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RESEARCH AND EDUCATION

Misfit simulation on implant prostheses with different combinations of engaging and nonengaging titanium bases. Part 2: Screw resistance test

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ABSTRACT

Statement of problem. Prosthesis fit is 1 of the main factors influencing the success and survival of an implant-supported screw-retained restoration. However, scientific validation of the performance of engaging and nonengaging components in a fixed partial denture (FPD) and the effect of their combinations on the fit of FPDs is lacking. The screw resistance test has been used for the fit assessment of screw-retained FPDs. However, objective assessments by using analog and digital devices are now available.

Purpose. The purpose of this in vitro study was to investigate the effect of engaging and nonengaging components on the fit of screw-retained frameworks, supported by 2 conical connection implants with simulated vertical and horizontal misfits, by performing 2 different screw resistance tests (analog and digital).

Material and methods. Thirty 2-implant-supported bar-shaped zirconia frameworks cemented on two 2-mm titanium bases were fabricated and divided into 3 groups (n=10) according to different abutment combinations: both engaging, engaging and nonengaging, both nonengaging. The fit of each framework was tested on the control cast and on 6 definitive casts simulating 50-, 100-, and 150-μm vertical and 35-, 70-, and 100-μm horizontal misfit levels. The abutment screws were tightened on each implant, and the screw rotation angle was measured both digitally, with a custom-made digital torque wrench and a computer software program, and conventionally, with an analog torque wrench and protractor. Clearly ill-fitting specimens were excluded. The data were statistically analyzed by 1-way analysis of variance (ANOVA) and the Tukey post hoc test (α=.05).

Results. Both engaging specimens on the 100-μm horizontal misfit group and on all vertical misfit groups were clearly ill-fitting and excluded. Statistically significant differences among groups with different combinations of abutments were found (P<.05). The engaging abutments had a higher angle of rotation than the nonengaging abutments on all casts. In the horizontal misfit group, both engaging specimens had the highest angle of rotation, followed by engaging and nonengaging and both engaging specimens. In the vertical misfit group, the engaging and nonengaging specimens had the highest angle of rotation on the side of the engaging abutment. The angle of rotation increased with the increasing level of misfit.

Conclusions. Both nonengaging frameworks showed superiority in misfit tolerance, as the angle of rotation was lower than that of the engaging and nonengaging and both engaging frameworks. Conventional and digital torque wrenches showed similar results. (J Prosthet Dent 2024;131:262-71)

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Clinical Implications

The use of an engaging abutment in implant-supported fixed partial dentures leads to an increased angle of rotation in the screw resistance test, which suggests a larger misfit.

The passive fit of implant-supported prostheses is critical to achieving a long-lasting outcome for dental implant treatment.[1] However, passive fit is a complex condition that may be poorly understood. The engineering definition of passive fit refers to the relative looseness (clearance) or tightness (interference) of the surfaces of the implants and the prosthetic component, which affects the motion of the parts or the force between them after assembly.[2] The term passive fit has also been defined as a condition which does not exert any stress or strain on the prosthetic components, implants, or peri-implant bone.[1] Nevertheless, the main condition of the ideal fit of the prosthetic framework to the implants is the absence of misfit.

Unfortunately, a complete passive fit of the prosthetic framework cannot be reached because of multiple errors that may occur in each clinical and laboratory step regardless of the method used to fabricate the framework.[3,4] Moreover, frameworks have been reported to deform even under optimal fit conditions.[5] Consequently, vertical, horizontal, angular, and rotational misfits of various magnitudes occur. A 150-µm misfit limit has been considered clinically acceptable to minimize the risk of biomechanical complications; however, this value has not been supported by strong scientific evidence.[2,6]

Achieving passive fit is challenging, especially with extensive multiple-implant-supported screw-retained fixed partial or complete dentures.[7-9] Moreover, passivity highly depends on the implant-abutment connection type and machining tolerances of the components.[10] External hexagon connections have been compared with internal hexagon connections in in vitro studies,[11,12] with a higher mean microgap between the walls of the abutment and the implant after cyclic loading being reported. Therefore, the external hexagon connection has been determined to be more prone to screw loosening, rotational misfit, and a less-effective microbial seal than internal connection implants.[13,14] Internal connections, in contrast, have been associated with a more stable implant-abutment interface but also require a more demanding clinical prosthetic workflow.[15]

Internal connection implants can be used with different abutment designs. Nonengaging abutments of internal connection implants are indicated for multiple-unit implant-supported screw-retained fixed partial dentures (FPDs) because of their better tolerances to higher implant angulations.[16,17] Engaging abutments are recommended for single crowns but, in practice, can be used for FPDs when implants are placed almost parallel.[18] Engaging abutments have also been combined with nonengaging abutments in clinical practice to increase the stability of FPDs.[10,19] This strategy can have a positive impact on the fit of the prosthesis and may improve the long-term integrity of the implant-abutment junction.[16] However, this approach lacks scientific evidence and needs more clinical and experimental investigations.

