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Survival and Complication Rates of Fixed Restorations Supported by Locking-Taper Implants: A Prospective Study with 1 to 10 Years of Follow-Up

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Abstract

Purpose: The aim of this 10-year follow-up study was to evaluate the implant survival and complication rates of fixed restorations supported by locking-taper implants.
Materials and Methods: Over a 10-year period (January 2002 to December 2011) all patients referred to a single private practice for treatment with fixed restorations (single crowns, SCs; fixed partial prostheses, FPPs; fixed full arches, FFAs) supported by dental implants were considered for inclusion in the study. At each annual follow-up session, clinical, radiographic, and prosthetic parameters were assessed. The surviving implant-supported restorations were defined as "complication free" in the absence of any biological or prosthetic (mechanical or technical) complication. The cumulative implant survival and the "complication-free" survival of fixed implant-supported restorations were identified using the Kaplan-Meier method. The Log-rank test was used to identify correlations between the study variables.
Results: In total, 1494 locking-taper implants (727 maxilla, 767 mandible) were placed in 642 patients (356 males, 286 females). Nineteen implants (12 maxilla, 7 mandible) failed. Implant failures were attributed to lack of osseointegration (14 implants), peri-implantitis (4 implants), and mechanical overloading (1 implant). An overall 10-year cumulative implant survival rate of 98.7% (98.3% maxilla, 99.1% mandible) was found. The implant survival rates did not significantly differ with respect to implant location, position, bone type, implant length and diameter, and type of restorations. Among the surviving implant-supported restorations (478 SC, 242 FPP, 19 FFA), a few biological (11/739: 1.4%) and prosthetic (27/739: 3.6%) complications were reported. The incidence of mechanical complications was low (3/739: 0.4%), with three loosened abutments in three SCs (3/478: 0.6%), and no abutment fractures; technical complications were more frequent (24/739: 3.2%), with an incidence of decementation of 2.0% (SC 2.0%, FPP 1.6%, FFA 5.2%) and ceramic/veneer chipping/fracture of 1.2% (SC 0.0%, FPP 2.8%, FFA 10.5%). A 10-year cumulative "complication-free" survival of restorations of 88.6% (SC 91.7%, FPP 83.1%, FFA 73.8%) was reported. The complication rates differ significantly with respect to the type of restoration ($p < 0.05$).
Conclusions: Fixed restorations on locking-taper implants seem to be a successful procedure for the rehabilitation of partially and completely edentulous arches

Implant treatment has proven to be a predictable modality for replacing missing or failing teeth with various types of fixed dental prostheses (FDPs), and more than 30 years of evidence of the clinical use of endosseous implants has revealed satisfactory long-term results.[1-3] Although dental implants have become the state of the art method for tooth replacement, implant-supported restorations are still subject to biological and prosthetic complications.[4,5] Prosthetic complications arising

in implant-supported fixed restorations range from mechanical complications, defined as failures or complications of prefabricated components (screw or abutment loosening, screw or abutment fracture) and technical complications, defined as superstructure-related failures or complications (ceramic or veneer fractures).[6,7]

Systematic reviews based on clinical studies have evaluated the survival and complication rates of fixed implant-supported reconstructions of different designs, and described a high incidence of mechanical complications after an observation period of at least 5 years, such as abutment screw fracture and loosening, with percentages between 1.3% and 9.3%, and 5.3% and 10.4%, respectively.[4,6,8-11] Screw loosening, in particular, appears to be a greater problem with single-tooth restorations replacing maxillary and mandibular molars, where the mechanical load is higher.[12,13] Clinical studies on single-unit restorations have reported abutment screw loosening percentages between 5% and 48%.[12-17] This may not lead to implant loss, but is significant in relation to the amount of repair and maintenance needed, and the time and cost, and may adversely affect the patient's satisfaction with the implant treatment.[5,11,18] As to the commonly observed mechanical failures, loosening and/or fracture of fixation screws or abutments have been related to the type of implant/abutment connection.[18,19] Currently, the most commonly used systems for securing the abutment to the implant involve screw-type connections,[18,19] and two basic designs are available for clinical use: butt-joint indexed external or internal connections. A butt joint only stabilizes the connection between the abutment and the implant fixture by the axial preload of the abutment screw. Occlusal force to the connection is concentrated at the abutment screw; thus, the optimum preload is critical for joint stability.[20,21] In fact, stability of screw-type connections is challenged by forces exceeding that of the torqued implant-abutment system: if occlusal loads exceed the preload, the screw can loosen or break.[20,21] In addition, lower masticatory forces, applied repeatedly, although they do not necessarily surpass the failure threshold of the assembly, may potentially lead to gradual loosening of the implant/abutment connection, as a result of fatigue.[20,21] A suitable alternative to butt-joint connections may be the introduction of frictional systems such as conical connections,[20] including pure interference-fit (locking-taper) connection implants.[22-26] In these screwless implant systems, the abutment is retained by means of friction force: the connection is based on the principle of "cold welding," as it relies on the large contact pressure and frictional resistance between the surfaces of the implant and the abutment.[22,23] The mechanical advantages of pure interference-fit connection over external and internal hexagonal design have been reported in several in vitro studies,[22-27] demonstrating that locking-taper implants may resist eccentric loads and bending moments, ensuring a remarkable stability at the implant/abutment connection. Previous clinical studies with locking-taper implants have confirmed a reduction of the incidence of prosthetic complications.[18,28-30] However, no studies deal with the prosthetic complications encountered during the maintenance phase with these implants in the long term. An accepted way of describing the susceptibility to complications is to report the "complication-free" survival rate.[31] This useful success index indicates a restoration is free of both biological and prosthetic problems.[31]

The aim of this prospective 10-year follow-up study was to assess the implant survival and "complication free" survival rate of fixed restorations supported by locking-taper implants, with particular attention to the evaluation of the incidence of mechanical (abutment loosening or fracture) and technical (loss of retention, veneer fracture) complications.

Materials and methods

Patient sample

Between January 2002 and December 2011, all patients referred to a private dental clinic (Gravedona, Como, Italy) for treatment with implant-supported fixed rehabilitations were considered for inclusion in the present study. Inclusion criteria were:

1. age >18 years;
2. good general and oral health;
3. adequate bone height and width to place an implant of 3.3 mm in diameter and 8.0 mm in length;
4. healed sites;
5. dentition in the opposing jaw.

Exclusion criteria were:

1. inadequate oral hygiene;
2. periodontal infections or diseases of the oral mucosa;
3. inadequate bone volume to place an implant of at least 3.3 mm in diameter and 8.0 mm length;
4. bone augmentation procedures;
5. uncontrolled diabetes mellitus;
6. coagulation disorders;
7. systemic immune disorders;
8. drug or alcohol abuse.

