misfit problems as "not so bad" (14,15) and the subgingival cement problems as "really bad". (2,7,8) However, multiple literature reviews conclude that both current installation systems are known to cause patients to suffer a similar and troubling prevalence of peri-implant disease and implant failure. (9,10) Some dentists may like to argue that these problems are inevitable and considered normal consequences of treatment that must be born by the patient. **The authors of this article respectfully disagree.**

It continues to be difficult to discuss solutions involving intra-oral cementation without referring to the **widespread misconception about the safety of the screw-in system of prosthesis installation**. (2,7) The study by Derks et al., 2016 (9) has shown prostheses retained by 4 or more implants have 15 times the rate of peri-implantitis than cases retained by fewer implants. What about the review by Lee et al, (2017) that indicates 81% of implant patients can expect to suffer implant loss or some form of peri-implant disease? (10) These studies implore us to improve treatment results.

The current screw-in system does not currently have an intra-oral cementation step, as abutments and prosthetic connectors are attached to the prosthesis in the dental laboratory. This extra-oral attachment step contributes to misfit implant parts in the mouth. (4) Imagine connecting high-precision implant parts to an inaccurate prosthesis made to fit an inaccurate dental model. The inaccuracy of this extra-oral system has been validated many times in the literature (14,15) and recently in a webinar by Henrik Andersen PhD, at ELOS MedTech. He has itemized the many error components involved in the making of a prosthesis, and concludes "Intra-oral cementation can be used to compensate for these errors". (16) In other words, intra-oral cementation can be used to help compensate for **Prosthesis Dimensional Error (PDE) and thus prevent misfit implant parts in the mouth.** (18) However, Dr. Andersen has not revealed a system of intra-oral cementation that can accomplish this task without exposing the patient to subgingival cement and/or open margins. **Extrapolated from the study of Wilson (2009),** residual subgingival cement alone may be responsible for 60% of the peri-implant disease experienced by patients with cemented crowns. (8)

From Wilson's Study, to estimate the proportion of peri-implant disease that can be attributed to subgingival cement, we must assume that the fit of the implant-abutment joints was optimized before the crowns were installed. . Unlike the screw-in system of installation, dentists with a reasonable level of knowledge and skill can optimize the implant-abutment connection before installing crowns by the cement-in system. (18) Thus, extrapolating from the results of Wilson, preventing residual subgingival cement could be expected to reduce complications by 60%. This reduction in the prevalence of peri-implant disease would usher in a new and much better standard of care for patients.

Knowing about the root causes of complications can give clinicians predictable ways to protect patients from related risk factors. Indeed, Dr. Svoboda has provided ample evidence for their existence and developed new dental terminology to facilitate their discussion. (12) He has also developed an installation system that was specifically designed to mitigate their negative effects. He calls it the **Reverse Margin System (RMS)**. The results of this experiment and many others continue to confirm their effects and support the development of research projects that may improve treatment outcomes. (17)

The focus of this research report is to compare the efficacy of the newer **Reverse Margin System (RMS)** to the common **Chamfer Margin System (CMS) in preventing subgingival cement and open margins.** These systems were tested under various conditions relevant to intra-oral prosthesis installation, namely Pressure and Subgingival Margin Depth.

1) Installation Pressure and Subgingival Cement

It is still common to use relatively high cementation pressure to seat a prosthesis in the mouth. These forces appear to vary greatly from about 4 Kg of finger pressure to 60 Kgs of force transferred to the prosthesis by the patient's bite. These forces were intended to help drive the prosthesis into place onto its retainers. (20-22) Using a 40 Ncm finger pressure to seat a crown is similar to pressing it into place with a 4 Kg weight. This was the average force exerted by multiple dentists asked to cement a single crown in vitro. (23) This reflects what many dentists were trained to do in dental school for use in clinical practice.

Intra-oral cementation attempts to overcome all resistance to optimal seating of the prosthesis by force. It attempts to overcome the resistance offered by contact with adjacent gingiva and teeth, and the ejection of excess cement from between the retainer and crown margins. It appears that little consideration was given to the effect of pressure on the prevalence of residual subgingival cement and open margins.

This experiment shows that higher cementation pressure caused more frequent breaches of the abutment margin by excess cement and its deeper injection into the tissue spaces. These results are consistent with previous reports. (17) While some RMS trials had excess cement breach its margins, the average cement travel past the CMS margins was consistently much higher. Indeed at the average pressure of installation of 4 Kg, the average extension of cement travel past the abutment margins was 40 times higher for the CMS as compared to the RMS. At lower pressures like 2 Kg and less, unlike the CMS, the RMS showed no cement breach of their abutment margins.

