The Evolution and Evaluation of Two Interference-Fit Implant Interfaces

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Abstract

Component misfit has been implicated as one of several important factors in screw-joint failure and screw loosening in dental implants. Recent evidence indicates that rotational misfit may be more important in screw-joint stability than originally anticipated. Efforts have been made to reduce and/or eliminate rotational misfit with different, nonrotating implant interfaces. The effectiveness of two interference-fit implant interfaces is reported in this article. The implants were evaluated for rotational movement, the intimacy and nature of hexagonal contact, the adequacy of the implant/abutment interface seal, and machining consistency of the hexagonals and implant. Currently available components are contrasted with components that were available initially in the evolution of these friction-fit/interference-fit interfaces. Significant improvements and refinements have been incorporated into the current generation of components.

Learning Objectives

After reading this article the reader should be able to:
- discuss the impact that component design and machining tolerances have on the implant/abutment fit and ultimate restorative stability.
- list the primary causes of screw-joint failure and screw loosening.
- explain the importance of using a reliable torque application system for seating implant components.
- compare two implant/abutment connections for component fit and stability.

While osseointegration continues to have a profound impact on dentistry, the profession's focus has now shifted from integration to eliminating the elusive 5% to 7% failure rate still encountered in partially edentulous and combination cases, and to a variety of mechanical and esthetic challenges that remain unresolved.[1-4] Currently, the most commonly used implant-interface continues to be the external hexagonal design introduced by Brånemark.[5] Expanded use in single and partially edentulous applications, however, has severely taxed the limits of this design. Originally intended as a coupling and rotational torque transfer mechanism used during the surgical placement of the implant, the external hexagon has evolved, by default, into a prosthetic indexing and antirotational mechanism.[6]

As the primary docking mechanism between the implant and abutment, the external hexagonal design has numerous deficiencies. Prosthetic complications, such as prosthetic and abutment-screw failures, gold cylinder and framework fractures, fixture fracture, and the loss of osseointegration, have been reported.[1-3,7,8] There are numerous reports in the implant literature of chronic screw loosening in single tooth, partially edentulous, and full-arch applications ranging from 6% to 38%.[3,9-13] The factors that affect external hexagon screw-joint stability have also been identified in a previous report.[14] Component misfit, along with several other factors, has also been implicated in single- and multiple-unit screw-joint failure and screw loosening.[15,16] However, the compromising effects of misfit on long-term prosthetic stability, have yet to be fully appreciated and universally acknowledged. For example, a design characteristic that permits horizontal and rotational movement, termed "freedom of fit," is reported to have been "conscientiously engineered" by one manufacturer into the implant's hexagonal tolerances to accommodate fitting errors.[17] White, however, notes that such misfits result in deformations that apply loads to gold screws, abutment screws, to the implant body, and, most importantly, to the implant-bone interface.[18] Misfits in complex, multiple-unit fixed prostheses on abutment teeth are compensated for by the 100 to 200 µm mobility of the periodontal ligament. In contrast, the clinical mobility of osseointegrated implants ranges from 17 to 66 µm and is attributed to osseous deformation.[19]

Ideally, a totally passive implant

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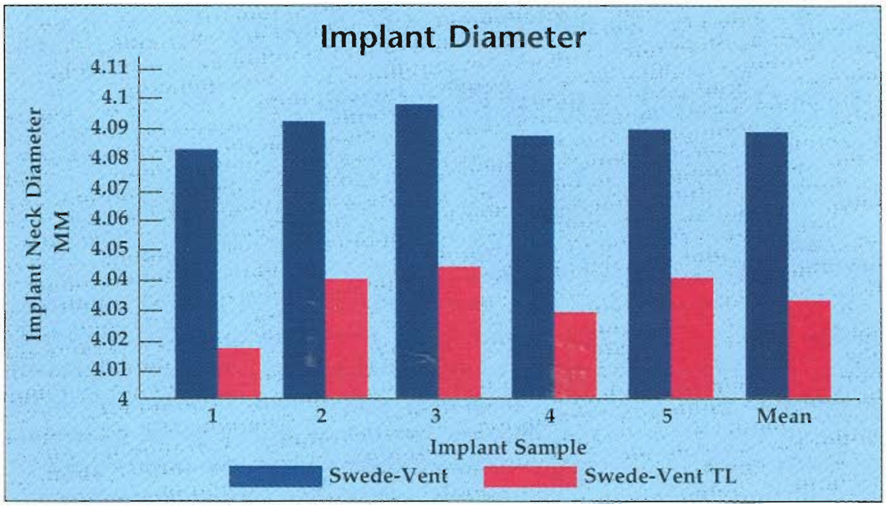

Figure 1—The mean Swede-Vent TL implant neck diameter was 0.055 mm smaller than the nontapered hexagonal variety previously produced. The size matches the abutment for a smooth interface transition.

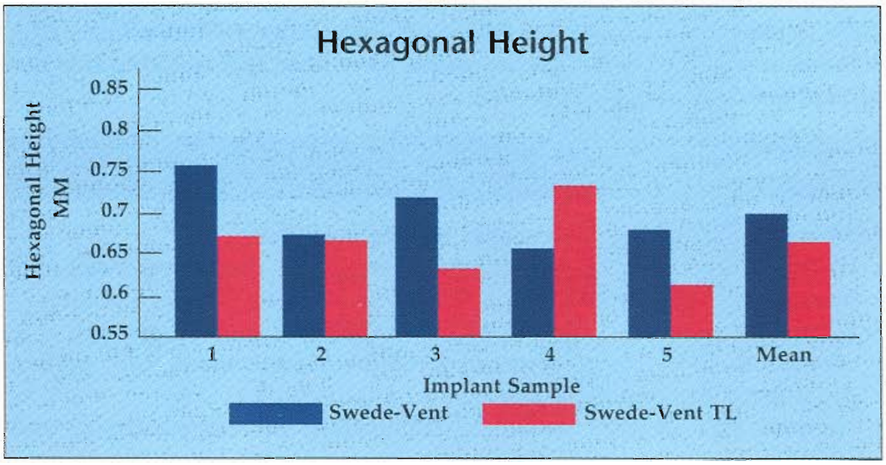

Figure 2—The mean external hexagonal height of the Swede-Vent TL was almost identical to its predecessor. Variations in the sample group for both were consistent with values of 0.100 mm and 0.113 mm, respectively.

