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ORIGINAL ARTICLE

Clinical and esthetic outcomes of screw-retained internal-connection veneered zirconia-ceramic CAD-CAM abutments in single implant reconstructions: Five-year results of a prospective case series investigation

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Abstract

Purpose: To evaluate the long-term clinical performance and survival, as well as the biological, esthetic, and technical complications of one-piece, internally-connected, screw-retained, computer aided-design and computer aided-manufacturing (CAD-CAM) veneered zirconia anterior and posterior implant-supported single restorations fabricated on regular diameter implants.

Materials and Methods: Following a 2-stage surgical procedure, 22 implants placed in anterior and posterior areas in 21 partially edentulous patients (mean age of 55 years; 9 males/12 females) were evaluated in terms of plaque index, pocket probing depth, bleeding on probing, level of oral hygiene, signs of mucositis/peri-implantitis, esthetic score, gingival zenith position, Papilla Index Score, thickness of peri-implant gingiva, radiographic marginal bone loss, and technical complications. Implants and restorations were prospectively followed from the insertion of the restoration (baseline), and up to 5 years postloading.

Results: After 5 years, radiological bone stability with no marginal bone loss (0.4 [0.4] vs. 0.5 [1.1] mm from 1- to 5-year follow-up) was recorded, with a 100% implant survival rate. Clinically, patients performed adequate oral hygiene, and tissues were kept healthy as determined by plaque index (PI) and oral hygiene index (OHI). The esthetic performance of the restorations revealed an increase in mucosal thickness from 3.2 (0.9) mm after 1 year to 3.3 (1.1) mm after 5 years, and a reduction in the gingival zenith position from 7.9 (1.5) mm after 1 year to 7.7 (1.5) mm at the 5-year recall examination. The prosthetic survival rate after 5 years was 78.9%, as 4 abutments fractured at different time points during the study. All abutment fractures occurred in the mandible, at the level of the second premolars and first molars.

Conclusions: After 5 years clinical function, Atlantis one-piece, screw-retained, internally connected CAD-CAM veneered zirconia implant-supported single crowns resulted in a relatively low survival rate, mainly associated with posterior single implant-supported reconstructions. However, due to the fact that the present clinical investigation used only one abutment design and reconstruction type, extrapolation of

data to different implant systems, abutment designs, and reconstruction types must be cautious.

KEYWORDS
CAD-CAM, clinical outcomes, internal connection, monolithic, screw-retained, zirconia abutment

Survival rates of single implant-supported reconstructions range between 89% and 94% at 10 years; however,[1,2] they are still considered a challenging restorative treatment due to different factors such as crown to implant ratio,[3] functional and esthetic requirements of the planned restoration,[4] tooth location,[5,6] three-dimensional (3D) implant position,[7] soft tissue thickness and translucency,[8] abutment material fatigue strength, biocompatibility, machinability, chemical stability,[9] implant-abutment connection type,[10] and clinician's experience.

Controversies exist when evaluating internally-connected one-piece monolithic zirconia abutments since several in vitro investigations evaluating different internally-connected implant-abutment connection designs have raised concerns when monolithic zirconia is used as abutment material.[11,12] On the contrary, other in vitro investigations have reported that one-piece zirconia abutments show greater strength compared to external-connection zirconia abutments.[13]

Clinical investigations and recent systematic reviews also show inconclusive clinical outcomes when considering all-ceramic implant-supported single crowns using internally-connected one-piece zirconia abutments. While most clinical investigations reporting on all-ceramic implant-supported single crowns use an external implant-abutment butt-joint interface and report high success rates,[14,15] other systematic reviews have not shown a statistically significant difference in the fracture rate of ceramic abutments with either internal or external connection design.[16]

Recent advancements in digital technologies, the absence of a cement interface,[17] and retrievability, simplify the fabrication of screw-retained restorations. However, the number of mid- and long-term clinical investigations evaluating computer-aided design and computer-aided manufacturing (CAD-CAM) all-ceramic screw-retained implant-supported single crowns using veneered one-piece zirconia abutments, including those evaluating peri-implant soft tissue outcomes,[18] is reduced when compared to those employing cemented all-ceramic single crowns on one-piece monolithic zirconia abutments.[19–21]

The variability in one-piece zirconia abutment fracture rates, the limited number of long-term investigations reporting peri-implant soft-tissue outcomes in CAD-CAM all-ceramic implant-supported restorations, and the controversies between in vitro investigations and clinical studies, suggests the need for additional clinical research evaluating the long-term clinical outcomes of one-piece screw-retained zirconia-ceramic implant-supported single crowns using internally-connected implant-abutment connection design. Therefore, the objective of this prospective, multi-center, clinical follow-up investigation was to evaluate the clinical performance and survival, as well as the biological, esthetic, and technical complications of one-piece, internally-connected, screw-retained, CAD-CAM veneered zirconia implant-supported single restorations fabricated on regular diameter implants.

