Parameters Determining Micromotion at the Implant-Abutment Interface

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Purpose: *Micromotion at the implant-abutment level has been reported to be a major determinant of long-term implant success, as technical problems ranging from screw loosening to screw fracture may occur as a consequence of excessive micromotion.* ***Materials and Methods:*** *Following published standards, implant-abutment assemblies were fixed in a universal testing machine at a 30-degree angle. A cyclic load of 200 N was applied to the specimens 10 times at a crosshead speed of 100 N/s while relative displacement between the implant and the abutment was quantified using extensometers. For five consecutive loading cycles per specimen, micromotion was recorded as a basis for statistical analysis, with two-sample t tests (Welch test) applied.* ***Results:*** *Micromotion at the implant-abutment interface ranged from 1.52 to 94.00 μm. While a significant effect of tightening torque was found, implant shoulder design did not reveal a significant effect in all cases. Lack of engagement of antirotational features of the implants resulted in increased micromotion. Casting onto prefabricated gold cylinders resulted in abutments with significantly less micromotion as compared to copy-milled and stock abutments. Computer-aided design/computer-assisted manufacture (CAD/CAM) zirconia abutments showed less micromotion than CAD/CAM titanium abutments. Inconsistent levels of micromotion were recorded for CAD/CAM abutments coupled to proprietary and competing implant systems. Great variations in micromotion were found with clone abutments and clone implant systems.* ***Conclusion:*** *A broad range of micromotion values was observed with the implant-abutment combinations investigated. There seems to be no perfect implant shoulder geometry or perfect fabrication technique that would result in no detectable micromotion.* INT J ORAL MAXILLOFAC IMPLANTS 2014;29:1338–1347. doi: 10.11607/jomi.3762

Key words: *biomechanics, clone abutments, implant-abutment connection, micromotion*

Although good survival rates for implant-supported reconstructions have been reported, technical and biologic complications are frequent.[1] In a review of the success of implant-supported single crowns, a cumulative incidence of screw or abutment loosening of 12.7% was found,[2] which seems to be consistent with other reports in this field.[3–5]

In this context, the stability of the implant-abutment connection has been identified as a major determinant for the long-term success of a dental implant.[1,6,7] At the prosthetic interface, clinical loading may result in micromotion of the components, which in turn may contribute to prosthesis failure[8] and tissue inflammation[9] resulting from bacterial colonization of the microgap.[10,11] Because movements between implant components also influence crestal bone changes around two-piece, nonsubmerged titanium implants,[12] the idea of platform switching was introduced as a possible solution.[13,14]

Different concepts for the design of the implant-abutment connection have been proposed in the past, which affect micromotion at the restorative interface[15,16] as well as the stability of the abutments used.[17–19] Given the superior mechanics of conical abutment connections,[20] alternative butt-joint designs have mostly been supplanted, although the problem of inevitable gaps between implant and abutment remains,[21] as cold welding does not occur when the abutment is tightened.[22] Precision of fit between implant and abutment, antirotational features,[23] and the preload on the screws constitute additional parameters of micromotion phenomena at the implant-abutment interface.

With the advent of zirconia ceramic as a restorative material, all-ceramic abutments have been introduced[24,25] as an alternative to traditional titanium components.[26] Although sufficient precision of fit and

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fracture strength have been reported for ceramic abutments, the choice of abutment material influences the strength of the abutment,[27,28] the degree of misfit,[29] and component wear at the implant-abutment interface,[30] with the potential for subsequent component loosening.

In addition to standardized stock abutments provided by implant manufacturers, a variety of fabrication techniques, ranging from “cast-to abutment cylinders”[31] and manual copy milling of presintered zirconia ceramic[32,33] to CAD/CAM options, are currently available.[34] Although an increase in misfit has been reported when associating implants and abutments from different manufacturers,[35,36] numerous companies nevertheless provide low-cost restorative components for well-established implant systems.

Despite the clinical importance of micromotion phenomena at the implant-abutment interface, no universally valid method for quantifying this phenomenon has been described yet. Methods that have been used include optical microscopy,[24] scanning laser microscopy,[24] and scanning electron microscopy,[21] as well as different forms of x-ray applications[37] such as microcomputed tomography[38] and synchrotron-based radiography.[39,40] Mechanical evaluations have been based on measurements of rotational freedom,[7] marginal discrepancy, and torque loss,[41] while finite element analysis[42] has been applied to simulate the effects of micromotion.

