THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Misfit simulation on implant prostheses with different combinations of engaging and nonengaging titanium bases. Part 1: Stereomicroscopic assessment of the active and passive fit

Vygandas Rutkunas, DDS, PhD,[a] Julius Dirse, DDS, MDSc,[b] Daniel Kules, DDS,[c] and Tomas Simonaitis, BDSc[d]

ABSTRACT

Statement of problem. Little is known about whether the misfit level of implant-supported screw-retained prostheses can be tolerated when different combinations of engaging and nonengaging titanium bases are used.

Purpose. The purpose of this in vitro study was to simulate prosthetic workflow distortions (horizontal and vertical) and to evaluate the fit (passive and active) of 2-implant-supported screw-retained zirconia frameworks with 3 different combinations of abutments: both engaging, engaging and nonengaging, and both nonengaging.

Material and methods. The fit of both engaging (n=10), engaging and nonengaging (n=10), and both nonengaging (n=10) 2-implant-supported zirconia frameworks was evaluated on control and definitive casts simulating 50-, 100-, and 150-μm vertical and 35-, 70-, 100-μm horizontal misfit levels. Stereomicroscopy was used to assess the passive fit (1 screw tightened) and active fit (both screws tightened) of the zirconia frameworks. Vertical deviations in the implant and abutment connection (the implant-abutment gap measured vertically) between the implant platform and reference line on the titanium base were measured. The Kruskal-Wallis and Mann-Whitney U tests (α=.05) were used to compare different implant-supported zirconia specimens on each definitive cast.

Results. When 1 screw was tightened, both engaging specimens had higher vertical deviations (ranging from 40.1 to 131.1 μm) in 35- and 70-μm horizontal misfit levels, as compared with engaging and nonengaging (19.8 to 85.1 μm) and both nonengaging (6.6 to 14.3 μm) specimens. Comparing medians of the 100-μm misfit in horizontal (engaging and nonengaging 140.4 μm; both nonengaging 151.6 μm) and vertical (engaging and nonengaging 49.8 μm; both nonengaging 42.6 μm) directions, the horizontal misfits caused larger vertical deviations. When both screws were tightened in 50-, 100-, and 150-μm vertical misfit groups, the vertical gap increase in the engaging and nonengaging specimens was significantly higher than that in both the nonengaging specimens (P<.001).

Conclusions. As the level of simulated misfit increased, the vertical gap between the implant and abutment increased. Horizontal misfits were less tolerated than vertical ones and may be more detrimental. Both nonengaging 2-implant-supported zirconia frameworks were found to tolerate the different misfit levels better, followed by engaging and nonengaging and both engaging frameworks. (J Prosthet Dent 2022;■:■-■)

Oral rehabilitation with implant-supported fixed partial dentures (FPDs) has been considered a highly successful therapeutic option for partially edentulous patients.[1,2] The predictability and long-term success of this treatment method depend on the accuracy of the prosthodontic workflow and the 3-dimensional fit of the prosthesis and prosthetic components.[3-6] A misfit can cause internal stresses in the prosthesis, implants, and

Funding: Supported in part by the Lithuanian Business Support Agency, grant #J05-LVPA-K-01-0055.
[a]Professor, Department of Prosthodontics, Institute of Odontology, Faculty of Medicine, Vilnius University, Vilnius, Lithuania.
[b]Postgraduate student, Institute of Odontology, Faculty of Medicine, Vilnius University, Vilnius, Lithuania.
[c]Undergraduate student, Institute of Odontology, Faculty of Medicine, Vilnius University, Vilnius, Lithuania.
[d]CAD-CAM Specialist, Digitorum LAB and Research Center, Vilnius, Lithuania.

Clinical Implications

Providing engaging abutments with implants as part of a 2-implant-supported prosthesis increases sensitivity to small distortions that occur during the prosthetic workflow and can therefore lead to a less-than-optimal fit.

tissues surrounding the implant,[7-11] which can contribute to screw loosening and deformation; fracturing of the screw, implant, or prosthesis; peri-implantitis; bone loss; and other adverse effects.[3,12-14] One of the main differences between cement- and screw-retained implant-supported FPDs is that cement-retained implant-supported FPDs can compensate for some misfit because of the cement layer.[15] Thus, the detection of any misfit in screw-retained FPDs is essential for the prevention of biological and technical complications.

Although different definitions have been published, the term "passive fit" is usually used to describe the ideal fit of the prosthetic framework to the implant when the opposing surfaces of the implants and the framework intaglio are in maximal spatial congruency without the generation of any stress.[3] However, a completely passive fit is almost impossible to achieve because of errors that may occur in each clinical and laboratory step.[16-21] The term "active fit" refers to the fit of a prosthetic framework at the definitive position, with all screws tightened.[3] However, a threshold for a clinically acceptable misfit has not been determined 3 although up to 150 μm of misfit has been considered as clinically acceptable.[22,23] While the degree of tolerable misfit remains unclear, clinicians should aim to achieve the greatest accuracy possible.

