Improving the Fit of Implant-Supported Superstructures Using the Spark Erosion Technique

Eduard Eisenmann, Dr Med Dent[1]/Ali Mokabberi, Dr Med Dent[2]/
Michael H. Walter, Dr Med Dent[3]/Wolfgang B. Freesmeyer, Dr Med Dent[4]

Purpose: *The purpose of this study was to determine whether the passive fit of the implant-retained single-cast framework could be improved by spark erosion treatment.* ***Materials and Methods:*** *An initial cast was produced in a transparent resin material. Five Brånemark System implants were arranged in the interforaminal region, and abutments were placed on them with a torque of 20 Ncm. An impression was made using a standard impression technique described by Brånemark. A corresponding master cast suitable for the spark erosion post-framework fabrication was produced. From this master cast, 12 frameworks were produced in a conventional single-cast procedure. Six of these were made of a high-gold alloy (Stabilor G); the other 6 were made of pure titanium (Biotan). These frameworks were then refined using the SAE Secotec Spark Erosion System. To measure the accuracy of the framework fit, the frameworks were measured before and after the spark erosion treatment using 2 different measurement methods—scanning electron microscopy to measure the gap widths (Sheffield test) and photoelastic stress analysis.* ***Results:*** *The results of both measurement techniques correlated and demonstrated significant improvement in the accuracy of fit or in the passive fit for all 12 frameworks after spark erosion treatment. This improvement was statistically significant for the titanium frameworks.* ***Discussion:*** *Dental practitioners and technicians should strive to achieve a precise passive fit of frameworks and superstructures to minimize additional stress at the interfaces of the prosthesis, abutment, and implant.* ***Conclusion:*** *The clinical use of the spark erosion technique to refine framework fit is recommended.* (More than 50 references.) INT J ORAL MAXILLOFAC IMPLANTS 2004;19:810–818

Key words: *implant-supported superstructures, passive fit, spark erosion technique*

The production of full-arch frameworks supported by osseointegrated implants constitutes a formidable challenge for dental technology. A very important objective is to achieve a passive fit of the framework to prevent biologic or technical failure. If full-arch or segmental frameworks do not fit correctly, loading may result in mechanical complications such as screw loosening or fracture of the individual components.[1–7] Biologic complications, such as soft tissue irritation, pain, stress, marginal bone loss, or loss of osseointegration, may also occur.[2,5,8–12]

Numerous scientific studies have cited the passive fit of a framework as an important prerequisite for the long-term osseointegration of implants.[13–22] Many methods for evaluating casting accuracy and framework fit before delivery have been suggested.[18,23,24] Cast superstructures can be disassembled and resoldered or rewelded if necessary, although this may result in new errors of fit. Stress generated by the firing cycle used for ceramic veneers also has the potential to compromise fit.[25]

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[1] Assistant Professor and Clinical Lecturer, Charité—Universitätsmedizin Berlin, Campus Benjamin Franklin, Department of Restorative Dentistry, Prosthetic Dentistry, Berlin, Germany; Private Practice in Implant Prosthetics, Mannheim, Germany.
[2] Private Practice, Berlin, Germany.
[3] Professor and Head, Department of Prosthetic Dentistry, University Hospital Carl Gustav Carus, Dresden University of Technology, Dresden, Germany.
[4] Professor and Head, Charité—Universitätsmedizin, Campus Benjamin Franklin, Department of Restorative Dentistry, Prosthetic Dentistry, Berlin, Germany.

Correspondence to: Prof Dr Wolfgang B. Freesmeyer, Clinic and Policlinic of Dentistry and Oral and Maxillofacial Surgery, Department of Restorative Dentistry, Prosthodontics, Assmannshauser Strasse 4-6, 14197 Berlin, Germany. Fax: + 49 30 8445 6238
E-mail: wolfgang.freesmeyer@medizin.fu-berlin.de

Producing passively fitting 1-piece frameworks for several implants may cause complications. The foundation of such a framework lacks forgiveness, since there is no periodontal ligament and the implants are essentially immobile.[26–28] Nonetheless, a number of authors consider 1-piece casting the technique of choice because it results in frameworks that are very stable and homogenous.[29,30]

Rübeling[31] described a procedure for improving the fit of single-cast frameworks using the SAE Secotec Spark Erosion System (SAE Dental, Bremerhaven, Germany). This procedure was examined in the present study using scanning electron microscopy (SEM) and photoelastic stress assessment to determine whether measured improvement can be demonstrated.

