COMPARISON OF THE COMPRESSIVE STRENGTH OF 3 DIFFERENT IMPLANT DESIGN SYSTEMS

Jose E. Pedroza, DMD, MS; Ysidora Torrealba, DDS, MSD; Augusto Elias, DMD, MSD; Walter Psoter, DDS, PhD

The aims of this study were twofold: to compare the static compressive strength at the implant-abutment interface of 3 design systems and to describe the implant abutment connection failure mode. A stainless steel holding device was designed to align the implants at 30° with respect to the y-axis. Sixty-nine specimens were used, 23 for each system. A computer-controlled universal testing machine (MTS 810) applied static compression loading by a unidirectional vertical piston until failure. Specimens were evaluated macroscopically for longitudinal displacement, abutment looseness, and screw and implant fracture. Data were analyzed by analysis of variance (ANOVA). The mean compressive strength for the Unipost system was 392.5 psi (SD $\pm$ 40.9), for the Spline system 342.8 psi (SD $\pm$ 25.8), and for the Screw-Vent system 269.1 psi (SD $\pm$ 30.7). The Unipost implant-abutment connection demonstrated a statistically significant superior mechanical stability ($P \leq .009$) compared with the Spline implant system. The Spline implant system showed a statistically significant higher compressive strength than the Screw-Vent implant system ($P \leq .009$). Regarding failure mode, the Unipost system consistently broke at the same site, while the other systems failed at different points of the connection. The Unipost system demonstrated excellent fracture resistance to compressive forces; this resistance may be attributed primarily to the diameter of the abutment screw and the 2.5-mm counter bore, representing the same and a unique piece of the implant. The Unipost implant system demonstrated a statistically significant superior compressive strength value compared with the Spline and Screw-Vent systems, at a 30° angulation.

Key Words: dental implants, implant-abutment connection, abutment screws

INTRODUCTION

Metal fatigue is perhaps the most common cause of structural failure, often causing implants to fracture. This failure is particularly important because further surgical procedures are required to remove and replace the fixture; under repeated loading, implants may fracture at stress levels below the ultimate strength of the material. Crack propagation originates from maximum stress locations and can lead to sudden and catastrophic failure after a number of years of trouble-free service or within hours of placement.[1–10]

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Recently, implant failure studies have focused on the threaded 1.5-mm gold screw and implant abutment that connects the prosthesis with the osseointegrated implant.[11–15] The high concentration of stress in the root of the screw threads is often the source of fatigue failure. Evidence suggests this screw thread component may be a weak link in the system and has been related, in part, to improper fit of the superstructure when multiple-implant-supported units are splinted together.[12–15] Prosthetic screws can loosen as a result of: (1) inadequate tightening, (2) poorly machined parts, (3) excessive loading, (4) screw design, or (5) elasticity of bone.[14–18]

To predict the fatigue life of an implant-abutment interface, the stress distribution must be determined.[13] When a total load applied to the screw exceeds the fatigue parameters, the ability to clamp the components together decreases dramatically.[5,19,20] Applying an appropriate amount of tightening torque to the screw to generate the maximum preload (always less than its fatigue limit) diminishes the failures associated with implant-abutment interface.[19–20] Bickford described screw joint failures in 2 stages. The first stage consists of external functional loading that gradually and effectively erodes the preload torque. Eventually, the critical load exceeds the preload of the screw joint and it becomes unstable. In the second stage, screw loosening, the external load rapidly erodes the remaining preload torque, resulting in vibration and micro-movements that lead to screw failure.[21]

Several implant-abutment interface failures are associated with engineering design and can be assessed in a laboratory setting.[22] Further, functional overload has been associated with screw loosening and sometimes, bone fractures, leading to loss of osseointegration.[18–21] Reliable data on screw joint stability have evolved from the Branemark external hexagon implant (Nobel Biocare AB, Göteborg, Sweden) and its clones. The most recent Branemark system and its clones present limitations with respect to abutment screw and implant body fractures.[22–29] The implant-abutment interface is generally described as an internal or external connection, characterized as a slip-fit joint, where a slight space exists between the mating parts (passive connection), or as a friction-fit joint, where no space exists between the mating components and the parts are literally forced together.[6,8,12,16,29,30]

The two connections differ with regard to the presence or absence of a geometric feature extending above the coronal surface of the implant body. Implant-abutment interface systems have been developed with varying degrees of success (ranging from peri-implant health to mechanical stability) to overcome the implant-abutment failure associated with either type of connection.[16,30] The Unipost implant system was developed in 1974 and has an internal connection; the implant-abutment interface consists of a screw that is fused to the abutment with a 2.5-mm counter bore cemented counterclockwise to the implant and cement abutment. In 1986, Screw-Vent patented the internal hexagonal connection, an implant body top that connects with the beveled abutment lead; the sharp internal corners of the implant body receive the male hexagon of the abutment. Calcitek developed the Spline system in 1992, an implant body consisting of 6 parallel splines that fit into the grooves of the abutment-matching components.