Various techniques have been introduced to assess prosthesis fit although no single method has been universally accepted.[24] During the clinical evaluation, the framework fit can be evaluated visually, tactilely, radiographically, or with a specific test such as the 1-screw (Sheffield) test or the screw resistance test.[24] All currently used clinical methods, however, are subjective, have many variables, and are dependent on the operator's skill.[25,26] These limitations can be overcome by combining available fit-assessment methods.

Internal connection implants can be used with engaging or nonengaging abutments. Nonengaging abutments of internal connection implants are indicated for multiple-unit implant-supported screw-retained FPDs because they can be used with nonparallel implants.[27,28] Engaging abutments are recommended for single crowns but can also be used with FPDs when implants are placed almost parallel.[29] Engaging abutments can also be combined with nonengaging abutments to increase the stability of FPDs.[30,31] This strategy might have a positive impact on the fit of the prosthesis and may improve the long-term integrity of the implant-abutment junction.[27] Scientific evidence supporting this approach is lacking, however, and further clinical and laboratory investigations are needed.

The authors are unaware of a study investigating how the engaging and nonengaging combinations of abutments can tolerate different misfits. Therefore, the aim of the present study was to simulate prosthetic workflow distortions (horizontal and vertical) and to evaluate the fit (passive and active) of 2-implant-supported screw-retained zirconia frameworks with 3 different combinations of abutments: both engaging, engaging and nonengaging, and both nonengaging. The null hypothesis was that the combination of abutments of 2-implant-supported screw-retained frameworks would not affect passive or active fit after simulating different vertical and horizontal misfits.

MATERIAL AND METHODS

The sample size for the present study was determined after a pilot study (n=5) from which a power analysis was performed with a software program (G*Power 3.1.9.2; Heinrich Heine-University). The effect size was 0.848 at 95% power; therefore, the minimum sample size for the study was 27 frameworks. As such, 10 specimens were used for each group.

A micromechanical custom-made stand (Standa 106263; Standa Ltd) (Fig. 1) containing 2 translation platforms and handles was used to modify the positions of the platforms in the vertical (y) and horizontal (x) directions with a tracking accuracy of 2 μm. Each micromechanical stand platform had a hole, which was used to attach 2 dummy implants (Conelog Screw-Line; Camlog Biotechnologies AG), Ø4.3×13 mm with 7.5-degree internal connection, with autopolymerizing acrylic resin (Pattern Resin LS; GC Corp). To simulate a mandibular second premolar-to-second molar restoration, implants were fixed with a distance of 22 mm between the centers of the top plane of the implants at 10 degrees to each other.

After implant fixation, 2 scan bodies (Conelog; Camlog Biotechnologies AG) were attached to the implants. The situation was scanned with a laboratory scanner (E4; 3Shape A/S). By using a computer-aided design and computer-aided manufacturing (CAD-CAM) standardized process, identical bar-shaped screw-retained FPD frameworks (n=30) were fabricated as follows: 10 with 2 engaging titanium (Ti) bases (E-E group), 10 with 1 engaging and 1 nonengaging Ti bases (E-NE group), and 10 with 2 nonengaging Ti bases (NE-NE group). For all frameworks, Ø4.3×2-mm Ti bases (Conelog) were used. Zirconia (Katana Zirconia HT; Kuraray

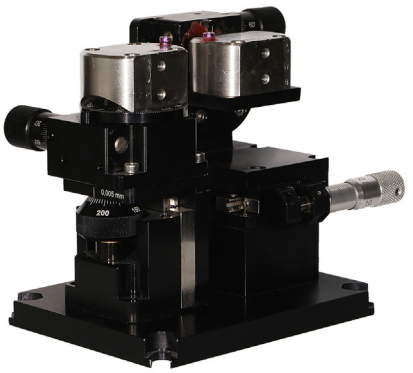

Figure 1. Micromechanical custom-made stand.

Noritake Dental Inc) was used to fabricate the frameworks according to the manufacturer's recommendations.

To create a control cast, 2 engaging Ti bases were cemented to the first framework ("zero" framework) without a cast (freehand) with the aid of a microscope (Mobiloskop S; Renfert GmbH), ensuring the best fit between the framework and the Ti bases (Fig. 2). Next, 2 dummy implants were attached to the "zero" framework (20 Ncm), and a control cast was created by using Type IV dental stone (GC Fujirock EP; GC Corp). The remaining 29 frameworks were cemented to dedicated Ti bases by using the same control cast to ensure an identical fit. The junctions between the zirconia and the Ti bases for each of the 30 frameworks were cemented with an adhesive luting system (Multilink Automix; Ivoclar AG) and were then polished and cleaned according to the recommendations of the cement manufacturer.