MATERIALS AND METHODS

An initial cast was produced in a transparent polycarbonate resin (PSM1; Vishay, Malvern, PA) with 5 Brånemark System implants (13 mm long and 3.75 mm wide; Nobel Biocare, Göteborg, Sweden) arranged in the interforaminal region. A 4-mm abutment was secured to each implant with a torque of 20 Ncm.

Subsequently, an elastomeric impression (Impregum; 3M Espe, St Paul, MN) was made with cylindric tapered impression copings placed on the initial model. The impression copings were then removed from the model, placed on the model analogs, and repositioned inside the impression. Subsequently, the diagnostic cast was produced. The square impression copings were then placed on the diagnostic cast and secured with long guide pins using a torque controller at 10 Ncm. The square impression copings were splinted with autopolymerizing pattern resin and left to set for 24 hours.

To control polymerization shrinkage, the resin connections between the square impression copings were vertically separated with using disks (Horico; Hopf, Ringleb, Berlin, Germany), yielding gaps between the impression copings that were less than 1 mm wide. The square impression copings with the resin were seated separately on the initial cast and reconnected using the pattern resin. The guide screws were tightened to 10 Ncm using the torque controller.

Finally, an impression was made with Impregum using the pick-up technique typically used for the Brånemark System. A corresponding master cast suitable for the spark erosion treatment was produced in stone (SAE-Special Die Stone, SAE Dental). From this master cast, 12 frameworks were cast in a conventional single-cast procedure as described by White.[30] Six of these were made of a gold alloy (Stabilor G; Dentsply/DeguDent, Hanau, Germany); the other 6 were cast in pure titanium (Biotan; Schutz Dental Group, Rosbach, Germany).

Two different methods of measurement were used in this study to determine passive fit—SEM measurement (Sheffield test) and photoelastic stress analysis using monochromatic light.

To examine the fit of a framework, the Sheffield test employs a single gold screw. It must be possible to completely tighten this single screw on a distal model abutment without creating a gap between the other abutment–gold cylinder interfaces. If the superstructure remains in place on the abutments medial to the tightened screw and on the screws on the opposite of the framework, the superstructure is said to have an acceptable passive fit. If the fit is not stress-free, the superstructure will be lifted when a screw is tightened, creating a gap.[12,18,28,30] (This is a clinical statement only. The test provides limited assessment in a single plane, but it is commonly used in clinical practice.)

Photoelastic stress analysis is a modeling method that uses the optical effect of double refraction of mechanically or thermally loaded transparent resins for analyzing stress. It is generally used to optically determine mechanical stress and, by implication, the accuracy of the fit.[32] Depending on the stress patterns inside the model, fringe lines are created by superimposing the partial rays that are aligned relative to each other, allowing the stress to be measured.

The fit of all 12 frameworks was then measured by SEM using a Cambridge Stereoscan 150 MK 2 (Cambridge, England) both before and after the spark erosion treatment using the Sheffield test. All measurements were made at a magnification of 200× at 8 predefined measuring points per implant (4 buccal, 4 lingual) without tilting the casts. Photoelastic stress analysis was also performed before and after spark erosion treatment after the framework was incrementally screwed to the model.

