

Evaluation of Microgap Size and Microbial Leakage in the Connection Area of 4 Abutments With Straumann (ITI) Implant

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A microgap between implant and abutment can lead to mechanical and biological problems such as abutment screw fracture and peri-implantitis. The aim of this study was to evaluate microgap size and microbial leakage in the connection area of 4 different abutments to ITI implants. In this experimental study, 36 abutments in 4 groups (including Cast On, Castable, Solid, and Synocta abutments) connected to Straumann fixtures (with their inner part inoculated with bacterial suspension) and microbial leakage were assessed at different times. The size of the microgap in 4 randomized locations was then measured by scanning electron microscope. The data were analyzed by SPSS software and by 1-way variance statistical test, Kruskal-Wallis, and their supplementary tests (Mann-Whitney HSD and Tukey's; $\alpha = .05$) at the next step. The effect of using different types of abutments was significant on the mean microgap size ($P < .001$) and on the mean number of leaked colonies (CFU/mL) through the connection area of the implant and abutment within the first 5 hours of the experiment ($P = .012$); however, it did not significantly influence microleakage at 24 hours, 48 hours, and 14 days ($P = .145$). Using Synocta abutments compared with Solid abutments will not provide us with more accommodation, and vice versa. Using Solid and Synocta abutments can significantly decrease the microgap size; however, Cast On abutments do not show a significant difference in terms of microgap compared with Castable abutments. Microleakage in the connection area is comparable for these 4 abutments.

Key Words: dental implants, dental abutments, dental leakage, microgap, microbiology, electron microscope tomography, dental casting method

INTRODUCTION

During the past 30 years, osseointegration has deeply changed restorative dental treatments and turned implantology into one of the most successful restorative techniques among medical and dental disciplines, with 90% success.^{1,2}

Implant systems usually have an abutment that attaches to the implant body with a screw.³ Despite all the benefits of these systems, there are still problems with implant systems.⁴ After attachment of the abutment to the implant, a microscopic gap appears in the contact area along the threads of the abutment's screw and in the base of the screw.

A number of factors affect the microgap and microleakage between the implant and abutment, some of which include the implant system used,^{5,6} geometry of the contact area between implant and abutment,⁷ use of self-cast abutments rather than mechanically provided ones,⁸ the amount of force used to tighten the abutment,⁹ and the use of self-screw abutments versus self-cement ones.^{10,11}

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Altogether, we can put the consequences of such a gap into 2 groups: (1) biological problems, including peri-implant mucositis, peri-implantitis, crestal bone loss, and halitosis,^{5,12} and (2) mechanical problems, including loosening of the abutment's screw and its failure, abutment failure, and even implant body failure.^{13,14} By means of this microgap, bacteria are able to penetrate through the inner space of the implant and proliferate there. Consequently, their toxins and metabolites can spread to peri-implant tissues. Then, inflammatory reactions occur, and the clinical manifestations will be peri-implantitis, peri-implant mucositis, and halitosis. The existence of halitosis after abutment attachment could be a reason for bacterial microleakage in one part of the system.⁵ Ericsson could prove inflammatory responses in tissues around the implant and abutment, even in plaque-controlled cases that include apparently healthy surface tissues and called them abutment-infiltrated connective tissue.^{15,16} The mechanical problems are related to loosening and failure of the maintaining screw.¹⁷ Experimental studies showed that screw-related failures (loosening or breakdown) are in relation to nonoccurrence of abutment and implant.^{18,19} Moreover, the gap between the implant and abutment can lead to a high stress rate in peri-implant bone and connecting components.^{20,21} Binon reported that the occurrence between implant compartments is critical because mismatch of compartments can cause rapid stress, which leads to loosening of the screw and its failure.¹⁴ Sakaguchi et al²² demonstrated that an unstable implant-abutment interface leads to undesirable stress in the contact area, and Boggan et al²³ pointed out that matching the implant and abutment in their interface with high precision can minimize unnecessary forces affecting the screw. The aim of this study was to evaluate the size of the microgap and amount of microleakage in the attachment of 4 different abutments (Solid, Synocta, Cast On, and CastableRine casted with metal base alloy and Castable Rhein casted with high noble alloy) compared with Straumann implants on their contact area.

METHODS AND MATERIALS

This is a clinical random study performed on 36 similar Straumann implants (regular neck; with same

platform diameter of 4.8 mm) divided into 4 distinct groups, each containing 9 samples using 4 different types of abutment: Solid, Synocta, Cast On (Straumann, Basel, Switzerland), and CastableRhein (Rhein 83, Bologna, Italy) casted with high noble alloy (Figure 1).

Abutments casting procedure

According to the manufacturer's (Straumann) instruction for Cast On abutments, Degubond 4 alloy (Degudent, Hanau, Germany) and a phosphate-bounded investment (Borsigstr, Germany, Ernst Hinrichs) were selected for the casting procedure. The same alloy was selected for casting 9 of Castable abutments (Rhein 83, Bologna, Italy).