Two new dummy implants were attached to the "zero" framework and were then attached to the holes in the platforms of the micromechanical stand with autopolymerizing acrylic resin (Pattern Resin LS; GC Corp). This position represented a passive fit (control group). After the "zero" framework was removed, the misfit was simulated by 50 μm in the vertical (V) direction by using the micromechanical stand. Then, 2 Ø4.3-mm open tray impression transfers (engaging) (Conelog; Camlog Biotechnologies AG) were fixed on the implants and connected together with dental floss (Oral-B Essential Floss; Procter & Gamble) and autopolymerizing resin. To reduce shrinkage, the splint was sectioned with a thin disk and reconnected with a small amount of resin after 30 minutes. Two actual implants (Conelog Screw-Line; Camlog Biotechnologies AG), Ø4.3×13 mm, were attached to the splinted transfers, and a definitive cast simulating the vertical misfit of 50 μm (V50 group) was fabricated with Type IV dental stone (GC Fujirock EP; GC Corp) (Fig. 3). In this same manner, definitive casts simulating 100- and 150-μm vertical (V100 and V150

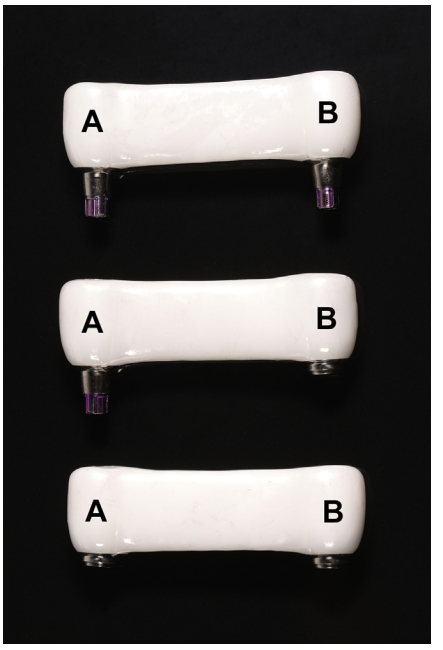

Figure 2. Zirconia framework cemented on titanium bases: top, E-E group; middle, E-NE group; bottom, NE-NE group. A and B denote different measurement sites. E, engaging; NE, nonengaging.

groups) and 35-, 70-, and 100-μm horizontal (H) misfits (H35, H70, and H100 groups) were fabricated.

Scan bodies were placed on the definitive and control casts and were scanned with a laboratory scanner (E4; 3Shape A/S) to verify the simulated level of misfit. Standard tessellation language (STL) files of the definitive casts were superimposed with the STL data of the control cast by using a software program (Geomagic Control X; 3D systems Inc), which confirmed that the simulated misfit error for each definitive cast was less than 10 μm.

Three types of zirconia specimens (E-E, E-NE, and NE-NE) were evaluated blindly by an experienced prosthodontist (V.R.) by using the control and definitive casts according to the criteria of obvious imbalance and incomplete seating, strong resistance felt during insertion with or without clicking, or a steep increase in the screw resistance felt from the beginning of the screw tightening. Based on these criteria, it was decided to exclude E-E specimens from the H100 and V50, V100, and V150 simulated misfit groups, as nonpassive fit was obvious in these scenarios.

A stereo microscope (Crystal-45; Konus Corp) was used to evaluate the active and passive fits of the zirconia specimens. Images were obtained at ×20 magnification with a camera (CMEX-10 Pro; Euromex Microscopen BV), and an image analysis software program (ImageFocus Alpha; Euromex Microscopen BV) was used for measurements. A 1-screw (Sheffield) test was used to evaluate the passive fit of the specimens in the control

Figure 3. Definitive cast made from Type IV dental stone.

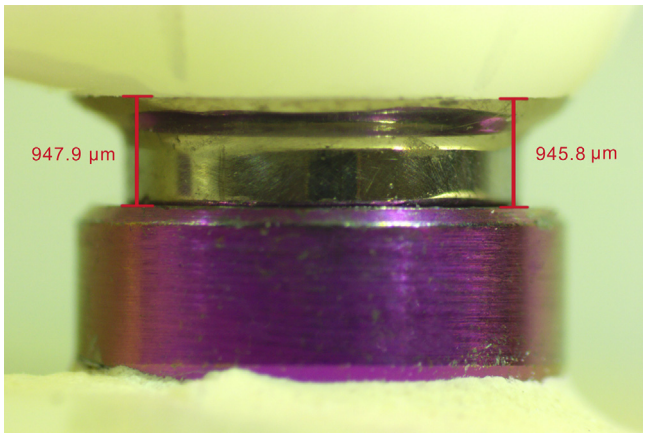

Figure 4. Distance between 2 parallel lines measured with stereo microscope.

and misfit groups. For all zirconia FPDs, the sides were marked A and B on the left and right, respectively. For each E-NE specimen, the engaging Ti base was on side A, and the nonengaging base was on side B. The abutment screw on side A was tightened to 10 Ncm, while the abutment located on side B was left without a screw. Images of the current position (passive fit) were obtained from the buccal and lingual sides of the side B implant by using a stereo microscope. After the 1-screw test, the abutment screws were tightened to 20 Ncm on both implants. The active fit was evaluated by capturing microscopic images of the buccal and oral aspects of sides A and B in this position. New screws were used for each specimen.