stack and prosthetic superstructure will significantly reduce many of the prosthetic complications previously cited. However, a totally passive fit is difficult to achieve when one considers the summary distortions that can be incorporated into an implant prosthesis during the clinical and laboratory fabrication stages. Tan has identified the worst case scenario, from impression to framework, as ranging from 291 µm to 357 µm, depending on the use of a one-piece casting or a soldered framework.[20] With diligence and carefully controlled clinical and laboratory protocols, summary discrepancies of less than 150 µm can be achieved in full-arch cases and three-dimensional distortion limited on the order of 20 µm between the gold cylinder and the implant.[21]

Passive-fitting implant pillars also experience deformation during loading. Sakaguchi and Borgersen evaluated implant off-axis cyclic loading with a two-dimensional finite element model and observed separation between the crown/abutment interface on the contralateral side of the load.[22] The results also indicated that asymmetric loading resulted in rotation of the screw. That action ultimately results in screw backout, loss of preload, and loosening. Because external loads (occlusal function) tend to amplify dynamic changes in screw-joints, misfits and preexisting deformation within an implant component stack will further exacerbate screw loosening. The importance of "tight" machining tolerances and accurate intercomponent fit in achieving a stable implant/screw-joint is only now coming into focus.

Binon et al reported vertical interface discrepancies at the implant/abutment level ranging from 20 to 66 µm and at the abutment/cylinder level from 14 µm to 161 µm.[23] Other investigators have reported x-y horizontal discrepancies between mated components of 85 µm and 23 to 99 µm.[24,25] Binon also reported the rotational misfit between the external hexagon of the implants and the internal hexagon of the abutment varies from 3 degrees to 10.1 degrees.[26] Consequently, exact rotational transference and indexing from the impression to the working cast and from the working cast back to the oral cavity can vary by several degrees, resulting in proximal contact and seating discrepancies.

The degree of rotational misfit can be directly correlated to size discrepancies between the flat-to-flat dimensions of the implant hexagonal and its corresponding abutment hexagonal recess.

The mean flat-to-flat size of numerous external hexagonal implant types has been reported to range from 2.677 mm to 2.707 mm.[27] Within each of these group types, the mean hexagonal size ranged from as little as 0.001 µm to as much as 0.027 µm. Equally revealing was the greatest flat-to-flat difference on the same hex, which ranged from 0.003 µm to 0.108 µm. The greater the difference between the three flats on the hexagonal, the more asymmetric it is, and the greater the potential for rotational misfit. These values are also indicative of variations in the machining tolerances, consistency, and quality control at the time of manufacture.

The importance of tight implant

and abutment hexagonal tolerances on joint stability cannot be understated. In a recent study, implants with a known external hexagonal size were mated with abutments with sequentially larger hexagonal recesses and asymmetrically loaded until screw-joint failure occurred.[28] The results indicated that there is a direct correlation between implant/abutment rotational misfit and screw-joint loosening. The better the matrix to patrix fit, the more stable the screw-joint. The best implant/abutment fit (<2 degrees of rotational misfit) resulted in the greatest resistance to screw loosening with a mean of 6.7 million cycles (a 26% increase over the next larger abutment size). Screw-joints with more than 5 degrees of rotational misfit generally performed in a similar manner, with screw loosening occurring between 1.1 and 2.5 million cycles. This is a 63% reduction from that obtained with the best-fitting implant/abutment hexagonal.

Efforts have been made by numerous manufacturers to reduce and/or eliminate rotational misfit. The Screw-Vent® Hex-Thread®[a] implant, introduced in 1986, combined a lead-in bevel and a 1.7-mm length internal hex that accepted both cemented and threaded abutments.[29] In 1988, the Swede-Vent® implant[a] was introduced by the same manufacturer with a standard 0.7-mm length external hex as a clone to the Nobelpharma Brånemark[b] implant.[29] In 1992, the Screw-Vent internal hex design was modified with a 1-degree self-locking taper to achieve frictional fit and reduce rotational misfit.[29] Subsequently, the Swede-Vent design was modified with a 1.5-degree taper to create an interference press fit.[29]

Anecdotal reports indicated difficulties in seating the early Screw-Vent design, perhaps because "interdigitating hexes are only one factor in achieving a stable connection and accurate transfer, because manufacturing variations can result in up to ⅒ mm space between the mating parts."[29] A preliminary evaluation of the Screw-Vent implant/abutment interface reported vertical discrepancies that ranged from 30 µm to 75 µm (standard deviation = 13.4).[27] The purpose of this study was to evaluate abutment seating, implant/abutment interface discrepancies, and the rotational misfit of two intentional interference/friction-fit hexagonal systems and to compare them to a previously reported evaluation.

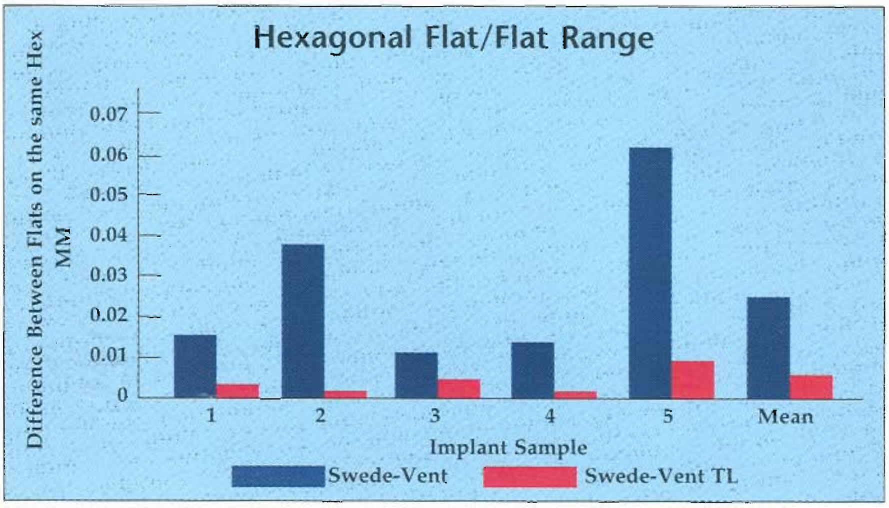

Figure 3—There is a noteworthy improvement in the machining consistency of the Swede-Vent TL hexagonal width. The mean flat-to-flat range for the Swede-Vent TL group was 0.002 mm, compared with its predecessor (0.027 mm). The greatest difference between flats on the same implant hexagon, illustrated in this graph, decreased significantly from 0.061 mm in the original sample to 0.005 mm for the Swede-Vent TL sample. This level of hexagonal consistency is necessary to attain predictable interference fit.