After spark erosion, the corresponding SEM measurements and the photoelastic images were assessed and compared to the frameworks' "as cast" condition. For statistical analysis of the SEM measurements, the test was used and based on the assumption that the calculated values were distributed normally. Comparisons between the conditions of the casts before and after spark erosion treatment were made both between the 2 groups (ie, gold alloy and titanium) and within the groups. For statistical analysis of the photoelastic results, the Mann-Whitney *U* test was used based on the assumption that these calculated values do not have a normal distribution. Analysis

Table 1 Mean Gap Widths (µm) Between Abutments and All Gold and Titanium Frameworks Before Spark Erosion Treatment

	Implant					
	1 (w/screw)	2	3	4	5	Mean
Gold alloy						
A	6.5	12.0	16.4	12.0	14.4	12.3
B	6.0	11.4	16.4	14.4	15.5	12.7
C	4.1	9.4	10.5	11.4	14.1	9.9
D	6.1	15.1	13.6	13.1	9.5	11.5
E	9.6	16.0	13.4	9.1	5.0	10.6
F	6.2	24.4	29.4	25.0	11.9	19.3
Titanium						
A	7.2	30.6	33.1	34.1	26.3	26.2
B	3.8	16.3	36.3	24.4	8.1	17.7
C	2.8	42.8	70.0	87.5	45.0	49.6
D	20.9	53.1	89.7	39.4	10.3	42.7
E	4.7	20.3	22.9	35.9	20.0	20.7
F	6.9	61.3	52.5	35.9	7.8	32.9

Figures shown are the means of the measurements at each of the 8 measurement points.

was performed as for the SEM measurements, ie, by comparing the individual frameworks within each group and by comparing the framework groups before and after spark erosion treatment. For this study, $P < .05$ was considered significant and $P < .01$ was considered highly significant.

RESULTS

SEM

A total of 960 SEM measurements were made for the Sheffield test; 480 before spark erosion treatment and 480 afterward.

Before spark erosion treatment, the gap widths of the titanium frameworks ranged from 17.7 µm to 49.6 µm, while the gap widths of the cast gold frameworks ranged from 9.9 to 19.3 µm (means given; see Table 1). After spark erosion treatment, the gap widths of the titanium frameworks were between 4.3 and 10.3 µm; those for the gold frameworks were between 5.2 and 7.4 µm (Figs 1 and 2).

The mean gap measurements after spark erosion treatment were calculated in the same manner and may be seen in Table 2. The statistical assessment derived from the measurements noted in Tables 1 and 2 is shown in Fig 3.

In the gold framework group, the gap width was noticeably smaller after spark erosion treatment; however, statistical analysis showed that the difference was not statistically significant ($P = .15$). In the titanium framework group, gap widths were considerably smaller following spark erosion, and this improvement proved to be highly significant ($P = .008$).

Statistical analysis of both framework groups before spark erosion showed the gold framework gaps to be considerably smaller than the titanium framework gaps. This difference was significant before ($P = .01$) and after ($P = .035$) spark erosion treatment.

Photoelastic Stress Analysis

For photoelastic stress analysis, 288 photographic images were taken, 144 before spark erosion treatment and 144 afterward.

The highest stress, 6.38 N/mm^2, was found for a titanium framework, and the lowest, 2.42 N/mm^2, for a gold framework. After spark erosion treatment, however, a reduction in the induced stress was observed for both types of framework. This was typically true for both the gold frameworks (0.57 orders) and the titanium frameworks (1.25 orders). Photoelastic stress analysis results before and after spark erosion treatment are shown in Table 3 and Fig 4.

The stress measured in gold frameworks significantly decreased after spark erosion treatment ($P = .001$).

A decrease in stress after spark erosion treatment was also found with titanium frameworks and was shown to be highly significant ($P = .003$).

Comparison of the 2 framework groups showed that the stress measurements for gold frameworks

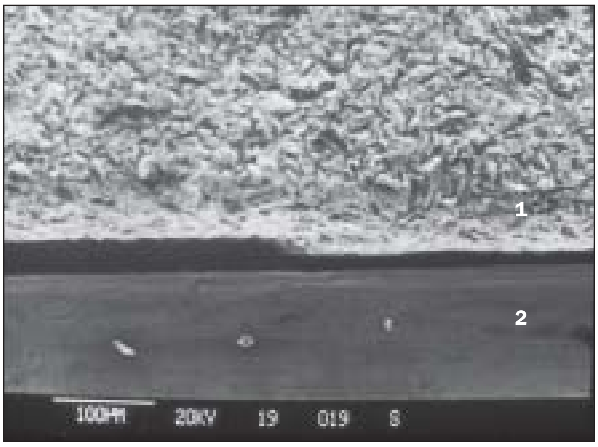

Fig 1a SEM measurement of the gap vertical axis widths using the Sheffield "one screw" test at a magnification of 200× before spark erosion treatment (the irregularity of the framework seat is clearly visible). 1 = framework; 2 = abutment.

