



Scanning Electron Microscope Analysis of Adhesively Bonded Two-piece Abutments versus One-piece CAD/CAM Zirconia Abutments

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ABSTRACT

Objectives: The aim of this study was compare two CAD/CAM zirconia abutments (1-piece abutment versus 2-pieces adhesively bonded abutment) for contamination, traces of processing and microscopic gaps.

Material and methods: Three groups consisting of five identical abutments were cleaning with a steam jet and ethanol and then scrutinized by a scanning electron microscope (LEO 1530 VP; Oberkochen, Germany). The first group (1) contained individual CAD/CAM abutments (Atlantis™; Dentsply Implants, Mölndal, Sweden); the second group (2) contained adhesive bases before they were connected to their copings (Astra Tech Cast Design 4.5; Dentsply Implants) while the third group (3) contained the same adhesive bases but with a zirconia coping attached (Ceramill ZI; Amann Girrbach, Pforzheim, Germany).

Results: All abutments in groups 1 and 3 and 4 out of 5 abutments in group 2 were found to be contaminated. Traces of processing were found only on the abutments in group 3. No microscopic gaps were present in groups 1 and 2. All 2-piece abutments in group 3 exhibited extensive bonding gaps that were unfilled, measuring 213 to >3,000 μm horizontally and 42 to 101 μm vertically.

Conclusions/Clinical relevance: Both the instances of contamination and the microscopic gaps of the 2-piece abutments could cause damage to the hard and soft tissues around the implant. This topic would merit further investigation..

Key words: CAD/CAM, Zirconia abutments

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INTRODUCTION

Stable hard and soft peri-implant tissues are of paramount importance for the function and aesthetics of implants and the restorations supported by them over the long term [1]. Significant factors that have a bearing on that stability are the shape of the abutment and sound connections at the implant/abutment interface [2]. Custom abutments greatly improve the emergence profile and offer support for the soft tissue around the implants [3,4]. Their use can shorten [5-8] and simplify [9] the treatment even as the cost will be lower.

These individual 1-piece abutments can be made from, for example, titanium, titanium nitride-coated titanium (Gold Hue) [10] or zirconia. The latter are aesthetically superior to titanium and Gold Hue abutments, which

are why they are a popular anterior alternative [11]; however, there has been a certain amount of controversy regarding their posterior deployment. In a study by Zembic et al., the success rate of 18 zirconia abutments used in the canine and posterior regions was 100% after an average follow-up time of 5.6 years [12]. On the other hand, Ferrari et al., in a recent 3-year randomized controlled clinical trial, reported significantly higher complication rates for individual zirconia compared to titanium and Gold Hue abutments, with multiple fractures at the implant/abutment interface [13]. These complications can be explained by the low resistance to fracture loads. Elsayed et al. found a fracture resistance of only 218.5 N in their in vitro study [14]. This value roughly corresponds to the maximum occlusal force in the anterior jaw.

For this reason, hybrid solutions (2-piece abutments) have been developed in which the implant/abutment connection is made of titanium and the prosthetic coping is made of, for example, zirconia, cast gold or, more

recently, lithium disilicate [15-18]. These abutments-like individual abutments made of titanium-can withstand extra-axial loads of about 900 N [14].

Implant failures can be traceable to biological in addition to technical complications. One potential cause is the presence of microscopic gaps at the implant/abutment interface of 2-piece implant systems, which have been crucially implicated as a factor in the formation of the bacterial biofilm in the sulci around the implants [19,20]. The sulci may then be penetrated by enzymes, acids, bacteria and bacterial products, resulting in inflammation, haemorrhages and marginal swelling [21], which may ultimately cause peri-implant bone resorption and loss [21-24].

Microscopic gaps and marginal bone resorption are less prominent around conical than around non-conical implant/abutment connections [21]. But gaps are not located only between the implants and their abutments; surfaces that can retain microorganisms may also be present on the abutments themselves, especially 2-piece ones.

Furthermore, with adhesively attached copings, harmful effects of the adhesive in the submucosal adhesive joint cannot be ruled out. So far, there are only a few studies that have looked into this. In an animal study, Mehl *et al.*, compared individual 1-piece titanium abutments with 2-piece abutments with titanium, lithium disilicate or zirconia copings adhesively attached (Multilink Hybrid Abutment; Ivoclar Vivadent, Schaan, Liechtenstein) to a titanium base (Conelog titanium base; Camlog Biotechnologies, Basel, Switzerland). There were no signs of the abutments influencing bone loss or the anatomy of the soft tissue around the implants, except that the junctional epithelium was longer around 1-piece titanium abutments than around 2-piece zirconia abutments [18]. It should be noted, however, that the observation time covered only the 6 months after the implant sites were re-entered [18]; possible late effects associated with the 2-piece abutments were not considered.

