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Scanning Electron Microscope Analysis of Cad/Cam Titanium Implant Abutments Versus Gold-Cast Ucla Abutments

Ali-Reza Ketabi[1*], Sandra Ketabi[1], B Helmstädter[2], Hans-Christoph Lauer[3] and Martin Brenner[1]

[1]*Private Dental Office, Epplestraße 29a, 70597 Stuttgart, Germany*
[2]*Dental Technician – Filder Zahntechnik Neuer Markt 570771, Leinfelden-Echterdingen, Germany*
[3]*Department of Prosthodontics, Hospital for Dental, Oral and Orthodontic Medicine, 70597 Stuttgart, Germany*

Abstract

Purpose: The objective of the study was to investigate one-piece CAD/CAM abutments made of titanium and gold-cast UCLA-type abutments for contamination, processing marks and microgaps via scanning electron microscope.

Material and Methods: Three groups with five identical abutments each were examined with a scanning electron microscope (LEO 1530 VP; Oberkochen, Germany) after cleaning using a steam jet and ethanol. Group 1 included custom CAD/CAM abutments (Atlantis™; Dentsply Implants, Mölndal, Sweden). Group 2 included UCLA-type cast bases prior to casting (Astra Tech Cast Design 4.5; Dentsply Implants). Group 3 included the identical cast bases with a cast-on abutment (gold alloy).

Results: Contaminants were found on all abutments of group 1, on 3 of 5 samples in group 2 and on 1 of 5 samples in group 3. Processing marks were visible on samples of groups 2 and 3. No microgaps were present in groups 1 and 2. For all group 3 cast-on abutments, large unfilled shrinking cavities with a horizontal extent between <10 and 221 µm and a vertical extent between <10 and 30 µm were found.

Conclusions: Both the contaminations and the microgaps of the casted two-piece abutments could be detrimental to the peri-implant hard and soft tissues. Further studies are needed in this regard.

Keywords: Cast abutment; Dental abutment; Scanning electron microscope; Contamination; Microgap

Introduction

The stability of peri-implant hard and soft tissues is crucial for the long-term functional and aesthetic success of implants and implant-supported restorations [1]. This stability is significantly influenced by a stable connection at the implant/abutment interface and the shape of the abutment [2]. The use of custom abutments allows for an optimized emergence profile and, hence, ideal support for the peri-implant soft tissue [3,4]. Furthermore, despite moderate cost, they can shorten treatment times [5-8] and simplify treatment protocols [9].

These custom one-piece abutments can be made from a variety of materials such as titanium, titanium nitride-coated titanium (Gold Hue) [10] or zirconia. Zirconia abutments are superior to titanium and Gold Hue abutments in terms of aesthetic parameters and are therefore widely used as an alternative in the anterior region [11]. Their use in the posterior region is currently controversial [12,13].

A well-tried alternative to individual CAD/CAM abutments are cast-on abutments (UCLA abutments). These consist of a cast base with a plastic cylinder which can be individualised by waxing up and casting of the abutment [14]. In this way, an anatomic contour and compensation of implant angulations can be achieved. However, disadvantages of cast abutments are that the required laboratory steps can possible cause implant/abutment misfit [15], the manufacturing process is more complex and time-consuming and the post-casting manipulation could produce inaccuracies [16]. For example, significantly reduced detorque values for abutment screws were reported for cast-on abutments compared to machined abutment [17], which lead to higher incidence rates of screw loosening [14].

Not only technical but also biological complications can result in implantological failures. One potential cause is microgaps at the implant/abutment interface of two-piece implant systems. These appear to play a crucial role in the bacterial colonization of the peri-implant sulcus [18,19], allowing penetration by acids, enzymes, bacteria and their metabolic products, which can cause inflammation, bleeding and swelling at the margin [20]. Moreover, the inflammation can induce peri-implant bone resorption [20-23].

Conical implant/abutment connections exhibit lower microgaps and less marginal bone resorption than non-conical ones [20]. However, gap formation is not limited to between the implant and the abutment. Retention surfaces for microorganisms are also conceivable on the abutment itself, especially with a two-part abutment.

Mehl et al. in an animal study on four mini-pigs compared custom titanium one-piece abutments with two-piece abutments with copings made titanium, zirconia or lithium disilicate, each attached to its titanium base (Conelog titanium base, Camlog Biotechnologies, Basel, Switzerland) with a plastic adhesive (Multilink Hybrid Abutment; Ivoclar Vivadent, Schaan. Liechtenstein). No influence of the abutments on peri-implant soft tissue anatomy or bone loss was determined, except for a longer junctional epithelium with one-piece titanium abutments compared to two-piece zirconia abutments [24]. However, the observation period was limited to 6 months after implant reentry [24], which meant that potential late effects of the two-part abutments could not be taken into account.