It may be difficult for dentists to measure exact cementation pressure while installing a prosthesis in the mouth. The authors found that using lighter forces, like 2 Kg or less can be more controlled and comfortable than exerting higher forces like 4 or 5 Kg. Indeed, the higher finger pressures were noticeably more difficult to control in this simple in vitro experiment.

Delivering high installation pressure to a prosthesis in a complex environment like the mouth can be even more challenging. In the mouth, the dentist's vision may be further obscured by adjacent teeth, gingiva, and the dentist's fingers. Among other things, even with a well-designed system like the RMS, poor control of the trajectory of a crown during its installation can inadvertently stimulate the Gingival Effects and cause the occurrence of subgingival cement. (26)

There are reports of residual subgingival cement even when margins were deemed equigingival. (27,28) According to the research of Dr. Svoboda, this may be another consequence of the Gingival Effects. Under high pressure, the movement of the prosthesis towards the underlying and adjacent gingiva can rapidly constrict the space between their opposing surfaces. This constriction of space can prevent the excess cement already between these two surfaces from exiting fast enough to accommodate the increasing volume of excess cement still being expressed from the prosthesis margins. This could cause the excess cement to pressurize and be injected into the adjacent subgingival spaces. (17)

Another factor that could account for this observation in vivo involves some error in accurately describing margin position. Margins deemed equigingival in vivo, may vary from slightly above to below the gingiva along its perimeter. Any contact of the prosthesis with adjacent or underlying tissue during installation can also stimulate the Gingival Effects and cause excess cement to travel deep into the subgingival tissue spaces. (17,28-30)

The RMS was much more effective at reducing the extent of cement extension into adjacent tissue spaces than the CMS under all conditions tested. The further the excess cement travels into the tissue spaces, the more difficult can be to locate and clean away. (6)

Unlike the CMS, the RMS was able to eliminate submarginal cement when crowns were cemented at a 2 Kg pressure or less. This appears to have great clinical significance, as residual excess cement is a common risk factor for peri-implant disease. (8)

2) Installation Pressure and Open Margins

The CMS resulted in 100% of its margins being open regardless of installation pressure. However, there was a trend to an increasing size of open margins with decreasing installation forces. This result was consistent with an earlier study comparing a stock abutment-crown CMS with an RMS. Unlike the RMS, 100% of the stock abutment-crown system complexes had open margins. The stock abutments had small chamfer margins around their perimeter that were symmetrical. The emergence profile of the molar crown from the abutment was rather abrupt. It was suggested that it might have been the Tissue Effect called Resistance to Displacement Effect (RTDE) caused by adjacent simulated gingiva that prevented the crowns from seating. (30) Again, the RMS crowns in this article did not interact with adjacent gingiva and did not have any open margins.

Unlike the RMS, the CMS and like systems are designed to have prosthesis margins in direct contact with retainer margins when installed. This design might have been developed to compensate for the low compressive strength and the high solubility characteristics of older types of cement. The small cement space might have been created to ensure that some of the intaglii of the prosthesis would contact the retainer and margin surfaces to reduce the compressive load on the cement.

As well, a reduced cement space at the margins may have been desired to reduce the size of cement voids when soluble cement was dissolved by oral fluids.

According to these results, higher cementation forces appear to have some efficacy at reducing the size of, but not eliminating, open margins. Is the RTDE exerted by adjacent tissues a primary cause of open margins? We will explore that possibility below.

The CMS has a small 45-micron cement space that diminishes to zero at the crown margins. This type of configuration may impede the expulsion of excess cement from the intaglio of the crown and thus keep the margins from seating. (24) Indeed, even the particle size of the cement may keep the margins from contacting, once the crown is seated. This small cement space feature is in common use today for systems that include the feather, butt and like margin variations.

In this study, **the installation of CMS crowns in the absence of adjacent or underlying gingiva and with or without resin cement did not result in any visible cement space at the margins**. The optical resolution of this experimental system was probably insufficient to detect open margins in the microscopic realm. Despite this limitation, it was able to detect open margins in all the CMS groups and a trend to larger vertical margin separations with lower installation pressures.

Today, with resin-based cement, there may be less concern over low compressive strength and cement washout. However, rough cement lines sticking out from between or under margins or residing within cement voids between margins could still expose adjacent tissues to conditions similar to residual subgingival cement. All these conditions could allow the attachment and growth of oral pathogens that could foster the development of peri-implant disease.