MATERIALS AND METHODS

Study design and subjects

This investigation is the 5-year follow-up of a previously published study, and the following description represents a summary of the originally reported methodology,[22] which was designed as a multicenter prospective case series investigation. The protocol was approved by the Ethics Committee on Human Research of the University of Granada (Ref. #918-2014), in accordance with the Declaration of Helsinki, and adhered to the STROBE guidelines for reporting observational studies. All patients signed an informed consent prior to enrollment.

Subjects in need of a single implant-supported restoration in anterior and posterior regions were consecutively recruited at the Department of Oral Surgery and Implant Dentistry, School of Dentistry, University of Granada, and at private clinics in Alicante and Granada, between June 2015 and April 2019.

At screening, inclusion criteria included partially edentulous patients missing one single tooth in the area of treatment, 18 years or older, successfully osseointegrated implants, and no active systemic disease, and smoking ≤ 10 cigarettes/day. Only patients with an American Society of Anesthesiologists Status I or II were included.[23] Exclusion criteria included subjects with uncontrolled/untreated periodontal disease, patients requiring hard/soft tissue augmentation, severe bruxism, and poor compliance with oral hygiene. Success was defined by the percentage of restorations that remained in situ without any modifications, whereas survival was defined by the percentage of restorations that remained in situ with or without modifications. Failure was defined by the percentage of restorations that needed to be replaced.[24]

Surgical protocol

Single standard diameter (3.6/4.2 mm) straight threaded, tapered apex, internal-connection implants (OsseoSpeed EV,

Astra Tech Implant System, Dentsply Sirona Implants, Mölndal, Sweden) were installed in healed alveolar ridges following a second-stage surgical procedure. After a 3-month osseointegration period, a second-stage surgical procedure was performed, and transmucosal healing abutments were connected, allowing 2 weeks for soft tissue healing before the final impression.

Prosthetic protocol

Implant-level, pick-up impressions were made using disposable plastic stock trays and polyether impression material (Permadyne Penta, 3M Espe AG, Seefeld, Germany). After master cast fabrication following the same laboratory procedures as described in a previous investigation,[22] a full-contour, diagnostic wax-up was fabricated according to the anatomical requirements of each restoration.

Diagnostic casts and wax-ups were then scanned, after which design software (Atlantis Virtual Abutment Design Software, Dentsply-Sirona Inc.) was used to custom design each individual zirconia abutment substructure. Custom, implant-supported, CAD-CAM screw-retained yttrium oxide partially stabilized tetragonal polycrystalline zirconia (Y-TZP) abutments (Atlantis Crown Abutment, Dentsply Sirona Implants, Mölndal, Sweden) were then fabricated. After clinical and radiographic verification of the precision of fit, zirconia abutments were completed by each of the two reference laboratories, using a hand build-up veneering ceramic technique. Abutment screws were then tightened to 25 Ncm after clinical and radiographical evaluation of precision of fit. Polytetrafluoroethylene tape and tooth colored composite resin material were used to seal the screw access channel.

Clinical evaluation

During the first year, included patients were recalled for baseline examination (BL) and at 3, 6, and 12 months, and those results were presented in a previous publication.[22] After the first year, patients were recalled annually for up to 5 years. For standardization purposes, all follow-up examinations were performed by experienced, calibrated prosthodontists (RDC and LG-G) at each study center, and consisted of biological parameters, esthetic and radiographic outcomes, and major and minor technical complications.