The specific aims of this study were twofold: to compare the static compressive strength at the implant-abutment interface of 3 design systems and to describe the failure mode of the implant-abutment connection.

MATERIALS AND METHODS

Sixty-nine screw implants and their prefabricated straight abutments were used in this study. Twenty-three models of each implant type were arbitrarily selected by the manufacturers from production inventory and were provided free of charge. They were: (1) 3.7 × 13-mm Screw-Vent implants, (2) 3.75 × 13-mm Spline Twist-MTX implants, and (3) 3.5 × 14-mm Unipost screw implants.

Abutment preparation

Two-piece metal sleeves (A2 tool steel), 10-mm long, were custom made for each implant system (Centerpulse, Calabasas, Calif), allowing for a perfect load distribution to the body implant (Figure 1a, b, and c). The sleeves were placed 2 mm below the bone line (Figure 1d).[26,28,32] Machining (Harding Super-Precision Machine) standardized abutments to extend 10 mm superior to the upper edge of the sleeves.

Application of the controlled torque

Screw-Vent and Spline implants were held rigidly in a special holding device while the abutment screw was tightened to 30 N with a Digital Torque Gauge Model BGI, ensuring solid fixation without rotation during tightening. Following the manufacture's protocol, 10 minutes later the Spline and Screw-Vent abutment screws were retorqued to 30 N; Unipost abutments were screwed and cemented counterclockwise to the implant body with Panavia 21.