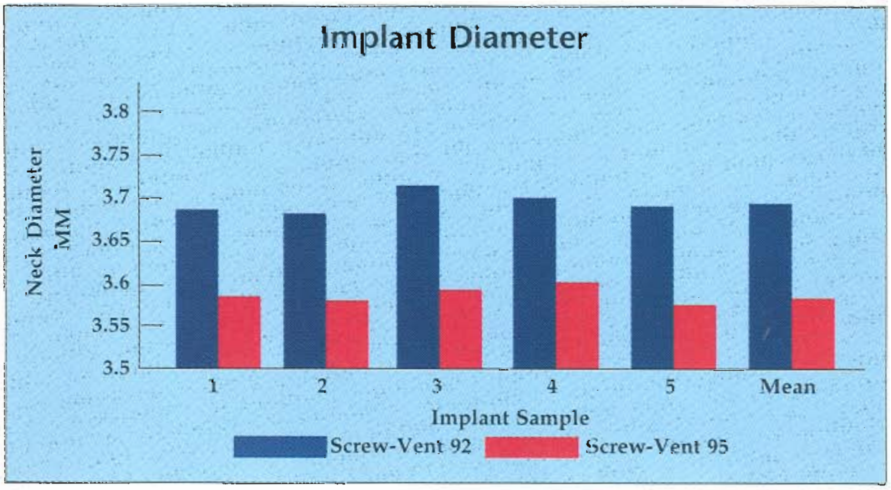

Figure 4—The mean Screw-Vent 95 implant neck diameter was 0.115 mm smaller than the SCV92 sample. This, coupled with other tolerance modifications, has resulted in a closer interface transition between abutment and implant.

Methods and Materials

Evaluation of the machining consistency was accomplished with direct measurement using a Model 293 digital micrometer[c] capable of 1-µm accuracy. Five implants and abutments were measured at each of the locations described. CoreVent Bio-Engineering, Inc., provided the

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[a] DENTSPLY Implant, Encino, CA 91436

[b] Nobelpharma USA, Westmont, IL 60559

[c] Mitutoyo, Tokyo, Japan

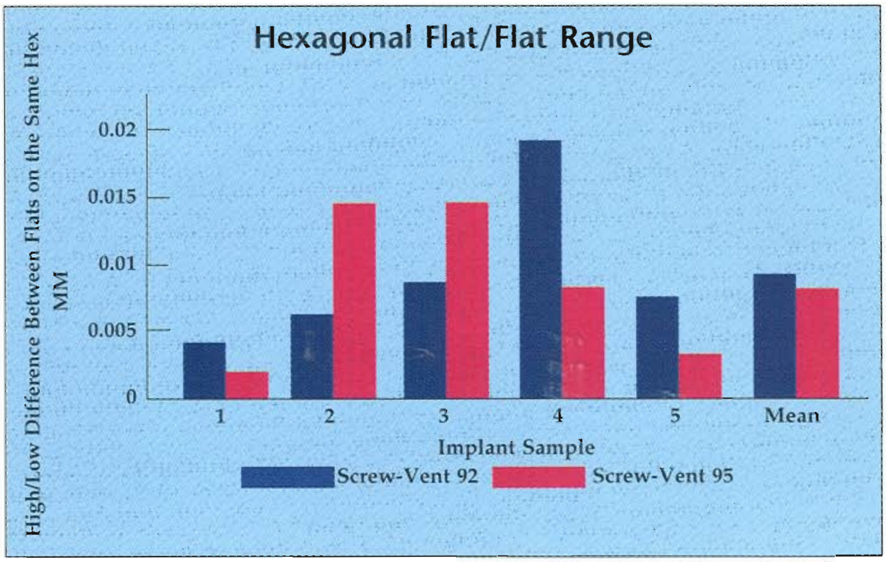


Figure 5—The mean flat-to-flat dimension for Screw-Vent abutments of both samples varied slightly. The high-low (range) for each hexagon is illustrated above. The means varied little, with 0.009 mm and 0.008 mm, respectively.

Table 1—Neck Diameter and Hex Height

Implant Type	Sample	Neck Diameter (mm)	Neck Diameter Range	Hex Height (mm)	Hex Height Range
Swede-Vent (SWV)	1	4.083		0.762	
	2	4.095		0.670	
	3	4.099		0.718	
	4	4.092		0.662	
	5	4.093		0.690	
	Mean	4.092	0.016	0.700	0.100
	STD	0.0053		0.0364	
	Variance	0.00003		0.00132	
Swede-Vent (SWV-TL)	1	4.019		0.670	
	2	4.040		0.664	
	3	4.046		0.641	
	4	4.037		0.738	
	5	4.043		0.625	
	Mean	4.037	0.027	0.668	0.113
	STD	0.0095		0.0387	
	Variance	0.00009		0.00150	

original Screw-Vent (SVA13) and Swede-Vent (13S) implants in 1991. DENTSPLY Implant provided the currently available Swede-Vent TL®,[a] and Screw-Vent implants and Hex-Lock™ abutments from inventory in sealed, sterile packages.

Measurements were made at these locations: implant coronal (head) diameter, height and width of the implant internal/external hexagon, length and width of the abutment internal/external hexagonal extension, and flat-to-flat measurements for each hexagon. Rotational freedom (misfit) was measured with a calibrated protractor table (previously described).[26] The more intimate the mating of the components are, the smaller the rotational movement. The following components were evaluated in the study: Swede-Vent 3.75 x 10; Swede-Vent TL 4.0 x 13; Swede-Vent TCAX abutment; Screw-Vent SVA 3.75 x 13; Screw-Vent SVP 3.75 x 16; Screw-Vent abutment HLA3F; Screw-Vent 3.75 x 10; Screw-Vent abutment HLA3F.