Unlike microgaps at the implant/abutment interface, retention

***Corresponding author:** Ali-Reza Ketabi, Private Dental Office, Epplestraße 29a, 70597 Stuttgart Germany, Tel: +49 711 6339697-0; Fax: +49 711 6339697-7; E-mail: ketabi@zahnarzt-stuttgart-dr-ketabi.de

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niches for micro-organisms on the surfaces of one-piece abutments and on the joints of two-part abutments have rarely been examined. Therefore, the aim of the present study was to examine, by scanning electron microscopic (SEM), the surfaces of custom one-piece titanium CAD/CAM abutments and of two-piece cast abutments. Furthermore, the abutments were examined for microcontamination as previously described by Canullo et al. [25,26], since these also adversely affect the initial healing of the soft tissue and can lead to inflammatory hard-tissue reactions with increased osteoclast activity [27,28].

Materials and Methods

Three different types of abutments were examined in the present study. Five samples were prepared for each abutment type and evaluated under the SEM, for a total of 15 samples tested. The abutments examined each belonged to one of following three groups:

Group 1 Custom CAD/CAM titanium abutments (Atlantis™; Dentsply Implants, Mölndal, Sweden). Group 2 Cast bases before the adhesive attachment of the coping (Astra Tech CastDesign 4.5; Dentsply Implants). Group 3 Cast bases after casting of the abutment (Astra Tech CastDesign 4.5; Dentsply Implants).

The template for the production of the abutments was a model analog of the same manufacturer (Astra Tech Osseospeed TX™; Dentsply Implants) with a diameter of 4.5 mm. A similar design was chosen for all abutments, so that the group 1 and 3 abutments had comparable external geometries as far as possible (Figure 1). The pattern for the design was a standardized wax-up. All manual work was performed by the same dental technician. For the production of the custom CAD/CAM abutments of group 1, the wax-up was scanned and manufactured by Dentsply in their CAM process.

The cast bases of group 2 were marked with a diamond cutter to identify the area to be examined by SEM in the region of the abutment index. They were then scanned by SEM to document the baseline situation. The preparation of the SEM images will be described below. The cast bases used were CastDesign abutments (Astra Tech CastDesign 4.5; Dentsply Implants). These were sandblasted with 110 µm aluminium oxide (2 bar) and cleaned with a steam jet. The coping was manually waxed up (Ceramill Gel; Amann Girrbach, Pforzheim, Germany), finished with a milling machine (S3 Master; Schick, Schemmerhofen, Germany) and embedded (Giroinvest Super, Amann Girrbach, Pforzheim, Germany). The muffle was preheated for 60 min at 700°C. In the next step, the abutment was casted under vacuum pressure with a high-gold alloy (Heraeus IQ, Heraeus-Kulzer, Hanau, Germany).After being unbedded, the objects were repositioned on the model analog and blasted with 50 µm glass beads. The transition area between the cast base and the casted abutment were high-gloss polished with a polishing wheel and a brush (BISON brush, Renfert GmbH, Hilzingen, Germany). Then the object was cleaned with a steam jet and examined under the SEM (group 3).

In preparation for the SEM analysis, the abutments were cleaned with ethanol (96%). The SEM images were taken under a LEO 1530 VP (LEO Elektronenmikroskopie, Oberkochen, Germany) at magnifications ranging from 50× to 5,000×. As part of the SEM analysis, the abutments were examined for microgaps, which if found were measured vertically and horizontally. In addition, other abnormalities such as contaminants, processing marks or adhesive residue were documented and an EDX analysis of the substances found was carried out if possible. Only the area marked at the abutment index was examined.

Results

A total of 15 abutments were subjected to SEM analysis. The results are shown in Tables 1-3. Furthermore, the SEM analyses of samples 1.1, 2.1, 3.1 and 3.4 are shown by way of example (Figures 2-5), as they exhibited particular conspicuous features. The evaluation is subdivided according to the respective groups:

Group 1

Custom CAD/CAM titanium abutments (Atlantis™; Dentsply implants, Mölndal, Sweden): Samples 1.1 to 1.5 showed neither microgaps nor traces of post-processing. Nevertheless, contaminants (titanium particles) were found on the surfaces of all abutments (Figure 2). They usually had a particle size between 10 and 100 µm. Most contaminants were found near the preparation margin. Further, three undefinable contamination particles were found on sample 1.3. Besides shallow grinding marks, to surface of all samples was smooth and homogenous.