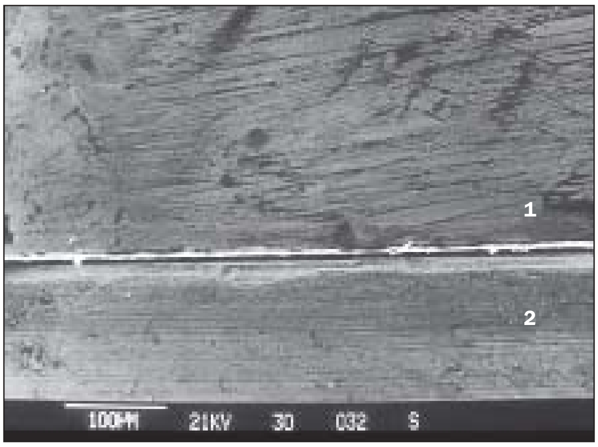

Fig 1b SEM measurement (same measuring point as Fig 1a) of the gap widths using the Sheffield "one screw" test at a magnification of 200× after spark erosion treatment. It can be clearly seen that the irregularity of the framework has disappeared. 1 = framework; 2 = abutment.

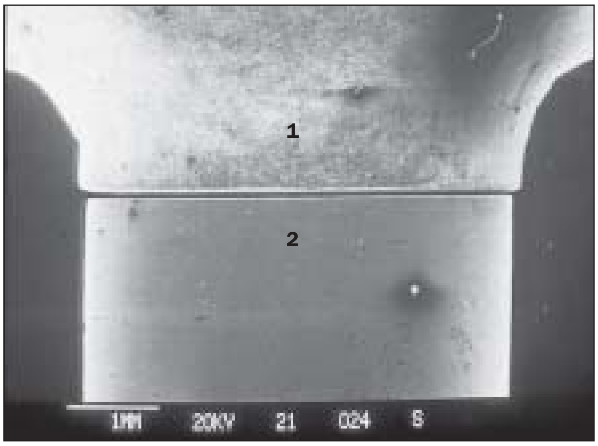

Fig 2a Sheffield test SEM image at ×20 magnification before spark erosion treatment (second abutment in the original model). A clear gap is visible between the framework and abutment. 1 = framework; 2 = abutment.

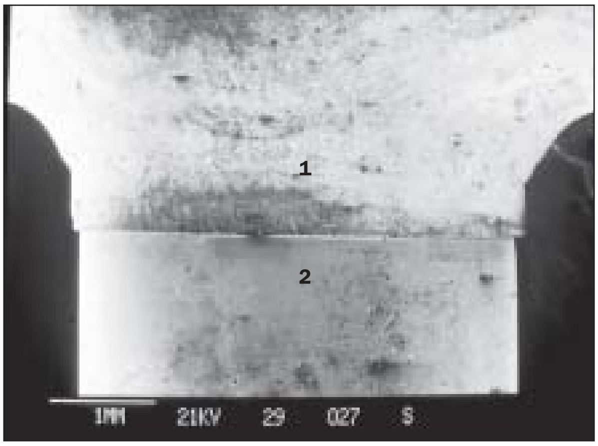

Fig 2b Scheffield SEM image at ×20 magnification, using the same framework and abutments as in Fig 2a, but after spark erosion treatment. The gap has disappeared, ie, metal-to-metal contact has been achieved without the gold screw being tightened. 1 = framework; 2 = abutment.

before spark erosion treatment were much smaller than those for titanium frameworks (*P* = .003). After spark erosion treatment, measured stresses in gold frameworks continued to be lower than measured stresses in titanium frameworks; however the difference was not statistically significant (*P* = .075).