Smoking habits and bruxism were taken into account but were not exclusion criteria for the present study. Patients received detailed information about the study protocol and were required to sign an informed consent form. The requirements of the World Medical Association's Declaration of Helsinki on experimentation involving human subjects (2000) and those of the Local Ethical Committee at the University of Varese, Italy, were met.

Presurgical preparation

Before the implant installation, a complete oral examination regarding periodontal disease, caries, and soft tissue disorders was carried out for each study participant. Patients received appropriate treatments and oral hygiene instruction. Panoramic radiographs and in some cases computed tomography (CT) scans were obtained before implant placement. CT data sets were acquired and then transferred to implant navigation software, to perform a 3D reconstruction of the maxillary bones. With this navigation software it was possible to correctly assess the width of each implant site, the thickness and the density of the cortical plates and the cancellous bone, and the ridge angulation. Preoperative work-ups also included an assessment of the edentulous ridges using casts and diagnostic wax-ups.

Figure 1 Schematic representation of the implant/abutment connection of the Exacone Implant System. The implant/abutment connection features a self-locking Morse taper combined with an internal hexagon for the repositioning of the abutment. The Morse taper presents a taper angle of 1.5°.

Surgical and restorative procedure

Sandblasted and acid-etched fixtures (Sistema Leone; Sesto Fiorentino, Firenze, Italy) were used.[18,30] These fixtures have a Morse taper implant/abutment connection with a 1.5° taper angle, together with an internal hexagon[18,30] (Fig 1). The implant neck was positioned at the bone crest level. A two-stage technique was used to place the implants, which were left submerged for a period of 3 to 4 months as previously described. After the healing period, interim prostheses consisting of single crowns (SCs), fixed partial prostheses (FPPs), and fixed full-arches (FFAs) were provided. The temporary restorations were maintained for 3 months, then definitive metal ceramic restorations were placed, and cemented with zinc oxide-eugenol cement (Temp-Bond; Kerr, Orange, CA). Occlusion was thoroughly checked.

Follow-up examinations

All patients were enrolled in an annual recall program. During each annual follow-up visit, the following clinical, radiographic, and prosthetic parameters were assessed by a surgeon and a prosthodontist, who were not directly involved in the treatment of the patients:

1. Clinical parameters. The following clinical parameters were investigated:
— presence/absence of pain or sensitivity;[32]
— presence/absence of suppuration or exudation;[32]
— presence/absence of implant mobility, tested manually using the handles of two dental mirrors;[32]
— periodontal probing depth (PPD) in mm, measured using a periodontal probe (PGF-GFSR; Hu-Friedy, Chicago, IL). For each implant, the PPD value was calculated based on the average of four measured values.[32]
2. Radiographic parameters. Periapical radiographs were taken for each fixture, with the aid of a Rinn alignment system (Dentsply, Elgin, IL).[33] Individual poly(vinyl siloxane) positioners were employed for precise repositioning and stabilization of the radiographic template. Radiographs were taken after implant placement and for each subsequent year.[33] Changes in peri-implant marginal bone level, as modifications in the distance from the implant shoulder to the first visible bone-to-implant contact (DIB), were measured on periapical radiographs taken immediately after installation and at each follow-up examination.[33] The DIB was measured in mm, at the mesial and distal implant side of each implant, with the aid of an ocular grid. To correct dimensional distortion, the apparent dimension of each implant was measured on the radiograph and then compared with the real implant length; mean values between the mesial and the distal measures were obtained for each implant.[33]
3. Prosthetic parameters. Occlusion was checked using articulator papers (Bausch articulating paper; Bausch Inc, Nashua, NH). All prosthetic complications, including mechanical (abutment loosening, abutment fracture) and technical complications (decementation, ceramic/veneer chipping or fracture) were registered. These complications were managed during the scheduled appointments. Otherwise, a new appointment was planned.

Outcome variables

The primary outcome variables were the implant survival and the "complication-free" survival rate of the implant-supported restoration. The evaluation of implant survival and the "complication-free" survival rate of the implant-supported restoration was performed according to the following clinical, radiographic, and prosthetic parameters:

1. Implant survival. Implant losses were all categorized as failures. Failure to osseointegrate with implant mobility in the absence of clinical signs of infection, persistent/recurrent infections (with pain, suppuration, bone loss), progressive marginal bone loss caused by mechanical overload, and implant body fracture were the conditions for which implant removal could be indicated. A distinction was made between "early" (before the abutment connection) or "late" (after the abutment connection) implant failures.[32,33]
2. "Complication free" survival rate of implant-supported restoration. The surviving implant-supported restorations were defined as "complication free" in the absence of any complication, during the entire follow-up period. Complications were divided into two types:
a. Biological complications, including:
— disturbances in the function of the implant characterized by a biological process affecting the supporting tissues and structures, such as soft tissue inflammation (peri-implant mucositis with pain/swelling) or peri-implant infection with fistula formation, pain, suppuration, or exudation (the threshold to define peri-implantitis was set at a probing pocket depth ≥6 mm with bleeding on probing/suppuration and a radiographic bone loss/distance

between the implant shoulder and the first visible DIB > 2.5 mm);
— bone loss, defined as a distance between the implant shoulder and the first visible DIB > 1.5 mm after the first year of function, or exceeding 0.2 mm for each following year, without clinical signs of peri-implant infection.[32,33]

b. Prosthetic complications, including:
— mechanical complications, defined as failures or complications related to implant prefabricated components, such as abutment loosening or abutment fracture;
— technical complications, defined as superstructure-related failures or complications, such as decementation or ceramic/veneer chipping or fractures.

Data analysis

Databases were created with Excel 2003 (Microsoft Excel; Microsoft Corporation, Redmond, WA) and used for the analysis. Descriptive statistics were used for patient demographics, distribution of implants, radiographic bone loss, and biologic and prosthetic complications. Absolute and relative frequency distributions were calculated for qualitative variables, and means ± standard deviations were calculated for quantitative variables. The implant survival and the "complication-free" survival rate of implant-supported restorations were the principal outcomes of the study and were analyzed as a function of time using the Kaplan-Meier survival estimator.[34] The cumulative implant survival rate was estimated by an implant-based analysis (at the implant level), while the cumulative "complication-free" survival rate of implant-supported restorations was estimated by a restoration-based analysis (at the restoration level). Variables including implant location (mandible or maxilla), implant position (incisors, cuspids, premolars, molars), bone type (type I, II, III, IV), implant length (8.0, 10.0, 12.0, 14.0 mm), implant diameter (3.3, 4.1, 4.8 mm), and the type of prosthetic restoration (SC, FPP, FFA) were analyzed at the implant level; the variable of prosthetic restoration (SC, FPP, FFA) was also analyzed at the restoration level. The quality of bone was identified at the time of implant placement, as previously described.[35] In both the implant-based and the restoration-based analysis, the Log-rank Mantel-Cox test was used to compare the primary outcomes within comparable subgroups. All computations were carried out with the statistical software package SPSS 17.0 (SPSS Inc.; Chicago, IL). The level of significance was set at 0.05.