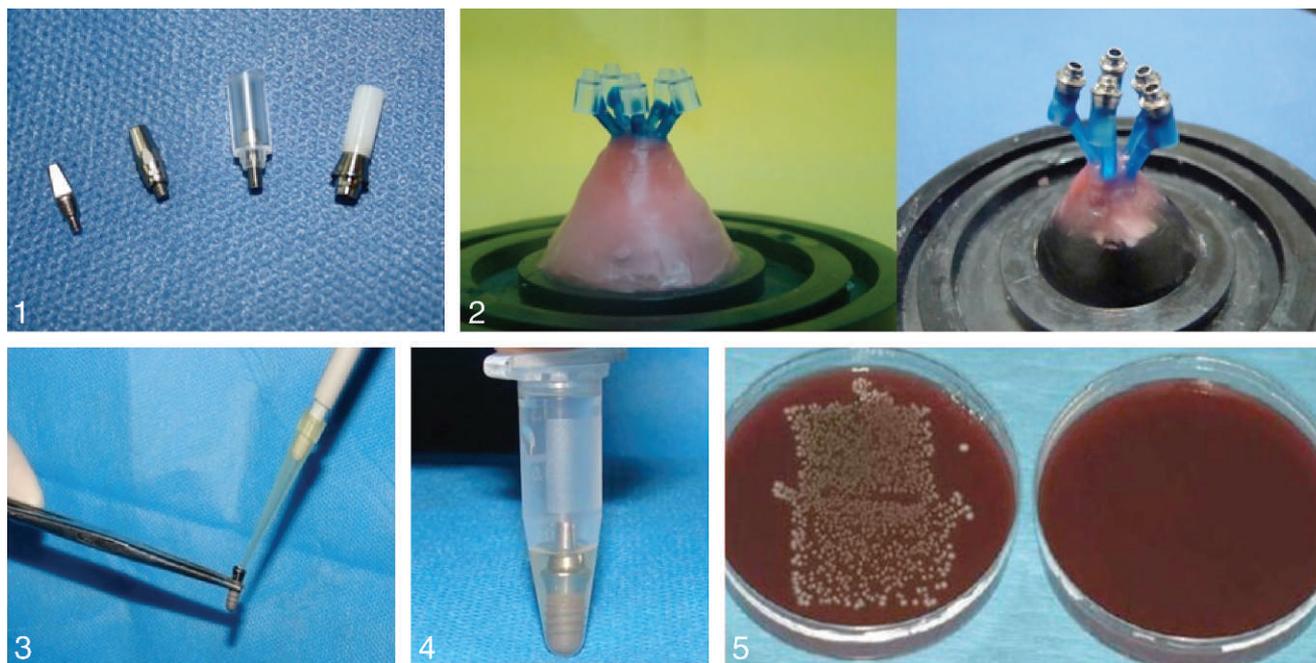
According to the instructions of the Cast On abutments' manufacturer, when choosing an alloy for the casting procedure, it is very critical to use abutments compatible with ceramic alloy (which forms the abutments' base). The melting range of the chosen alloy should not exceed 1350°C. Appropriate recommended alloys by the manufacturer are the following:

- High noble alloys
- Precious alloys with 25% minimum weight of platinum and gold
- Palladium-based alloys with 50% minimum weight of palladium

Selected alloys must also meet ISO 1562 and ISO 9693 standards. The alloys used in this study (Degubond 4), based on ADA standards, were high noble alloys and also qualify for ISO 1562 and ISO 9693; therefore, it was consonant with manufacturer criteria. Both groups of castable abutments (including Cast On abutments and 1 group of Castable abutments) were connected to cylinders according to the manufacturer's instruction (Figure 2).

Abutments casting

Abutments, in both groups according to the manufacturer, were connected to fixtures. To cast 9 of Cast On and Castable abutments, 65% investment special solution and 35% distilled water were added for every 100 g of investment powder. The mixture of powder and solution was poured into a cylinder after 60 seconds under vacuum condition, and then each mold was allowed to set



FIGURES 1–5. **FIGURE 1.** Solid, Synocta, Cast On, and Castable abutments. **FIGURE 2.** Cast On and Castable abutments connected to cylinders. **FIGURE 3.** Inoculation of 0.5 μL of bacterial suspensions into implant. **FIGURE 4.** Abutment in TSB culture. **FIGURE 5.** Colony growth on blood agar culture.

for a minimum of 60 minutes. Each mold was then placed in a cold furnace (Degudant), and the temperature was adjusted so that it would increase 5°C to 7°C each minute to reach the temperature for wax removal.

According to the manufacturer of Cast On abutments, rapid techniques of casting were not applied. Divesting was then carried out carefully with an ultrasound procedure after completion of the casting operation and cooling of the cylinders. According to the manufacturer of Cast On abutments, sandblasting was not applied because there was a potential risk of destruction and loss of details between the abutment and implant. No polishing or finishing was carried out on the abutment. In the case of a definite defect or failure in the casting procedure in each abutment, that sample was isolated and excluded from the study, and casting was repeated. All lab processes were done by 1 technician.