A trained and blinded investigator (D.K.) analyzed all the images captured and made measurements at 4 specific locations on each implant: mesiolingual (ML), distolingual (DL), mesiobuccal (MB), and distobuccal (DB). Two lines were drawn, parallel to the implant platform and titanium base-zirconia interface, and the distance between the lines was measured (Fig. 4). Measurements from the 4 specific locations on side B were used for the passive fit assessment, whereas for the active fit assessments, the measurements for all 8 locations, 4 from each implant, were analyzed. Root mean squared (RMS) values of the calculated differences between each definitive (H35, H70, H100, V50, V100, V150) and control cast for each point were used. The calculated vertical deviations were considered the vertical gaps between the implants and the abutments.

The active and passive fit values were compared among the specimens (E-E, E-NE, and NE-NE) of the various misfit groups. The Shapiro-Wilk test was used to determine whether the data were normally distributed. As the variables did not show a normal distribution, the median (Mdn), interquartile range (IQR), and minimum and maximum values in µm were calculated for each group. The Kruskal-Wallis test, with the post hoc Dunn and Mann-Whitney U tests, was used to compare the different implant-supported zirconia specimens (E-E, E-NE, NE-NE) on each definitive cast (H35, H70, H100, V50, V100, V150), except for the groups that were excluded after the initial assessment (H100, V50, V100, V150 groups with E-E FPDs). The Wilcoxon signed-rank test was used to compare zirconia specimens at different levels of misfit. A software package (R v.4.0.3; University of Auckland) was used for statistical calculations (α=.05).

RESULTS

From the assessment of passive fit, the E-E specimens had larger vertical deviations (increases in the vertical implant-abutment gap) in the H35 and H70 groups than in the E-NE and NE-NE specimens (Table 1, Fig. 5A). Additionally, larger vertical deviations were observed in the E-NE specimens than in the NE-NE specimens at all levels of the simulated misfit, except for the H100 and V150 misfit groups. Overall, an increase in the vertical gap was observed with an increase in the simulated misfit. Comparing the groups of 100-µm misfit in the horizontal (Mdn E-NE=140.4 µm; Mdn NE-NE=151.6 µm) and vertical (Mdn E-NE=49.8 µm; Mdn NE-NE=42.6 µm) directions, misfits in the horizontal direction were less tolerated. The Wilcoxon signed-rank test indicated that this difference was statistically significant: T(E-NE)=0, P<.001, T(NE-NE)=0, P<.001.

The results of the active fit (both screws tightened) are presented in Table 2 and Figure 5B. Vertical deviations for active fit were higher in the group with a 100-µm misfit simulated in the vertical direction (Mdn E-NE=10.2 µm) than in the group where it was simulated in the horizontal direction (Mdn E-NE=7.0 µm). The Wilcoxon signed-rank test indicated that this difference was statistically significant: T(E-NE)=2320, P<.001. In the V50, V100, and V150 misfit groups, the increase in the vertical gap of the E-NE specimens was significantly higher than that of the NE-NE specimens (P<.001). When the misfit

Table 1. Median, IQR, minimum, and maximum values (μm) of vertical gap increase in different groups (each group n=40, 10 frameworks measured at 4 locations each) when evaluating passive fit

	Median (IQR)			Min-Max			Kruskal-Wallis/Mann-Whitney U	
Passive Fit	**E-E**	**E-NE**	**NE-NE**	**E-E**	**E-NE**	**NE-NE**	**H/W Value**	***P***
H35	40.1 (32.0-49.8)[a]	19.8 (13.7-23.9)[b]	6.6 (4.6-11.9)[c]	17.0-69.0	0.4-38.5	1.5-18.0	82.18	<.001
H70	131.1 (119.2-137.1)[a]	85.1 (81.6-88.6)[b]	14.3 (8.5-22.6)[c]	109.5-153.0	69.9-93.3	1.7-35.5	105.79	<.001
H100	–	140.4 (134.4-146.3)	151.6 (141.9-163.3)	–	121.5-158.4	131.3-176.1	1247	<.001
V50	–	24.9 (21.7-26.3)	11.6 (8.3-17.5)	–	12.4-30.1	0.2-23.7	117	<.001
V100	–	49.8 (46.8-52.3)	42.56 (36.4-52.0)	–	37.7-55.5	26.5-63.5	502	.004
V150	–	66.8 (63.2-68.9)	86.55 (82.5-92.3)	–	54.5-75.7	79.6-100.5	1600	<.001

E, engaging; H, horizontal; IQR, interquartile range; max, maximum; min, minimum; NE, nonengaging; V, vertical. Different superscript lowercase letters in same row indicate Dunn test significant differences among different abutment combinations (*P*<.001).