It was the purpose of this study to establish a biomechanical approach to directly measure relative motion at the implant-abutment interface and to quantify micromotion in a variety of implant-abutment combinations. The effects of the following parameters were to be investigated: geometry of the implant-abutment interface (internal octagon, internal cross-fit, external hexagon, internal double hexagon, internal hexagon, internal trilobe); fabrication method of the abutment (stock, provisional stock, computer-aided design/computer-assisted manufacture [CAD/CAM], cast on, copy milled); engagement of antirotational features; abutment material (titanium, zirconia); tightening torque; and type of manufacturer (original, clone).

MATERIALS AND METHODS

Experimental Setup

Adhering to the requirements set under International Organization for Standardization protocol 14801 for testing the mechanical performance of dental implants,[18,43,44] implants (Table 1) were embedded perpendicularly in hollow aluminum bars with autopolymerizing polyurethane resin (Biresin, Sika Deutschland). To that end, the implants were fixed in a surveyor and lowered into the resin until 3 mm of the implant body extended from the top surface of the bar. The specimens were positioned in a universal testing machine (inspect mini 3kN, Hegewald und Peschke) at a 30-degree angle with respect to the implant axis,[36] and abutments ($n = 5$ per abutment type) were tightened on the implant shoulder by applying the abutment manufacturers’ recommended torque with the corresponding hand ratchets. All implant-abutment combinations were cyclically loaded 10 times with a force of 200 N at a crosshead speed of 100 N/s, while the displacement of both the abutment and the implant was quantified using two newly designed devices that transferred the displacement of the implant component onto bars equipped with extensometers (Sandner Messtechnik) (Fig 1). The combination of force magnitude, implant displacement, and abutment displacement was recorded for five consecutive loading cycles using a measurement amplifier (Quantum X, Hottinger Baldwin Messtechnik) and analysis software (catman, Hottinger Baldwin Messtechnik) (Fig 2).

Implant-Abutment Combinations

The implant-abutment combinations investigated and their abbreviations are given in Table 1. With the exception of “cast-to abutments” and “custom-made copy-milled zirconia abutments” for the Straumann Regular Neck implant system, all samples were used as provided by the manufacturers. However, the height of the abutments extending from the implant shoulder was standardized to 5.5 mm by manually shortening longer abutments.

The cast-to abutments were modified by casting with high noble alloy (Wegold Norm, Wegold Edelmetalle) to reflect the geometry of abutments for cement-retained restorations. Similarly, synOcta posts for provisional restorations were used as a basis for manual copy milling (Ceramill multi-x, AmannGirrbach) of zirconia abutments. The cylinders were modified by adding wax until the external shape of abutments for cement-retained restorations was achieved. Following removal of the retaining screw, these patterns were scanned manually, while the definitive abutments were copied in unsintered zirconia ceramic (Ceramill zi, AmannGirrbach). Following the sintering process, the retaining screws from the cylinders were used to fix the abutments on the implants.

The titanium bases for bonded abutments (CAD star, Medentis) were extended to a height of 5.5 mm using composite resin (Tetric Evo Ceram, Ivoclar Vivadent). The original study plan also included titanium bases for Straumann Bone Level implants (Medentis), which could not be provided by the manufacturer. Furthermore, only one ATLANTIS CAD/CAM abutment