Results

Implant-supported rehabilitations

From January 2002 to December 2011, 664 patients (368 men, 296 women) were considered for inclusion in this prospective clinical study. With regard to the inclusion/exclusion criteria, 22 patients could not take part (9 for inadequate bone height and width, 13 for poor oral hygiene and active periodontal infections). In total, 642 patients (356 men, 286 women, aged 20 to 82 years) fulfilled the inclusion criteria, presenting no conditions listed in the exclusion criteria, and were subsequently enrolled in this study. Among these, 72 were smokers and 45 were bruxers. A total of 1494 implants were placed; 727 fixtures (48.7%) were inserted in the upper jaw, and 767 fixtures (51.3%) were inserted in the lower jaw; 228 (15.2%) implants were placed in the maxillary anterior region, while 499 implants (33.4%) were placed in the maxillary posterior region; 114 implants (7.6%) were placed in the mandibular anterior region, and 653 implants (43.8%) in the mandibular posterior region. The distribution of the implants by position was in accordance with Figure 2. The most frequently used implant diameter was 4.1 mm, with 820 implants (54.8%), followed by 4.8 mm, with 417 implants (28.0%), and 3.3 mm, with 257 implants (17.2%). Despite the implant diameter, the most frequently inserted implants were 12.0 mm long (767 implants, 51.3%), 10.0 mm long (356 implants, 23.9%), and 14.0 mm long (272 implants, 18.2%), while 8.0 mm implants (99 implants, 6.6%) were the least used. The most frequent indication was the treatment of partially edentulous patients (636 implants, 42.6%) while the least frequent was the restoration of fully edentulous patients (376 implants, 25.1%); 482 implants (32.3%) were used to restore single-tooth gaps.

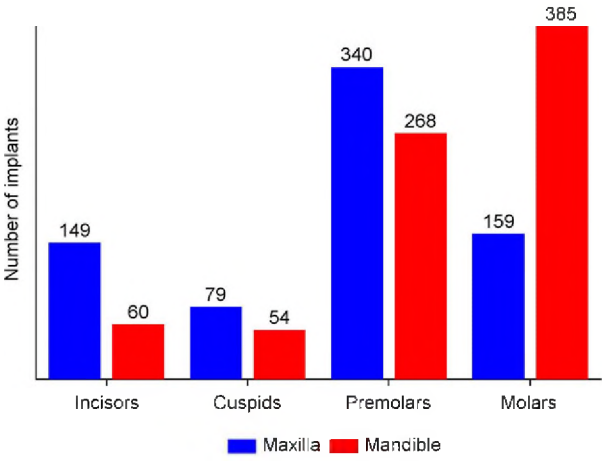

Figure 2 Implant distribution by position.

Implant survival

Of the 642 patients treated from 2002 to 2011, 18 were classified as dropouts, because they were lost to follow-up. Among these, four had died, five missed the last scheduled appointment because of serious illness, and four were not available because they moved to other cities/countries; finally, five patients simply did not consult the clinic again for follow-up. At the end of analysis (December 2012), 624 patients had completed the follow-up evaluation in full. Nineteen implants failed in 18 patients. At the end of this study, an overall cumulative implant survival rate of 98.7% was achieved after 10 years, with 1475 surviving implants. In the upper jaw, the cumulative survival rate was 98.3%, with 12 failures. In the lower jaw, the cumulative survival rate was 99.1%, with 7 failures. As to the position of the failed fixtures, 10 were molars (five maxilla, five mandible), eight were premolars (six maxilla, two mandible), and one was a maxillary incisor. The majority of implants (16) were lost within the healing period, before the connection of the prosthetic abutment. These fixtures were classified as "early failures" due to

Table 1 Details of implant failures: FO, failure to osseointegrate/implant mobility without clinical signs of infection; PI, peri-implantitis; MO, mechanical overload

	Time (month)	Reason	Location	Position	Bone type	Length (mm)	Diameter (mm)	Total
Early failures	4	FO	Maxilla	Premolar	III	12	3.3	16
	4	FO	Maxilla	Premolar	IV	14	3.3	
	3	FO	Mandible	Molar	III	14	4.1	
	4	FO	Maxilla	Premolar	III	12	4.1	
	4	FO	Mandible	Molar	III	12	4.1	
	3	FO	Mandible	Molar	III	12	4.1	
	4	FO	Maxilla	Molar	II	10	4.1	
	3	FO	Mandible	Molar	IV	10	4.1	
	4	FO	Maxilla	Molar	IV	14	4.1	
	4	PI	maxilla	Premolar	IV	10	4.1	
	4	FO	Maxilla	Incisor	II	14	4.1	
	4	PI	Maxilla	Premolar	IV	12	4.1	
	3	FO	Mandible	Premolar	III	14	4.8	
	4	FO	Maxilla	Premolar	IV	10	4.8	
	4	FO	Maxilla	Molar	IV	12	4.8	
	4	FO	Maxilla	Molar	IV	8	4.8	
Late failures	24	MO	Mandible	Premolar	III	12	3.3	3
	24	PI	Mandible	Molar	IV	12	4.1	
	48	PI	Maxilla	Molar	III	12	4.1	

lack of osseointegration/implant mobility without any clinical sign of infection (14 implants), or recurrent/persistent peri-implantitis (two implants) with pain and suppuration, before functional loading. Three implants failed after the abutment connection, and were classified as "late failures." Two of these implants failed 2 years after placement, one because of progressive bone loss caused by mechanical overloading, without signs of infection, and the other because of severe bone loss due to recurrent/persistent peri-implant infections. In addition, another implant failed 4 years after placement, because of recurrent/persistent peri-implant infections with pain, suppuration and severe bone loss. The details of the failed implants are reported in Table 1. The evaluation of the potential influence of different implant-related variables on implant survival is shown in Table 2. The implant survival rate did not differ significantly with respect to implant location, position, bone type, implant length, diameter, and type of prosthetic restoration.