Contamination of samples and microbiological surveys

To perform the microbial microleakage test, 36 of the Straumann implants and 36 of the abutments under study were sterilized in the standard condition (15 psi pressure and 121°C) by autoclave

(Sirona, Sandrigo, Italy). All implements applied in this procedure were sterilized as well.

In this study, *Escherichia coli* bacteria, which are Gram-negative, motile, facultative anaerobic bacteria 1.1 to $1.5\ \mu\text{m}$ in diameter and 2 to $6\ \mu\text{m}$ in length, were used. These bacteria are among medium-sized oral bacteria.

A pure *E coli* culture (ATCC 25 922) underwent the study for microbiological purposes. The bacterial suspension was obtained by culturing the microorganism on blood agar (Mark Darmstadt, Germany), incubating for 24 hours, and diluting in TSB (Difco, Lawrence, Kan) until McFarland's 0.5% standard density (1.5×10^8 CFU/mL) was provided.

Each implant was fixed with a hemostat so that $0.5\ \mu\text{L}$ of bacterial suspensions with delicate micropipette was inoculated into its inner space (Figure 3). Afterward, the abutments of each group were installed with a special torque range of the ITI system and a force of $35\ \text{N}/\text{cm}^2$. To make sure that the outer surface of the implant-abutment complex did not get polluted during work, sterile cone-shaped paper covers were put on the complex, and sampling was done. Each of the cone-shaped paper covers was soaked in 5 mL of nutrient broth and incubated at 37°C to diagnose probable superficial pollution of samples during working.

In the case of a positive culture result during working, the sample was isolated and removed from the study, and inoculation after sterilization was repeated.

All samples were put into Eppendorf microtubes, and TSB culture (Figure 4) was added so that the surface of the culture was located below the abutment's access space. Each group was coded from 1 to 9. In addition, the 50 μ L of culture around the implants was replaced every 12 hours.

All samples were then transferred into the incubator, and after 5, 24, and 48 hours and 14 days, 0.1 mL of culture around the implants was taken with the sampler and cultured on blood agar plates. In this situation, the number of bacteria might be uncountable, so another 0.1 mL was removed from the culture of each sample, and a dilution of 1/10 was prepared and cultured on the plate as well. In the case of bacterial microleakage between abutments and implant, the colonies would be visible on the plate and therefore countable (Figure 5). Then, regarding the number of colonies grown on the culture, the number of colonies in 1 mL of culture around the implants during that specific time was calculated (CFU/mL).

To ensure the presence of *E coli* on plates, some biochemical tests, such as Indol, methyl red, vogesproskauer, and citrate, were performed.

All of the above processes, including preparing bacterial suspension, preparing cultures, inoculation of suspension into implant, injection of culture into Eppendorf microtubes, and culturing on agar plates, were done under hood (JalTajhiz, Tehran, Iran). The space under the hood was sterilized with an ultraviolet ray for 1 hour, and disposable sterile gloves were also worn during the operations to reduce the environment pollution to a minimum level. All microbial tests were done by 1 technician, who was unaware of the group samplings.

Microgap assessment by scanning electron microscope

Scanning electron microscope (SEM) images are available in Figure 6. After completion of microbiological tests, all samples were placed into ultrasonic equipment (Golten/Whaledent, Mahwan, NJ) and then sterilized in an autoclave. Using the gold sputtering equipment (Bal-Tec, Hayloft, Germany), the power-conducting quality of the samples was measured under the mechanism of physical vapor

disposition with definite time, and at the final step, each sample's microgap was assessed with an electron microscope (Philips x120, Netherland, Eindhoven) at an appropriate voltage (15 kV). The tests were then pursued with proper voltage (15 kV) with an electronic microscope (Phillips) in the next step. The size of the microgap at 4 points in each sample (which were selected randomly) was assessed and compared with the number on a scale bar, determining a proportion.

Data analysis

All results were analyzed by 1-way variance statistical test, Kruskal-Wallis, and their supplementary tests (Mann-Whitney HSD and Tukey's; $\alpha = .05$).

RESULTS

One-way variance analysis showed that there is a significant difference in the mean microgap between the different groups of abutments in this study ($P < .001$). Cast On abutments showed the highest and Solid abutments showed the lowest mean microgap. The average amount and standard deviation of the microgap between ITI implants and 4 different types of abutments are reported in Table 1, and a 2-by-2 comparison of these abutments' microgap is reported in Table 2. A comparison between the mean microgaps of abutments is illustrated in Figure 7.

The Kruskal-Wallis test showed that in just 5 hours, the mean number of leaked colonies was significantly different between the different groups ($P = .012$). But the mean number of leaked colonies after 24 and 48 hours and also after 14 days did not show a significant difference between the 4 groups under investigation ($P = .145$). In the first 5 hours, the highest amount of mean number of leaked colonies was related to Cast On abutments, and the least amount was seen in Synocta abutments.

Different amounts of mean number and standard deviation of leaked colonies in each group at different times in the study are presented in Table 3 and Figure 8. The calculated P value from the 2-by-2 comparison of the mean number of leaked colonies during the 5 hours is available in Table 4.