Table 1 Abbreviations for All Implant-Abutment Combinations Investigated

Implant system/abutment	Abutment manufacturer	Torque (Ncm)	Abbreviation
Standard implant (4.1 × 10 mm, Regular Neck; Straumann)			
Two-piece cementable abutment	Straumann	5	ST-1 – 5 Ncm
Two-piece cementable abutment	Straumann	15	ST-1 – 15 Ncm
Two-piece cementable abutment	Straumann	35	ST-1 – 35 Ncm
One-piece cementable abutment conical	Straumann	35	ST-2
Cast-to abutment	Straumann	35	ST-3
Provisional abutment	Straumann	15	ST-4
CAD/CAM abutment titanium	Straumann	35	ST-5
CAD/CAM abutment zirconia	Straumann	35	ST-6
Two-piece cementable abutment	Dr Ihde Dental	35	ST-7
Copy-milled zirconia abutment	Schmidtler Zahntechnik	35	ST-8
Two-piece cementable abutment	Medentika	35	ST-9
Titanium base for bonded abutments	CADstar	35	ST-10
CAD/CAM abutment titanium	DENTSPLY Implants	35	ST-11
CAD/CAM abutment titanium	Nobel Biocare	35	ST-12
Allfit Implant SSO (4.1 × 11 mm; Dr Ihde Dental)			
One-piece cementable abutment conical	Dr Ihde Dental	35	DI-1
Two-piece cementable abutment	Dr Ihde Dental	35	DI-2
Two-piece cementable abutment conical	Dr Ihde Dental	35	DI-3
Bone Level Implant (4.1 × 10 mm, Regular Cross-Fit Connection; Straumann)			
Two-piece cementable abutment	Straumann	35	SB-1
Two-piece cementable abutment	Medentika	35	SB-2
Titanium base for bonded abutments	CADstar	35	SB-3
CAD/CAM abutment titanium	DENTSPLY Implants	35	SB-4
CAD/CAM abutment titanium	Nobel Biocare	35	SB-5
Brånemark System (4.0 × 10 mm, Regular Platform; Nobel Biocare)			
Two-piece cementable abutment	Nobel Biocare	35	NB-1
CAD/CAM abutment titanium	Nobel Biocare	35	NB-2
CAD/CAM abutment zirconia	Nobel Biocare	35	NB-3
Two-piece cementable abutment	Medentika	35	NB-4
Titanium base for bonded abutments	CADstar	35	NB-5
CAD/CAM abutment titanium	DENTSPLY Implants	35	NB-6
Nobel Active (4.3 × 10 mm, Regular Platform; Nobel Biocare)			
Two-piece cementable abutment	Nobel Biocare	35	NA-1
CAD/CAM abutment titanium	Nobel Biocare	35	NA-2
Two-piece cementable abutment	Medentika	35	NA-3
Titanium base for bonded abutments	CADstar	35	NA-4
CAD/CAM abutment titanium	DENTSPLY Implants	35	NA-5
Replace Select Tapered (4.3 × 10 mm, Regular Platform; Nobel Biocare)			
Two-piece cementable abutment	Nobel Biocare	35	NR-1
CAD/CAM abutment titanium	Nobel Biocare	35	NR-2
Two-piece cementable abutment	Medentika	35	NR-3
Titanium base for bonded abutments	CADstar	35	NR-4
CAD/CAM abutment titanium	DENTSPLY Implants	35	NR-5
OsseoSpeed TX 4.0S (3.5/4.0 × 11 mm, turquoise; AstraTech/DENTSPLY Implants)			
Two-piece cementable abutment	DENTSPLY Implants	20	DA-1
CAD/CAM abutment titanium	DENTSPLY Implants	20	DA-2
Two-piece cementable abutment	Medentika	25	DA-3
Titanium base for bonded abutments	Medentis	20	DA-4
Titanium base for bonded abutments	CADstar	20	DA-5
CAD/CAM abutment titanium	Nobel Biocare	20	DA-6
AlfaGate SCIP (3.75 × 10 mm; AlfaGate)			
Two-piece cementable abutment	AlfaGate	25	AG

Five of each type of abutment were tested. All abutments showed antirotational features at the implant-abutment interface unless explicitly stated. CAD/CAM = computer-aided design/computer-assisted manufacture.

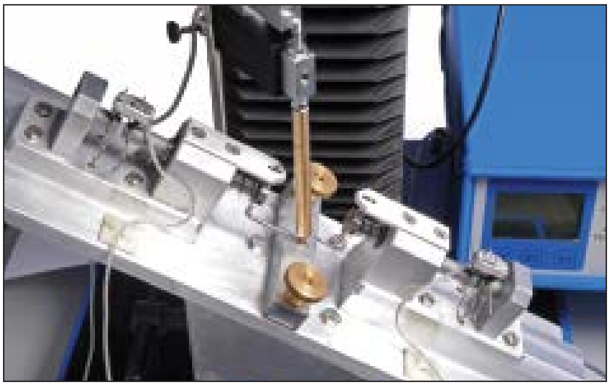

Fig 1 Experimental setup with an implant-abutment assembly embedded in an aluminum bar and positioned in a universal testing machine at a 30-degree angle to the long axis of the implant; the vertical brass-colored bar represents the load applicator. Mechanical probes are touching (*left*) the implant shoulder and (*right*) the abutment to transfer any movement to the remotely positioned extensometers.

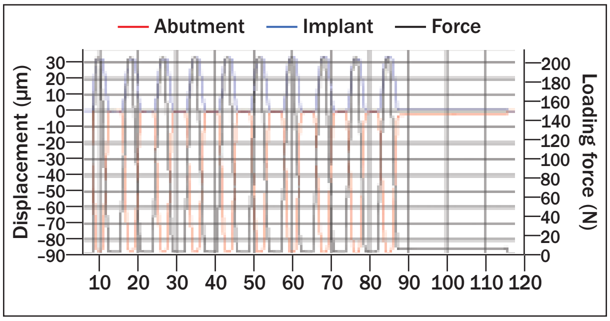

Fig 2 Screenshot from the analysis software showing the correlation of implant and abutment displacement with loading force. A total of 10 loading cycles were performed for each implant-abutment combination, and five datasets per combination formed the basis for statistical analysis. Note: Because of the experimental setup, movements of the abutment bear a negative sign.

in titanium per group was provided by the manufacturer because these abutments were to be used as part of an in vitro study. Also, no zirconia abutments were provided by ATLANTIS. This was done even though, in all cases, regular orders were placed and the market prices would have been paid.