The photoelastic stress images comparing the image of the unloaded initial cast with that of the screw-connected framework after spark erosion treatment, as shown in Fig 5, were similar to those of the initial cast without the framework in place (Fig 6). In Fig 7, which shows a typical initial case with the screw-connected framework before spark erosion treatment, clearly asymmetric lines are visible. Thus photoelastic stress analysis affirmed the benefits of correcting cast frameworks with spark erosion in regard to enhancing the interface fit.

The results of the both SEM measurements and photoelastic stress analysis showed that the measured gap widths were already very small (ie, within component machining tolerances) before spark erosion treatment. The fit of both gold and titanium frameworks was already good compared to data reported in clinical studies.[17]

DISCUSSION

When comparing the values for the titanium frameworks with those of the gold frameworks before

Table 2 Mean Gap Widths (µm) Between Abutments and All Gold and Titanium Frameworks After Spark Erosion Treatment

	Implant					
	1 (w/screw)	2	3	4	5	Mean
Gold alloy						
A	2.2	7.0	10.9	8.6	5.1	6.7
B	2.4	5.0	9.8	8.5	6.3	6.4
C	1.2	4.3	8.1	8.9	3.4	5.2
D	1.6	4.9	10.5	8.2	3.4	5.7
E	2.4	8.0	10.9	11.9	4.0	7.4
F	1.0	6.4	8.6	8.8	4.5	5.8
Titanium						
A	1.5	7.1	11.1	9.9	5.1	6.9
B	1.8	9.1	19.9	14.9	5.9	10.3
C	1.1	7.6	13.3	13.6	4.0	7.9
D	4.0	10.4	17.0	14.1	5.3	10.2
E	1.6	7.5	8.3	8.3	3.8	5.9
F	1.3	6.2	5.1	5.9	3.3	4.3

Figures shown are the means of the measurements at each of the 8 measurement points.

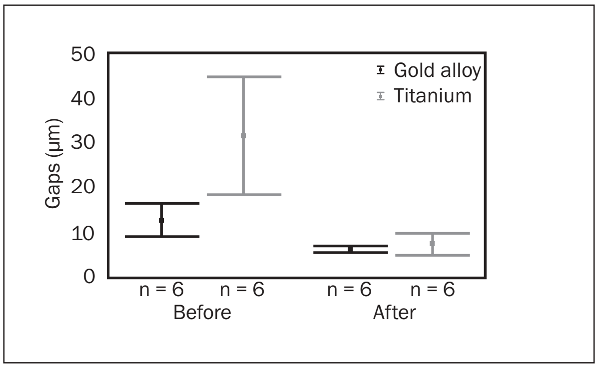

Fig 3 Gap widths before and after spark erosion treatment calculated using SEM. Brackets indicate 95% confidence intervals.

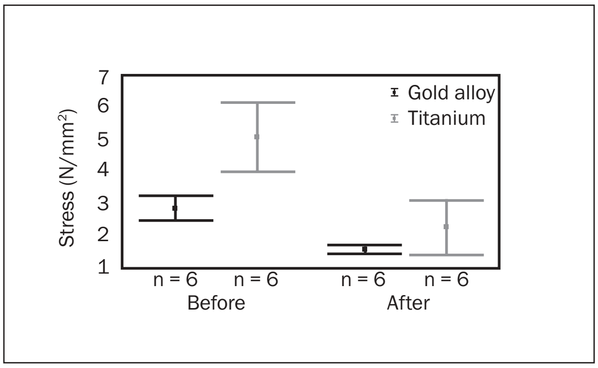

Fig 4 Photoelastic stress analysis results before and after spark erosion treatment.