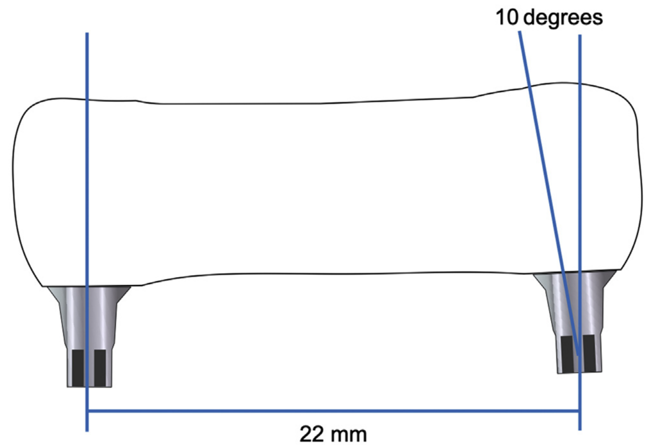

Figure 1. Schematic image of fixed partial denture.

The precision of fit between a framework and the supporting implants is difficult to assess clinically.[20] Various in vivo techniques have been introduced to assess the fit of the prosthesis, but all of them are subjective, have many variables, and are dependent on the operator's skills.[21,22] Moreover, the clinical inspection of an implant-abutment junction is difficult or even impossible when it is located subgingivally.[7] Thus, a convenient and objective technique which could be used daily in clinical practice is of considerable value.

One of the most promising techniques for evaluating the passive fit of the prosthetic framework on the implants is the screw resistance test. This technique can be used either in a conventional (analog) or a digital way. The first protocol of the screw resistance test, based on the assumption that 150 µm is an acceptable vertical discrepancy, was published by Jemt and Lie in 1995.[6] The protocol involved tightening every screw of the prosthetic framework individually until initial finger resistance was achieved. A misfit was diagnosed if more than half a turn of the conventional torque wrench was needed to tighten the screw from 10 to 15 Ncm.[6,7] The most recent digital update of the technique by Calderini et al[20] has allowed a more precise evaluation of the fit of the framework by measuring the torque and the angle of screw rotation simultaneously.[7] While tightening the screw with the

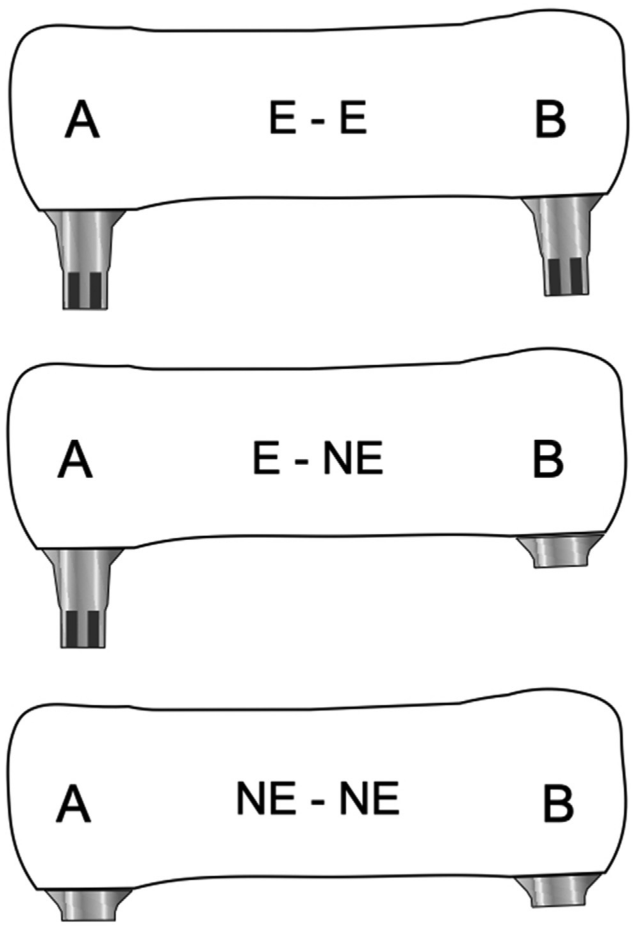

Figure 2. Schematic image of fixed partial denture with different Ti-bases.

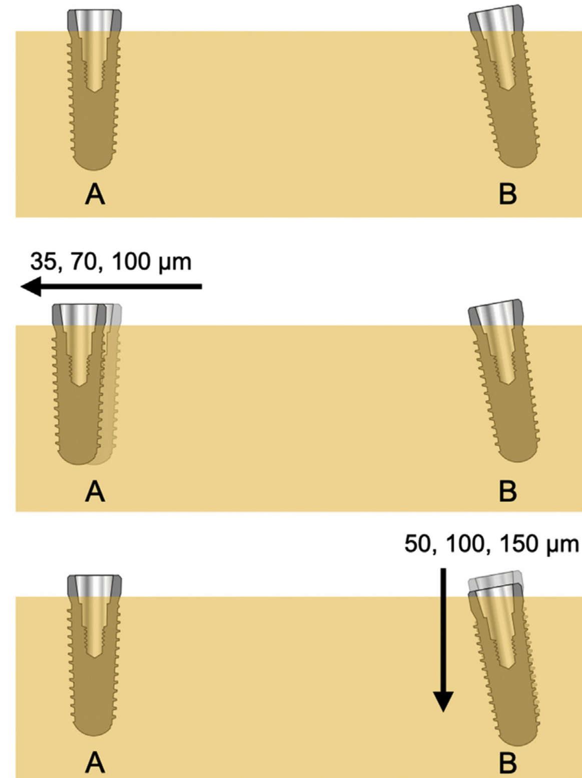

Figure 3. Schematic image of different misfit casts.

digital torque wrench, the computer software program monitors the torque changes and the angle of screw rotation to create torque-angle signatures. These signatures present the dynamics of the variables and reflect the fit of the framework. Therefore, this precise analysis can be used for an objective clinical assessment of the fit between a framework and implants, as well as by the dental laboratory technician.[20]

The authors are unaware of a study comparing the fit of implant-supported screw-retained prostheses with different combinations of engaging and nonengaging titanium bases (Ti-bases). Therefore, the aim of the study was to evaluate the influence of different abutment combinations (both engaging, engaging and nonengaging, and both nonengaging) on the fit of restorations with horizontal and vertical misfits by using 2 different screw resistance tests. The null hypothesis was that the type of abutment combination of 2-implant-supported screw-retained frameworks would not influence the passive or active fit after simulating different vertical and horizontal misfits.