The original Screw-Vent components were tightened to bounce-back with a ratchet driver supplied by the manufacturer. The Swede-Vent TL and Screw-Vent PSV10 implant abutment stacks were tightened to 30 Ncm with the DENTSPLY Precision Torque System®,[a] (PTS). After measurements were taken, the samples were embedded in resin under vacuum, sectioned, and polished. Optical and scanning electron microscopy (SEM) were used on each of the samples at low and high power.

Results

For the sake of clarity, the following designations will be used to identify the implant groups and their corresponding abutments: SWV = original Swede-Vent group; SWV-TL = Swede-Vent TL; SCV92 = original Screw-Vent (SVA & SVP); and SCV95 = Screw-Vent PSV10.

The mean diameter at the neck of the SWV-TL was 4.037 mm (STD 0.0095) with a high/low range of 0.027 mm. The mean hexagonal height was 0.668 mm (STD 0.0387) with a range of 0.113 mm (Table 1). The mean hexagonal flat-to-flat measurement of the samples was 2.715 mm (STD 0.0103) (Table 2). The greatest difference between flats in the sample was 0.031 mm, and the greatest difference between flats on the same hexagonal was 0.005 mm.

The mean neck diameter of the SCV95 was 3.579 mm (STD 0.0060) with a high/low range of 0.016 mm (Table 3). The mean Screw-Vent Hex-Lock abutment (TCAX) base width was 4.494 mm with a range of 0.006 mm. The sample mean for the Screw-Vent Hex-Lock abutment's (HLA3F) hexagonal length was 1.558 mm (STD 0.0423) with a

Table 2—Difference Between Flats for Samples

Implant Type	Sample	Hexagonal Size (mm) Flat 1	Flat 2	Flat 3		Flat-to-Flat Range	Greatest Difference Between Flats for the Entire Sample (Range)
Swede-Vent (SWV)	1	2.682	2.687	2.696		0.014	
	2	2.728	2.701	2.692		0.036	
	3	2.702	2.690	2.696		0.012	
	4	2.694	2.682	2.695		0.013	
	5	2.790	2.729	2.736		0.061*	0.108
	Mean				2.707	0.027	
	STD				0.0276		
	Variance				0.0008		
Swede-Vent TL (SWV-TL)	1	2.697	2.695	2.697		0.002	
	2	2.714	2.715	2.715		0.001	
	3	2.716	2.718	2.719		0.003	
	4	2.725	2.725	2.726		0.001	
	5	2.725	2.724	2.720		0.005*	0.031
	Mean				2.715	0.002	
	STD				0.0103		
	Variance				0.0001		

* Greatest difference between flats on the same hexagonal

range of 0.116 mm (Table 3). The mean flat-to-flat measurement for the sample was 2.446 mm (STD 0.0076) with a range of 0.008 mm (Table 4). The greatest difference between flats on the same hexagon was 0.014 mm, and the greatest difference between flats in the sample was 0.027 mm.

Rotational freedom (misfit) for the SWV-TL implant/abutment stack was 0-degrees when coupled with minimal finger pressure and when fully tightened with a torque driver. The SCV95 implant/abutment stack recorded 0.4-degree rotation with minimal finger pressure and 0-degree rotation when properly tightened with the torque wrench (Table 5).

Comparison With Original Data

Comparison of the data sets previously reported and the current data indicate the following[27]: The mean 4.092-mm-neck diameter of the SWV implant was slightly larger than the 4.037-mm mean recorded for the SWV-TL (Figure 1). The high/low range for the two groups were 0.016 mm and 0.027 mm respectively (Table 1). The mean external hexagonal height for both groups was almost identical with 0.700 mm (SWV) and 0.668 mm (SWV-TL) (Figure 2).

In addition, there was no discernible difference in the low/high ranges for both of the groups, with values of 0.100 mm and 0.113 mm respectively (Table 1).

The mean flat-to-flat size for the SWV group was 2.707 (STD 0.0276) compared to 2.715 (STD 0.0103) for the SWV-TL group (Table 2). There is a noteworthy improvement in the consistency of the hexagonal size for the SWV-TL group. Mean flat-to-flat range for the SWV-TL group was 0.002 mm compared to 0.027 mm for the original SWV group (Table 2). The greatest difference between flats on the same hexagon also decreased from 0.061 mm (SWV) to 0.005 mm (SWV-TL) (Figure 3). The greatest difference between flats within each sample group also decreased from 0.108 mm (SWV) to 0.031 mm for the SWV-TL group (Table 2).

The mean implant neck diameter for the SCV95 group was 0.115 mm smaller than the SCV92 group, with means of 3.579 mm and 3.694 mm respectively (Figure 4). The high/low range decreased from 0.030 mm (SCV92) to 0.016 mm for SCV95. The mean abutment hexagonal extension length for the SCV92 group was 1.582 mm. The SCV95 hexagonal length was slightly shorter at 1.558 mm (Table 3). The high/low range for each group was 0.134 mm and 0.116 mm respectively. The mean hexagonal flat-to-flat dimension for SCV92 was 2.412 mm compared to 2.446 mm for SCV95 with comparable ranges of 0.009 mm and 0.008 mm respectively (Figure 5). The greatest difference between flats on the same hexagon varied little, with values of 0.019 mm for the SCV92 and 0.014 mm for the new sample group.