Complications

During the follow-up period, three prostheses had to be removed due to late implant failures. These failures affected a SC and two FPPs; for this reason, these restorations had to be renewed. Among the surviving 739 implant-supported restorations (478 SCs, 242 FPPs, 19 FFAs), during the 10-year follow-up period, a 1.4% overall incidence of biologic complications was reported. In fact, biological complications were recorded for 11 restorations (15 implants). Of these implants, two exhibited peri-implant mucositis, with clinical signs of soft tissue inflammation (redness, swelling, and bleeding), while

Table 2 Cumulative implant survival rate

	Number of implants	Implant failures	Cumulative survival rate (%)	*p*-Value
Location				
Maxilla	727	12	98.3	0.206
Mandible	767	7	99.1	
Position				
Incisors	209	1	99.5	0.256
Cuspids	133	0	100	
Premolars	608	8	98.7	
Molars	544	10	98.1	
Bone type				
Type I	84	1	98.8	0.198
Type II	292	2	99.3	
Type III	727	7	99.0	
Type IV	391	9	97.7	
Length (mm)				
8.0	99	1	99.0	0.825
10.0	356	4	98.9	
12.0	767	9	98.8	
14.0	272	5	98.2	
Diameter (mm)				
3.3	257	3	98.8	0.733
4.1	820	12	98.5	
4.8	417	4	99.0	
Restoration				
SCs	482	4	99.2	0.538
FPPs	636	10	98.4	
FFAs	376	5	98.6	

Statistically significant difference $P < 0.05$

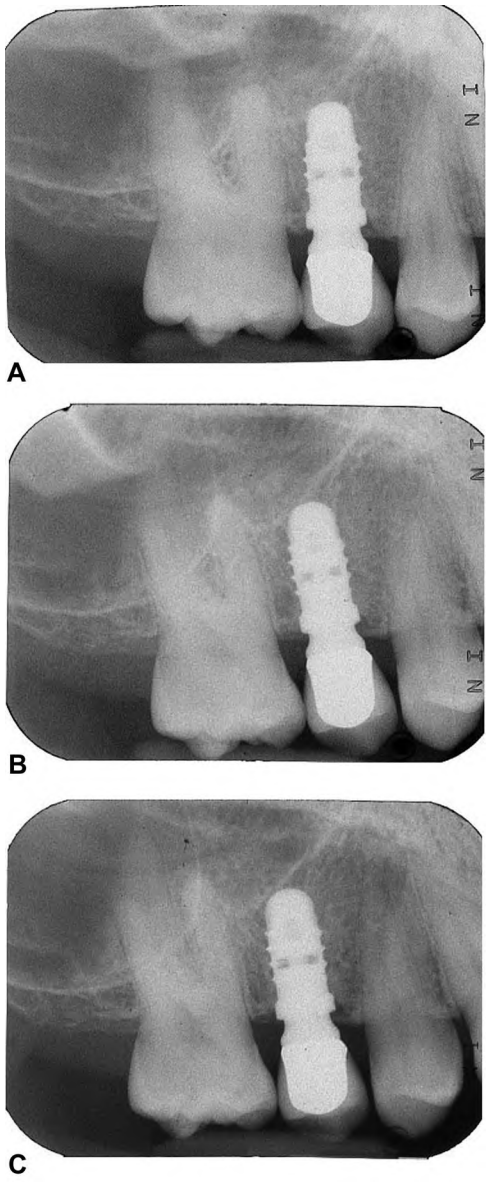

Figure 3 Maxillary second premolar. (A) Radiographic control of the implant after 1 year of function; (B) radiographic control of the implant after 5 years of function; (C) radiographic control of the implant after 10 years of function.

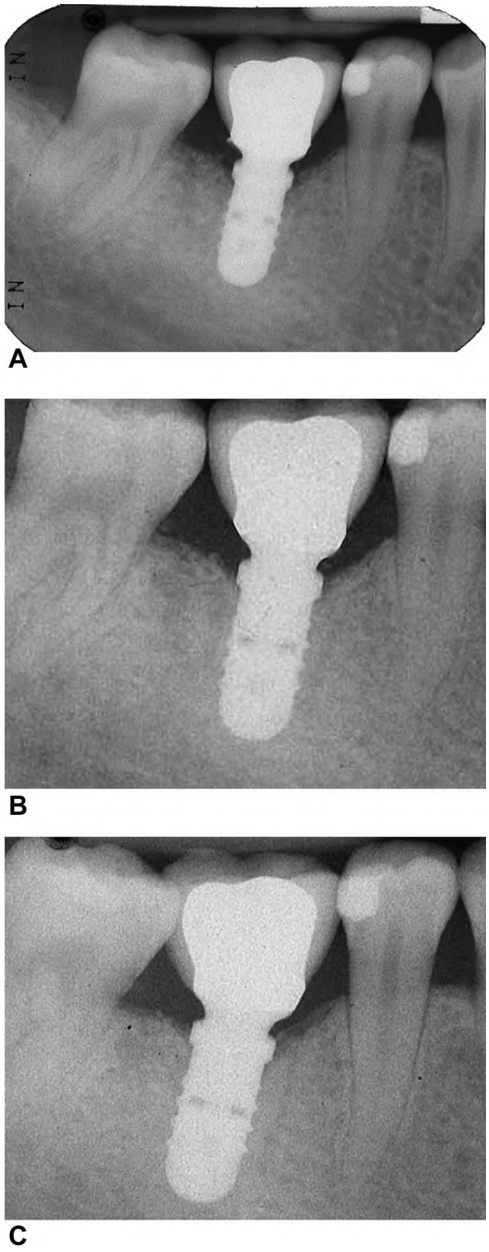

Figure 4 Mandibular first molar. (A) Radiographic control of the implant after 1 year of function; (B) radiographic control of the implant after 5 years of function; (C) radiographic control of the implant after 10 years of function.

seven restorations (10 implants) were associated with peri-implant infection with pain, PPD ≥6 mm with bleeding on probing/suppuration and severe bone loss (DIB > 2.5 mm). In all these cases, however, the anti-infection therapy was successful, and the implants were maintained. Finally, three restorations (three implants) were associated with bone loss (DIB > 1.5 mm after the first year of function) without clinical signs of peri-implant infection. All other implants were clinically and radiographically successful, as they did not show any biological complication. They did not cause pain or exhibit clinical mobility, suppuration, or exudation, with a DIB < 1.5 mm after the first year of function and not exceeding 0.2 mm for each subsequent year. The radiographic evaluation of the implants revealed a DIB (mean ± SD) of 0.33 (± 0.23), 0.45 (± 0.26), and 0.78 (± 0.33) mm after 1, 5, and 10 years, respectively. The changes in bone levels over time were minimal (Figs 3 and 4; Table 3). Globally, there was a low incidence of mechanical complications related to prefabricated components (0.4%). Three prosthetic abutments became loose during the first year of loading in three SCs located in the posterior mandible. These abutments were reinserted, and no further loosening was observed in the period of the present study. The incidence of