MATERIAL AND METHODS

The present study was based on the materials and methods used in a previous study.[23] The sample size of each group was based on a pilot study with 5 specimens from each group. Based on data from the pilot study, the effect size d was found to be 0.848. The sample size was calculated by using a statistical software program (G*Power 3.1.9.2; Heinrich Heine-University Düsseldorf) and applying ANOVA: fixed effects, omnibus, 1-way test. A significance level of α=.05, effect size d 0.848, and a power of 95% gave a sample size of 9. To adjust for nonparametric statistical analysis scenarios, 15% was added to the computed sample size, giving a sample size of 10.

Thirty identical 3-unit zirconia (KATANA Zirconia HT; Kuraray Noritake Dental Inc) bar-shaped 2-implant-supported (FPD) frameworks were manufactured by using standardized computer-aided design and computer-aided manufacturing (CAD-CAM) technology according to the manufacturer's recommendations. The FPDs simulated a clinical situation of a mandibular premolar, first molar pontic, and a molar with a 22-mm distance and internal inclination of 10 degrees between implants (Fig. 1).

The frameworks were divided into 3 groups of 10 where 2 Ti-bases (Conelog; Camlog Biotechnologies

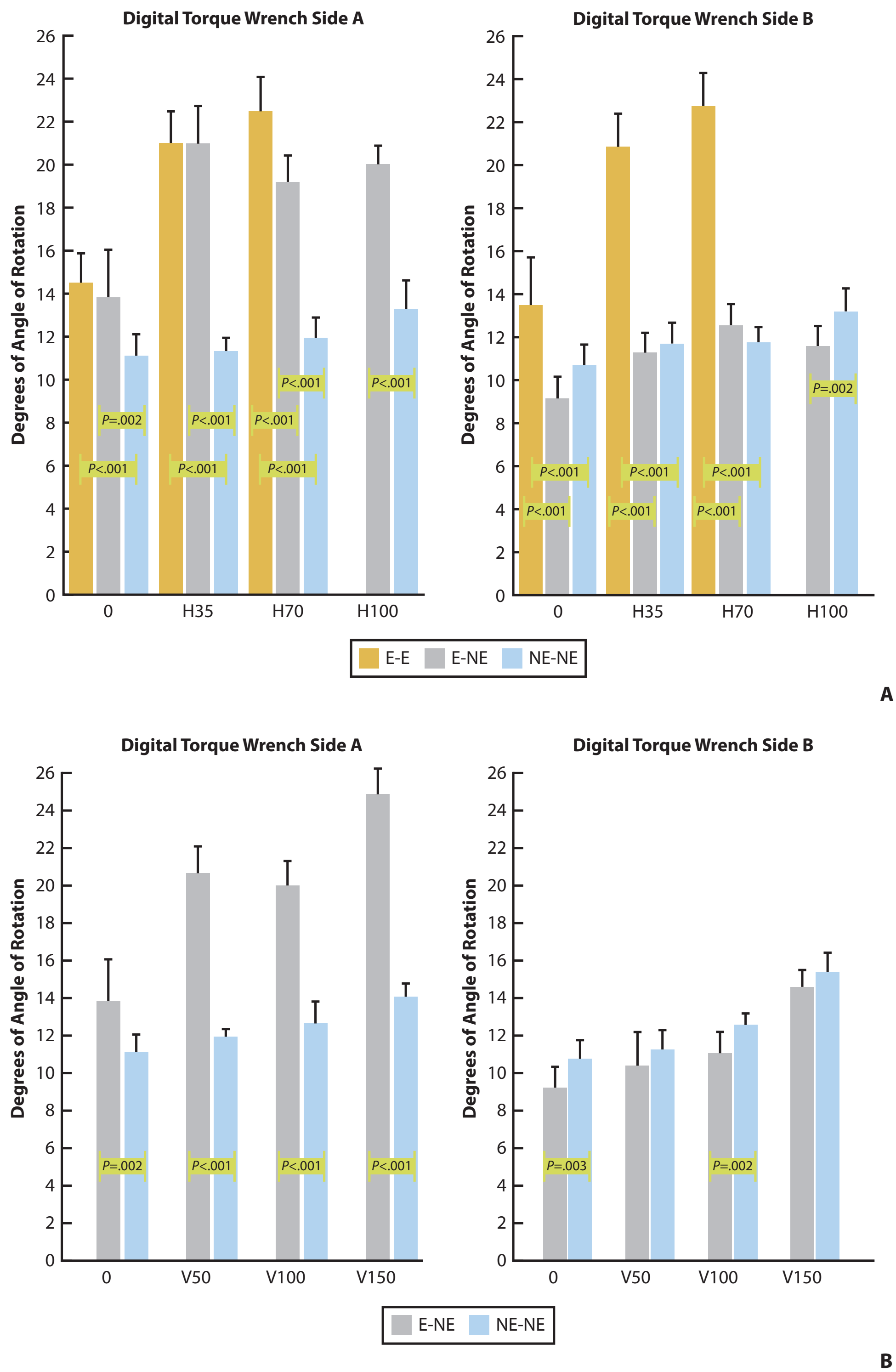

Figure 4. A, B, Angle of rotation (*M+SD*) for digital torque wrench. Statistically significant differences among groups marked by *red* horizontal bar. Engaging abutments marked with *dotted* outline. H, horizontal misfit; V, vertical misfit.