Optical and SEM Evaluation

Optical micrographs of the Screw-Vent (SCV95)/Hex-Lock abutment (HLA3F) illustrate the frictional fit

Table 3—SCV92 and SCV95 Sample Comparisons

	Sample	Implant Neck Diameter (mm)	Implant Neck Diameter Range	Abutment Hex Length (mm)	Abutment Hex Length Range
Screw-Vent 92	1	3.684		1.529	
(SCV92)	2	3.679		1.585	
	3	3.709		1.561	
	4	3.701		1.572	
	5	3.695		1.663	
	Mean	**3.694**	**0.030**	**1.582**	**0.134**
	STD	0.0109		0.0445	
	Variance	0.00012		0.00198	
Screw-Vent 95	1	3.585		1.533	
(SCV95)	2	3.575		1.524	
	3	3.581		1.537	
	4	3.584		1.640	
	5	3.569		1.555	
	Mean	**3.579**	**0.016**	**1.558**	**0.116**
	STD	0.0060		0.0423	
	Variance	0.00004		0.00179	

Figure 6—Optical cross-sectional micrographs of each of the Screw-Vent 95 implant/abutment pillars were evaluated. This illustrates the characteristic intimate contact and frictional fit between the internal straight hexagon of the implant and the external 1-degree tapered external hexagon of the abutment. The implant/abutment beveled seating surface also demonstrates full contact and intimate seal. Note the crisp, sharp, internal threads in the implant and corresponding full engagement of the abutment screw threads.

between the internal straight hexagonal inside the implant and the external 1-degree taper on the abutment's external hexagonal extension (Figure 6). The crisp, sharp internal threads of the implant clearly show full engagement of the abutment screw thread. An X20 optical micrograph illustrates the tight, locking fit along the full length of the internal and external hexagonal flats (Figure 7). The 45-degree beveled implant/abutment seating surfaces contact intimately without any discernible interface gap.

The SEMs are representative of the five samples evaluated, and document, at high magnification, the intimate contact between the full length of the hexagonal flat and the 45-degree bevel (Figures 8A through 8C). The X150 SEM of the external contact area between the abutment and the implant illustrates a slight interface shoulder that extends approximately 30 µm to 40 µm toward the contact with the abutment seating surface. The mating surfaces beyond that point are in intimate contact for the full length of the seating surface (Figure 8B).

In contrast, optical micrographs of the original Screw-Vent (SCV92) implant/abutment cross-sections indicate differences and deficiencies that have been eliminated in the currently available Screw-Vent implants and Hex-Lock abutments (Figures 9). The SCV92 micrographs depict incomplete external/internal hexagonal contacts and an implant/abutment interface gap that extends to the midpoint of the 45-degree bevel (Figures 10A and 10B). Machining tolerances have been refined in the SCV95/HLA3F to eliminate the 30 to 70 µm interface gaps previously reported.[27] The internal screw threads of the SCV95 implant have also been refined (Figure 11). Careful analysis of the two different threads indicates that the SCV92 threads appear to be oversized with a poor thread match to the abutment screw. This is in sharp contrast with the crisp, well-defined internal threads of the SCV95, which fully engage the abutment screw (Figure 6). Oversized and poorly aligned screw threads can result in axial misalignment, incomplete screw seating, thread stripping, and screw failure as a result of back out (personal communication, JD Geller, Geller Microanalytical Laboratory, Topsfield, MA, June 14, 1995).

Optical cross-sectional micrographs of each of the five Swede-Vent TL® (SWV-TL)/Taper Lock™ abutments (TCAX) used in the study document the intimate interference fit between the external 1.5-degree taper on the external hexagon of the implant and the straight internal hexagonal receptacle of the abutment (Figure 12). The crisp, sharp internal threads of the implant demonstrate excellent contact and engagement with the abutment screw threads for optimal engagement. An

Table 4—Abutment Sample Comparisons

		Hexagonal Size (mm)					
Abutment	**Sample**	**Flat 1**	**Flat 2**	**Flat 3**		**Flat-to-Flat Range**	**Greatest Difference Between Flats for the Entire Sample (Range)**
Screw-Vent 92 (SCV92)	1	2.415	2.415	2.411		0.004	
	2	2.412	2.414	2.418		0.006	
	3	2.403	2.401	2.410		0.009	
	4	2.412	2.421	2.402		0.019*	
	5	2.422	2.420	2.414		0.008	0.021
	Mean				**2.412**	**0.009**	
	STD				0.0064		
	Variance				0.00004		
Screw-Vent 95 (SCV95)	1	2.436	2.434	2.436		0.002	
	2	2.437	2.442	2.451		0.014*	
	3	2.449	2.455	2.441		0.014	
	4	2.445	2.461	2.452		0.009	
	5	2.450	2.447	2.450		0.003	0.027
	Mean				**2.446**	**0.008**	
	STD				**0.0076**		
	Variance			**0.00006**			

*Greatest difference between flats on the same hexagonal

Table 5—Hexagonal Misfit

Implant Type	**Rotational Movement* (Misfit in Degrees)**	**N**
Screw-Vent 92	1.4	25
Screw-Vent 95	0.4	20
Swede-Vent TL	0	20
Swede-Vent 92**	—	—

* Abutment implant stack assembled with light finger tightening
**Swede-Vent 92 data did not report rotational movement (two-piece standard abutment not tested)

X20 optical micrograph of the hexagonal contact and seating surface of the implant/abutment interface illustrates excellent interface integrity (Figure 13).

The SEM views at X50, X100, and X1000 magnifications are representative of the SEMs taken of each of the sectioned implants and clearly illustrate the intimate contact between the tapered external and internal hexagonal flats of the implant and abutment (Figures 14A through 14C). The implant/abutment contact line in the X100 magnification indicates that the interference fit between the engaged hexagons initiate at the center of the mating components and extends apically. The X1000 magnification SEM of the engaged surfaces depicts a virtual cold weld of the contacting interference-fit surfaces (Figure 14C).

Torque and Preload

Applying the correct torque to an implant screw is critical to the functional success of the implant system. This is usually accomplished when the operator applies torque with a