DISCUSSION

Multiunit implant systems present a microgap in the implants-abutments interface, which can act as a

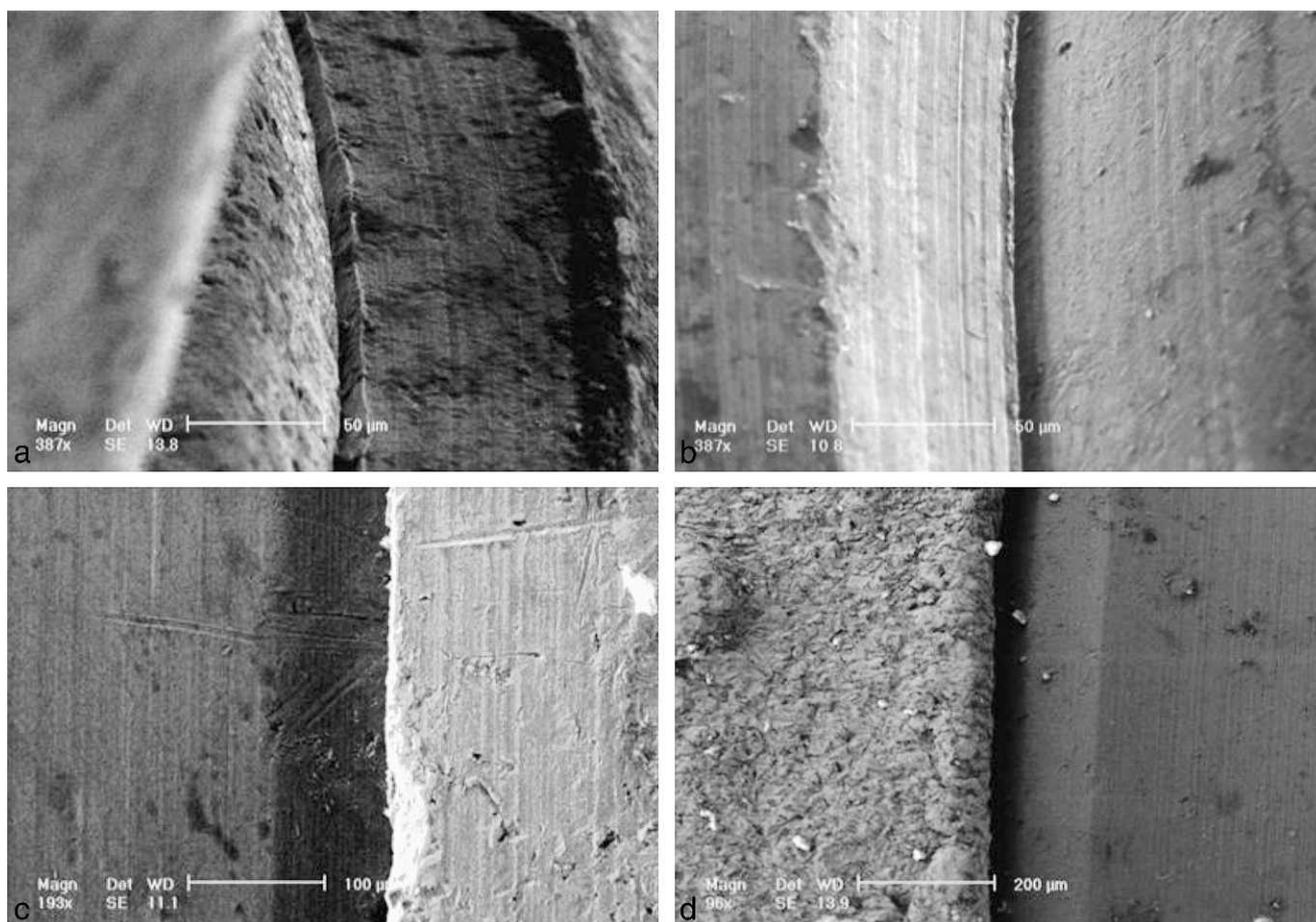


FIGURE 6. Scanning electron microscope images of the contact area between implants and abutments. (a) Synocta abutment-ITI implant contact area. (b) Solid abutment-ITI implant contact area. (c) Cast On abutment-ITI implant contact area. (d) Castable abutment-ITI implant contact area.

nutritional source for oral microorganisms.²⁴ The size of this microgap has been reported as a wide range of 1 to 50 μm, and it is highly dependent on the size of implant and the torque used to fix abutments.^{23,25} In this study, there is a significant difference in the mean microgap among 4 different abutments, but this difference is not seen in the number of leaked colonies.