While microscopic gaps at the implant/abutment interface have occasionally been looked into, niches for bacteria on 1-piece abutment surfaces and at 2-piece abutment interfaces have not. The present study intended to examine the surfaces of individual 1-piece CAD/CAM abutments and of 2-piece abutments using a scanning electron microscopic (SEM). Abutments were additionally examined for micro-contaminants as described by Canullo *et al.* [25,26] that have a detrimental effect on primary soft-tissue healing and may produce inflammatory reactions in the hard tissue associated with increased activity of osteoclasts [27,28].

MATERIAL AND METHODS

The present study examined three groups containing three types of abutments, with five specimens being

prepared for each type and examined under the SEM (15 specimens in total):

Group 1: Individual CAD/CAM zirconia abutments (Atlantis™; Dentsply Implants, Mölndal, Sweden)

Group 2: Adhesive bases with no copings attached (Astra Tech CastDesign 4.5; Dentsply Implants)

Group 3: Adhesive bases with their copings adhesively attached.

All of the manual working steps were performed by a single dental technician. The abutments were produced based on an implant analogue (Astra Tech Osseospeed TX™; Dentsply Implants) 4.3 mm in diameter. All abutments followed a similar design; with the result that the external shapes of the abutments in groups 1 and 3 was similar (Figure 1). The design was based on a standard wax pattern, which was scanned and manufactured by Dentsply (CAM) to produce the individual CAD/CAM abutments of group 1.

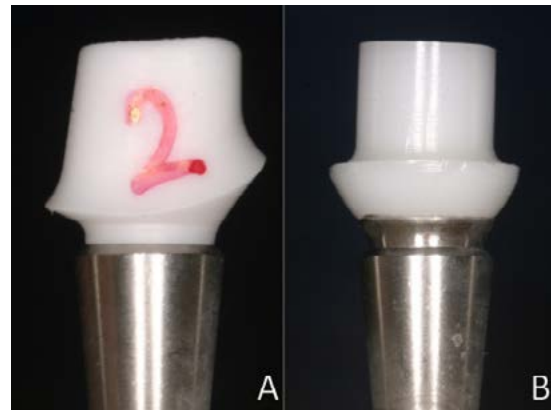


Figure 1: Digital photograph of a zirconia abutment (sample 1.2) and a two-piece abutment after luting of the zirconia coping (sample 3.2)

The area to be examined by SEM were dented with a cutter in the region of the abutment connection for the group 2 adhesive bases, which were CastDesign abutments, and the bases were scanned by the SEM to obtain a set of baseline data. The copings were made manually from light-curing resin (Ceramill Gel; Amann Girrback, Pforzheim, Germany) and completed in a milling unit (S3 Master; Schick, Schemmerhofen, Germany). The models were then milled from zirconia blanks (Ceramill ZI, Amann Girrback) by a copy-milling process (Ceramill Multi-X; Amann Girrback) and sintered at 1,450°C for 510 minutes. The adhesive surfaces of the abutments were air-abraded with 110 µm alumina at 2 bar of pressure and cleaned by steam jet. (The zirconia copings were cleaned by steam jet only.) Subsequently, the zirconia coping was adhesively bonded to the adhesive base (Panavia F 2.0; Kuraray Noritake, Tokyo, Japan). Excess adhesive was removed with a rubber polisher for ceramics and the joint was polished with a bison brush (Renfert, Hilzingen, Germany) and Pasta Grigia diamond polishing paste (Anaxdent, Stuttgart,

Germany). The specimens (group 3) were subsequently cleaned by steam jet and examined under the SEM.

Once the abutments had been cleaned with 96% ethanol, SEM images with a LEO 1530 VP (LEO Elektronenmikroskopie, Oberkochen, Germany) were taken at between 50X to 5,000X. Here the abutments were inspected for microscopic gaps whose horizontal and vertical dimensions, if any, were measured. Other anomalies such as contaminants, traces of processing or adhering residue were documented; where possible, any substances that were found were subjected to EDX analysis (in the marked area at the abutment connection only).