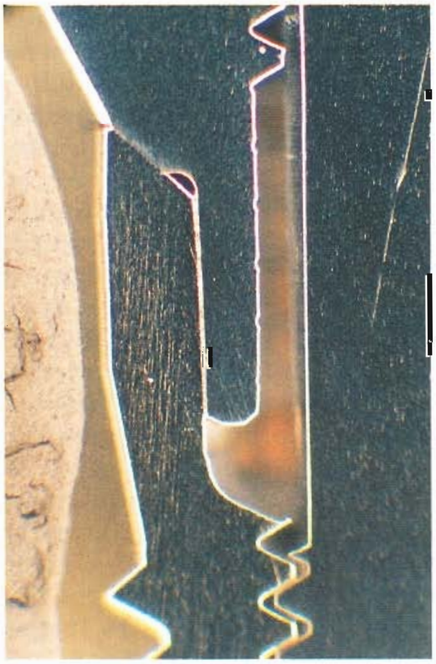
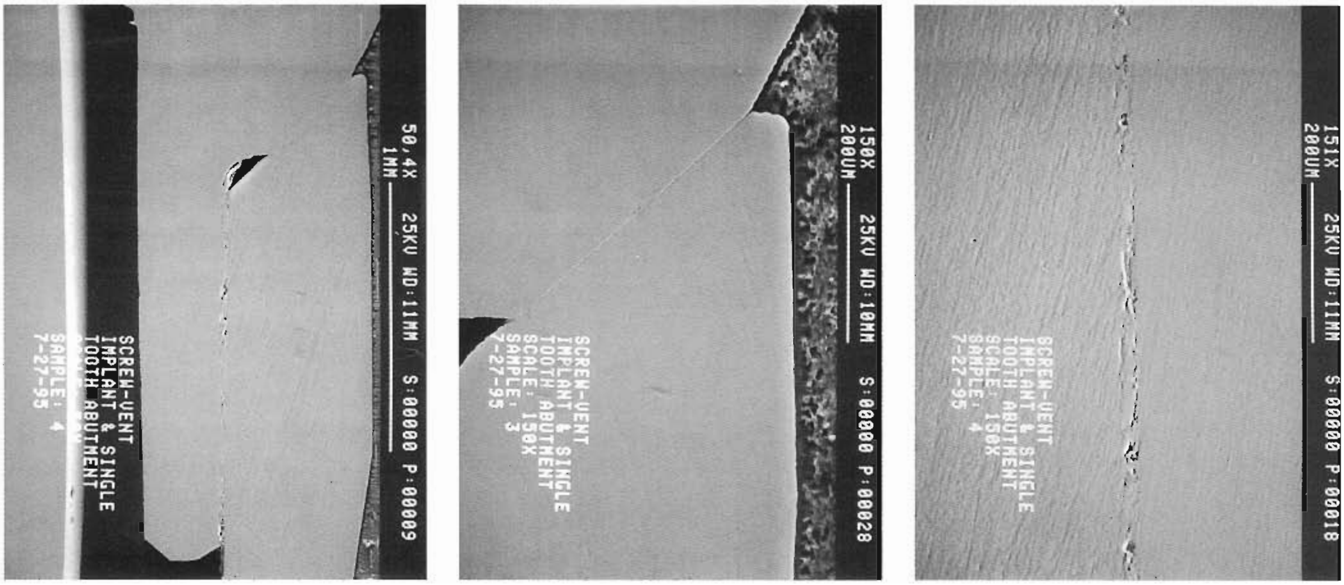


Figure 7—Higher magnification optical micrograph illustrating the friction/interference fit along the entire length of the internal and external tapered hexagonal flats. The 45-degree beveled implant/abutment seating surfaces contact intimately without any discernible interface gap.



Figures 8A through 8C—SEM micrographs, representative of all the cross sections at X50, and X150 magnification illustrate surface contact. Figure A (left) shows intimate contact of the new SCV95 implant at both the beveled implant/abutment interface and the hexagonal engagement area. Figure B clearly shows full contact along the beveled interface and attainment of a full interface seal. A slight interface shoulder of approximately 30 to 40 μm was seen at each implant/abutment interface. Figure C is a higher magnification of the hexagonal engagement between the flats of the implant and the abutment.

hex tool or screwdriver with his or her fingers. This torque application, which depends on the radius of the driving tool, is translated into a preload that holds the components together. The preload or clamping force is the only force that will resist the patient's functional occlusal forces and will keep the attached abutment from separating from the implant. If the clamping force (preload) is exceeded by the chewing force, and the component pillar has no antirotational feature (such as a hexagon, octagon, or spline), or is part of a multiunit fixed-partial denture, the abutment will unthread from the implant. Even when an antirotational feature is present, problems can arise when the machining tolerances of the mating parts exceed a critical level. As previously noted, rotational "misfit," "play," or "freedom" above 2 degrees can result in vibration and micromovement between the components during functional loading, which systematically erodes the clamping force until screw-joint failure occurs.

The torque required to generate optimal clamping force for a particular implant system depends on the screw design, thread quality, type of metal used, its physical characteristics, and the quality of the component's mating surfaces. The use of hand drivers for torque application above 20 Ncm is discouraged because of the high degree of unpredictability and variation that typically occurs among clinicians. The Goheen et al study indicated that even experienced clinicians undertightened by 30% to 50% when hand-tightening screws to target values. Screws clinically tightened only to that level would loosen under much lighter occlusal loads.[30] Also, hand drivers are very difficult to use in some areas of the mouth and pose a higher risk of swallowing and aspiration.

More predictable torque application is achieved with a mechanical torque wrench. Access, speed, and safety are also greatly enhanced.

Antirotation

To prevent screw loosening and ultimate prosthetic failure, several alternative implant/abutment couplings have evolved. Octagonal, locking tapers, splines, and pins have been incorporated in the mating surfaces of the components in an effort to achieve optimal rotational stability. The external hexagonal also has evolved in a number of different directions. Initial efforts to stabilize the external hexagon for single-implant application led to the use of gold-alloy retaining screws with higher torque applications that elastically deformed the screw to work as a spring or lock washer. Although the engineering concept had considerable merit for enhancing screw-loosening resistance, the basic design is limited in its overall success. Long-term occlusal loading predisposes the screw to continued deformation beyond the mechanical characteristics of the gold alloy screw, which can result in fracture. The recent focus on rotational misfit has resulted in reassessment of the machining tolerances of external hexagonals and their abutment counterparts.[28] Several manufacturers have reduced the rotational misfit between coupling hexagons to less than 4 degrees in an effort to