Statistical Analysis

Statistical analysis was based on the relative displacement of the abutment; ie, the implant displacement measured was subtracted from the abutment displacement measured. Because regression analysis indicated neither a uniform effect of repeated testing nor any effect of slightly varying loading magnitudes, one mean value of micromotion was obtained for each implant-abutment combination. Comparative statistical analysis was then based on Welch tests, with the level of significance set at $\alpha = .05$.

RESULTS

The mean values for micromotion at the implant-abutment interface ranged from 1.52 µm (for titanium bases for bonded abutments on Nobel Biocare Replace implants) to 94.00 µm (for two-piece cementable abutments on Straumann Tissue Level implants tightened with 5 Ncm) (Fig 3).

Effect of Different Tightening Torques

When tightening the two-piece cementable stock abutments for the Straumann Tissue Level implants with torque values ranging from 5 to 35 Ncm, significant differences were observed (Table 2), confirming an inverse correlation between tightening torque and micromotion. However, when two-piece cementable stock abutments (ST-1 – 35 Ncm) tightened at 35 Ncm were compared with provisional abutments (ST-4) for the Straumann Tissue Level implant system, tightened at 15 Ncm, no significant difference in micromotion could be observed ($P = .1338$). In contrast, for the OsseoSpeed implant system, significantly greater micromotion was observed for clone (DA-3) than for original two-piece cementable abutments (DA-1), although the clone abutments had been tightened to 25 Ncm, while the original abutments were fixed with 20 Ncm of torque ($P = .0000$).

Effect of Implant-Abutment Interface Geometry

To evaluate the effect of different implant shoulder geometries, implants combined with their original two-piece cementable abutments were compared. The lowest levels of micromotion were recorded for Nobel Biocare Replace implants, while the greatest levels of micromotion were observed with Straumann Tissue Level and Dr Ihde implants. As shown in Table 3, no significant difference in micromotion could be found for Straumann Tissue Level vs Dr Ihde ($P = .1123$), Straumann Bone Level vs Nobel Biocare Brånemark ($P = .1329$), Straumann Bone Level vs OsseoSpeed ($P = .5040$), or Nobel Biocare Active vs AlfaGate ($P = .6212$).

Effect of Abutment Fabrication Method

Micromotion levels of cast-on abutments, copy-milled zirconia abutments, and provisional abutments were compared with those of two-piece cementable stock abutments for the Straumann Tissue Level implant system (Table 4). Significantly lower values for cast-on abutments were observed as compared to copy-milled ($P = .0181$) and stock abutments ($P = .0000$).

Figs 3a to 3g *Mean micromotion values at the implant-abutment interface and standard deviations for all combinations tested. The abbreviations used are introduced in Table 1.*

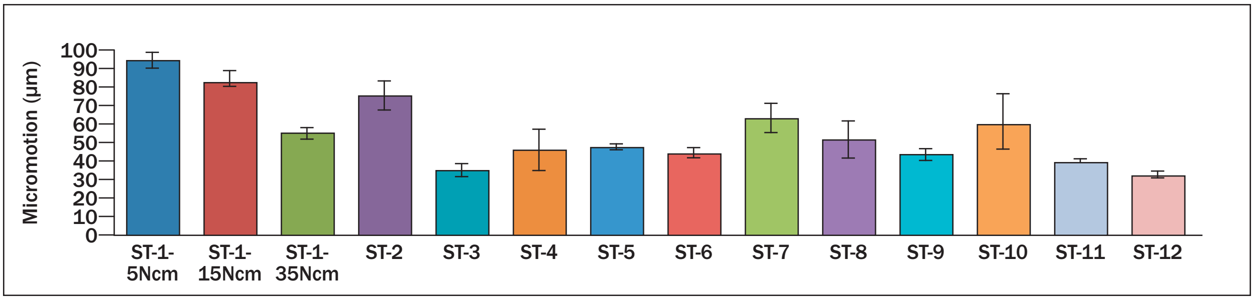

Fig 3a Micromotion values for Straumann Tissue Level implant-abutment combinations.