RESULTS

The study examined 15 abutments by SEM (Tables 1-3). Furthermore, SEM analyses of the particularly conspicuous specimens 1b, 2b and 3b are shown (Figures 2-4). Evaluation was arranged by groups, as follows.

Group 1

Individual CAD/CAM zirconia abutments

The surfaces of specimens 1a to 1e were homogenous without microscopic gaps or traces of processing. Contaminants, by contrast, were found on all abutment

Table 1: SEM analysis of the ATLANTIS® zirconia abutments

Sample	Gaps/pits			Contamination			Processing marks		
	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.
1.1	none	-	-	small contamination near the abutment margin	10-100 (round)	9	none	-	-
				filament	423×20	1			
				filament	238×20	1			
1.2	none	-	-	round contamination	30-70 (round)	4	none	-	-
				minor debris at the abutment margin	<10	>100			
				debris	25×20	1			
1.3	none	-	-	minor debris at the abutment margin	<10	>100	none	-	-
				small metal particle	3 (round)	1			
1.4	none	-	-	minor debris at the abutment margin	<10	>100	none	-	-
				debris at the abutment margin	10-35 (round)	8			
1.5	none	-	-	minor debris at the abutment margin	<10	>100	none	-	-

Table 2: CastDesign™ base before luting of the zirconia abutment

Sample	Gaps/pits			Contamination			Processing marks		
	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.
2.1	none	-	-	small particles (dust)	10-15	23	none	-	-
2.2	inhomogeneous edge	1,757 × 81	1	contamination particles at the inhomogeneous edge	<10	>100	none	-	-
2.3	none	-	-	small particle (dust)	10	1	none	-	-
2.4	none	-	-	none	-	-	none	-	-
2.5	none	-	-	small particles (dust)	10	3	none	-	-

Table 3: CastDesign™ base after luting of the zirconia abutment

Sample	Gaps/pits			Contamination			Processing marks		
	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.	Description	Size (µm)	Qty.
3.1	unfilled bonding gap	>2,210 × 65 to >2,055 × 101	2	undefinable contamination in the bonding gap	118×23	3	superficial scratches	171×26 to 1266×48	7
		>1,419 × 79 to >1,677 × 83		adhesive remnants outside the bonding gap	411×83	1	superficial scratches near the bonding gap	120×8 to 145×8	2
3.3	unfilled bonding gap	>1,620 × 61	1	spherical particles	46 (round)	2	scratches	422×7	4
	unfilled bonding gap	470 × 43	1				scratches	378×7	2
	unfilled bonding gap	> 408 × 92	1				-	-	-
3.4	unfilled bonding gap	>1,181 × 92	1	spherical particle	63 (round)	1	none	-	-
	unfilled bonding gap	213 × 42	1						
3.5	unfilled bonding gap	>3,000 × 72	1	filament	662 (length)	1	none	-	-
				spherical particle	20	1			

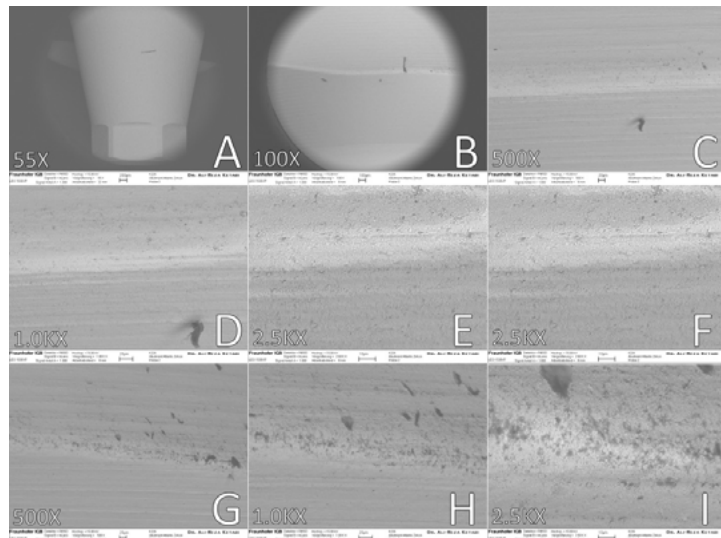


Figure 2: SEM analysis of a zirconia CAD/CAM abutment (sample 1.2) (Many small contaminations can be seen at the preparation line)