Open margins may also be visible on dental x-ray images. This may not be good for patients or dentists that depend on patient referrals from colleagues.

In this experiment, the crowns were taken out of contact with adjacent teeth to eliminate their impact on the lateral alignment of the installed crown. In a previous study, illustrations were used to demonstrate how the CMS design, with its contacting margins and small cement space, can make it particularly intolerant of PDE. A tight contact with an adjacent tooth could cause the CMS crown to shift laterally along the abutment margins and retaining element incline planes, and thus cause open and overhanging margins. (17) This would expose the patient to the risk of related biological complications.

None of the RMS trials had any open margins under any of the installation pressures tested. The RMS for single crowns uses a larger 80-micron cement space, that does not pinch off at the prosthesis margins, but is continuous between the abutment and crown interface. This larger cement space configuration appears to offer much less resistance to the outflow of excess cement from the crown during installation.

Also, unlike the CMS with its touching abutment-crown margins, the RMS cement space feature and abutment margin configuration can compensate somewhat for crown rotational and alignment error, without causing open and overhanging margins. It is possible to safely increase this cement space when there is an anticipated need. (17,20,26,31)

A larger multiunit prosthesis can be expected to need larger cement spaces to tolerate a larger PDE than would be anticipated for a single crown. Perhaps a 120-micron cement space for a 3 unit bridge and a 150-micron cement space for an all-on-x type prosthesis might be a good starting point. Indeed, an 80-micron cement space gives the RMS crown a tolerance of 80 microns before its contact with the inner surface of the abutment margin or vertical retaining element could affect the quality of its seating. Thus the RMS can prevent open and overhanging margins. (17)

This tolerance of expected PDE without causing poor margins is a unique and important feature of the RMS that makes this design suitable for safer prosthesis installation.

3) Margin Depth and Subgingival Cement

It can be difficult for the clinician to control the exact relationship of crown margins to adjacent gingiva when restoring dental implants. This uncertainty may be affected by the limitations of current digital design programs, the difference in the shape of the trans-tissue portal relative to the shape of the final abutment-prosthesis complex, and differences in healing and maintenance characteristics of adjacent gingiva. For example, thicker gingiva may be more stable than thinner gingiva when interacting with an implant-prosthesis complex.

When a healing abutment perimeter is smaller than that of a final abutment-crown complex, the complex will need to displace adjacent gingiva laterally during its installation. This lateral movement can stretch the trans-tissue portal opening and cause the gingival margin to move laterally and towards its hard tissue tether, like the underlying periosteum and bone. It appears to be easier to predict the abutment margin-gingival margin relationship if the healing abutment used to shape the trans-tissue portal has a similar shape to the intended final abutment-prosthesis complex. (17,31)

In this experiment, the position of the CMS and RMS abutment margins below the simulated gingiva in the Lingual and Buccal locations were controlled and confirmed at 1/2 mm and 1 mm subgingival respectively. In the clinical situation, this amount of margin position control may be difficult to achieve. Indeed, it may be difficult to manage margin position to adjacent gingiva more accurately than about ±0.5 mm. (clinical experience)

The CMS 0.5 mm subgingival margins had less cement going past their margins than their 1 mm subgingival margin counterparts under different pressure conditions. (Figure 10,11) This is likely the result of the Gingival Effects.

Deeper margins can trap greater volumes of excess cement in the subgingival environment during crown installation. Crown movement towards the abutment during installation, can thus pressurize and propel more cement deeper into the submarginal tissue environment. (29) **Lower cementation forces did not propel excess cement as deeply into the tissue spaces as higher pressures.** These results are consistent with previous studies where crowns were cemented onto chamfer margins in vitro (17, 27), and in other studies in vivo. (28)

None of the RMS 0.5 mm subgingival margins had any cement breach its margins at any pressure, and at 2Kg or less pressure, even the 1 mm margin had no evidence of submarginal cement. The higher cementation pressures did cause some excess cement to breach the abutment margins. This may be a result of poor angular control of the crown during the cementation process whereby the Gingival Effects were inadvertently stimulated. There appears to be considerably more control of the cementation process during low-pressure conditions of 2 Kg or less.