Biological evaluation

Biological parameters included (1) probing pocket depth (PPD) measured in the implant restorations, from the mucosal/gingival margin to the bottom of the probeable pocket using a periodontal probe to the nearest 0.5 mm, at four sites of the restoration (mesial, distal, buccal, and lingual); (2) plaque index (PI),[25] which was assessed using a 4-point scale (0 = no plaque, 1 = detectable plaque present upon probing, 2 = moderate plaque present upon probing, 3 = 1-2 mm thick plaque present in vestibular and interproximal spaces); (3) bleeding on probing (BOP) was assessed as absent = 0 and present = 1, in the implant restoration and in the adjacent mesial and distal teeth; (4) oral hygiene index (OHI), determined by the examiners according to a four point scale (1 = excellent, 2 = good, 3 = poor, 4 = very poor); and (5) signs of mucositis (minor biological outcome) and/or peri-implantitis (major biological outcome).[26]

Esthetic evaluation

Esthetic outcome was analyzed by investigators at each study center using the following parameters: a 4-point esthetic score (ES) defined as 1 = excellent, 2 = good, 3 = poor, and 4 = very poor; an evaluation of the buccal gingival zenith position (GZP), assessed by measuring from the most apical aspect of the buccal gingival margin to the incisal edge of the prosthetic crown, using a periodontal probe to the nearest 0.5 mm; and an assessment of the height of mesial and distal papilla performed using the Papilla Index Score (PIS) (0 = no papilla, 1 = less than half of papilla present, 2 = half of papilla present, 3 = papilla completely fills interproximal space, and 4 = interproximal hyperplastic tissue present.[27] Finally, the thickness of the peri-implant attached gingiva (TKG) was assessed 1 mm below the gingival margin using an endodontic file and a rubber stop (# 20 endodontic K-file, Dentsply Maillefer, Switzerland) to measure the distance from the outer surface of the attached gingiva to the underlying ceramic surface.

Technical evaluation

Technical complication evaluation (TC) consisted of recording data on major technical complications such as abutment fracture/restoration loss, and minor technical complications such as abutment screw loosening/fracture, wear of the veneering porcelain (no wear, small facet, or marked facet), tattooing of the gingival tissues, and veneering porcelain chipping/fracture.

Radiographic evaluation

Intraoral radiographs were made using the long-cone paralleling technique with a film holder (Rinn, Dentsply-Sirona Inc.). Bone levels around implants and adjacent teeth were measured by an independent radiologist (University of Gothenburg), considering either the implant shoulder or the cemento-enamel junction as a reference point. These measures were obtained both at the mesial and distal sides. Bone level change with respect to restoration delivery was also calculated for each measurement at each of the subsequent time points. Additionally, the distances from the implant to the

anterior and posterior adjacent teeth were measured at the time of implant placement.

For radiographic evaluation, all radiographs were displayed in software (Illustrator CS; Adobe Systems Inc., San Jose, CA) on a 24-inch LCD screen (iMac, Apple Inc., Cupertino, CA). The screen resolution was 1920 × 1200 pixels. The measuring tool of the software was used to make the measurement, taking the magnification into account. The magnification was calculated by dividing the implant diameter displayed on the screen by the actual diameter of the implant. Marginal bone level (MBL) was determined by measuring the distance between the implant shoulder and the marginal bone to implant contact at the mesial and distal aspects of each implant. Bone level was presented as the mean values for distal and mesial surfaces at each time point. All measurements were made to the nearest 0.1 mm.

Statistical analysis

All data were registered in a Microsoft Excel for Mac OS X (version 16.16.27) spreadsheet for tabulation and subsequent analysis by IBM SPSS Statistics 28 (release 28.0.0.1) software as well as for graphical representation. Descriptive summaries were performed for each variable. Absolute values and percentages are presented for categorical variables, while means and standard deviations were calculated for continuous variables. Over time, changes in continuous variables were evaluated with the Related-Samples Friedman's Two-Way Analysis of Variance by Ranks. If significant differences were detected, post hoc Bonferroni correction for multiple comparisons was conducted for pair-wise evaluation. Changes in categorical variables were evaluated by the Cramèr's V test. In all cases, values of p below 0.05 were considered statistically significant.

RESULTS

A total of 20 patients and 21 implants were included in the study at insertion of the restoration (baseline). From these, 16 patients (9 females and 7 males) attended the 5-year follow-up examination; one patient died before the 3-year follow-up, another patient dropped out of the study before the 2-year follow-up, and 4 patients were excluded from subsequent evaluation because their abutments failed due to fracture before the 2-, 3-, and 4-year follow-ups, respectively. All four patients who lost their original restoration experienced abutment fractures in the mandible (2 first molars and 2 second premolars). In all four patients, new restorations were fabricated and followed according to a conventional clinical protocol but were excluded from final statistical analysis. Thus, at the 5-year recall evaluation, 10 implants were placed in the maxilla and 6 in the mandible, which accounted for 3 incisors, 11 premolars, and 2 molars.