In this study, the mean microgaps of Solid and Synocta abutments were reported as 7 and 10 μm,

respectively, which was significantly lower than the mean microgap of 2 μm for other castable abutments. In the study by Tsuge et al,²⁶ the size of the microgap between 5 different types of machined abutments and their related fixtures was reported as less than 10 μm. Also, in the study by Piattelli et al,¹⁰ the amount of the microgap between premachined metal abutments and 3i implants, measured by electron microscope, was reported as 4.33 μm. In a survey conducted by Kano

TABLE 1

The average amount and standard deviation of microgaps between implants and studied abutments

Abutment	Mean	SD	95% Confidence Interval		Min	Max
			Lower Bound	Upper Bound		
Solid	7.03	5.98	2.43	11.64	2.23	21.13
Synocta	10.36	7.01	4.98	15.75	3.61	21.65
Cast On	95.92	8.75	89.19	102.65	81.43	110
Castable (high noble)	74.43	45.02	39.82	109.04	20.20	144.50

Abutment	Subset for alpha = .05	
	1	2
Solid	7.03	
Synocta	10.36	
Cast On		95.92
Castable (high noble)		74.43
Sig	.99	.08

et al,²⁷ Conexao master systems premachined titanium abutments showed the least vertical misfit (5.6 μm) compared with Cast On (11.1 μm) abutments and Castable abutments, casted with Ni-Cr (8 μm). The results of this study are concurrent with articles that are mentioned above and also with studies that reported a microgap less than 10 μm for metal abutments, manufactured by the factory.^{6,28-30} The amount of the mean microgap and mean number of leaked colonies (CFU/mL) in both groups of premachined metal abutments (Synocta and Solid) were not significantly different. The presence or absence of antirotation in the static condition does affect the size of the microgap and amount of microleakage in these 2 abutments and Straumann implants.

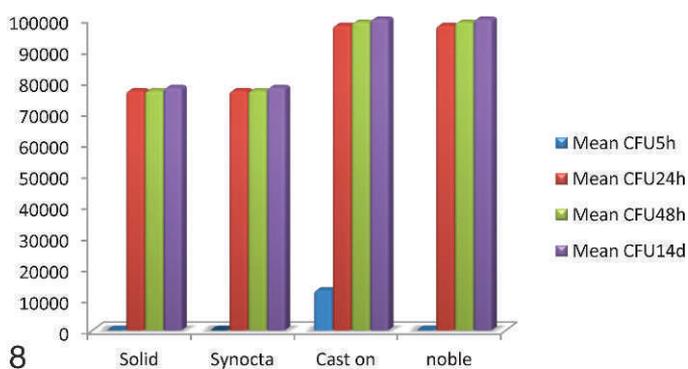
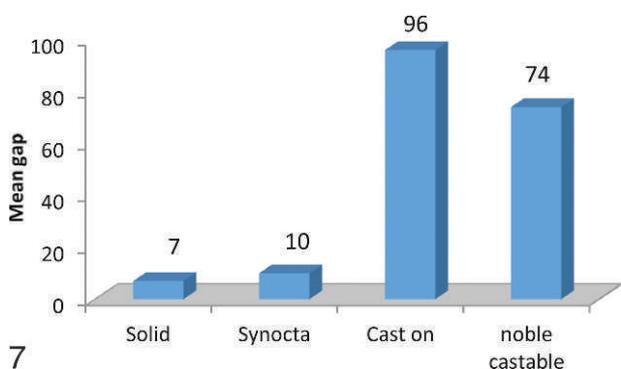
Adaptation between Straumann implant's antirotation feature and Synocta abutments requires precision and low machining tolerance, in the way that even a little error in machining procedures can cause a misfit between abutment and implant. Three main reasons that have been clarified for the presence of microgap between implants and premachined abutment are none perceive machining; using heavy torque during the abutment's

closure, which can cause distortion; and maladaptation of male and female.⁶

In this study, there was no significant difference between the mean microgap of Cast On and Castable abutments casted with high noble, which is in contrast with the results of Byrne et al,³¹ indicating that the adaptation between the implant and Cast On abutment is better than the adaptation between the implant and Castable abutments. Other contradictive studies include Carvalho et al and Neves et al, which reported better adaptation with Cast On abutments compared with Castable ones.^{32,33} Some studies have reported that when Cast On abutments have been evaluated in terms of the casting procedure's effect on marginal adaptation and amount of preload and rotational misfit, these parameters did not change, and the integrity of all parts was preserved during the laboratory procedure.^{27,28,34}

Aside from these reports, in the study by Kano et al,²⁷ which was done to measure the amount of misfit between Conexao master implants and 4 different types of abutments by optical microscope, the authors showed that among Cast On and Castable abutments casted by Ni-Cr and Cr-Co, there is no difference in their vertical misfit. Barbosa et al,³⁵ in their study, concluded that the adaptation between Castable abutments casted with Ni-Cr and Conexao system implants, measured by optical microscope with ×500 magnification, is comparable with the Cast On abutments' adaptation and implants.

Also in the study by Kano et al, the authors tried to investigate the effect of the casting procedure on detorque, and they showed that different methods of casting can decrease the percentage of imposed torque during abutment closure and that this



FIGURES 7 AND 8. FIGURE 7. A comparison between the mean microgaps of abutments and ITI implants. FIGURE 8. The mean number of leaked colonies in 4 groups during the study.