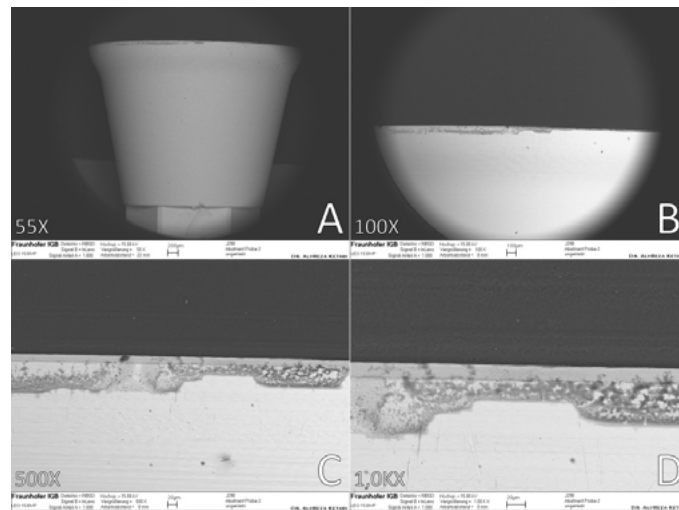


Figure 3: SEM analysis of a cast abutment before luting of the coping (sample 2.2) (An inhomogeneous edge contaminated with many small particles is apparent)

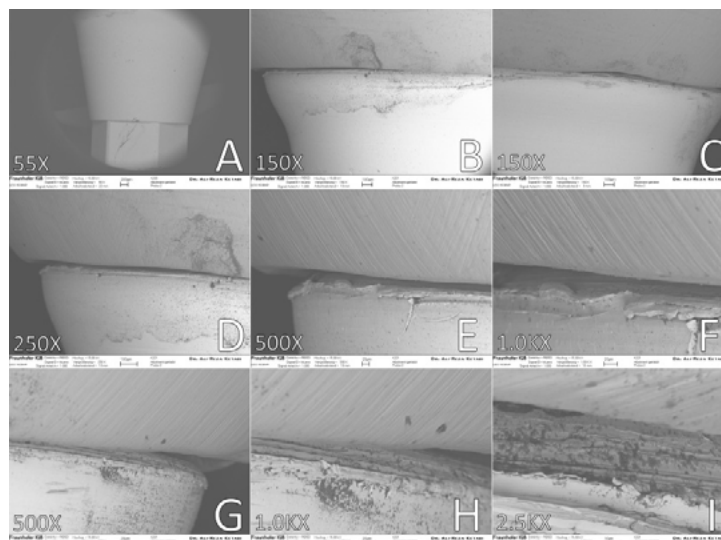


Figure 4: SEM analysis of a two-piece abutment after adhesive fixation of the coping (sample 3.2) (A large unfilled bonding gap with contamination particles and adhesive remnants outside the bonding gap are visible)

surfaces, mostly particles 1 to 100 μm in size; most were discovered close to the preparation margins. The exact type of contamination could not be specified. Particularly extensive contamination was seen on specimen 1b (Figure 2), including two filaments with diameters of 20 μm and lengths of 238 and 423 μm . Furthermore, a metal particle with a size of 3 μm was found on specimen 1d.

Group 2

Adhesive bases with no copings attached

Specimens 2a to 2e showed no pits or traces of processing. However, specimen 2b exhibited an inhomogeneous edge profile of the adhesive base, 1,757 μm in length with a vertical extent of 81 μm and clear deposits (Figure 3). The remaining adhesive bases 2a, 2c and 2e exhibited only minor contamination with particle sizes of 10 to 15 μm . No contamination was detected on specimen 2d.