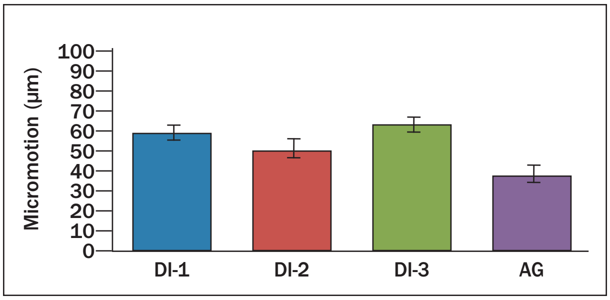

Fig 3b Micromotion values for Dr Ihde and AlfaGate implant-abutment combinations.

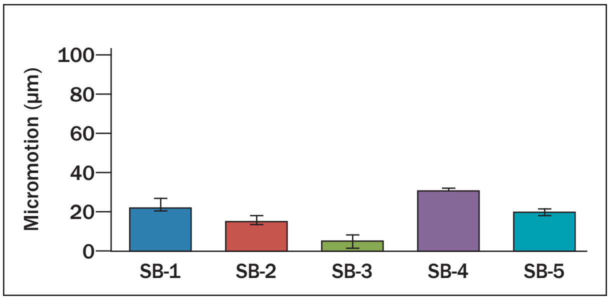

Fig 3c Micromotion values for Straumann Bone Level implant-abutment combinations.

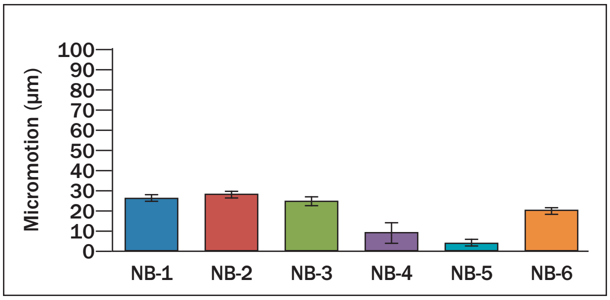

Fig 3d Micromotion values for Nobel Biocare Brånemark System implant-abutment combinations.

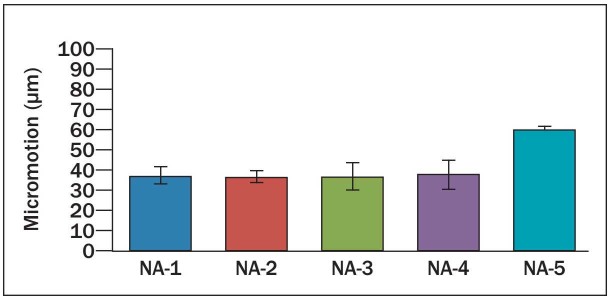

Fig 3e Micromotion values for Nobel Biocare NobelActive implant-abutment combinations.

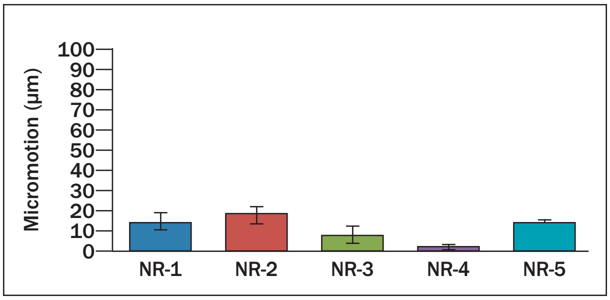

Fig 3f Micromotion values for Nobel Biocare Replace Select implant-abutment combinations.

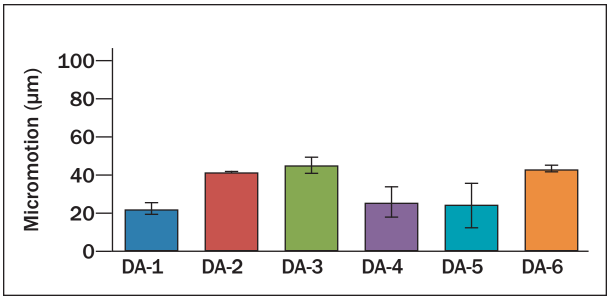

Fig 3g Micromotion values for Dentsply/AstraTech OsseoSpeed implant-abutment combinations.

Effect of Abutment Material for CAD/CAM Abutments

Zirconia and titanium CAD/CAM abutments were compared based on the Straumann Tissue Level implant system and the Nobel Biocare Brånemark implant system. The abutments were obtained from the implant manufacturers' CAD/CAM systems. In both cases, significantly less micromotion was observed

Table 2 Between-Group Comparisons of the Effect of Different Tightening Torques

	ST-1 – 5 Ncm	ST-1 – 15 Ncm	ST-1 – 35 Ncm
ST-1 – 5 Ncm		.0019*	.0000*
ST-1 – 15 Ncm			.0000*
ST-1 – 35 Ncm			

*Significant (Welch test).