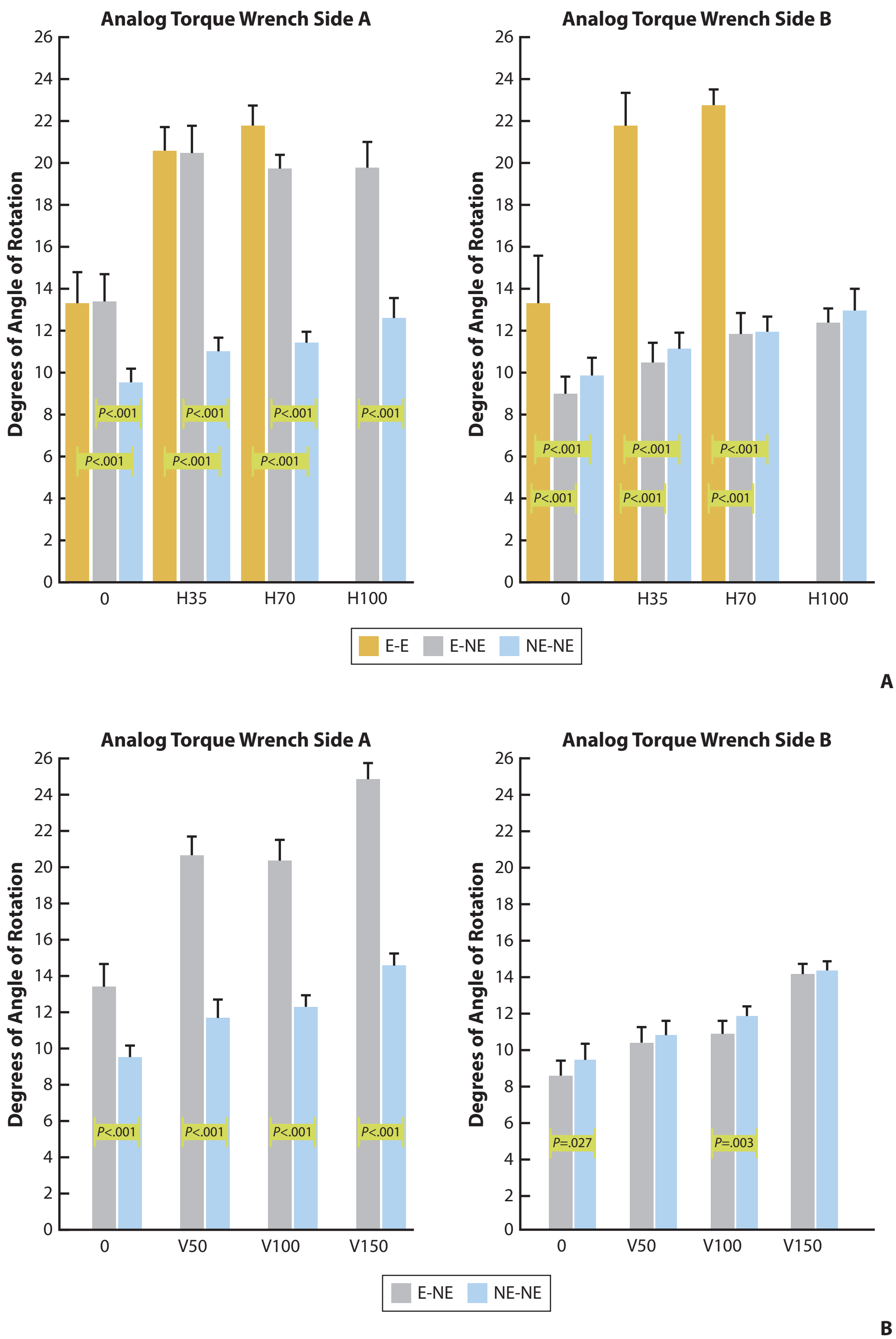

Figure 5. A, B, Angle of rotation (*M+SD*) for analog torque wrench. Statistically significant differences among groups marked by *red* horizontal bar. Engaging abutments marked with *dotted* outline. H, horizontal misfit; V, vertical misfit.