TABLE 3

Different amounts of mean number and standard deviation of leaked colonies in each group at different times

Abutment		CFU (5 h)	CFU (24 h)	CFU (48 h)	CFU (14 d)
Solid	Mean	230 ± 80	$(77 \pm 44) \times 10^3$	$(77 \pm 44) \times 10^3$	$(78 \pm 43) \times 10^3$
Synocta	Mean	0	$(77 \pm 43) \times 10^3$	$(77 \pm 42) \times 10^3$	$(78 \pm 44) \times 10^3$
Cast On	Mean	$(13 \pm 33) \times 10^3$	$98 \times 10^3 \pm 0$	$99 \times 10^3 \pm 0$	$10^5 \pm 0$
Castable (high noble)	Mean	140 ± 340	$98 \times 10^3 \pm 0$	$99 \times 10^3 \pm 0$	$10^5 \pm 0$

reduction is comparable in Cast On and Castable abutments casted with Ni-Cr and Cr-Co alloys. By using SEM images from the underside surface of these kinds of abutments and comparing them with prefabricated metal abutments, the authors concluded that the casting procedure can cause irregularities in these kinds of abutments' interface and implants.³⁶ In another study, they showed that the rotational misfit between Cast On abutments and plastic abutments casted with Ni-Cr alloys were comparable, but both showed higher rotational misfit compared with prefabricated metal abutments.³⁷

Maybe one of the reasons for the higher amount of the Cast On and Castable abutments' microgap in a recent study compared with Solid and Synocta abutments is the lack of any finishing and polishing procedure on the fitting surfaces of these abutments. Carr et al²⁸ pointed out that finishing and polishing procedures can improve the amount of preload in castable abutments and significantly reduce drawbacks of the casting procedure. They also declared that the effect of the casting procedure on Cast On abutments is highly dependent on the manufacturer, and some factory-made abutments are obviously affected by casting procedures. These differences can suggest that the metal substance's features that constitute the abutment and implant interface could be changed during casting.²⁸

Another probable reason that no differences were reported in the mean microgap between Cast On and Castable abutments in this study is that the

flow of alloy into the screws' internal thread and Cast On abutments' margin that can cause surface roughness in that area eventually leads to abutment misfit and its distortion due to increased stress because of casting procedures' heat or distortion due to surrounding casting shrinkage.³¹

Despite this study, here was a meaningful difference between the mean microgap of 4 different kinds of abutments ($P < .001$), but there were no differences between the mean number of leaked colonies in these abutments ($P = .145$). In this study, the mean number of leaked colonies from the premachined titanium abutment interface was reported to be 77×10^3 (CFU/mL) after 24 hours. Piattelli et al¹⁰ evaluated *Pseudomonas aeruginosa* microleakage from 3i implants and premachined metal abutments interface, and the number of leaked colonies was reported to be 3×10^4 after 72 hours in 1 mL. In this study, except for 2 samples from the Solid and Synocta study, all samples had obvious microleakage in the first 24 hours, and these 2 samples from mentioned groups have not been contaminated until day 14. In the study by Jansen et al,⁶ in the benefit system with conical abutments from 23 samples, just 1 of them did not show any microleakage until day 14, and other samples had been contaminated. Some samples without microleakage at 24 hours remained uncontaminated as a common finding in both studies (Jansen et al and the present study).

In this study, *E coli* bacteria, a Gram-negative, mobile, facultative anaerobic bacteria with 1.1 to 1.5 μm diameter and length of 2 to 6 μm , was used.

TABLE 4

Calculated *P* value from 2-by-2 comparison of mean number of leaked colonies during 5 hours

	Synocta	Solid	Cast On	Castable (High Noble)
Synocta	—	.317	.012	.146
	Solid	—	.040	.541
		Cast On	—	.108
			Castable (high noble)	—

This bacteria can be seen in the healthy oral environment, and it belongs to medium-size oral bacteria.⁶ In this study, Solid abutments represented the lowest amount of microleakage (2.23 μm), and the highest microgap was reported in Castable abutments casted with high noble (144.5). While the bacteria diameter (1.1–1.5 μm) is smaller than the smallest microgap (2.23 μm), it is not surprising to find similar microleakage among groups.

In the Jansen et al study,⁶ it was shown that despite the small size of the microgap, the amount of microbial microleakage in bonafit systems with conical abutments and Astra is too much, and according to results from other studies, it can be concluded that the relation between the amount of microleakage and the size of the gap is not statistically meaningful.⁶

In the study by Nascimento et al,³⁸ the amount of bacterial microleakage from the implant and Cast On and Castable abutment interface, which were cast with Ni-Cr alloy, was comparable, and it was similar to our results.

Also in another study by Nascimento et al,³⁹ the authors evaluated the amount of microbial microleakage in Branemark implants and the Cast On and Castable abutments interface casted with Ni-Cr alloy by using checkerboard DNA-DNA hybridization, and they concluded that the amount of microleakage is identical in these 2 kinds of abutments. The authors of this article explained the results of their study according to the results by Kano et al,²⁷ indicating that there is no vertical misfit in Cast On and Castable abutments.