Table 3 Between-Group Comparisons of the Effect of the Geometry of the Implant-Abutment Interface

	ST-1 – 35 Ncm	DI-2	SB-1	NB-1	NA-1	NR-1	DA-1	AG
ST-1 – 35 Ncm								
DI-2	.1123							
SB-1	.0000*	.0000*						
NB-1	.0000*	.0001*	.1329					
NA-1	.0001*	.0010*	.0004*	.0019*				
NR-1	.0000*	.0000*	.0037*	.0014*	.0000*			
DA-1	.0000*	.0000*	.5040	.0424*	.0002*	.0083*		
AG	.0003*	.0027*	.0005*	.0022*	.6212	.0000*	.0003*	

*Significant (Welch test).

Table 4 Between-Group Comparisons of Effect of the Abutment Fabrication Method

	ST-1 – 35 Ncm	ST-3	ST-4	ST-8
ST-1 – 35 Ncm				
ST-3	.0000*			
ST-4	.1338	.0886		
ST-8	.4186	.0181*	.4542	

*Significant (Welch test).

with the zirconia abutments (ST-5 vs ST-6, $P = .0209$ for Straumann Tissue Level; NB-2 vs NB-3, $P = .0210$ for Nobel Biocare Brånemark) than with the titanium abutments.

Effect of CAD/CAM Fabrication

With Straumann Tissue Level implants, significantly less micromotion was observed with CAD/CAM titanium abutments obtained from a proprietary CAD/CAM system (Straumann CARES) as compared to two-piece antirotational stock abutments. However, abutments obtained from a competing CAD/CAM system (Nobel Biocare Procera) showed the lowest levels of micromotion in that context. For Nobel Biocare implants, no difference in micromotion between CAD/CAM and stock abutments was observed.

For OsseoSpeed implants, CAD/CAM fabrication of abutments in general caused greater micromotion, as compared to the use of stock abutments. However, because of the small sample size, statistical tests could not be applied here (Table 5).

With the exception of Nobel Biocare NobelActive implants, comparable or lower levels of micromotion were seen with ATLANTIS abutments on competing implant systems, as compared to the proprietary implant system (OsseoSpeed). Again, this could not be verified statistically because of the small sample size.

Significantly greater micromotion was observed in Nobel Biocare Procera abutments placed on Straumann Tissue Level implants as compared to both Nobel Biocare Brånemark and Nobel Biocare Replace implants. However, Nobel Biocare Procera abutments on Nobel Biocare Active implants showed greater micromotion than Nobel Biocare Procera abutments on Straumann Tissue Level implants. Nobel Biocare Procera abutments on Straumann Bone Level and Nobel Biocare Replace implants performed equally well, whereas those abutments placed on Nobel Biocare Replace and Nobel Biocare NobelActive implants showed significantly more micromotion. On OsseoSpeed implants, Nobel Biocare Procera abutments in general performed worse than on proprietary implant systems (Table 6).

Table 5 Between-Group Comparison of the Effect of CAD/CAM Fabrication on Proprietary Implant Systems

	ST-1 – 35 Ncm	ST-11	ST-12
ST-5	.0025*	NA	.0000*
	NB-1	**NB-6**	
NB-2	.0735	NA	
	NA-1	**NA-5**	
NA-2	.6390	NA	
	NR-1	**NR-5**	
NR-2	.1697	NA	
	DA-1	**DA-6**	
DA-2	NA	NA	

*Significant (Welch test).
NA = not applicable (only one specimen in the ATLANTIS abutment group).

Table 6 Between-Group Comparison of Micromotion of Nobel Biocare Procera Abutments on Proprietary Versus Competing Implant Systems

	ST-12	SB-5	DA-6
NB-2	.0009*	.0003*	.0000*
NA-2	.0420*	.0000*	.0010*
NR-2	.0007*	.2657	.0000*

*Significant (Welch test).

Table 7 Between-Group Comparison of Effect of Clone Abutments

	ST-7	ST-9	ST-10
ST-1 – 35 Ncm	.1029	.0002*	.4064
	SB-2	**SB-3**	
SB-1	.0020*	.0001*	
	NB-4	**NB-5**	
NB-1	.0014*	.0000*	
	NA-3	**NA-4**	
NA-1	.8759	.8776	
	NR-3	**NR-4**	
NR-1	.0158*	.0007*	
	DA-3	**DA-4**	**DA-5**
DA-1	.0000*	.3917	.7225

*Significant (Welch test).