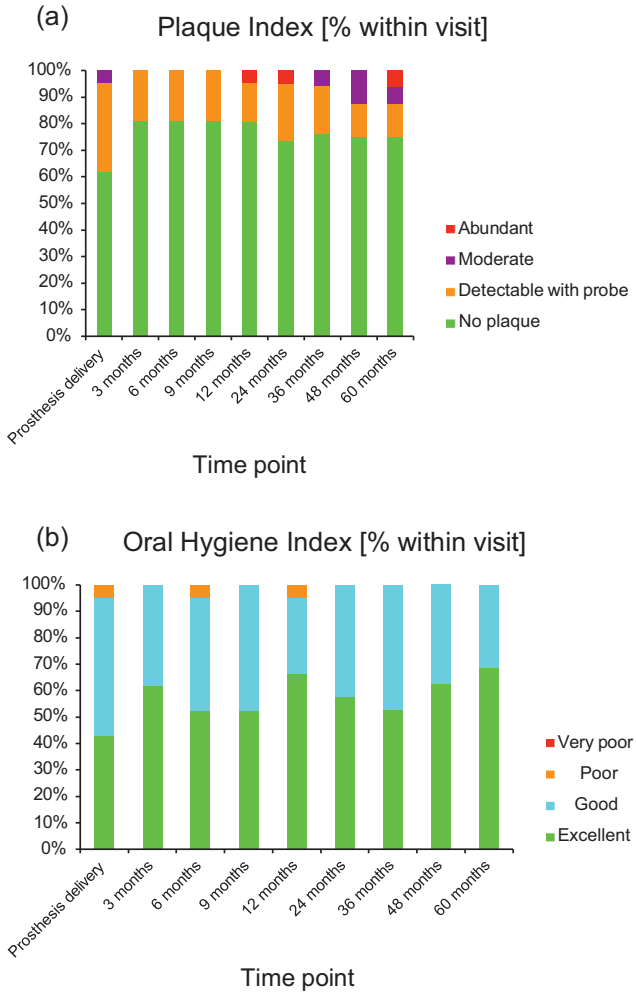


FIGURE 1 (a) PI and (b) OHI percentages over time. OHI, oral hygiene index; PI, plaque index.

Clinical outcomes

In general, patients showed adequate oral hygiene and maintained healthy tissues as determined by both PI and OHI index (Figures 1a and b). Oral hygiene level was "good" or "excellent," with no patients showing "poor" or "very poor" oral hygiene after 5 years. Regarding PI, although the percentage of patients showing "no plaque" increased from 61.9% at baseline, to 81.0% at 1 year and to 75.0% after 5 years, there was also a slight increase in patients showing "moderate" plaque from baseline (4.8%) to 5 years (6.3%).

PPD was measured at 4 sites around the implant restorations, and the average value was calculated; BOP was measured in the implant as well as mesial and distal teeth. A slightly higher PPD (2.8 (1.1) mm) was detected at the 5-year follow-up examination compared to the 1-year mean PPD (2.5 (0.7) mm) (Figures 2a and b). In any case, the differences were not statistically significant (p = 0.404, Related-Samples Friedman's Two-Way Analysis of Variance by Ranks). BOP was more frequent in the distal teeth and