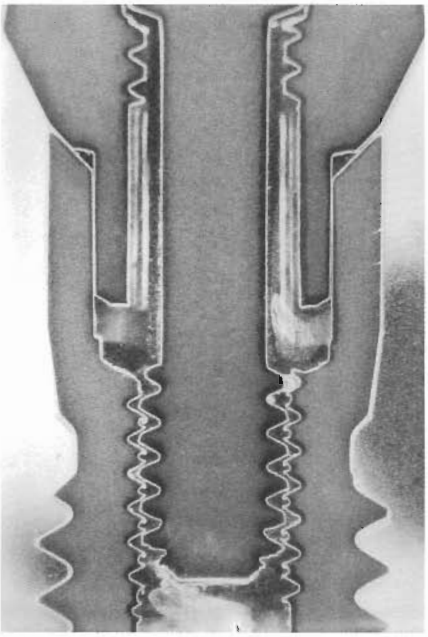
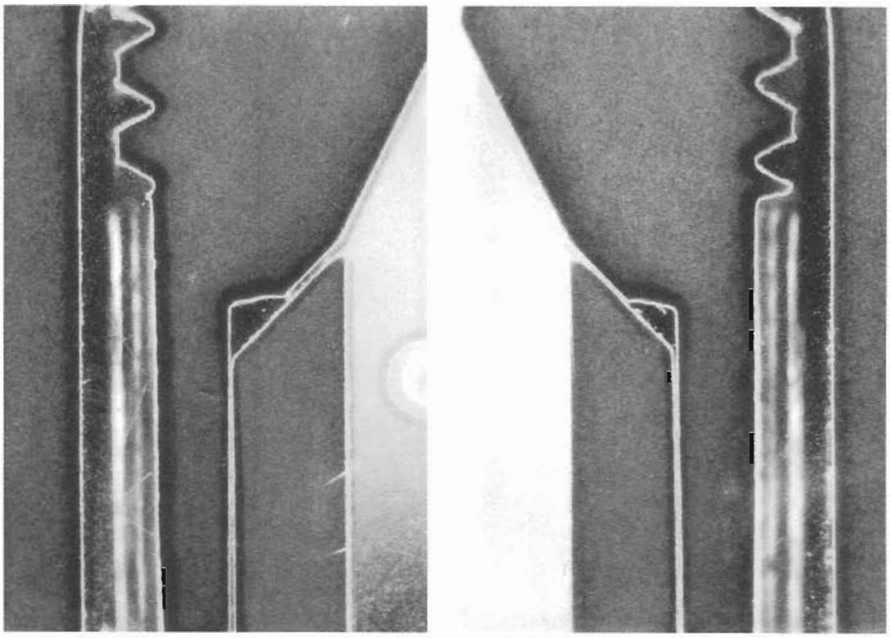


Figure 9—Optical micrographs of the old Screw-Vent (SCV92) indicate incomplete hexagonal engagement, implant/abutment interface gaps that extend to the midpoint of the 45-degree seating bevel, and internal screw threads that appear to be oversized.



Figures 10A and 10B—Higher magnification optical micrographs of the implant/abutment seating bevel that demonstrates the 30 μm to 70 μm interface discrepancy previously reported for early-generation Screw-Vent implants.

reduce screw-joint failure. A custom-abutment laboratory technique for use with a variety of hexagonal sizes that eliminates rotational misfit has also been developed.[31] The ultimate extension of that concept for an external hexagonal implant involves the 1.5-degree tapered-lock developed by DENTSPLY Implant. This friction-fit hexagon, the Swede-Vent TL, has effectively eliminated all rotational misfit.

Another design concept that uses an internal hexagonal recess within the implant body and a tapered hexagonal extension on the abutment has been developed by DENTSPLY Implant. Conceptually, by manufacturing the male antirotational hexagon with a self-locking taper and seating it into the mating female hexagon with frictional resistance, the intimate locking connection eliminates the effect of occlusal vibration. The longer hexagonal connection also distributes forces deeper within the implant and shields the retention screw from excessive loading. Lateral forces are transmitted directly to the walls of the implant and the implant/abutment mating bevels, providing greater resistance to interface opening than with a butt-joint connection.

Although these designs meet the desired functional characteristics for a successful single-tooth restoration, care is required to guarantee that the abutment seats flush onto or into the implant. Continued evolution of the self-locking tapered systems has led to further definition of the torque required to seat the abutment completely. Initially, functional retention required "10-20 Ncm force during tightening of the fixation screw to fully seat the abutment."[32] The current manufacturers' recommendation for the friction-fit Hex-Lock abutment (HLA3F/HLA4F) is 30 Ncm. To achieve this torque in a predictable manner, DENTSPLY Implant has designed a Precision Torque System (PTS).

Summary

Although there are a variety of single-tooth implant/abutment designs, unless functional chewing forces are eliminated from the system, the opportunity for screw-joint loosening cannot be totally controlled. The dynamics of chewing applies and removes a variable force to the retaining screw that holds the restoration in place. If micromovement readily occurs within the implant pillar assembly in a vertical, horizontal, or rotational manner because of misfit between the assembled parts, the screw-joint will rapidly fail. In single-implant applications in particular, if rotational movement or misfit exists between the mating interlocking components, the retaining screw will be subject to increased load, vibration, dissipation of preload, and ultimate unraveling. Refinements to existing systems and the introduction of numerous new designs are all efforts to extend the resistance and stability of the implant screw-joint for as long a time interval as possible.

It is important for the clinician to realize that regardless of specific design, screw-joint stability involves a number of critical factors.[14,33] Three of the primary factors are: (1) ad-

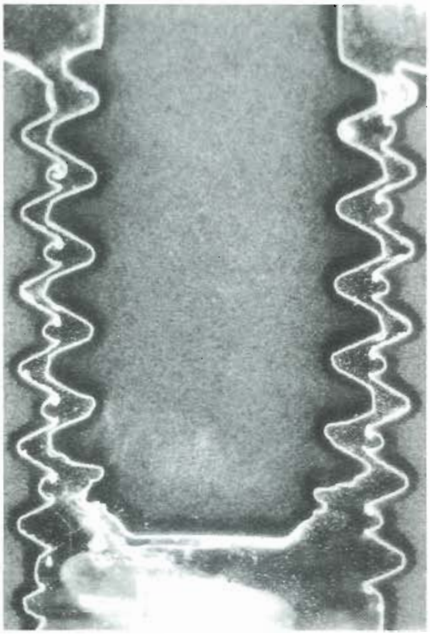


Figure 11—Representative optical micrographs of the abutment screw thread area on early Screw-Vent implants illustrate threads that appear to be oversized with a poor match to the abutment screw threads. Note the significant difference in thread engagement of the threads depicted in Figure 6 and Figure 7.