Table 3 Peri-implant bone loss (as distance between the implant shoulder and the first visible bone-to-implant contact, DIB, in mm)

Year	Mean	SD	Median	CI (95%)
1	0.33	0.23	0.3	0.32–0.34
5	0.45	0.26	0.4	0.43–0.47
10	0.78	0.33	0.7	0.72–0.84

abutment loosening was 0.6% for SCs only. No mechanical complications were observed at the implant/abutment connection for FPPs and FFAs, and no abutment fractures were found. These reported mechanical complications required only minor interventions (<10 minutes chairtime), and no additional costs had to be charged to the patients. The overall incidence of technical complications was slightly higher (3.2%). In fact, 10 SCs, 11 FPPs, and 3 FFAs had some technical complication; however, most of these were minor, such as decementation/loss of retention, with an overall incidence of 2.0% (SC 2.0%, FPP 1.6%, FFA 5.2%), and no additional costs were charged since they required < 10 minutes chairtime. Finally, the overall incidence of ceramic/veneer chipping/fracture of the laboratory-fabricated prostheses was 1.2%. Fracture of the porcelain occurred in seven FPPs and in two FFAs, with an incidence of 2.8% and 10.5%, respectively. In these cases, major interventions (>60 minutes chairtime) were needed, since new restorations were provided to the patients. For this reason, additional costs had to be charged. Additional costs included dental laboratory costs for new FPPs, FFAs, and new porcelain on the frames. The biological and prosthetic complications encountered in this study are summarized in Table 4. In conclusion, a 10-year overall cumulative "complication-free" survival of restorations of 88.6% (SC 91.7%, FPP 83.1%, FFA 73.8%) was reported. The complication rates differed significantly with respect to the type of prosthetic restoration ($p < 0.05$), as there were significantly fewer complications on SCs than on FPPs and FFAs (Figs 5 and 6).

Table 4 Incidence of complications among the different implant-supported restorations

	Single crowns (SCs)	Fixed partial prostheses (FPPs)	Fixed full arches (FFAs)	All restorations
Biological complications				
Soft tissue inflammation	0/478 (0.0%)	1/242 (0.4%)	0/19 (0.0%)	1/739 (0.1%)
Peri-implantitis	2/478 (0.4%)	4/242 (1.6%)	1/19 (5.2%)	7/739 (0.9%)
Peri-implant bone loss	0/478 (0.0%)	3/242 (1.2%)	0/19 (0.0%)	3/739 (0.4%)
Prosthetic complications				
Abutment loosening	3/478 (0.6%)	0/242 (0.0%)	0/19 (0.0%)	3/739 (0.4%)
Abutment fracture	0/478 (0.0%)	0/242 (0.0%)	0/19 (0.0%)	0/739 (0.0%)
Loss of retention	10/478 (2.0%)	4/242 (1.6%)	1/19 (5.2%)	15/739 (2.0%)
Ceramic chipping/fracture	0/478 (0.0%)	7/242 (2.8%)	2/19 (10.5%)	9/739 (1.2%)
Total	15/478 (3.1%)	19/242 (7.8%)	4/19 (21.0%)	38/739 (5.1%)

Discussion

Despite good survival of implant-supported restorations, long-term clinical reports of dental implants have shown some biological and prosthetic complications; in particular, mechanical and technical complications have frequently been reported.[5,6,21] In a recent review of the 5-year prosthetic complication rates of fixed implant rehabilitations for fully edentulous patients, Papaspyridakos et al[8] reported a satisfactory implant survival rate, but a high disappointing incidence of veneering chipping/fracture (33.3%), occlusal screw loosening (22.9%), and abutment screw loosening (10.8%). Two reviews demonstrated that after 5 years of service, the survival of implants ranged from 94.3% for cantilever FPPs[4] to 95.6% for conventional FPPs.[9] However, a high incidence of prosthetic complications, such as ceramic fracture and abutment screw loosening, has been reported.[4,9] Finally, a systematic review on single-tooth implant restorations reported a 5-year cumulative incidence of abutment screw loosening of 8.8%.[11] Butt-joints or slip-fit joints, indexed external or internal, are still the most widely used connection types in dental implants.[19,20] Although implants featuring an external hexagon are still widespread in the market, this connection is considered slightly unstable, as a result of horizontal and rotational misfits under loading.[19-21] In fact, it seems to be easily affected by mechanical complications, particularly in single-tooth restorations, with a high incidence of abutment screw loosening.[12-17] To fix some of the inherent problems associated with external-hex butt-joint connections, internal-hexagon connections have been introduced.[19] These have been claimed to be more mechanically stable, since the load is distributed deep within the implant, where engagement with a long internal wall shields the abutment screw.[19-22] However, instability at the implant/abutment interface, whether caused by occlusal loads, inadequate screw preload, poor accuracy of thread coupling, or large manufacturing tolerances, may lead to mechanical complications, such as screw loosening.[22-26] This can be a maintenance and repair burden for both the patient and the practitioner, and a challenging complication.[18,36] In fact, in cement-retained, implant-supported restorations, the abutment screw comes loose from the implant body, whereas the crown usually remains cemented to the abutment. In such situations, crown removal without damage to the implant components is difficult.[36] Screw-retained, implant-supported restorations may facilitate the clinician's intervention in the case of abutment screw loosening; however, the presence of an occlusal access hole may disrupt the structural continuity of the porcelain, resulting in increased technical complication rates.[7,37]

In a recent 15-year follow-up study comparing the complications of screw- and cement-retained implant-supported restorations, significantly higher ceramic fracture (38% vs. 4%) rates were found with screw-retained restorations.[38] These