Group 3

Adhesive bases with their copings adhesively attached

Following the adhesive connection of the zirconia copings, the SEM analysis showed large, unfilled gaps at the joint between the adhesive base and the coping for all specimens (3a to 3e). The smallest gap had a length of 213 μm and a height of 42 μm (specimen 3d). The largest gaps were found in specimen 3e (consistently over the entire examined length of >3,000 μm with a height of up to 72 μm) and specimen 3a (length >2,055 μm and height up to 101 μm). Further, specimens 3a to 3c exhibited traces of processing on the surface or at the transition to the adhesive joint, especially in specimen 3a with seven scratches between 171 \times 26 μm and 1,266 \times 48 μm . Furthermore, all five specimens were contaminated. For specimens 3a, 3c, 3d and 3e, contamination occurred sporadically with a size of between 20 and 118 μm . The contaminants in the specimen 3a were located too deep in the adhesive gap and therefore could not be analysed by EDX. Spherical particles with diameters between 20 and 63 μm were detected on specimens 3c to 3e. The EDX analysis revealed that these were particles of the adhesive. On specimen 3e, a filament with a length of 662 μm was found on the adhesive base surface. Particularly many contaminants were seen on specimen 3b (Figure 4). Here the adhesive base was already contaminated soiled before the adhesive connection (specimen 2b). In addition to numerous minor impurities, adhesive residue was seen outside the adhesive gap on the surface of the adhesive base, 411 \times 83 μm in size.

DISCUSSION

All abutments of groups 1 and 3 were shown by SEM to be contaminated, which agrees with the data of Canullo *et al.* who had discovered internal and external abutment surface contamination in spite of standard cleaning [25,26]. Contamination may trigger peri-implantitis, particularly near the interface of the implant and the soft tissue [29]. Plaque deposits and bacterial biofilm are implicated in the development of peri-implantitis, with

texture and abutment roughness an important factor [30-36]. There has also been proof of contamination at the dental laboratory or by members of the dental team [26].

If no microscopic contaminants are present, this may attenuate the hard-tissue and soft-tissue reaction near the abutment after its connection, with less bacterial biofilm and less osteoclast activity [28]. Metal particles such as those on specimen 1d can initiate immune reactions [27]. Contaminants were found on all specimens in the present study, despite extensive cleaning using ethanol and a steam jet.

Gehrke *et al.* found unsatisfactory results for zirconia abutments after cleaning by steam jet only and therefore recommended ultrasonic cleaning. According to their SEM analysis, this cleaning procedure did remove all contamination, so they recommended a validated protocol for polishing and cleaning [29].

All 2-piece abutments (group 3) tested were compromised by large, unfilled gaps between the adhesive bases and the copings. Three of five specimens showed traces of processing on the adhesive base surfaces, providing retention spaces of various depths to accommodate bacteria at the implant/tissue interface of 2-piece abutments close to the peri-implant bone.

Microscopic gaps at the implant/abutment interface have a negative effect on peri-implant bone, an observation that been extensively reported [37]. Bacterial biofilm at the implant neck can cause peri-implantitis, bone loss and, ultimately, implant failure [38]. The type of implant/abutment connection plays an important role in bacterial leaks [37]. Many studies therefore examined microleakage in connection with different types of implant/abutment connections. Most studies, *in vivo* as well as *in vitro*, demonstrated a better seal and less bacterial biofilm on internal than in external connections [39,40], especially of the morse-taper kind [41].

However, there have been no studies on microscopic gaps on 2-piece abutments to date, even though these are not a rare occurrence, as the present SEM analysis has shown. All specimens in this group exhibited distinct gaps with vertical dimensions of up to 101 μm , many times more than at the implant/abutment interface (approximately 10 μm for external, 2 to 3 μm for conical connections [42]. The location of this gap is usually submucosal in the case of 2-piece abutments, very close to the crestal bone; the distance is just 1 mm in the present implant system. Colonization by bacteria may damage the peri-implant hard and soft tissue, a topic that merits further investigation. For the 1-piece CAD/CAM abutments of group 1, on the other hand, gap formation of this type is practically impossible, but here the fracture resistance of the zirconia abutments has been a matter of discussion [12-14,43-45].

As specimen 3b shows, adhesive residue on the surface of the 2-piece abutments cannot be excluded even with careful polishing and cleaning. This residue is often

involved in the development of mucositis and peri-implantitis, as a recent systematic review by Quaranta *et al.* has shown. This is especially true for methacrylates [46], commonly used for adhesive connection of the copings of 2-piece abutments.

CONCLUSION AND CLINICAL RELEVANCE

All tested abutments in groups 1 and 3 were shown by the SEM to be contaminated. A standardized cleaning protocol proven to be effective would therefore be required. The SEM analysis that identified the extensive gaps near bone pointed to another potential problem, one for which only one animal study with a brief follow-up period has been published to date [18]. It should be noted that the evaluation of gaps by this method could cause a large distortion due to the parallax effect. Slight rotations in the XYZ axis could change the measurement.

Further research over longer periods is urgently required.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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