Table 3 Photoelastic Stress Analysis Results Before and After Spark Erosion Treatment

	Stress (N/mm^2)		Stress reduction posttreatment (N/mm^2)
	Before	After	
Gold alloy			
A	2.86	1.76	1.10
B	2.86	1.76	1.10
C	2.42	1.54	0.88
D	2.86	1.54	1.32
E	2.86	1.76	1.10
F	3.52	1.54	1.98
Titanium			
A	4.40	1.76	2.64
B	4.40	2.86	1.54
C	6.16	2.64	3.52
D	6.38	3.52	2.86
E	3.96	1.76	2.20
F	5.28	1.54	3.74

spark erosion treatment, the differences were highly significant statistically, ie, the primary fit of the gold frameworks was better than that of the titanium frameworks. Looking at the measured mean gap widths after spark erosion treatment, an improved fit was found for both framework groups. The mean gap width was 6.20 µm for gold frameworks and 7.58 µm for titanium frameworks.

For titanium frameworks, the differences in fit before and after spark erosion treatment were highly significant. For the gold frameworks, there was also a marked improvement. After spark erosion treatment, the gap width values still tended to be more favorable for the gold frameworks than for the titanium frameworks. However, the difference between the 2 groups was no longer statistically significant.

According to Klineberg and Murray, frameworks with gap widths up to 30 µm across 90% of the

Fig 5 Initial cast with titanium framework after spark erosion treatment. All gold screws were screwed tight.

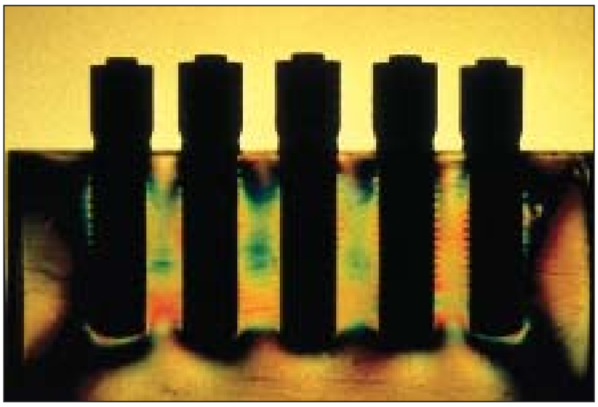

Fig 6 Initial cast made of transparent acrylic resin with 5 Brånemark System implants.

abutment cylinder area can be considered to have a good passive fit.[33]

Carr and associates, quoting Brånemark,[34] suggested that a gap width between abutment and superstructure of < 10 µm be considered to be a passive fit. If this precondition is met, bone remodeling relative to cellular turnover necessary to maintain osseointegration should not be adversely affected.

Statistical analysis of the SEM measurements showed that the fits of the gold frameworks in their original state, before spark erosion treatment, were acceptable according to the criteria of Klineberg and Murray, with a confidence interval between 9.16 and 16.27 µm. The titanium frameworks, by contrast, exhibited an acceptable fit only after spark erosion treatment, with a confidence interval between 5.08 and 10.08 µm.

The results of the photoelastic stress analysis also showed that the 6 gold frameworks already had an excellent fit in their as-cast state; the additional stress induced compared to the unloaded cast was minimal. The 6 titanium frameworks, on the other hand, exhibited a much less precise fit initially. The highest photoelastic stress (6.38 N/mm^2) was found in a cast titanium framework, and the lowest (2.42 N/mm^2) in a gold framework.

Figure 6, which shows a photoelastic stress image of the initial cast before spark erosion treatment and without screw-connected framework, shows that stress was induced before the implants were loaded. This induced stress is unavoidable, as the implants must be firmly anchored to their environment, resulting in forces that induce stress. However, this stress must be as evenly distributed as possible (ie, stress distribution should be as symmetric or homogenous as possible).

By connecting the frameworks to the implant abutments, additional asymmetric stress is induced. If the framework fit is not passive, the resulting stress is a considerable burden on the peri-implant bone.[2,5,17,23,35–41]