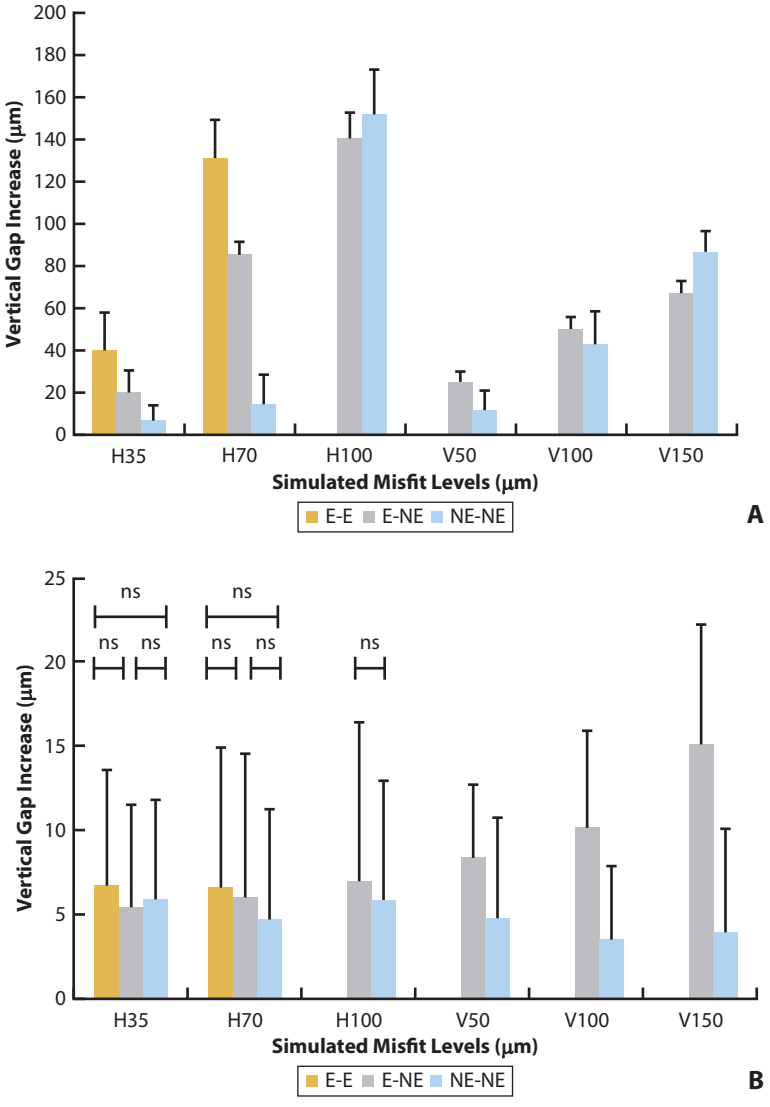

Figure 5. Fit comparisons (median and interquartile range) between groups with different abutment combinations (E-E, E-NE, NE-NE) and simulated misfit levels (H35, H70, H100, V50, V100, V150). A, Passive fit. B, Active fit. E, engaging; H, horizontal; NE, nonengaging; NS, nonsignificant (*P*>.05) differences; V, vertical.

Table 2. Median, IQR, minimum, and maximum values (μm) of vertical gap increase in different groups (each group n=80, 10 frameworks measured at 8 locations each) when evaluating active fit

	Median (IQR)			Min-Max			Kruskal-Wallis/Mann-Whitney U	
Active Fit	E-E	E-NE	NE-NE	E-E	E-NE	NE-NE	H/W Value	*P*
H35	6.8 (3.3-10.2)[a]	5.4 (2.7-8.8)[a]	5.9 (2.5-8.5)[a]	0-19.9	0.1-20.8	0-18.3	1.67	.43
H70	6.6 (3.5-11.8)[a]	6.1 (2.3-10.8)[a]	4.8 (1.7-8.2)[a]	0-17.6	0-23.6	0-22.9	5.81	.055
H100	–	7.0 (3.2-12.7)	5.8 (2.6-9.7)	–	0-21.7	0.1-18.6	2789	.16
V50	–	8.4 (6.2-10.5)	4.8 (1.8-7.8)	–	1.4-20.1	0.1-15.6	1666	<.001
V100	–	10.2 (7.5-13.3)	3.5 (1.4-5.7)	–	1.9-23.7	0-16.7	849	<.001
V150	–	15.1 (11.8-19.0)	3.9 (1.4-7.6)	–	5.8-37.1	0.2-15.1	383	<.001

E, engaging; H, horizontal; IQR, interquartile range; max, maximum; min, minimum; NE, nonengaging; V, vertical. Different superscript lowercase letters in same row indicate Dunn test significant differences among different abutment combinations (*P*<.001).

was simulated in the horizontal direction, no significant difference was observed between the zirconia specimen groups.