Although in our study, the average number of leaked colonies in different groups showed a significant difference in the first 5 hours and did not show any significant difference at other times, only among Solid and Synocta abutments, 2 of 9 samples remained tight and were not contaminated. Also, in the first 5 hours, no microbial microleakage was reported in Synocta abutments, and after that time, the least amount of microleakage was related to Solid abutments. The highest amount of microleakage in the first 5 hours was related to Cast On abutments, and these results indicate a slower rate of microleakage from premachined titanium abutments interface with implant in the first hours compared with Castable abutments. However, after a while, this difference among different groups would be diminished, and

it may be due to *E coli's* small diameter and its slow reproduction time.

Another explanation for the lack of significant difference in microleakage of quadratic groups is due to the use of an average scale to represent the size of the microgap in different groups. A gap with an appropriate size in just 1 point is enough for the existence of microleakage from the implant-abutment interface, and it doesn't require a big gap surrounding all perimeters of the interface. At some points, the size of this gap is bigger than the average sizes, and in some parts it is even smaller, so it is recommended that beside average numbers, the maximum numbers should also be mentioned. A microgap between implants and abutments is a 3-dimensional space, and just by surveying the outer part of this space, we cannot generalize the results to all space and we cannot judge all of this space by evaluating the outer part of the space, so it is recommended to use an appropriate method to survey the 3-dimensional space between abutments and implants because SEM is not a proper tool to investigate this space. Also, it is better to compare some finished and polished Castable abutments with the control group to recognize the probable effects of these procedures on the amount of microgap and microleakage.

CONCLUSION

1. Using Solid abutments instead of Synocta, and vice versa, does not have any significant effect on the reduction of the microgap.
2. Using premachined titanium abutments (Solid and Synocta) can reduce the amount of microgap between implants and abutments compared with Cast On and Castable abutments.
3. Using Cast On abutments compared with Castable abutments casted with high noble alloys cannot significantly reduce the size of the microgap.
4. Solid and Synocta abutments (premachined titanium), Cast On and Castable abutments casted with high noble alloys do not lead to any differences in the amount of microleakage in their interface with implants; therefore, the possibility of biological problems such as peri-implant mucositis, peri-implantitis, and halitosis are identical in the 5 different groups.