Effect of Antirotational Features

When engaging (ST-1) and nonengaging (ST-2) cementable abutments for the Straumann Tissue Level implant system were compared, significantly greater micromotion was found with the nonengaging abutments (*P* = .0037). A similar relationship was found for the Dr Ihde implant system, regardless of whether the nonengaging abutment was a one-piece component (DI-1 vs DI-2, *P* = .0102) or a two-piece component (DI-3 vs DI-2, *P* = .0012). No difference in micromotion was found for nonengaging one-piece (DI-1) and two-piece (DI-3) cementable abutments on Dr Ihde implants (*P* = .1076).

Effect of Stock Abutment Manufacturer

For the Straumann Tissue Level implant system, significantly less micromotion was recorded for cementable clone abutments fabricated by Medentika, as compared to proprietary cementable abutments (ST-1 – 35 Ncm vs ST-9, *P* = .0002). For the Straumann Bone Level implant system, the same observation was made for both cementable clone abutments by Medentika (SB-1 vs SB-2, *P* = .0020) and titanium bases for bonded abutments by CADstar (SB-1 vs SB-3, *P* = .0001).

While for Nobel Biocare NobelActive implants, no difference in micromotion was observed between proprietary and clone abutments for the Nobel Biocare Brånemark and the Nobel Biocare Replace implant systems, significantly less micromotion was recorded with clone cementable abutments by Medentika and titanium bases by CADstar (Table 7). In contrast, with the OsseoSpeed implant system, the use of clone cementable abutments by Medentika led to a significant increase in micromotion as compared to the use of original abutments (DA-1 vs DA-3, *P* = .0000). However, no difference in micromotion was recorded between original abutments and clone abutments by Medentis or with titanium bases by CADstar on OsseoSpeed implants.

Effect of Implant Manufacturer

In a comparison of low-cost and high-value implant systems with comparable implant shoulder geometry, no significant difference could be found when two-piece cementable abutments on implants with internal-octagon connections were considered (ST-1 vs DI-2, *P* = .1123). However, when these implants combined with one-piece nonengaging cementable abutments were compared, the low-cost implant system showed less micromotion (ST-2 vs DI-1, *P* = .0093).

Two-piece cementable abutments on implants with internal-hexagon connections showed no difference in micromotion when Nobel Biocare NobelActive and AlfaGate were compared (NA-1 vs AG, *P* = .6212), whereas AlfaGate showed greater levels of micromotion than the OsseoSpeed implant system (DA-1 vs AG, *P* = .0003). Simultaneously, significantly greater micromotion was measured with Nobel Biocare NobelActive implants as compared to OsseoSpeed implants (NA-1 vs DA-1, *P* = .0002).

DISCUSSION

This study was characterized by a novel measurement technique that directly assessed the relative motion at the implant-abutment interface that occurred as a consequence of occlusal loading. Consequently, comparability of the results with already published data[37] may be limited. In addition, the measurement technique applied required access to both the implant shoulder and the abutment to determine the displacement of both components. In a clinical situation, however, a restoration would have been present, creating a second interface (abutment-restoration) at which micromotion might have also occurred. For these reasons, the clinical situation could not be completely mimicked in this investigation.

Despite the fact that any movements of the implants and the abutments were directly captured with extremely sensitive technology, the values representing relative displacement of the abutment can only serve for comparisons within the given setup. It must be kept in mind that a systematic measurement error resulted from the setup because of the positioning of the mechanical probes at different heights on the implant and on the abutment. While it would seem to be technically impossible, real micromotion would have to be captured with both sensors positioned at the same height or by excluding any movement of the implant. Both tissue-level and bone-level implants were investigated, with the abutments extending 5.5 mm above the implant shoulder. In clinical settings, however, abutments on bone-level implants are necessarily longer than abutments on tissue-level implants. The increased lever arm in such a situation may have influenced the resulting micromotion phenomena. Because of the need for standardization, this variable was not taken into account here.

In the current study, no thermomechanical aging was performed, although previous studies have shown that aging may negatively affect the level of micromotion,[40] particularly when zirconia abutments and titanium implants are combined.[30] No uniform effect of repeated loading was seen in the data collected, indicating that wear phenomena at the implant-abutment interface during cyclic loading had not occurred.[45] Nevertheless, this must be seen as a limitation of the study. In clinical practice, cyclic loading occurs, which may cause settling effects of the abutment, which in turn would affect the amount of micromotion. The main reasons for not simulating clinical long-term use of the abutments as part of this study were, first, that after tightening the abutment and inserting the restorations, clinicians tend not to retighten after a fixed period of time unless the restoration becomes loose. Additionally, two different factors seem to be responsible for initial and long-term micromotion. While initial micromotion depends predominantly on the fabrication accuracy achieved, long-term micromotion appears to be related primarily to wear phenomena at the implant-abutment interface.[30]

In this study, only a limited number of abutments per type coming from a certain batch could be investigated. Given the substantial variations occasionally observed between different batches, the findings presented must not be generalized.[44] Because only one sample per ATLANTIS abutment group could be obtained from the manufacturer, these abutments were excluded from statistical analyses.