DISCUSSION

The results of the present study showed that the abutment combination (E-E, E-NE, and NE-NE) can affect the passive and active fits differently when distortions occur in the horizontal and vertical directions. Therefore, the null hypothesis was rejected. Of the tested abutment combinations, NE-NE specimens were least affected by the vertical and horizontal misfits tested, while the most affected were E-E specimens, for which the nonpassive fit was clear. Therefore, the H100 and V50/100/150 misfit groups for the E-E specimen group were not evaluated. The lack of nonpassive fit can be explained by the fact that engaging abutments are inserted deeper into the internal connection of the implant. Additionally, the presented study simulated a 10-degree angle between the implants, a discrepancy that could further complicate the seating of this type of abutment. The authors are unaware of a previous study that compared the tolerance of different abutment types to a variety of misfit levels. Therefore, a direct comparison with other studies was not possible.

Few studies have evaluated the effects of using different abutment combinations with internal connection implant FPDs (E-E, E-NE, and NE-NE) on the passive fit.[29-31] Even though in the present study 2-implant-supported frameworks with NE-NE abutments showed the highest tolerance to a simulated misfit, this particular abutment combination has been reported to cause higher stress and strain in the implant-abutment interface and cortical bone, followed by frameworks with E-NE and E-E abutments.[29,31] This difference may be attributed to the decreased extension of NE abutments into the internal connection of the implant.[31] These studies[29,31] investigated different types of abutment combinations in the complete passive fit situation, but, in clinical situations, a completely passive fit of the prosthetic framework is almost impossible to achieve.[16,17] Also previous studies investigated framework fit on parallel implants, or on implants angled up to 5 degrees.[29-31] Different implant angles should be investigated, as it is difficult to place implants completely parallel in clinical practice.[20]

Microscopy has been used to evaluate the fit of partial or complete arch implant-supported fixed prostheses connected to external connection implants or multiunit abutments.[4-6,18,19,21] Under standardized conditions, microscopy measurements can be comparable and moderately accurate.[24] The mean vertical gap has been reported to be reduced from 100 to 120 μm to 5 to 10 μm if the 1-screw test is replaced with the definitive fit (active fit) test for misfit assessment.[6,18,19] Unfortunately, studies that evaluated the fit of FPDs on internal conical connection implants by using this technique are lacking. A decrease, however, in the vertical gap was also observed during active fit testing in the current study. Moreover, frameworks with NE-NE abutments were able to adapt better than the frameworks with E-NE and E-E abutments, since the vertical gaps were reduced from 150 μm to 5 μm after tightening all screws. This phenomenon of mimicking the accurate framework may depend on the implant-abutment interface and/or machining tolerances of the components [14,27] or may be from microdeformations of the screws, abutments, implants, framework, and/or model representing bone.[18,29]

The results of the present study indicated that the vertical gap increased with an increase in misfit level. The same trend was observed in finite element analysis (FEA) studies of internal conical connection implants,[7-9] where, with increased levels of misfit, the stress levels in the peri-implant bone and prosthesis increased in the direction of the misfit. When comparing equivalent horizontal and vertical misfits in the present study, horizontal misfits caused a larger vertical gap than vertical misfits, suggesting that horizontal misfits may be more detrimental. Although no direct comparisons can be made, other FEA studies, which tested different misfits on 2 external connection implants, also reported that vertical

misfit may be less detrimental than horizontal.[10,12,13] Moreover, Winter et al[10] reported that an angular misfit was the most detrimental, although Manzella et al[11] reported that vertical misfits were more detrimental than horizontal misfits on 4- to 6-implant multiunit abutments, suggesting that the horizontal displacement of each multiunit was within the range of the machining tolerances.

The present study design included horizontal (50, 100, 150 μm) and vertical (50, 100, 150 μm) distortions. These displacement values have been used previously to assess the impact on passive fit.[7,11] During the pilot study, it was not possible, however, to place the zirconia FPDs on a cast simulating a horizontal 150-μm misfit. Therefore, horizontal misfits were only simulated up to 100 μm. The effects of a simulated horizontal 200-μm misfit on FPDs with internal conical connection implants have been reported.[9] The ability to insert a prosthesis with such a high misfit can be explained by the fact that Astra Tech implants with an 11-degree conical connection were used, whereas, in the present study, Conelog implants with a 7.5-degree conical connection were used. Additionally, titanium fixed prosthesis-type frameworks (Atlantis Superstructures; Dentsply Sirona) were evaluated in the previous study, which allowed more freedom in the implant abutment connection than in the original abutments.[5,32]

Marginal gaps ranging from 10 μm to 150 μm have been reported to be clinically acceptable in the long term.[22,23] However, the degree of tolerable misfit remains unclear because of the lack of clinical studies.[3] In a recent review, a gap less than 25 μm at the interface (vertical or horizontal) was proposed to be clinically acceptable for 3-unit FPDs after assessment with the 1-screw test.[3] According to this threshold of clinical acceptance and the results of the present study, horizontal and vertical distortions in the prosthetic workflow for the NE-NE 3-unit framework should be less than 70 μm and 50 μm, respectively, while for the E-NE 3-unit framework, they should be 35 μm and 50 μm, respectively. For the E-E 3-unit framework, no acceptable threshold of prosthetic workflow distortion was determined, so they are less recommended for use with FPDs supported by 2 or more moderately angled implants.