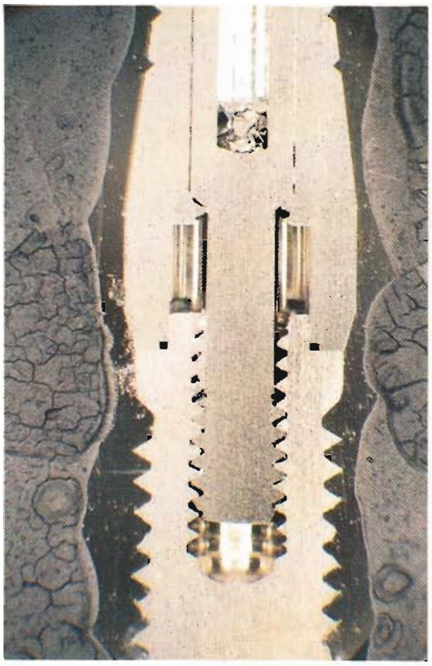


Figure 12—Optical cross-sectional micrographs of each of the Swede-Vent TL implant/Taper Lock abutment pillar were evaluated. This illustrates the typical intimate fit between the external 1.5-degree tapered hexagonal and the straight internal hexagonal receptacle of the abutment.

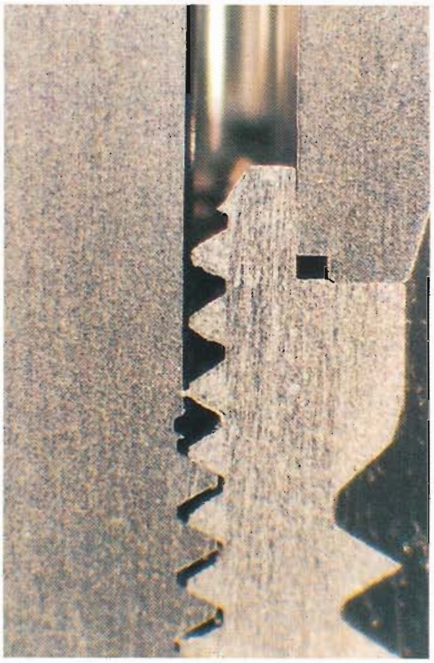


Figure 13—Higher magnification of the hexagonal engagement and the implant/abutment interface, demonstrating excellent intimate contact.

equate preload (clamping force) which correlates to the amount of torque applied to the screw; (2) the dimensional tolerance of the implant components and the exactness of the fit; and (3) the basic antirotational characteristics of the implant interface (hex, octagon, spline, etc).

Conclusions

Two friction-fit hexagonal implant systems were evaluated and contrasted for machining consistency, interface fit, and rotational stability. From the data presented, the following conclusions can be drawn:

1. Rotational freedom (misfit) for the Swede-Vent TL and Screw-Vent implant/abutment systems with minimal finger pressure tightening was 0 degrees and 0.4 degrees, respectively. Rotational freedom was 0 for both systems when fully tightened to 30 Ncm.
2. The SEM cross sections of both systems document intimate hexagonal contact and interference fit that results in abutment rotational stability.
3. Refinements in machining tolerances and the availability of a reliable method of torque application have resulted in predictable and consistent implant/abutment interface seals.

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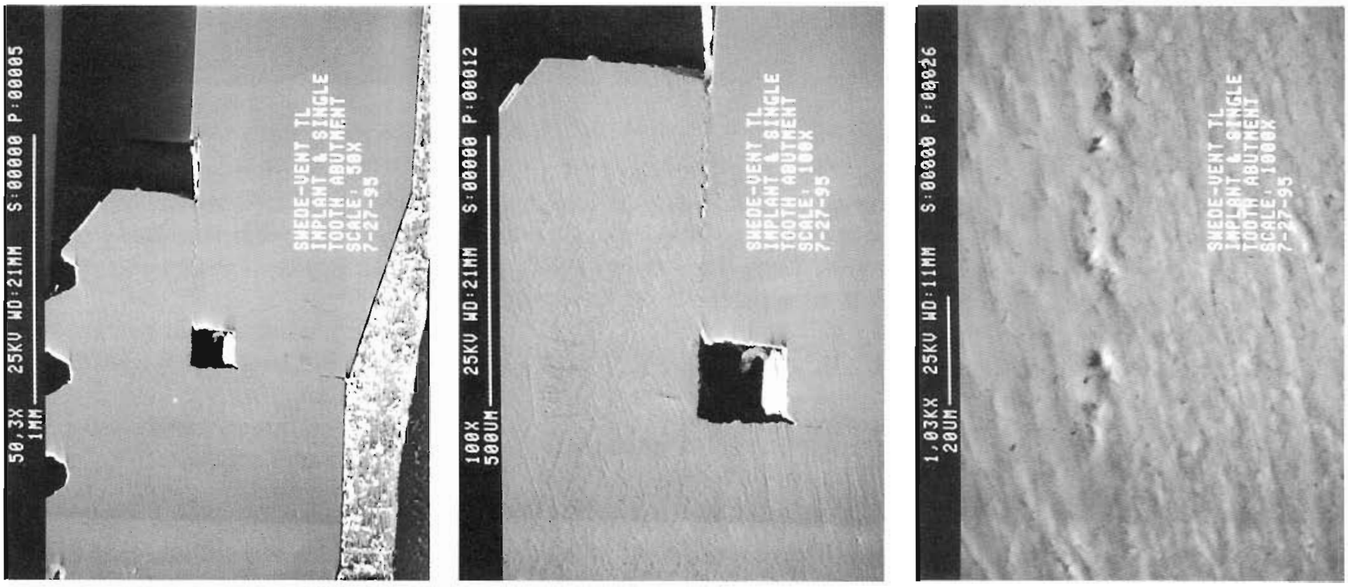

Figures 14A through 14C—SEM micrographs at X50, X100, and X1000 magnifications of the hexagonal engagement. The X1000 magnification depicts the "cold weld" of the friction fit between the engaged hexagons. This lock eliminates rotational misfit and increases joint stability.

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