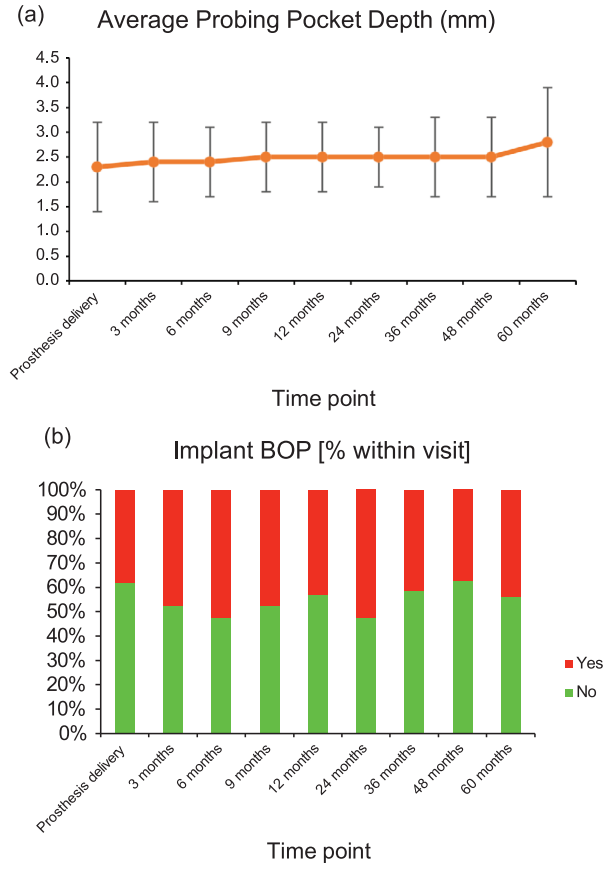


FIGURE 2 (a) Average PPD and (b) BOP over time. BOP, bleeding on probing; PPD, probing pocket depth.

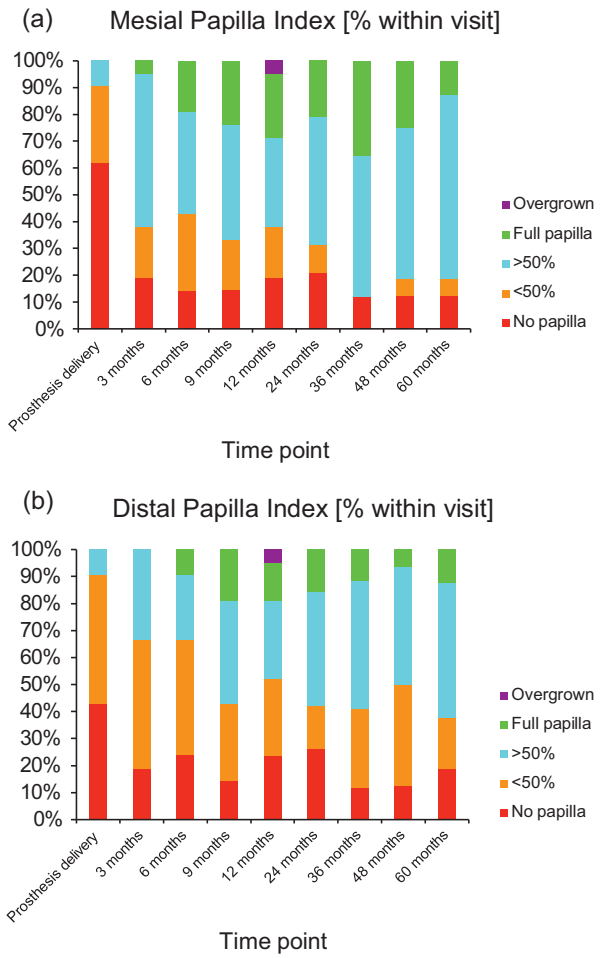


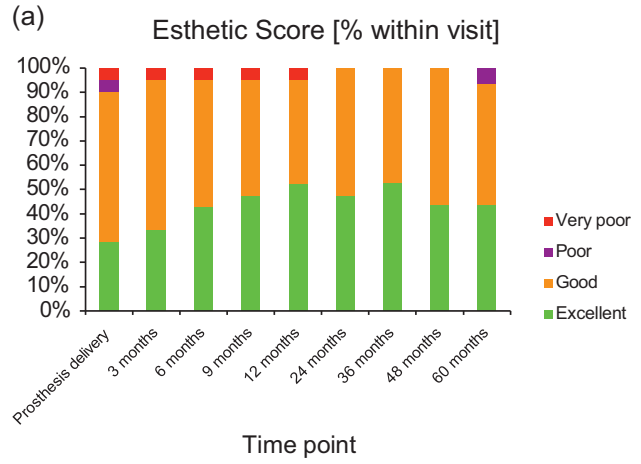
FIGURE 3 (a) Mesial and (b) distal papilla index over time.

implants as compared to mesial teeth. Particularly around implants, the percentage of sites with positive BOP increased from 38.1% at baseline to 42.9% at 1 year and 43.8% at 5 years (Figure 2b). Differences between the data at 1 and 5 years were not statistically significant ($p = 0.696$; Cramèr's V test).