The RMS consistently outperformed the CMS in reducing the average depth of excess cement breach of the abutment margin, even under the 1 mm deep margin and high-pressure conditions. **Unlike the CMS, the RMS was able to prevent the occurrence of subgingival cement at 2 Kg or less cementation pressure when margins were placed up to 1 mm subgingival.**

This may have several positive clinical implications, as the RMS was able to prevent the occurrence and extension of subgingival cement at low pressure. Deeper subgingival cement extensions common to the CMS, are reported to be more difficult to locate and clean away. (6,27)

4) Margin Depth and Open Margins

In trials using the CMS, increasing margin depth increased the size of open margins, while increasing installation pressure decreased them. Even 0.5 mm subgingival margins caused open margins. Controls without gingiva, and with and without cement had no open margins. It appears that the Resistance to Displacement Effect (RTDE) by adjacent gingiva increased with increasing margin depth and thereby prevented crowns from seating optimally. This was expressed as larger open margins with deeper margins and reduced installation pressure. (30)

RMS abutments are designed to push adjacent gingiva laterally, away from the base of the crown. In addition, to further ensure space between the crown exterior surface and gingiva, the RMS crowns have a concave shape adjacent to the gingiva. This keeps the adjacent tissue from touching the gingiva and creates space for the outflow of excess cement. (17) These complimentary design features are capable of preventing both of the Tissue Effects, namely the Gingival Effects causing subgingival cement, and the RTDE causing open margins.

Thus, unlike the CMS, the RMS crowns did not interact with adjacent gingiva and did not show any evidence of open margins. These results are consistent with a previous similar experiment, where the cementation of crowns onto stock abutments was compared to those cemented onto RMS abutments. All stock abutment trials had both abundant subgingival cement and open margins, while the RMS crowns had none. Indeed, it was this experiment that inspired Dr. Svoboda to name this Resistance to Displacement Effect. (30)

It appears that the RTDE by adjacent gingiva was primarily responsible for the open margins observed when cementing the CMS crowns. The RMS crowns did not interact with adjacent gingiva and consistently prevented open margins under all installation pressures tested.

Dr. Svoboda has named and described the root causes of complications as Prosthesis Dimensional Error (PDE) and the Tissue Effects. The two named Tissue Effects are the Gingival Effects (GE) and the Resistance to Displacement Effects RTDE). (12) These experimental results and many others are consistent with those concepts.

Unlike the screw-in system of prosthesis installation, an installation by intra-oral cementation provides dentists with a means of optimizing the fit of implant parts, like the implant to abutment and abutment to prosthetic connector joints. (18) Unlike the CMS, the RMS can also prevent submarginal cement, open margins and more. (20) By preventing several risk factors for mechanical and related biological complications, the RMS appears to have great clinical relevance. It promises to be key in the development of a new and better standard of care for patients. (19)

Conclusions

1) The RMS consistently outperformed the CMS in preventing subgingival cement and open margins. Unlike the CMS, both these complications were eliminated by the RMS when crowns were cemented at low pressure, 2Kg or less. **Thus, the RMS offers clinicians a means of protecting patients from these common risk factors for peri-implant disease.**

2) At installation pressures commonly used for crown installation, all the CMS trials had both submarginal cement and open margins. Reducing pressure reduced submarginal cement but increased open margins. Increasing margin depth also increased submarginal cement and open margins. **Unlike the RMS, the CMS does not seem to be well-designed for safer low-pressure cementation.**

3) CMS crowns with subgingival margins are designed to displace adjacent gingiva during their installation. Deeper margins caused increased interaction with adjacent gingiva, more submarginal cement and larger open margins. Increased interaction with adjacent tissues appears to cause an increased amount of submarginal cement and increased separation of open margins. **These results demonstrate the problematic effect of adjacent gingiva on submarginal cement and open margins.** Both are recognized as longstanding risk factors for dental disease. Unlike the CMS, the RMS was de-

signed to eliminate or minimize crown interaction with adjacent gingiva and was successful in eliminating both submarginal cement and open margins, even under lower pressure installation conditions.

4) These results are consistent with Dr. Svoboda's proposed root causes of complications, namely the Gingival Effects causing subgingival cement and the Resistance to Displacement Effects causing open margins. **The RMS demonstrated its efficacy in mitigating both these Tissue Effects.**

5) Unlike the prevalent screw-in system of prosthesis installation, dentists now know that **the RMS of installation can consistently prevent several risk factors for peri-implant disease**, including misfit implant-abutment joints, subgingival cement, and open margins.

6) **More clinical studies are warranted to demonstrate the efficacy of the RMS in making dental treatment better.**

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