The amount of tightening torque significantly affected the level of micromotion when one specific abutment type was considered; this seems to be consistent with previous reports.[9] However, based on the fact that provisional abutments tightened at 15 Ncm and definitive abutments tightened at 35 Ncm on the same implant system did not differ with respect to the resulting micromotion, it appears that the optimal tightening torque is abutment specific. While in this case the definitive abutment was only joined with the implant by engaging the internal surfaces, the provisional abutment also rested on the external implant surfaces.

In the literature, there seems to be a consensus that the geometry of the implant-abutment interface has a significant effect on resulting micromotion,[31,42,46] with externally connected implant systems experiencing screw loosening as a consequence of micromotion more frequently.[5] In the current study, however, maximum micromotion was found in implants with internal-octagon connections, while the internal trilobe connection resulted in the least amount of micromotion recorded. Only one study was found in the literature stating that the type of implant-abutment connection did not have an effect on abutment screw loosening.[17]

Copy-milling of zirconia abutments as a low-cost alternative to established fabrication methods has become popular, although it has been shown that these abutments fit less accurately than prefabricated abutments.[33,47] However, in this study, no significant difference in micromotion between stock titanium abutments and copy-milled zirconia abutments was found. Casting onto prefabricated gold cylinders resulted in well-fitting abutments with the lowest levels of micromotion, which seems to be consistent with previous reports.[48]

Contradictory findings on the fit of zirconia abutments on titanium implants can be found in the literature.[29,49] In this study, CAD/CAM zirconia abutments without metal inserts were compared to CAD/CAM titanium abutments; the zirconia abutments revealed lower levels of micromotion.

Inconsistent results were found when comparing CAD/CAM abutments from proprietary and competing manufacturers with original stock abutments on the different implant systems. In most cases, the CAD/CAM abutments performed as well as stock abutments. This appears to be in accordance with previous studies indicating low levels of rotational misfit for CAD/CAM abutments.[48,50] In contrast, Alves da Cunha and coworkers described Nobel Biocare Procera zirconia abutments on competing implant systems as showing significant amounts of vertical misfit.[35]

A consistent tendency toward greater levels of micromotion was found for nonengaging abutments as compared to engaging abutments, regardless of the implant system considered. This is contradicted by a previous report indicating that the elimination of an antirotational feature did not affect abutment removal torque values following fatigue testing.[23]

Greater levels of variation appear to be present in clone abutments manufactured for high-value implant systems. Whereas Medentika cementable abutments showed significantly less micromotion than stock abutments in four of the six tested implant systems (Straumann Tissue Level, Straumann Bone Level, Nobel Biocare Brånemark, Nobel Biocare Replace Select), no difference was found for Nobel Biocare NobelActive implants, and significantly greater micromotion was found for OsseoSpeed implants. A comparable observation was made for titanium bases for bonded abutments fabricated by CADstar. Whereas for three implant systems (Straumann Bone Level, Nobel Biocare Brånemark, Nobel Biocare Replace Select), significantly lower micromotion was found for these abutments as compared to stock abutments, with the remaining three implant systems, no significant difference was revealed. However, it must be kept in mind that, to achieve standardized abutment heights of 5.5 mm extending from the implant shoulder for all specimens tested, composite resin was added to the titanium bases for bonded restorations. It may be argued that the material characteristics of comparably soft resin may have affected the measurement results in such a way that the applied force was absorbed by the resin material to some extent. While this may be seen as a limitation of the study, the purpose of adding composite resin instead of a zirconia structure was to avoid altering the quality of the interface established by the abutment manufacturer. Although study designs differ substantially, these findings to some extent contradict previous reports of greater rotational misfit[34] and increased risk of abutment screw loosening with nonoriginal abutments.[36] Similarly, no clear tendency could be observed when comparing high-value implant systems with low-cost clones. Depending on the abutment type considered, both lower and greater levels of micromotion were observed.

CONCLUSION

Using a novel mechanical approach for assessing micromotion phenomena at the implant-abutment interface, the current study showed that relative displacement of the components occurred at varying magnitudes. Based on the results presented here, it cannot be predicted that a certain type of abutment will always lead to a certain level of micromotion. However, the practitioner should be advised that strict adherence to manufacturers' guidelines (eg, with respect to tightening torque) may help reduce implant-abutment micromotion. Given the fact that micromovement occurs during the initial phase of loading, it might be advisable to routinely retighten the abutment screws, which might have lost preload.

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