Limitations of the present study included that an implant system (Conelog Screw-Line) with a 7.5-degree conical connection was used, while other implant systems may have a larger or smaller conical connection. Higher degree of conical connection may increase tolerance for various misfits. Furthermore, the present study investigated frameworks' fit on implants angled at 10 degrees to each other, while in clinical practice, the angulation between implants could be smaller or larger. Another limitation was that the present study investigated horizontal and vertical misfits separately, while in clinical practice, usually 3D misfit error occurs. In this study, the same zirconia frameworks and casts were used for all 3 groups (E-E, E-NE, NE-NE specimens), and a possible limitation could be wear of the titanium bases and implants. This potential limitation is, however, not considered to have any significant effect on the results, as the situation was the same in all 3 groups. Further research is needed to estimate the effects of implant angulation and number, connection, and abutment type on the level of misfit that can be tolerated to prevent biological and technical complications.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. With an increased level of simulated misfit, there is a subsequent increase in the vertical gap between the implant and abutment.
2. Horizontal misfits caused larger vertical gaps than vertical misfits and should, therefore, be regarded as more detrimental.
3. Both nonengaging abutment combination tolerated different misfit levels best, followed by engaging and nonengaging and both engaging combinations, as a result of which the both engaging combination is less recommended for 2-implant-supported FPDs because of extreme sensitivity to the small distortions occurring with that prosthetic workflow.

REFERENCES

1. Chappuis V, Buser R, Brägger U, Bornstein MM, Salvi GE, Buser D. Long-term outcomes of dental implants with a titanium plasma-sprayed surface: a 20-year prospective case series study in partially edentulous patients. Clin Implant Dent Relat Res 2013;15:780-90.
2. Srinivasan M, Meyer S, Mombelli A, Müller F. Dental implants in the elderly population: a systematic review and meta-analysis. Clin Oral Implants Res 2017;28:920-30.
3. Katsoulis J, Takeichi T, Sol Gaviria A, Peter L, Katsoulis K. Misfit of implant prostheses and its impact on clinical outcomes. Definition, assessment and a systematic review of the literature. Eur J Oral Implantol 2017;10:121-38.
4. da Cunha Fontoura D, de Magalhães Barros V, de Magalhães CS, Vaz RR, Moreira AN. Evaluation of vertical misfit of CAD/CAM implant-supported titanium and zirconia frameworks. Int J Oral Maxillofac Implants 2018;33:1027-32.
5. Katsoulis J, Mericske-Stern R, Rotkina L, Zbaren C, Enkling N, Blatz MB. Precision of fit of implant-supported screw-retained 10-unit computer-aided-designed and computer-aided-manufactured frameworks made from zirconium dioxide and titanium: an in vitro study. Clin Oral Implants Res 2014;25:165-74.
6. de França DGB, Morais MHST, das Neves FD, Barbosa GAS. Influence of CAD/CAM on the fit accuracy of implant-supported zirconia and cobalt-chromium fixed dental prostheses. J Prosthet Dent 2015;113:22-8.
7. Janda M, Larsson C, Mattheos N. Influence of misfit on the occurrence of porcelain veneer fractures in implant-supported metal-ceramic fixed dental prostheses. Part 2: a three-dimensional finite element analysis. Int J Prosthodont 2021;34:458-62.
8. Jimbo R, Halldin A, Janda M, Wennerberg A, Vandeweghe S. Vertical fracture and marginal bone loss of internal-connection implants: a finite element analysis. Int J Oral Maxillofac Implants 2013;28:e171-6.
9. Toia M, Stocchero M, Jinno Y, Wennerberg A, Becktor JP, Jimbo R, et al. Effect of misfit at implant-level framework and supporting bone on internal connection implants: mechanical and finite element analysis. Int J Oral Maxillofac Implants 2019;34:320-8.
10. Winter W, Mohrle S, Holst S, Karl M. Bone loading caused by different types of misfits of implant-supported fixed dental prostheses: a three-dimensional