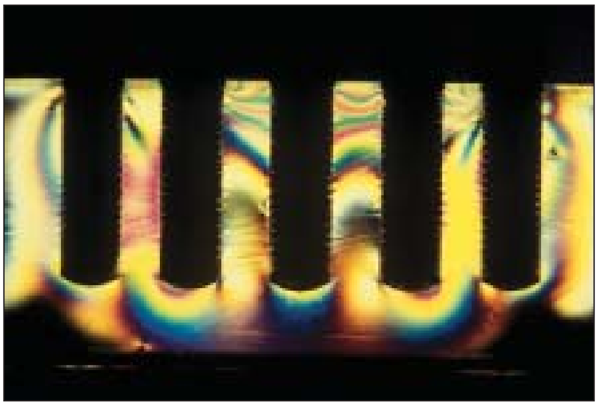

Fig 7 Similar initial cast from the preliminary study of transparent acrylic resin before spark erosion treatment with 5 Brånemark System implants and a framework (screwed-on), showing lack of passive fit. Compared with Fig 6, additional asymmetric stress "fringe" lines are clearly visible, caused by the screwed-in framework lacking passive fit.

The results of this study showed that, following spark erosion treatment, the fits of all frameworks were acceptable according to the Klineberg and Murray criteria.[33] Titanium and gold frameworks treated using the spark erosion technique were equivalent with regard to fit. The literature suggests that these frameworks satisfy the criteria for a passive fit. The clinical use of the spark erosion technique for the treatment of superstructures can therefore be recommended.

The spark erosion technique has the potential to improve framework fit. Complications that could result from poorly fitting frameworks are deformation, loosened gold screws, fractured gold screws, fractured abutment screws, fractured frameworks, microfractures of the peri-implant bones, or even loss of osseointegration.[6,12,15,19,42–45]

Numerous studies have described methods for improving framework fit. Jemt and associates[46] described a method in which a titanium superstructure is produced in 1 piece by a computerized numerically controlled milling machine. Other methods worth mentioning are the Cresco Ti precision technique[47] and the Procera technique.[48]

When discrepancies in fit are found and the restoration does not fit passively, it is currently still common practice to perform time-consuming procedures such as segmenting, indexing, and reconnection of the segments by laser welding or soldering. These techniques may, among other things, promote framework fractures and compromise the stability and homogeneity of the entire restoration.[18,24,46,49]

Applying ceramic veneer to a framework can result in distortion of a well-fitting framework. The studies mentioned[46–48] examined only the passive fit of the framework. Changes in framework fit after veneering were not assessed. The spark erosion technique can be used to correct framework fit after ceramic veneering, too.

Commercially pure titanium has been the material of choice for dental implants in the oral environment for many years. The biocompatibility argument requires that the frameworks supported by titanium implants also be made of commercially pure titanium, resulting in a monometallic restoration for the patient.[49–53] Since the titanium frameworks can achieve a passive fit using spark erosion treatment, monometallic implant-supported restorations with an acceptable fit can be produced.

Tan and colleagues,[23] discussing biocompatibility, reported that it is probable that the initial preload between the implant and the adjacent peri-implant bone is reduced by physiologic bone transformation. It is unknown, however, how long it takes until this transformation reduces the persistent stress.[23] Moreover, the elasticity of bone might also compensate for negative stress resulting from misfit. Stress in the bone is an important stimulus for bone apposition and bone resorption. This is why it is so important to be cognizant of this biologic aspect of implant restoration. Such cognizance will enable us to better understand the consequences of an ill-fitting framework being placed on implants.[2] Windhagen and Thorey also concluded that additional studies of the biomechanical reaction of the bone to different types of loading are required to better understand the biologic response to different levels of framework fit.[54]

As long as it remains unclear what bone biologic reaction to chronic loading will be and whether and how much bone resorption or bone apposition will occur, clinicians should strive to achieve a precise passive fit of the implant frameworks to minimize additional stress at the implant-bone interface.

CONCLUSION

The results of this study show that single-cast frameworks treated with the SAE Secotec Spark Erosion System exhibited gap width within the range considered acceptable for passively fitting frameworks. It was demonstrated that the spark erosion technique can result in noticeably greater precision in producing single-cast frameworks and in ensuring a passive fit of these frameworks for implant-supported restorations. This was demonstrated both by SEM and by photoelastic stress analysis. The SAE Secotec Spark Erosion System permits the refinement of metals in a manner largely independent of their physical properties. This allows the correction of errors in the fit of frameworks even after ceramic veneering.

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