Table 1. Angle of rotation (M, SD, and N)

		Digital Torque Wrench								Analog Torque Wrench							
		Side A				Side B				Side A				Side B			
Group		M	SD	N		M	SD	N		M	SD	N		M	SD	N	
0	E-E	14.5	1.4	10	$F(2, 27)=12.25$ $P<.001$	13.6	2.2	10	$F(2, 27)=21.08$ $P<.001$	13.3	1.3	10	$F(2, 27)=38.13$ $P<.001$	13.6	2.1	10	$F(2, 27)=34.72$ $P<.001$
	E-NE	13.8	2.2	10		9.2	1.0	10		13.4	1.3	10		8.7	0.8	10	
	NE-NE	11.1	1.0	10		10.8	1.0	10		9.5	0.7	10		9.6	0.8	10	
H35	E-E	21.0	1.5	10	$F(2, 27)=159.58$ $P<.001$	21.0	1.6	10	$F(2, 27)=193.48$ $P<.001$	20.6	1.1	10	$F(2, 27)=284.05$ $P<.001$	21.1	1.5	10	$F(2, 27)=297.26$ $P<.001$
	E-NE	20.1	1.8	10		11.3	1.0	10		20.5	1.3	10		10.2	0.9	10	
	NE-NE	11.5	0.6	10		11.8	01.0	10		11.0	0.7	10		10.8	0.8	10	
H70	E-E	22.4	1.7	10	$F(2, 27)=167.95$ $P<.001$	22.9	1.6	10	$F(2, 27)=279.58$ $P<.001$	21.8	0.9	10	$F(2, 27)=579.13$ $P<.001$	22.1	0.7	10	$F(2, 27)=562.80$ $P<.001$
	E-NE	19.2	1.2	10		12.6	1.0	10		19.7	0.7	10		11.5	1.0	10	
	NE-NE	12.0	1.0	10		11.8	0.7	10		11.4	0.5	10		11.6	0.7	10	
H100	E-NE	12.0	0.9	10	$F(2, 27)=172.86$ $P<.001$	11.7	1.0	10	$F(1, 18)=12.80$ $P=.002$	19.8	1.2	10	$F(1, 18)=233.28$ $P<.001$	12.0	0.7	10	$F(1, 18)=2.61$ $P=.123$
	NE-NE	13.3	1.3	10		13.3	1.1	10		12.6	0.8	10		12.6	1.0	10	
V50	E-NE	20.7	1.5	10	$F(1, 18)=313.07$ $P<.001$	10.4	1.8	10	$F(1, 18)=1.60$ $P=.222$	20.7	1.0	10	$F(1, 18)=45.00$ $P<.001$	10.6	0.8	10	$F(1, 18)=1.16$ $P=.295$
	NE-NE	12.0	0.5	10		11.2	1.0	10		11.7	1.0	10		11.0	0.8	10	
V100	E-NE	20.0	1.3	10	$F(1, 18)=170.58$ $P<.001$	11.1	1.1	10	$F(1, 18)=12.65$ $P=.002$	20.4	1.1	10	$F(1, 18)=407.23$ $P<.001$	11.1	0.7	10	$F(1, 18)=11.54$ $P=.003$
	NE-NE	12.6	1.2	10		12.5	0.7	10		12.3	0.7	10		12.1	0.6	10	
V150	E-NE	24.9	1.4	10	$F(1, 18)=454.12$ $P<.001$	14.5	1.0	10	$F(1, 18)=3.41$ $P=.081$	24.9	0.9	10	$F(1, 18)=844.97$ $P<.001$	14.5	0.5	10	$F(1, 18)=0.78$ $P=.388$
	NE-NE	14.5	0.7	10		15.4	1.0	10		14.6	0.7	10		14.7	0.5	10	

One-way ANOVA. Results from Tukey's post hoc test can be found in Figures 4, 5.

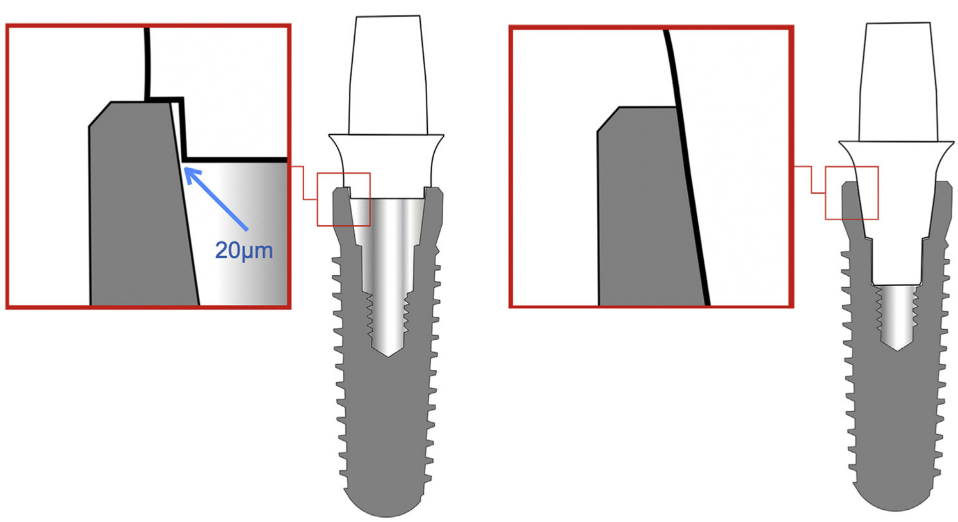

Figure 6. Schematic drawing of different abutment configurations.

AG), Ø4.3×2 mm, were cemented on each FPD in the following manner: 2 engaging Ti-bases, side A and B (E-E specimens); 1 engaging Ti-base on side A and 1 nonengaging Ti-base on side B (E-NE specimens); 2 nonengaging Ti-bases, side A and B (NE-NE specimens) (Fig. 2).