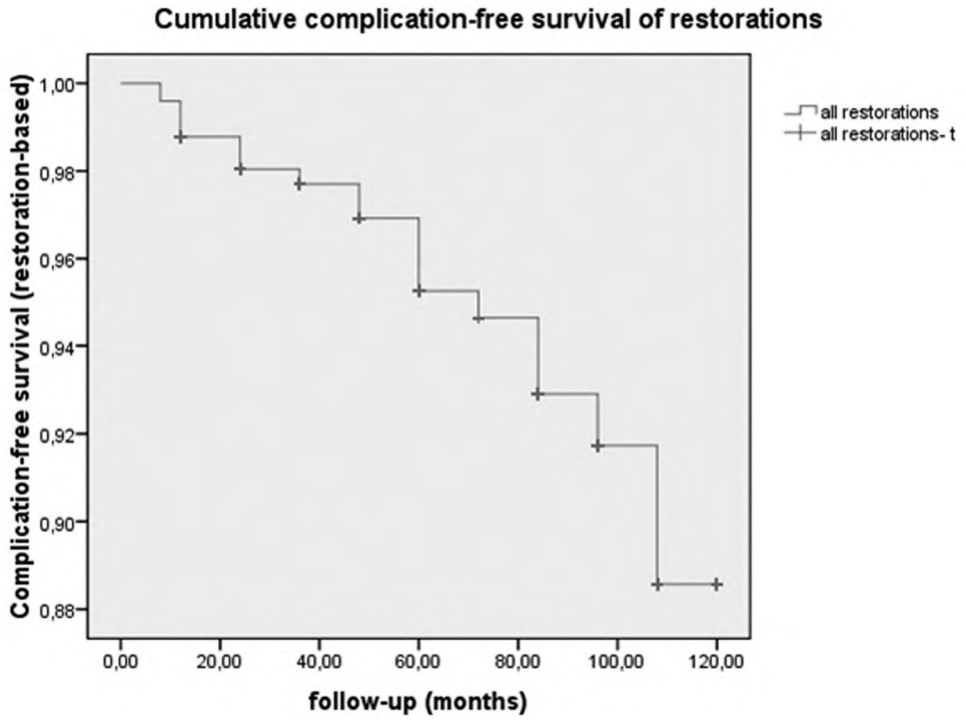

Figure 5 Overall cumulative "complication-free" survival of restorations.

superstructure-related complications can lead to additional costs and time investment during the follow-up years.[38,39] At present, patients' expectations related to the longevity of required reconstructions are high, due to the considerable costs involved for FDPs on implants.[5,9] In addition, most of the patients are between 40 to 50 years old when provided with oral implants; with increasing life expectancy, it is likely that these patients will need their implant-supported restorations to function for decades.[9,10]

Choosing from available options, the longevity and complication rates of restorations should be considered, to reduce the complexity of maintenance service expected. In this context, a fixture-abutment connection offering some degree of biomechanical security is essential,[40] and the stability of the implant/abutment connection becomes a key factor for the success of the restoration.[19,20] In an attempt to reduce the incidence of prosthetic complications, conical interface designs with friction fit joints have been developed.[19,20,22-27,41-43] Unlike the external hexagon, the conical interface results in a relatively tight junction due to friction between implant and abutment.[41-43] Conical interfaces have been proposed to be more biomechanically stable than external or internal hexagonal implant/abutment connections,[19,24-27,41-45] and more resistant to abutment movement and micro-gap enlargement under loading, as demonstrated in a recent systematic review of the literature.[46] Among conical interfaces, the self-locking (Morse taper) connection is defined as a tapered connection with an angle $< 1.5°$.[22] In this pure locking-taper connection, implant-abutment mating occurs only by friction between the opposing surfaces, and a connecting screw, which represents the weakest point of many systems, is absent.[18,22] The major advantage of this type of connection is mechanical stability. In fact, there are no micromovements at the interface between components, and many fewer clinical complications are associated with them.[22] In the present research on Morse taper connection implants supporting fixed restorations, a satisfactory 10-year cumulative implant survival rate of 98.7% (98.3% maxilla, 99.1% mandible) was found. These results are in agreement with those reported in several other long-term clinical studies.[1-3,5,8-12] However, when compared to the evidence emerging from the current literature,[4,6,8-11] the incidence of complications reported in the present work was low (38/739: 5.1%), particularly with regard to prosthetic complications (27/739: 3.6%). Among the surviving implant-supported restorations (478 SCs, 242 FPPs, 19 FFAs), the incidence of mechanical complications (failures or complications of prefabricated components) was very low (0.4%), with only three loosened abutments in three SCs located in the posterior areas, over a 10-year period; in addition, no abutment fractures were noticed. These results are in accordance with previous clinical studies on locking-taper connection implants, where the incidence of mechanical complications was low.[18,28-30] Technical, suprastructure-related complications were more frequent (24/739: 3.2%), with an overall incidence of decementation of 2.0% (SC 2.0%, FPP 1.6%, FFA 5.2%) and ceramic/veneer chipping/fracture of 1.2% (SC 0.0%, FPP 2.8%, FFA 10.5%); however, the rate of technical complications reported in this study was lower than that reported in the current literature with butt-joint connection implant systems.[4,8-11]

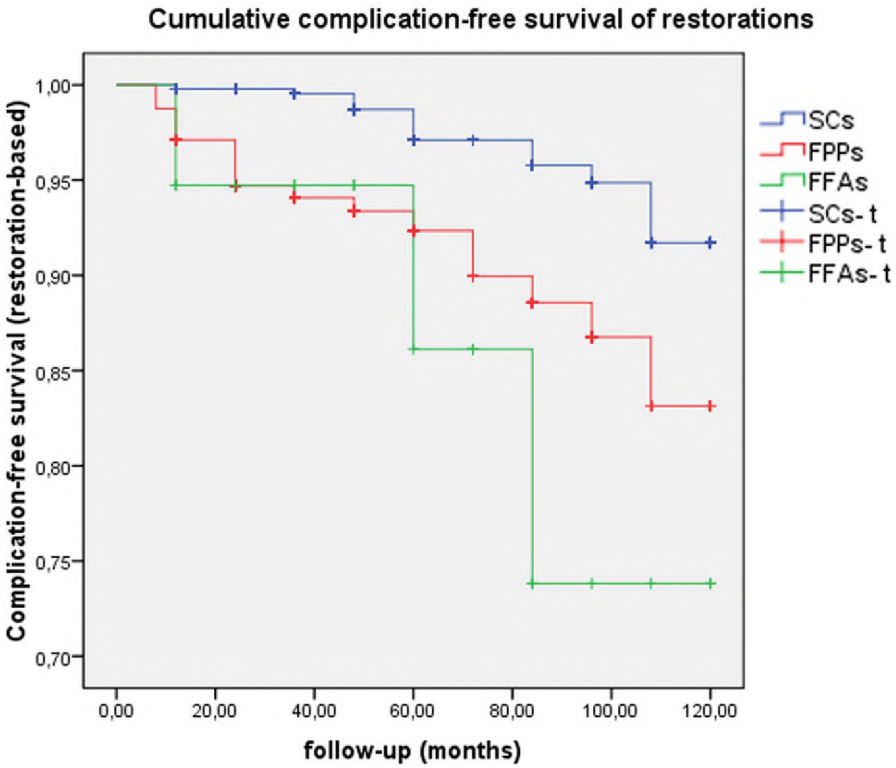

Figure 6 Cumulative "complication-free" survival of SCs, FFPs, and FFAs. The complication rates differ significantly with respect to the type of prosthetic restoration ($p < 0.05$), as there were significantly fewer complications on SCs than on FPPs and FFAs.