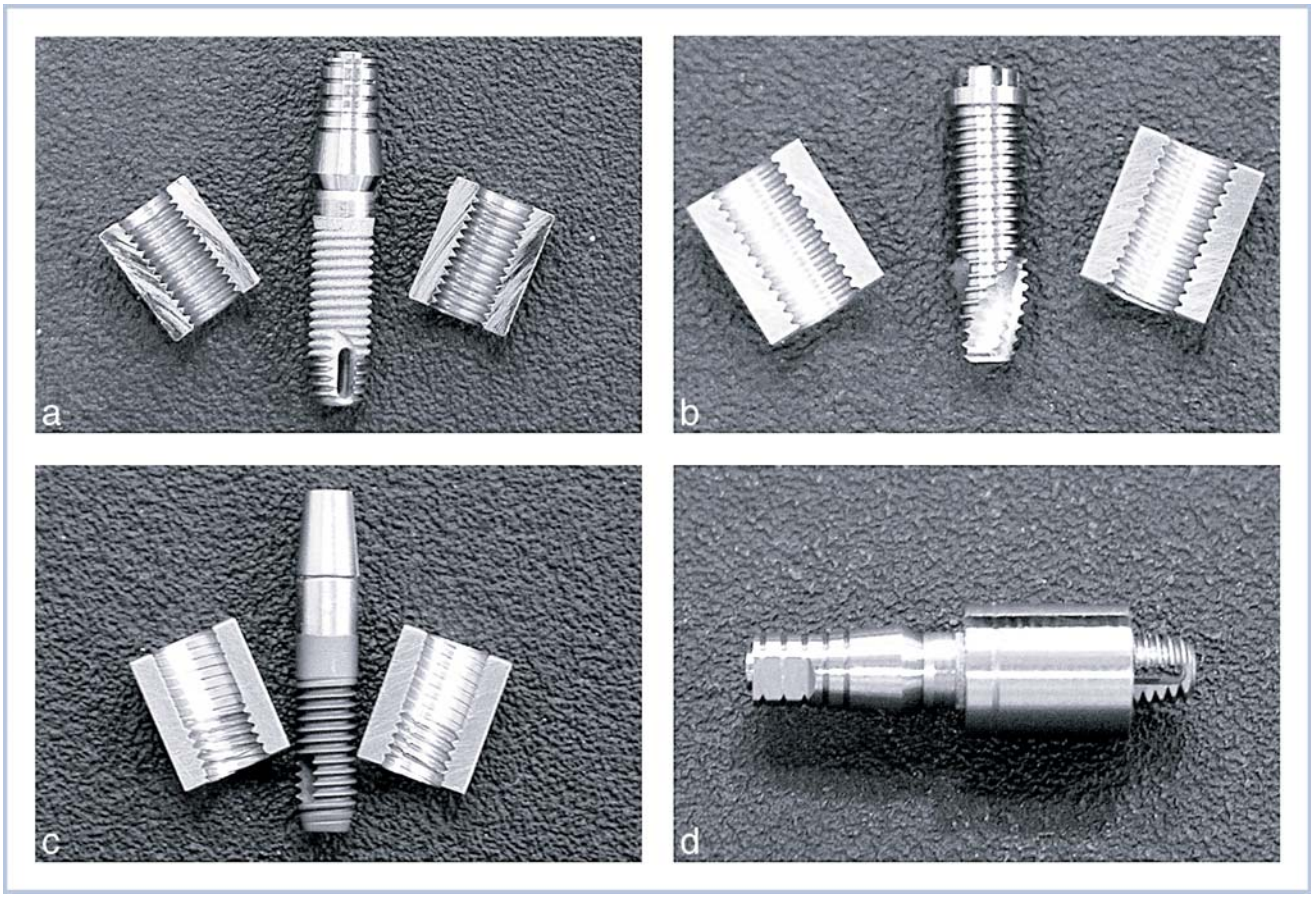


FIGURE 1. (a) Screw-Vent system sleeves. (b) Spline system sleeves. (c) Unipost system sleeves. (d) Implant sleeves 2 mm below the bone line.

Alignment of implants in a holding device

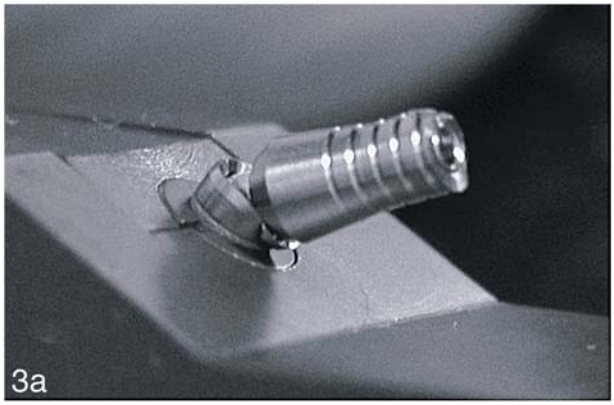
A comparator machine (Deltronic MPC-4) verified the 10-mm spacing from the top of the abutment to the top of the sleeves for each system. Each unit and their respective sleeves were placed into a rigid 30° steel test block (A2 tool steel; Centerpulse; Figure 2). The top of the sleeves was flat to the rigid 30° test block. To prevent slippage during testing, a 0.65 × 0.75 in plate was placed at the contact point of the implants (Figure 2).