To ensure equal fit, 2 engaging abutments were cemented onto 1 randomly selected FPD framework with a hybrid abutment cement (Multilink Automix; Ivoclar AG) according to the manufacturer's recommendations. The process was performed under a microscope (Mobiliskope S; Renfer GmbH) to ensure complete seating. After cementation, 2 dummy implants (Conelog Screw-Line; Camlog Biotechnologies AG) were placed on the Ti-bases and tightened to 20 Ncm. Type IV dental stone (GC FUJIROCK EP; GC Corp) was poured around the dummy implants to create a cast. The remaining FPD frameworks were cemented onto the Ti-bases by using this control cast.

Seven definitive casts with different misfits were fabricated by using 2 implants (Conelog Screw-Line; Camlog Biotechnologies AG), Ø4.3×13 mm, in each cast. One cast had no misfit (control cast). Three casts had a horizontal misfit of 35, 70, and 100 µm. The misfit was created by placing the side A implant in a straight distal direction, increasing the distance between

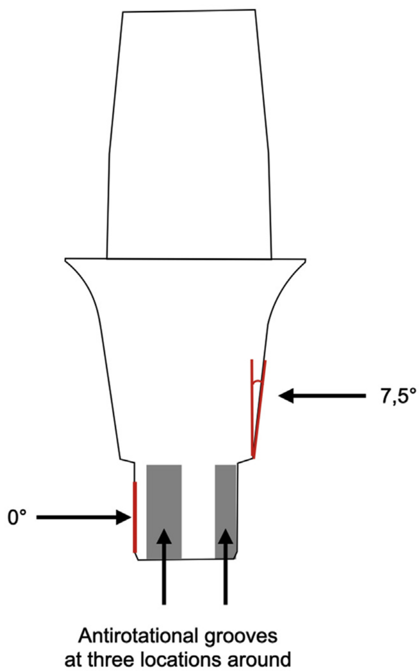

Figure 7. Schematic of engaging abutment.

implants. Three casts had a vertical misfit of 50, 100, and 150 μm. The misfit was created by placing the side B implant in a straight apical direction (Fig. 3). The misfit was verified with a laboratory scanner (E4; 3Shape A/S). 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). The misfit simulation error in all definitive casts was confirmed to be less than 10 μm.

A custom-made digital torque wrench (Digitorum) consisting of a light source that illuminated a photonic lattice mounted on an analog torque wrench (Institut Straumann AG) was fabricated. When the torque wrench was activated by the handle, a number of pixels on the photonic lattice were blocked or activated. This information was registered wirelessly by a calibrated computer software program, which converted the data into torque units (Ncm). A gyroscope registered the degree and screw rotation, and an accelerometer and a magnetometer were used to fine-tune the result. The accuracy of the digital torque wrench was validated by repeated angle and torque measurements (N=10).

The FPDs were evaluated by a blinded experienced prosthodontist (V.R.) according to 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. If any of these criteria were identified, the FPD was excluded from the study.

The FPDs were mounted on the casts, and the abutment screws were tightened to 10 Ncm on each side by using an analog torque wrench (Camlog J5320.1030; Camlog Biotechnologies AG), starting with side A. Subsequently the screws were tightened to 20 cm with a digital torque wrench on both sides, starting with side A. The degree of screw rotation was registered with a computer software program (Digitorum). The same procedure was then repeated by using an analog torque wrench. The degree of screw rotation was measured with an analog protractor (Steel Protractor 486.502; Scala Messzeuge GmbH).

Statistical analysis was done for 4 variants of angle of rotation: digital torque wrench side A, digital torque wrench side B, analog torque wrench+protractor side A, and analog torque wrench+protractor side B. Normal distribution was tested by using the Shapiro-Wilk test, and equal variances with the Levene test. Angles of rotation were compared by using analysis of variance (1-way ANOVA). In cases where there were 3 connections, the Tukey HSD test was performed separately for each side. All statistical analyses were performed with a statistical software program (IBM SPSS Statistics for Windows, v27; IBM Corp) (α=.05).

RESULTS

The Shapiro-Wilk and Levene tests showed no major deviations from these assumptions in any case. E-E specimens from H100, V50/100/150 misfit groups were excluded during initial assessment as an obvious nonpassive fit was noted. Degrees of angle of rotation are presented in Figures 4, 5 and Table 1, with statistically significant differences found among groups (P<.05). In the horizontal misfit group, the E-E specimens had the highest angle of rotation, and the NE-NE, the lowest. In the vertical misfit group, where the E-E specimens were excluded, the E-NE specimens had the highest angle of rotation on side A, while on side B, the differences were smaller.

DISCUSSION

As significant differences were found among specimens with abutment combinations, the null hypothesis was rejected. The E abutments had a higher angle of rotation than the NE for all types of misfit.

The differences among the specimens can be explained by different factors. The NE abutment rests on the implant shoulder and has a small gap of 20 μm in the implant cone, between the internal wall of the implant and the abutment (Fig. 6). This allowed a certain freedom of movement in 2 dimensions (x+y), which resulted in a smaller angle of rotation than that of engaging abutments (Fig. 6).