While at baseline, a PIS of 0–1 (no papilla/< 50%) was detected at 90.5% of the mesial and distal papilla sites; at 5-year recall evaluation, the 0–1 PIS decreased to 18.8% at mesial sites and 37.6% at distal sites. On the other hand, at baseline, the 2–3 PIS (> 50%/full papilla) was present in only 9.5% of the mesial and distal sites, while at the 5-year recall examination, the 2–3 PIS (> 50%/full papilla) increased to a total of 81.3% in the mesial sites and 62.5% in the distal sites (Figures 3a and b). Interestingly, the comparison between data at 1- and 5-year of follow up showed statistically significant differences only for the mesial papilla but not in the distal papilla ($p = 0.008$ and $p = 0.122$, respectively; Cramèr's V test).

The ES data indicated that the percentage of restorations categorized as "Excellent" decreased from 52.4% at 1 year to 43.8% at the 5-year recall examination (Figure 4a); these changes were statistically significant ($p = 0.035$; Cramèr's V test). If analyzed in detail, this could be explained by the changes in the number of patients evaluated because of the dropouts and abutment failures, given that most of those who finalized the 5-year follow-up maintained the same ES as in the 1-year follow-up. In addition, the patient whose ES was categorized as "very poor" at baseline and follow-ups until 1 year, was the patient who dropped-out. Regarding the GZP analysis, a decreasing trend was observed from 8.2 (1.4) mm at baseline, to 7.9 (1.5) mm after 1 year, reaching 7.7 (1.5) mm at the 5-year recall examination (Figure 4b). The evaluation of statistical significance showed that although the overall changes were statistically different ($p < 0.001$; Related-Samples Friedman's Two-Way Analysis of Variance by Ranks), the pairwise comparisons showed that only the differences between baseline and the 5-year follow-up were significant ($p = 0.020$; post hoc Bonferroni correction for multiple tests).

Finally, the thickness of the peri-implant gingiva (TKG) showed an increase throughout the investigation, from 2.8 (0.8) mm observed at baseline, to 3.2 (0.9) mm after 1 year and 3.3 (1.1) mm detected at the 5-year recall evaluation (Figure 5). Differences over time were not statistically significant ($p = 0.433$; Related-Samples Friedman's Two-Way Analysis of Variance by Ranks).



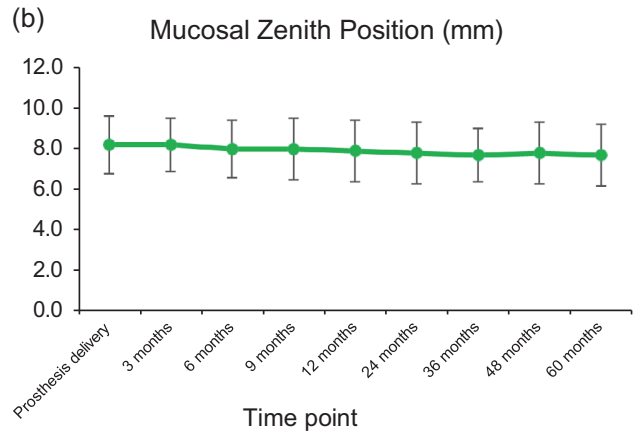


FIGURE 4 (a) Esthetic score and (b) gingival zenith position over time.

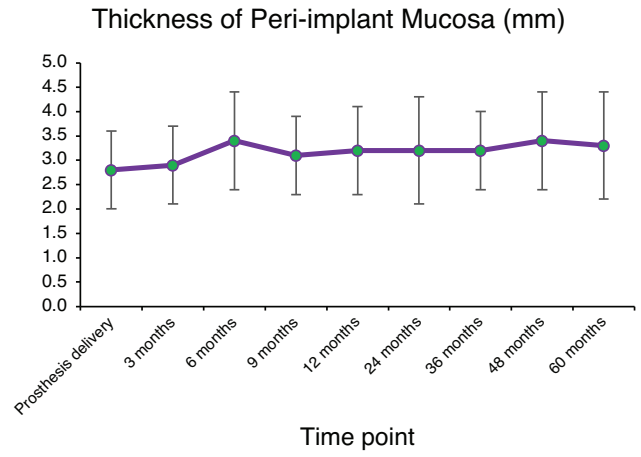


FIGURE 5 Thickness of peri-implant gingiva over time.