Group 2

Cast bases before the adhesive attachment of the coping (Astra Tech Cast Design 4.5; Dentsply implants): Samples 2.1 to 2.5 showed no gaps or pits. However, sample 2.1 exhibited seven superficial scratches with a length between 28 and 117 µm nearby the abutment margin (Figure 3). Further, samples 2.1 and 2.4 showed minor contaminations with a size between 1 and 100 µm. Sample 2.3 showed small contamination particles with a diameter between 10 and 100 µm

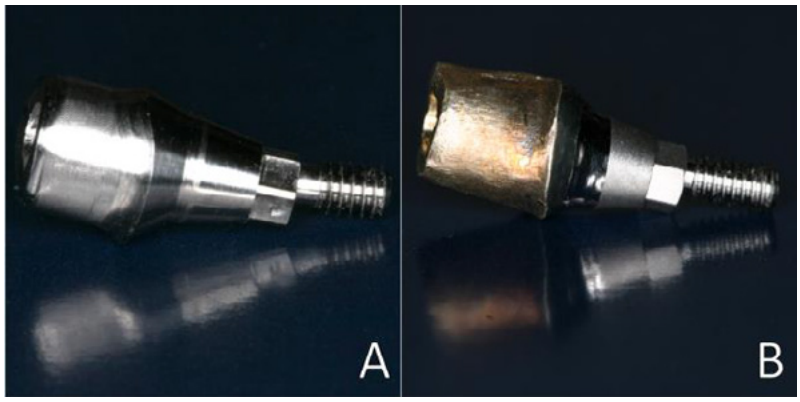

Figure 1: Digital photograph of a titanium CAD/CAM abutment (A - sample 1.1) and a UCLA-type cast-on abutment (B - sample 3.1).

Sample	Gaps/pits			Contamination			Processing marks		
	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.
1.1	none	-	-	titanium particle	97 × 87	1	none	-	-
				titanium particle	50 × 25	1			
				titanium particles	15 (round)	5			
1.2	none	-	-	titanium particle	76 × 59	1	none	-	-
				titanium particle	88 × 65	1			
				titanium particles	15 (round)	5			
				titanium particles	<10 (round)	>10			
1.3	none	-	-	titanium particle	15 (round)	8	none	-	-
				undefinable contamination	10 (round)	3			
1.4	none	-	-	titanium particle	60 × 42	1	none	-	-
				minor debris at the abutment margin	<10 (round)	> 10			
1.5	none	-	-	titanium particle	45 × 28	1	none	-	-
				titanium particle	64 × 48	1			
				titanium particle	71 × 36	1			
				titanium particle	56 × 48	1			
				titanium particles	30 (round)	5			

Table 1: SEM analysis of the titanium CAD/CAM abutments.

Sample	Gaps/pits			Contamination			Processing marks		
	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.
2.1	none	-	-	deposits at the abutment margin	< 10	12	scratches	28 - 117	7
2.2	none	-	-	none	-	-	none	-	-
2.3	none	-	-	small contamination particles on the entire surface	10 - 100 (round)	> 100	none	-	-
2.4	none	-	-	contamination	118 x 10	1	none	-	-
2.5	none	-	-	none	-	-	none	-	-

Table 2: SEM analysis of the cast bases before casting of the abutments.

Sample	Gaps/pits			Contamination			Processing marks		
	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.
3.1	hollow below the margin	779 × 450	1	contamination particles	Oct-30	25	scratches	>150 x 7	3
	shrink holes at the margin	Oct-27	13						
	shrink hole at the margin	39 × 33	1						
	shrink hole at the margin	116 × 26	1						
3.2	shrink hole at the margin	46 × 24	1	none	-	-	scratches	13-21 x 3	2
	shrink hole at the margin	221 × 30	1						
3.3	shrink hole at the margin	46 × 25	1	none	-	-	scratches / ratter marks	25 x 4	53
	shrink hole at the margin	167 × 29	1						
3.4	shrink holes at the margin	164 × 26	9	none	-	-	none	-	-
	shrinkage cavities on the entire surface	<10	>1000						
3.5	shrink holes at the margin	80 × 12 - 145 × 2	3	none	-	-	none	-	-
	shrink hole at the margin	11 × 6	1						

Table 3: SEM analysis of the UCLA-type cast abutments after casting.