At the end of our present study, a 10-year overall cumulative "complication-free" survival of restorations of 88.6% (SC 91.7%, FPP 83.1%, FFA 73.8%) was reported; the complication rates differed significantly with respect to the type of prosthetic restoration ($p < 0.05$). This statistically significant difference may be related to the major incidence of technical complications among more complex prosthetic rehabilitations, such as FPPs and FFAs; however, it can also be interpreted as a result of the reduction of mechanical complications (such as abutment loosening and fractures) that generally affect single-unit restorations, particularly in the posterior regions of both jaws. When using the "complication-free" survival index, one has to keep in mind that 'free of complication' comprises both biological and prosthetic problems.[31] In our present study, among the surviving implant-supported restorations, only a few biological complications (11/739: 1.4%) were encountered during the 10-year follow-up period. Two implants showed clinical signs of peri-implant mucositis, 10 implants exhibited peri-implantitis with pain, PPD ≥6 mm, bleeding on probing/suppuration and severe bone loss (DIB > 2.5 mm), and three implants were associated with bone loss (DIB > 1.5 mm after the first year of function) without clinical signs of peri-implant infection.

It has been demonstrated that all fixtures with screw-type implant/abutment connections have a micro-gap of variable dimensions (40–100 μm) between the implant and the abutment.[47-50] Several in vitro studies have suggested that the presence of this micro-gap could result in microbiological colonization.[47-50] The colonization of bacteria inside the implant system and the penetration of bacteria or their products via the micro-gap may be a risk for soft-tissue inflammation and bone loss.[47-50] Even though complete prevention of microbial penetration into the internal part of the implants has not been demonstrated in vitro, the most favorable results have been reported when implants with a locking-taper connection have been used.[49-51] By reducing micro-gap dimensions (1–3 μm), the Morse taper implant-abutment connection may offer an efficient seal against bacterial penetration.[49-51] This may ensure minimum levels of inflammation of the peri-implant tissues, protecting the bone from resorption.[51] In this study, minimum peri-implant bone resorption was seen over 10 years, with a DIB (mean ± SD) of 0.33 (± 0.23), 0.45 (± 0.26), and 0.78 (± 0.33) mm after 1, 5, and 10 years, respectively.

Conclusions

In the past, the main focus of clinical studies was the success of osseointegration and the survival of implants; the outcome of implant therapy was often presented without providing detailed information on the prosthetic rehabilitations, and it was commonly accepted that biological and prosthetic complications may occur with implant-supported fixed restorations. Managing these complications, however, can cause extra chairside time, additional costs, and patient dissatisfaction; for this reason, the number of mechanical and technical complications

under loading should be minimized. In this scenario, the implant/abutment connection may well be regarded as a key factor in the long-term success. In the present prospective study on locking-taper connection implants, an overall cumulative implant survival and a cumulative "complication-free" survival of restorations of 98.7% (98.3% maxilla, 99.1% mandible) and 88.6% (SC 91.7%, FPP 83.1%, FFA 73.8%) were reported, respectively, after 10 years of follow-up. A very low incidence of mechanical (3/739: 0.4%) and technical (24/739: 3.2%) complications was found. Within the limits of this study, the use of locking-taper implants seems to be a successful procedure for the rehabilitation of partially and completely edentulous arches, as the high mechanical stability of this connection seems to be able to minimize the incidence of prosthetic complications in the long term. Further long-term follow-up studies on locking-taper connection implants are needed to confirm these results.

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References

1. Wittneben JG, Buser D, Salvi GE, et al: Complication and failure rates with implant-supported fixed dental prostheses and single crowns: a 10-year retrospective study. Clin Implant Dent Relat Res. 2013 Apr 2. doi:10.1111/cid.12066. [Epub ahead of print]
2. Chappuis V, Buser R, Brägger U, et al: Long-term outcomes of dental implants with a titanium plasma-sprayed surface: a 20-year prospective case series study in partially edentulous patients. Clin Implant Dent Relat Res 2013;15:780-790
3. Simonis P, Dufour T, Tenenbaum H: Long-term implant survival and success: a 10–16-year follow-up of non-submerged dental implants. Clin Oral Implants Res 2010;21:772-777
4. Aglietta M, Siciliano VI, Zwahlen M, et al: A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. Clin Oral Implants Res 2009;20:441-451
5. Albrektsson T, Donos N: Implant survival and complications. The Third EAO consensus conference 2012. Clin Oral Implants Res 2012;23(Suppl 6):63-65
6. Salvi GE, Brägger U: Mechanical and technical risks in implant therapy. Int J Oral Maxillofac Implants 2009;24(Suppl):69-85
7. Al-Omari WM, Shadid R, Abu-Naba'a L, et al: Porcelain fracture resistance of screw-retained, cement-retained, and screw-cement-retained implant-supported metal ceramic posterior crowns. J Prosthodont 2010;19:263-273
8. Papaspyridakos P, Chen CJ, Chuang SK, et al: A systematic review of biologic and technical complications with fixed implant rehabilitations for edentulous patients. Int J Oral Maxillofac Implants 2012;27:102-110
9. Pjetursson BE, Thoma D, Jung R, et al: A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res 2012;23(Suppl 6):22-38
10. Romeo E, Storelli S: Systematic review of the survival rate and the biological, technical, and aesthetic complications of fixed dental prostheses with cantilevers on implants reported in longitudinal studies with a mean of 5 years follow-up. Clin Oral Implants Res 2012;23(Suppl 6):39-49
11. Jung RE, Zembic A, Pjetursson BE, et al: Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012;23(Suppl 6):2-21
12. Camargos G de V, do Prado CJ, das Neves FD, et al: Clinical outcomes of single dental implants with external connections: results after 2 to 13 years. Int J Oral Maxillofac Implants 2012;27:935-944
13. Haas R, Polak C, Fürhauser R, et al: A long-term follow-up of 76 Brånemark single-tooth implants. Clin Oral Implants Res 2002;13:38-43
14. Levine RA, Clem DS 3rd, Wilson TG Jr, et al: Multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: results of loading for 2 or more years. Int J Oral Maxillofac Implants 1999;14:516-520
15. Wannfors K, Smedberg JI: A prospective clinical evaluation of different single-tooth restoration designs on osseointegrated implants. Clin Oral Implants Res 1999;10:453-458
16. Henry PJ, Laney WR, Jemt T, et al: Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1996;11:450-455
17. Balshi TJ, Hernandez RE, Pryszlak MC, et al: A comparative study of one implant versus two replacing a single molar. Int J Oral Maxillofac Implants 1996;11:372-378
18. Mangano C, Mangano F, Piattelli A, et al: Prospective clinical evaluation of 307 single tooth Morse taper connection implants: a multicenter study. Int J Oral Maxillofac Implants 2010;25:394-400
19. Freitas-Júnior AC, Almeida EO, Bonfante EA, et al: Reliability and failure modes of internal conical dental implant connections. Clin Oral Implants Res 2013;24:197-202
20. Dittmer S, Dittmer MP, Kohorst P, et al: Effect of implant-abutment connection design on load bearing capacity and failure mode of implants. J Prosthodont 2011;20:510-516
21. Park JK, Choi JU, Jeon YC, et al: Effects of abutment screw coating on implant preload. J Prosthodont 2010;19:458-464
22. Sannino G, Barlattani A: Mechanical evaluation of an implant-abutment self-locking taper connection: finite element analysis and experimental tests. Int J Oral Maxillofac Implants 2013;28:e17-26
23. Norton MR: Assessment of cold welding properties of the internal conical interface of two commercially available implant systems. J Prosthet Dent 1999;81:159-166
24. Cehreli MC, Akca K, Iplikcxioglu H, et al: Dynamic fatigue resistance of implant-abutment junction in an internally notched Morse-taper oral implant: influence of abutment design. Clin Oral Implants Res 2004;15:459-465
25. Almeida EO, Freitas AC Jr, Bonfante EA, et al: Mechanical testing of implant-supported anterior crowns with different implant/abutment connections. Int J Oral Maxillofac Implants 2013;28:103-108
26. Zielak JC, Rorbacker M, Gomes R, et al: In vitro evaluation of the removal force of abutments in frictional dental implants. J Oral Implantol 2011;37:519-523
27. Jorge JR, Barao VA, Delben JA, et al: The role of implant/abutment system on torque maintenance of retention screws and vertical misfit of implant-supported crowns before and after mechanical cycling. Int J Oral Maxillofac Implants 2013;28:415-422
28. Mangano C, Bartolucci E: Single tooth replacement by Morse taper connection implants: a retrospective study of 80 implants. Int J Oral Maxillofac Implants 2001;16:675-680