For the vertical misfit, the differences could also be explained by the fact that the side B implant was tilted 10 degrees. The internal cone of the Conelog implant is

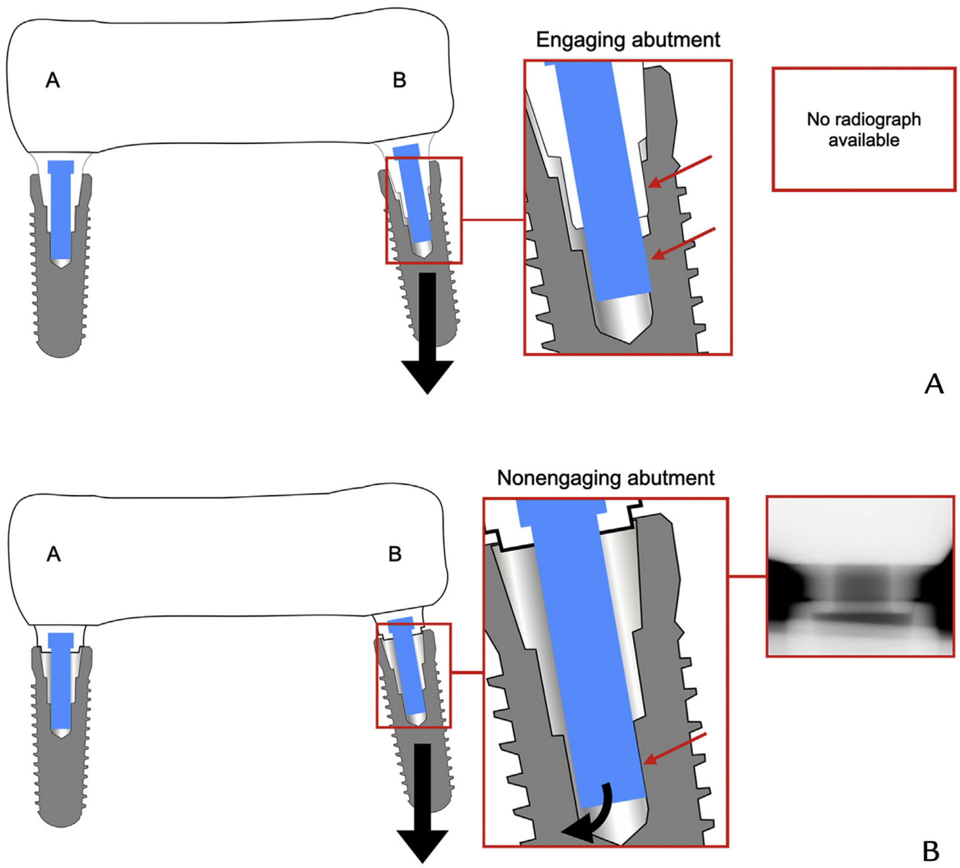

Figure 8. A, B, Schematic drawings of different abutment configurations for vertical misfit in tilted side B implant. Implant has been moved in straight apical direction. For engaging abutment, abutment touches distal wall when placing fixed partial denture, and screw will be pressed distally. For nonengaging abutment, there will be no pressure between abutment and implant, but screw will be guided against distal wall. *Red arrows* indicate pressure zones. *Black arrows* indicate movement.

7.5 degrees, and the antirotational part is 0 degrees and has 3 antirotational grooves (Fig. 7). As the implant was moved in a straight apical direction, the E abutment touched the distal wall when placing the FPD (Fig. 8, Supplemental Videos 1 and 2, available online). In addition, the screw will be pressed distally as the E abutment screw channel will guide it toward the distal wall, causing the angle rotation to increase. This would also explain the considerable misfit for E-E specimens on H100, V50/100/150 definitive casts, which led them to be excluded. For the NE abutment, there was a small freedom of movement in the abutment (Fig. 6), with no pressure between the abutment and implant. The screw was guided against the distal wall in a similar way as with the E abutments (Fig. 8). However, this did not result in the same misfit and angle of rotation as the screw channel in the NE abutment was much shorter, reducing the guiding of the screw that may rotate slightly in the mesial direction.

For the horizontal group, the side A implant was moved distally. The FPDs in the E group touched the mesial wall first when placed (Fig. 9, Supplemental Videos 3 and 4, available online). The FPD will thus not go into place completely but be slightly raised. This was confirmed by a previous study.[23] The abutment screws will be guided and pressed against the mesial wall and give a higher degree of rotation. Since there is no engaging cone in the NE abutments, the effect will not be the same, resulting in a lower angle of rotation.

There were differences between E and NE abutments even in the control cast without misfit. The misfit simulation error in all definitive casts was confirmed to be less than 10 μm. However, despite careful framework manufacturing processes and abutment cementation, there will always be a small discrepancy. The design of the NE abutments, with the previously mentioned tolerance of 20 μm between the abutment and implant, explains the differences in the control cast as well. In contrast, E abutments have a larger contact area with the implant internal walls, and therefore, the insertion resistance is higher.

Sides A and B were separated in data gathering and analysis and compared separately. However, if there had been a misfit on any side, there would have been a misfit for the entire FPD. In the clinical situation, there is a mixture of vertical and horizontal misfits, combining