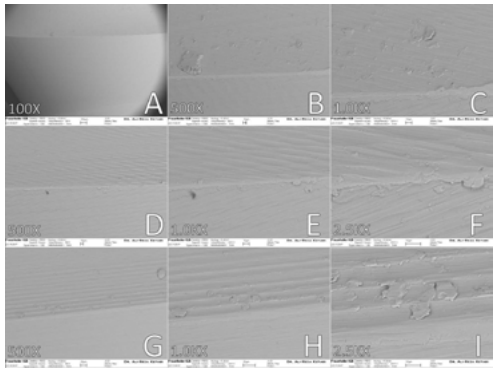

Figure 2: SEM analysis of a titanium CAD/CAM abutment (sample 1.1). Numerous titanium particles can be seen in the area of the preparation line.

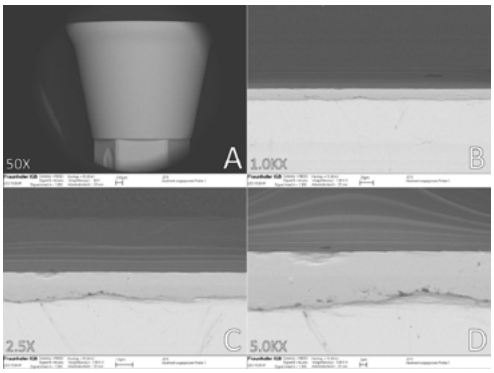

Figure 3: SEM analysis of a cast base before casting of the abutment (sample 2.1). A small area of the edge is inhomogenous and contaminated with small particles.

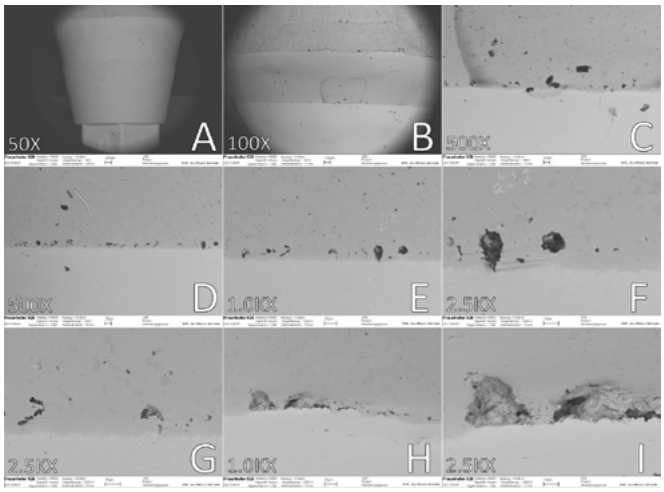

Figure 4: SEM analysis of a UCLA-type abutment after casting and polishing (sample 3.1). A large hollow is visible in picture B. Further, many shrinking cavities can be detected, particularly in the transition area between the cast base and the abutment.

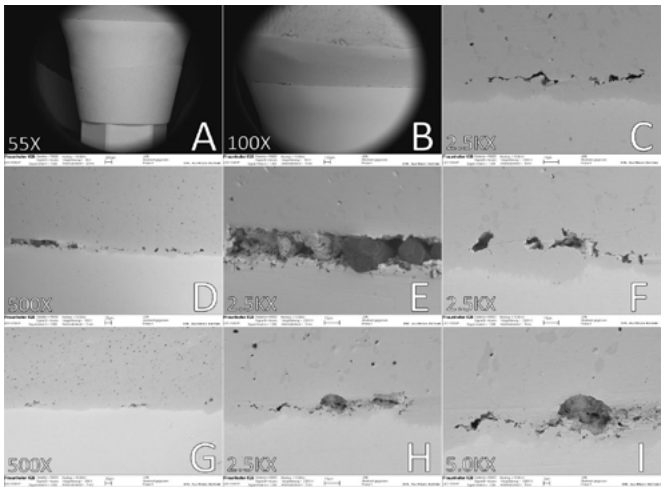

Figure 5: SEM analysis of sample 3.4. Many small shrink holes appear on the surface of the cast abutment. Larger cavities are found in the transition area between the cast base and the abutment

covering the entire cast base surface. No contamination was detected in the examined area of samples 2.2 and 2.5.