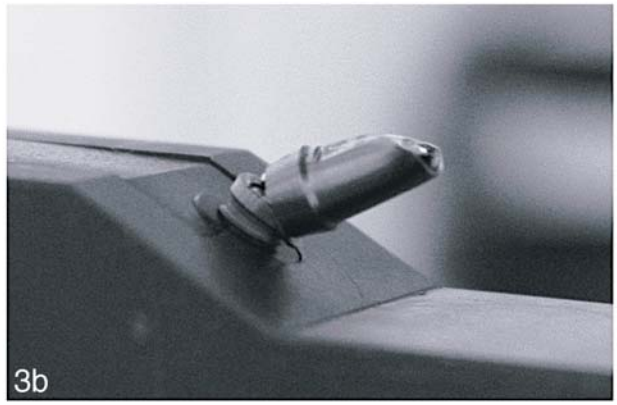
Testing

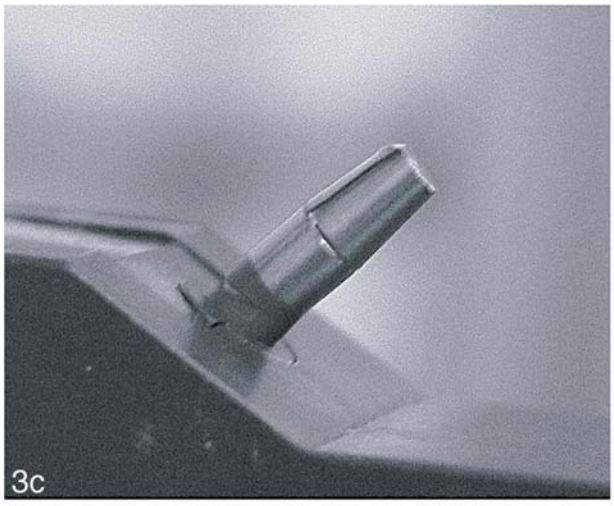
Individual units were placed with their respective sleeves on a rigid-rigid 30° fixture. A material test system (MTS 810) was used to apply a static compression load. The applied force was continually monitored by a computer (Software Test Ware SX).

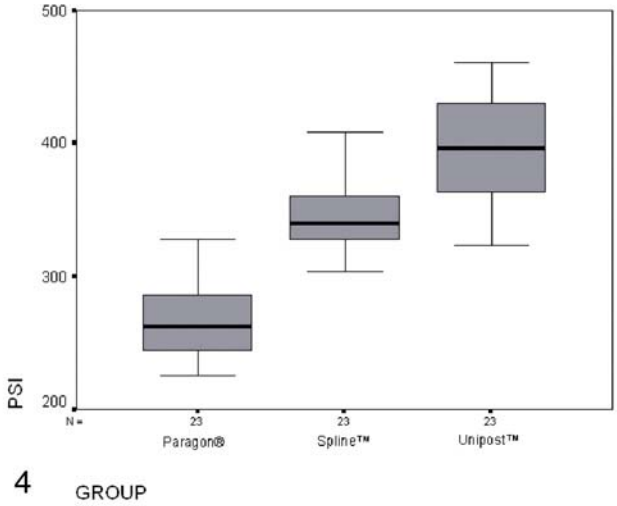
The compression load was applied to each angulated implant/abutment assembly by a unidirectional vertical platform and loaded with compression at a rate of 0.02 in/min until failure, defined as a fracture of the implant body or the implant-abutment interface. The maximum single impact load to failure (in lb) was computer recorded, and a force vs displacement curve for each unit was produced.[3] Finally, implants were examined macroscopically and microscopically to determine failure mode.

FIGURE 2. Test block with 30° angulation of implant.









FIGURES 3 AND 4. FIGURE 3. (a–c) Implant failure. FIGURE 4. Box plots of compression load (in psi) at implant failure for 3 implant systems.

Statistical analysis

This was an experimental in vitro study to compare the compressive resistance of 3 different implant-abutment design systems. The outcome variable tested was compressive strength; the dependent variable was the implant-abutment system.

Sixty-nine implant units were tested (23 for each implant system). The null hypothesis assumed no significant difference in the compressive testing between the implant systems (Screw-Vent, Spline, and Unipost). An analysis of variance (ANOVA) was performed on logarithmically transformed data; adjusted *P* values ($P \leq .05$) were used for multiple comparisons using the Student-Newman-Keuls (SNK) test.

RESULTS

The Unipost implant system presented a higher mean resistance value to lateral and oblique loads (392.5 lb) than the Spline (342.7 lb) and the Screw-Vent (269.1 lb) systems (Figure 3a and b). Table 1 presents the descriptive statistics for implant failures in psi; statistically significant differences were observed ($P \leq .009$). The box-plot graphs for the compressive strength values for the 3 implant systems appear in Figure 4.

An SNK test was performed to rank the mean values for compressive strength of the 3 implant systems. The

TABLE 1

Descriptive statistics for compressive strength (in psi) at implant failures

Type of Implant	N	Minimum	Maximum	Mean	SD
Screw-Vent	23	224.6	327.8	269.1	30.7
Spline	23	303.1	108.2	342.8	25.9
Unipost	23	323.1	461.8	392.5	41.0
Total	69	224.6	461.8	334.8	60.6

pairwise comparison showed Screw-Vent is different from Spline and Unipost; Spline is different from Unipost and Screw-Vent ($\alpha = .05$).

The failure mode was consistent for all Unipost test samples. Failure was observed at the first thread of the implant body; no deformation or fractures were observed at the abutment or abutment screws (Figure 5a and b). Failure for the Spline test samples was observed at the splines of the implant body, where the entire lateral functional load is carried. Two implant bodies bent at the spline level and 21 fractured at the spline (Figure 6a and b). All Screw-Vent system samples fractured at the implant body; 7 fractured at the abutment screws (Figure 7a and b).