29. Urdaneta RA, Marincola M, Weed M, et al: A screwless and cementless technique for the restoration of single-tooth implants: a retrospective cohort study. J Prosthodont 2008;17:562-571
30. Mangano C, Mangano F, Shibli J, et al: Prospective evaluation of 2549 Morse taper connection implants: 1- to 6- year data. J Periodontol 2011;82:52-61
31. Kreissl ME, Gerds T, Muche R, et al: Technical complications of implant-supported fixed partial dentures in partially edentulous cases after an average observation period of 5 years. Clin Oral Implants Res 2007;18:720-726
32. Heckmann SM, Schrott A, Graef F, et al: Mandibular two-implant telescopic overdentures. Clin Oral Implants Res 2004;15:560-569
33. Weber HP, Crohin CC, Fiorellini JP: A 5-year prospective clinical and radiographic study of non-submerged dental implants. Clin Oral Implants Res 2000;11:144-153
34. Kaplan EL, Meier P: Non parametric estimation from incomplete observation. J Am Stat Assoc 1958;53:467-481
35. Mangano FG, Shibli JA, Sammons RL, et al: Short (8-mm) locking-taper implants supporting single crowns in posterior region: a prospective clinical study with 1-to 10-years of follow-up. Clin Oral Implants Res 2013 Apr 28. doi: 10.1111/clr.12181. [Epub ahead of print]
36. Patil PG: A technique for repairing a loosening abutment screw for a cement-retained implant prosthesis. J Prosthodont 2011;20:652-655
37. Sadowsky SJ, Bedrossian E: Evidenced-based criteria for differential treatment planning of implant restorations for the partially edentulous patient. J Prosthodont 2013;22:319-329
38. Nissan J, Narobi D, Gross O, et al: Long-term outcome of cemented versus screw-retained implant-supported partial restorations. Int J Oral Maxillofac Implants 2011;26:1102-1107
39. De Boever AL, Keersmaekers K, Vanmaele G, et al: Prosthetic complications in fixed endosseous implant-borne reconstructions after an observations period of at least 40 months. J Oral Rehabil 2006:33;833-839
40. Nishioka RS, de Vasconcellos LG, de Melo Nishioka GN: Comparative strain gauge analysis of external and internal hexagon, Morse taper, and influence of straight and offset implant configuration. Implant Dent 2011;20:e24-32
41. Bozkaya D, Muftu S: Mechanics of the tapered interference fit in dental implants. J Biomech 2003;36:1649-1658
42. Merz BR, Hunenbart S, Belser UC: Mechanics of the implant-abutment connection: an 8-degree taper compared to a butt joint connection. Int J Oral Maxillofac Implants 2000;15:519-526
43. Steinebrunner L, Wolfart S, Ludwig K, et al: Implant-abutment interface design affects fatigue and fracture strength of implants. Clin Oral Implants Res 2008;19:1276-1284
44. Pellizzer EP, Carli RI, Falcón-Antenucci RM, et al: Photoelastic analysis of stress distribution with different implant systems. J Oral Implantol 2011 Dec 30 [Epub ahead of print]
45. Takahashi JM, Dayrell AC, Consani RL, et al: Stress evaluation of implant-abutment connections under different loading conditions: a 3D-FE study. J Oral Implantol. 2013 Apr 10 [Epub ahead of print]
46. Schmitt C, Nogueira-Filho G, Tenenbaum HC, et al: Performance of conical abutment (Morse Taper) connection implants: a systematic review. J Biomed Mater Res A 2014;102:552-574
47. Broggini N, McManus LM, Hermann JS, et al: Persistent acute inflammation at the implant-abutment interface. J Dent Res 2003;82:232-237
48. Piattelli A, Vrespa G, Petrone G, et al: Role of the microgap between implant and abutment: a retrospective histologic evaluation in monkeys. J Periodontol 2003;74:346-352
49. Jaworski ME, Melo AC, Picheth CM, et al: Analysis of the bacterial seal at the implant-abutment interface in external-hexagon and Morse taper-connection implants: an in vitro study using a new methodology. Int J Oral Maxillofac Implants 2012;27:1091-1095
50. Koutouzis T, Mesia R, Calderon N, et al: The effect of dynamic loading on bacterial colonization of the dental implant fixture-abutment interface: an in-vitro study. J Oral Implantol 2012 May 7 [Epub ahead of print]
51. Dibart S, Warbington M, Su MF, et al: In vitro evaluation of the implant-abutment bacterial seal: the locking taper system. Int J Oral Maxillofac Implants 2005;20:732-737