ABBREVIATION

SEM: scanning electron microscope

REFERENCES

1. Chuang SK, Cai T. Predicting clustered dental implant survival using frailty methods. *J Dent Res*. 2006;85:1147.
2. Susarla SM, Chuang SK, Dodson TB. Delayed versus immediate loading of implants: survival analysis and risk factors for dental implant failure. *J Oral Maxillofacial Surg*. 2008;66:251–255.
3. Eposito M, Thomsen P, Molne J, Gretzer C, Ericson LE, Lekholm U. Immunohistochemistry of soft tissues surrounding late failures of Branemark implants. *Clin Oral Implants Res*. 1997;8:352–366.
4. Do Nascimento C, Pedrazzi V, Miani PK, Moreira LD, De Albuquerque Junior RF. Influence of repeated screw tightening on bacterial leakage along the implant–abutment interface. *Clin Oral Implants Res*. 2009;20:1394–1397.
5. Gross M, Abramovich I, Weiss EI. Microleakage at the abutment-implant interface of osseointegrated implants: a comparative study. *Int J Oral Maxillofacial Implants*. 1999;14:94.
6. Jansen VK, Conrads G, Richter EJ. Microbial leakage and marginal fit of the implant-abutment interface. *Int J Oral Maxillofac Implants*. 1997;12:527–540.
7. Tesmer M, Wallet S, Koutouzis T, Lundgren T. Bacterial colonization of the dental implant fixture-abutment interface: an in vitro study. *J Periodontol*. 2009;80:1991–1997.
8. Gould TR, Brunette DM, Westbury L. The attachment mechanism of epithelial cells to titanium in vitro. *J Periodontol Res*. 1981;16:611–616.
9. Gross MWE, Abramovich I. A comparative study of microleakage at the abutment interface. *Implant Dent*. 1996;5:288.
10. Piattelli A, Scarano A, Paolantonio M, et al. Fluids and microbial penetration in the internal part of cement-retained versus screw-retained implant-abutment connections. *J Periodontol*. 2001;72:1146–1150.
11. Scarano A, Assenza B, Piattelli M, et al. A 16-year study of the microgap between 272 human titanium implants and their abutments. *J Oral Implantol*. 2005;31:269–275.
12. Quirynen M, Van Steenberghe D. Bacterial colonization of the internal part of two stage implants: an in vivo study. *Clin Oral Implants Res*. 1993;4:158–161.
13. Adell R, Lekholm U, Rockler B, Branemark PIA. 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg*. 1981;10:387–416.
14. Binon PP. Implants and components: entering the new millennium. *Int J Oral Maxillofacial Implants*. 2000;15:76.
15. Ericsson I, Nilner K, Klinge B, Glantz PO. Radiographical and histological characteristics of submerged and nonsubmerged titanium implants: an experimental study in the Labrador dog. *Clin Oral Implants Res*. 1996;7:20–26.
16. Ericsson I, Persson LG, Berglundh T, Marinello CP, Lindhe J, Klinge B. Different types of inflammatory reactions in peri-implant soft tissues. *J Clin Periodontol*. 1995;22:255–261.
17. Yokoyama K, Ichikawa T, Murakami H, Miyamoto Y, Asaoka K. Fracture mechanisms of retrieved titanium screw thread in dental implant. *Biomaterials*. 2002;23:2459–2465.
18. Khraisat A, Hashimoto A, Nomura S, Miyakawa O. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. *J Prosthet Dent*. 2004;91:326–334.
19. Lewis SG. An overview of Branemark system restorative options. *J Esthet Dent*. 1996;8(suppl):3–44.
20. Alkan I, Sertgoz A, Ekici B. Influence of occlusal forces on stress distribution in preloaded dental implant screws. *J Prosthet Dent*. 2004;91:319–325.
21. Watanabe F, Uno I, Hata Y, Neuendorff G, Kirsch A. Analysis of stress distribution in a screw-retained implant prosthesis. *Int J Oral Maxillofac Implants*. 2000;15:209–218.
22. Sakaguchi RI, Borgersen SE. Nonlinear finite element contact analysis of dental implant components. *Int J Oral Maxillofac Implants*. 1993;8:655–661.
23. Boggan RS, Strong JT, Misch CE, Bidez MW. Influence of hex geometry and prosthetic table width on static and fatigue strength of dental implants. *J Prosthet Dent*. 1999;82:436–440.
24. Quirynen M, Bollen C, Eysen H, Van Steenberghe D. Microbial penetration along the implant components of the Branemark system. An in vitro study. *Clin Oral Implants Res*. 1994;5:239–244.
25. Binon PP, Weir DJ, Marshall SJ. Surface analysis of an original Branemark implant and three related clones. *Int J Oral Maxillofac Implants*. 1992;7:168–175.
26. Tsuge T, Hagiwara Y, Matsumura H. Marginal fit and microgaps of implant-abutment interface with internal anti-rotation configuration. *Dent Mater J*. 2008;27:29–34.
27. Kano SC, Binon PP, Curtis DA. A classification system to measure the implant-abutment microgap. *Int J Oral Maxillofacial Implants*. 2007;22:879.
28. Carr AB, Brunski JB, Hurley E. Effects of fabrication, finishing, and polishing procedures on preload in prostheses using conventional “gold” and plastic cylinders. *Int J Oral Maxillofac Implants*. 1996;11:589–598.
29. Binon PP. Evaluation of three slip fit hexagonal implants. *Implant Dent*. 1996;5:235–248.
30. Guindy JS, Besimo CE, Besimo R, Schiel H, Meyer J. Bacterial leakage into and from prefabricated screw-retained implant-borne crowns in vitro. *J Oral Rehabil*. 1998;25:403–408.
31. Byrne D, Houston F, Cleary R, Claffey N. The fit of cast and premachined implant abutments. *J Prosthet Dent*. 1998;80:184–192.
32. Carvalho MBI, Costa E, Nishioka R, Bottino M, Neisser M. Fit microscope evaluation between implant and gold UCLA abutments and Teflon UCLA, casting in titanium and nickel–chromium–titanium: in vitro study. *BCI*. 2002;9:105–110.
33. Neves FPH, Fernandes Neto A, Prado R. Comparative study on the abutment implant fit of seven different systems. *J Dent Res*. 2001;80:1031.
34. Vigolo P, Majzoub Z, Cordioli G. Measurement of the dimensions and abutment rotational freedom of gold-machined 3i UCLA-type abutments in the as-received condition, after casting with a noble metal alloy and porcelain firing. *J Prosthet Dent*. 2000;84:548–553.
35. Barbosa GAS, Simamoto Júnior PC, Fernandes Neto AJ, Mattos MGC, Neves FD. Prosthetic laboratory influence on the vertical misfit at the implant/UCLA abutment interface. *Braz Dent J*. 2007;18:2.
36. Kano SC, Binon P, Bonfante G, Curtis DA. Effect of casting procedures on screw loosening in UCLA type abutments. *J Prosthodont*. 2006;15:77–81.
37. Kano SC, Binon PP, Bonfante G, Curtis DA. The effect of casting procedures on rotational misfit in castable abutments. *Int J Oral Maxillofac Implants*. 2007;22:575–579.
38. do Nascimento C, Barbosa RE, Issa JP, Watanabe E, Ito IY, Albuquerque RF Jr. Bacterial leakage along the implant-abutment interface of premachined or cast components. *Int J Oral Maxillofac Surg*. 2008;37:177–180.
39. do Nascimento C, Barbosa RE, Issa JP, Watanabe E, Ito IY, de Albuquerque Junior RF. Use of checkerboard DNA-DNA hybridization to evaluate the internal contamination of dental implants and comparison of bacterial leakage with cast or premachined abutments. *Clin Oral Implants Res*. 2009;20:571–577.