Discussion

Loosening and fracture are potential problems for all types of implant abutments and their screws, generally arising from the design of the screw, the implant-abutment interface, the distribution of the occlusal load to the osseointegrated implants, or the design of the implant body.[4–7,14,15] The fabrication of a clinically excellent restoration requires the application of torque to the screws during abutment and prosthesis implant connection procedures. The manufacturer determines optimal torque and preload values.[15] The diameter of the screws is important for the strength of the implant system. When a screw is tightened, a tensile force (preload) is concentrated in the stem of the screw and acts from the screw's head to the threads (the weaker point). The preload should be as high as possible to maximize the contact force between the abutment and the implant, always following the manufacturer instructions. The implant-abutment interface requires adequate mechanical characteristics to resist the functional occlusal loads; distributing the occlusal loading over the implants may minimize failures.[9,14,19] Additionally, the cantilever length must be as short as possible to minimize the excessive load to the last implant.[29] Finally, the implant body design should provide for soft-tissue attachment and new bone formation. Bone loss around the implant should be minimized to reduce the distance between the top of the bone and the top of the abutment.[31,32,33]

In vitro compressive (loading) studies provide the clinicians with comparisons of how implant systems resist fractures. In this investigation Screw-Vent and Spline systems were evaluated by a static compressive load and showed an adequate strength of over 200 lb and a strong implant-abutment coupling that resisted screw loosening. The Spline implant system's mean maximum compression impact load to failure was 337.6 lb; Screw-Vent was 264 lb. No previous reports in the literature have compared these 2 systems. This is the first study that compared the compressive strength of Screw-Vent, Spline, and Unipost implant systems with one another.

This investigation evaluated the 3 implant systems (Screw-Vent, Spline, Unipost) using 30° off-axis static compressive loading corresponding to a common, although undesirable, clinical scenario. The mean maximum single impact load of 461.8 lb in Unipost indicated excellent resistance to lateral loads; this may be attributed primarily to the diameter of the abutment screw with its 2.5-mm counter bore and the union with the abutment, representing a unique piece. Otherwise, the abutment is screwed to the implant body counterclockwise to avoid loosening the abutment during its preparation in the mouth.

The maximum single impact load of the Spline system was 408.2 lb. This system provides 1 mm^2 of surface contact, 0.6 mm thick. The splines of the implant bodies carry the entire lateral functional load. The outer seating shoulder acts in concert with the splines to provide additional lateral and oblique resistance.[30] The manner in which the splines of the Spline system failed, showed that functional loads are buffered by the splines' projections (all joints failed with fractured splines), followed by slow plastic deformation of the abutment screw and the neck of the implant body.

The internal hexagonal joint of the Screw-Vent system has excellent anti-rotational capacity but has relatively weak joints.[3,6] Sharp corners set up stress concentration points during lateral and oblique loading that can result in wall fracture during fatigue and compressive loading.[6] The mean maximum single impact load of the Screw-Vent system in this study was 327.8 lb.

All Screw-Vent and some Spline samples fractured at the neck of the implant body during compression testing; all joints failed with the 1.5-mm abutment screws and spline fractures. A slow elastic and plastic deformation of the abutment screws and the abutment followed. One or 2 mm of bone is lost around the implant body of osseointegrated implants after the first year; therefore, that part of the implant will not be supported by bone, rendering it more susceptible to fracture.[26,28,32]

The results of the present study show a statistically significant difference in favor of the Unipost implant system over Spline and Screw-Vent implant systems ($P \leq .009$), compressive force failure being 130% and 163% higher for the Unipost system, respectively.

Figures 5–7. Figure 5. (a and b) Examples of failure mode for Unipost. Figure 6. (a and b) Examples of failure mode for Spline. Figure 7. (a and b) Examples of failure mode for Screw-Vent.

Conclusions

Within the limits of this in-vitro study, the following conclusions were drawn: (1) The Unipost implant system was superior to the Spline and Screw-Vent systems in terms of failure, defined by fracture to static compressive loading. (2) Generally, Unipost failure occurred at the first thread of the implant body. This may be attributed to the holding device, 2 mm below the bone line; part of the implant remained without support and is thus more susceptible to fracture.[26,28,32] (3) Fatigue failure from cycle compressive forces may be more or less likely in a clinical situation. Further studies of fatigue failures in implants may provide additional findings to assess the clinical significance of the findings reported here.

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