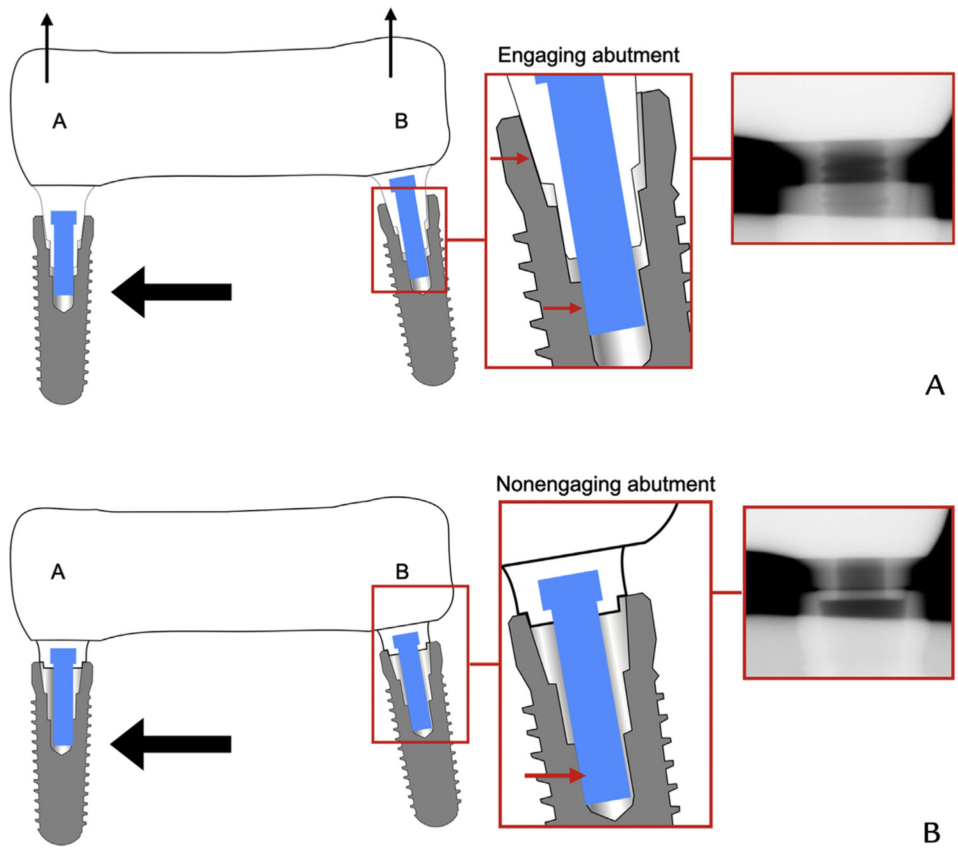

Figure 9. A, B, Schematic drawings of different abutment configurations for horizontal misfit in side A implant. Implant has been moved in straight horizontal direction. Fixed partial denture in engaging group will touch mesial wall first when placed. Fixed partial denture will thus not go into place completely but be slightly raised. Abutment screws will be guided and pressed against mesial wall and give a higher degree of rotation. Since there is no engaging cone in nonengaging abutment, effect will not be same. *Red arrows* indicate pressure zones. *Black arrows* indicate movement.

these factors. This study suggests that bilateral engaging abutments should not be used for fixed partial dentures, as a higher degree of misfit was found in the E-E specimens. With unilateral engaging abutments (E-NE specimens), no specimens were excluded based on subjective evaluation. However, in the majority of tested scenarios, the rotation angle was significantly higher than that in the NE-NE specimens, indicating a larger misfit in the E-NE specimens. Therefore, the risk of a less passive fit with E-E and E-NE abutment combinations is increased.

Similar results have been described in the previous study[23] where the fit of E-E, E-NE, and NE-NE frameworks on the implants with identical simulated positioning errors was evaluated by measuring the vertical gap between the implant and the abutment. In the study, the NE-NE combination was found to be the most adaptable to different misfit levels followed by E-NE and E-E combinations. Hence, the E-E combination was not recommended. Moreover, the tendencies of decreasing tolerance to the increasing level of simulated misfit were observed in the present as well as the previous study. One of the main differences between the results of these studies is that, in the previous study, H100 misfit caused higher vertical discrepancies than V100 misfit, but in the current study, the effect of both simulated misfits was similar.

The results measured by the digital and analog torque wrenches corresponded to a high degree. This suggests that the newly developed digital instrument is at least as reliable as the analog torque wrench with a protractor in determining misfit. However, a torque wrench with a protractor is difficult to use clinically. The digital torque wrench provides improved clinical use, has the potential to provide an exact degree of angle of rotation, and could prove a straightforward and valuable tool for evaluating fit and identifying misfit clinically. The question remains, however, of what angle of rotation value constitutes an appropriate fit or when an appropriate fit is achieved. This could be overcome if the digital torque wrench software program would give a digital torque angle signature analysis as has been presented by Calderini et al.[20]

In the present study, the same FPDs, screws, and casts were used as in a previous study.[21] The FPDs were tightened twice during the previous study. The preload of a screw decreases during repetitive use.[24] That the FPDs were tightened a third and fourth time in the present study can thus be a limitation, as the preload can be reduced. However, according to Guzaitis et al,[24] a screw can be retightened 10 times without losing considerable preload. Thus, this potential limitation is not considered to have any substantial effect on the results. Furthermore, as the situation was the same for all 3 groups (E-E, E-NE, and NE-NE specimens), it is unlikely to have caused the differences in results. In addition, the experimental design did not include analogs, which can show considerable wear.

CONCLUSIONS

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

1. A relationship was found between the simulated level of the misfit and angle of rotation.
2. Fixed partial dentures with nonengaging abutments tolerated the misfit better and had the lowest angle of rotation.
3. A significantly higher angle of rotation (misfit) was observed in both engaging and in engaging and nonengaging abutment combinations; however, the engaging and nonengaging abutment combination had a better fit when rated subjectively.
4. A digital torque wrench may be considered an alternative to the traditional screw resistance test.

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