finite element analysis based on experimental results. Int J Oral Maxillofac Implants 2010;25:947-52.
11. Manzella C, Bignardi C, Burello V, Carossa S, Schierano G. Method to improve passive fit of frameworks on implant-supported prostheses: an in vitro study. J Prosthet Dent 2016;116:52-8.
12. Spazzin AO, Dos Santos MBF, Sobrinho LC, Consani RLX, Mesquita MF. Effects of horizontal misfit and bar framework material on the stress distribution of an overdenture-retaining bar system: a 3D finite element analysis. J Prosthodont 2011;20:517-22.
13. Spazzin AO, Abreu RT, Noritomi PY, Consani RLX, Mesquita MF. Evaluation of stress distribution in overdenture-retaining bar with different levels of vertical misfit. J Prosthodont 2011;20:280-5.
14. Gil FJ, Herrero-Climent M, Lázaro P, Rios JV. Implant-abutment connections: influence of the design on the microgap and their fatigue and fracture behavior of dental implants. J Mater Sci Mater Med 2014;25:1825-30.
15. Wittneben J-G, Joda T, Weber H-P, Brägger U. Screw retained vs. cement retained implant-supported fixed dental prosthesis. Periodontol 2000 2017;73:141-51.
16. Arcuri L, Pozzi A, Lio F, Rompen E, Zechner W, Nardi A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: a randomized in vitro trial. J Prosthodont Res 2020;64:128-36.
17. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004;15:466-73.
18. Abduo J, Lyons K. Effect of vertical misfit on strain within screw-retained implant titanium and zirconia frameworks. J Prosthodont Res 2012;56:102-9.
19. Berejuk HM, Shimizu RH, de Mattias Sartori IA, Valgas L, Tiossi R. Vertical microgap and passivity of fit of three-unit implant-supported frameworks fabricated using different techniques. Int J Oral Maxillofac Implants 2014;29:1064-70.
20. Mayer Y, Machtei E. Divergence correction associated with implant placement: a radiographic study. Int J Oral Maxillofac Implants 2009;24:1033-9.
21. Kioleoglou I, Pissiotis A, Konstantinos M. Accuracy of fit of implant-supported bars fabricated on definitive casts made by different dental stones. J Clin Exp Dent 2018;10:e252-63.
22. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991;6:270-6.
23. Brånemark PI. Osseointegration and its experimental background. J Prosthet Dent 1983;50:399-410.
24. Abduo J, Bennani V, Waddell N, Lyons K, Swain M. Assessing the fit of implant fixed prostheses: a critical review. Int J Oral Maxillofac Implants 2010;25:506-15.
25. Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. J Prosthet Dent 1999;81:7-13.
26. Hayashi M, Watts DC, Ebisu S, Wilson NHF. Influence of vision on the evaluation of marginal discrepancies in restorations. Oper Dent 2005;30:598-601.
27. Schoenbaum TR, Stevenson RG, Balinghasay E. The hemi-engaging fixed dental implant prosthesis: a technique for improved stability and handling. J Prosthet Dent 2018;120:17-9.
28. Choi J-H, Lim Y-J, Yim S-H, Kim C-W. Evaluation of the accuracy of implant-level impression techniques for internal-connection implant prostheses in parallel and divergent models. Int J Oral Maxillofac Implants 2007;22:761-8.
29. Epprecht A, Zeltner M, Benic G, Özcan M. A strain gauge analysis comparing 4-unit veneered zirconium dioxide implant-borne fixed dental prosthesis on engaging and non-engaging abutments before and after torque application. Clin Exp Dent Res 2018;4:13-8.
30. Dogus SM, Kurtz KS, Watanabe I, Griggs JA. Effect of engaging abutment position in implant-borne, screw-retained three-unit fixed cantilevered prostheses. J Prosthodont 2011;20:348-54.
31. Savignano R, Soltanzadeh P, Suprono MS. Computational biomechanical analysis of engaging and nonengaging abutments for implant screw-retained fixed dental prostheses. J Prosthodont 2021;30:604-9.
32. Tallarico M, Fiorellini J, Nakajima Y, Omori Y, Takahisa I, Canullo L. Mechanical outcomes, microleakage, and marginal accuracy at the implant-abutment interface of original versus nonoriginal implant abutments: a systematic review of in vitro studies. Biomed Res Int 2018;2018:2958982.

Corresponding author:
Prof Vygandas Rutkunas
Department of Prosthodontics
Institute of Odontology
Faculty of Medicine
Vilnius University
115 Žalgirio St, Vilnius LT-08217
LITHUANIA
Email: vygandasr@gmail.com

Acknowledgments
The authors thank the Institute of Photonics and Nanotechnology of Vilnius University for providing the stereomicroscope and useful methodological advice.

CRediT authorship contribution statement
Vygandas Rutkunas: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – review & editing, Visualization, Supervision, Project administration. **Julius Dirse:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **Daniel Kules:** Investigation, Data curation, Writing – original draft, Visualization. **Tomas Simonaitis:** Specimen preparation, Investigation.

https://doi.org/10.1016/j.prosdent.2022.04.009