Group 3

Cast abutments after casting of the abutment (Astra Tech Cast Design 4.5; Dentsply implants):

Following the casting of the abutments, the SEM analysis of the examined area showed multiple shrink holes at the transition area between the cast base and the abutment. These shrinkage cavities had a size between 11 × 6 and 221 × 30 µm. Further, sample 3.4 exhibited numerous small shrinkage cavities with a diameter below 10 µm covering the entire surface of the abutment. On sample 3.1 a large hollow of 779 × 450 µm could be seen on the surface of the cast base. No contaminants could be found, except for sample 3.1, where 25 particles with a diameter of 10 to 30 µm were present. Furthermore, processing marks in the form of scratches and ratter marks were detected on samples 3.1, 3.2 and 3.3. The length ranged between 13 and 150 µm and the width between 3 and 7 µm.

Discussion

As the above results of the SEM analysis show, contaminants were found on all abutments of group 1 and on samples 2.1, 2.3, 2.4 and 3.1. This is consistent with the findings of studies by Canullo et al. who found contamination on the inner and outer surfaces of abutments despite the use of common cleaning procedures [25,26]. These impurities can cause inflammatory processes of the peri-implant soft tissue, especially in the area of the implant/soft-tissue interface [29]. Plaque accumulation and bacterial colonisation of the abutment surface is believed to play an important role in the pathogenesis of peri-implant infection. Here, the surface texture and roughness of the abutments is a crucial factor [30-36]. Contamination during processing in the dental laboratory or by auxiliary staff has also been proven [26].

On the other hand, the absence of microscopic contaminants can reduce the hard and soft-tissue reaction after abutment connection, accompanied by reduced bacterial adhesion and less osteoclast activity [28]. Small titanium particles, such as those found on all samples of group 1, can trigger immunological reactions [27]. Residue was found on all samples in the present study despite intensive cleaning with a steam jet and ethanol.

Similarly, Gehrke et al. obtained insufficient cleaning results after cleaning zirconia abutments by steam jet only. They therefore advise cleaning by a defined ultrasonic cleaning process to reduce contamination. Still, according to their SEM analysis, this cleaning procedure did achieve a complete absence of any contamination. Consequently, Gehrke et al. recommend the development of a validated polishing and cleaning protocol [29].

Another potential problem that affected all of the cast abutments (group 3) tested was numerous cavities in the form of shrinking holes at the transition area and on the entire surface of sample 3.4. Three out of five samples showed processing marks on the surface of the cast bases. Both create superficial as well as deep retention niches for microorganisms at the critical implant/tissue interface of two-part abutments, in close proximity to the peri-implant bone.

The detrimental effect of microgaps at the implant/abutment interface on peri-implant bone has been amply described in the literature [37]. The accumulation of microbes at the implant neck can lead to inflammation of the peri-implant soft tissue, to bone loss and ultimately to implant failure [38]. The nature of the implant/abutment connection plays a very important role in bacterial leakage [37]. Therefore, many studies have dealt with microleakage at different types of implant/abutment connections. The majority of in-vivo and in-vitro studies showed a better bacterial seal and lower bacterial colonisation in internal than in external implant/abutment connections [39,40], especially when morse taper connections were used [41].

Unlike the well-researched microleakage at the implant/abutment connection, there have as yet been no studies on microgaps at two-part abutments. As the present SEM analysis shows, they are not a rare phenomenon. All five specimens showed distinct gaps with a vertical extent of up to 221 µm and a width up to 30 µm, which is many times that of gaps at the implant/abutment interface (about 10 µm for external connections and 2 to 3 µm for conical connections [42]). This gap is usually located submucosally with two-piece abutments, at a minimal distance from the crestal bone. In the implant system used in the study, the distance is only one millimetre. If the cavity is colonised by

microorganisms, this may have a detrimental effect on the peri-implant hard and soft tissues, something that should be investigated in further studies. In contrast, gap formation of this type is practically excluded with the use of the one-piece CAD/CAM abutments of group 1.

Conclusion

The SEM analysis showed contaminants on all tested abutments in group 1, as well as on the samples 2.1, 2.3., 2.4 and 3.1. According to the literature, there is currently no proven method for cleaning abutments before intraoral placement [29]. What is needed here is a standardized and sufficient cleaning protocol. In addition, the SEM analysis with the identification of the numerous cavities near the bone has pointed out another potential problem about which only a single animal experimental study with a short follow-up period is currently extant exists in the current literature [24]. Further studies with longer observation periods are needed.

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Declarations of Interest

None.

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