Two implants showed signs of mucositis at 2 and 5 years of follow-up, while another 2 showed signs of mucositis at 4 and 5 years. Additionally, one implant (mandibular right first molar) showed signs of mucositis at 4 years without bone loss, but showed signs of peri-implantitis at the 5-year recall evaluation, with an average PPD of 6 mm, BOP, and radiographic marginal bone loss of 4.6 mm. This same patient had an abutment fracture in her mandibular left first molar detected at the 4-year recall examination as well. It is worth noting that this patient had a history of mild smoking and non-severe bruxism when first included in the study.

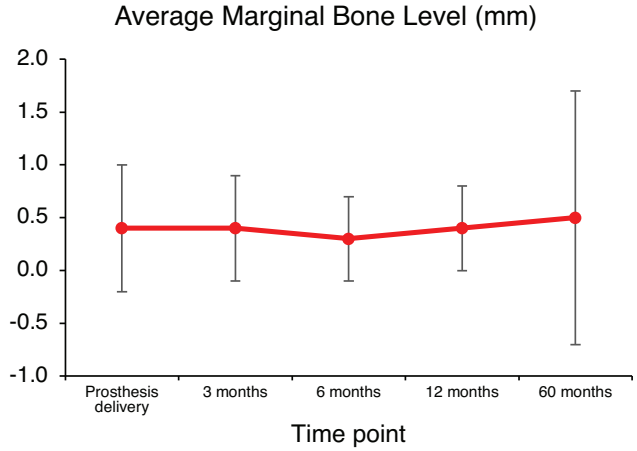


FIGURE 6 Mesial and distal average marginal bone level over time.

Probably because of the data from this patient, although mean marginal bone loss at the 1-year follow-up (0.4 [0.4] mm) was similar to the 5-year follow-up (0.5 [1.2] mm), a higher standard deviation could be observed. In fact, no significant differences were detected in the average MBL when evaluating all time points ($p = 0.768$; Related-Samples Friedman's Two-Way Analysis of Variance by Ranks) (Figure 6).

Regarding technical complications (Table 1), between the 1- and 5-year recall examinations, abutment fractures were the main major technical complication. In total, four abutment fractures were detected. Two abutment fractures in the mandible (one second premolar and one first molar) were recorded at the 3-year recall examination. The mandibular molar fractured when the patient chewed into an olive bone, while the premolar fractured due to occlusal overload. This patient had lost his mandibular left first and second molars the previous year but decided not to replace them, which could have increased the occlusal overload on the contralateral side where the implant restoration was located. Another abutment fracture (first mandibular molar) was detected at the 4-year recall examination. During a clinical consultation, the patient reported an increase in her emotional stress and bruxism habit in the last 2 years. In one more patient, abutment fracture of a mandibular second premolar was detected at the 5-year follow-up. Thus, over the course of the study, a total of 4 abutments fractured, resulting in a prosthetic reconstruction survival rate at 5 years of 78.9%, without accounting for the patient who dropped-out of the study and the one who died (Figures 7 a,b,c).

Minor technical complications were noted between 1 and 5 years postloading, each occurring in only one patient. Complications included a gingival tattoo in peri-implant gingiva adjacent to the implant restoration noted at the 2-year

TABLE 1 Technical complications (within visit %).

	No	Loss of composite covering the screw-access hole	Slight wear of occlusal porcelain without chipping	Slight wear of occlusal porcelain with chipping	Screw loosening	Mucosal tattoo	Abutment fracture
Baseline	21 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
3 months	15 (71.4%)	4 (19.0%)	1 (4.8%)	0 (0.0%)	1 (4.8%)	0 (0.0%)	0 (0.0%)
6 months	19 (90.5%)	1 (4.8%)	1 (4.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
9 months	21 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
12 months	21 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
2 years	17 (85.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (5.0%)	2 (10.0%)
3 years	15 (88.2%)	1 (5.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (5.9%)	0 (0.0%)
4 years	14 (82.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (5.9%)	1 (5.9%)	1 (5.9%)
5 years	13 (81.3%)	0 (0.0%)	0 (0.0%)	1 (6.3%)	0 (0.0%)	1 (6.3%)	1 (6.3%)

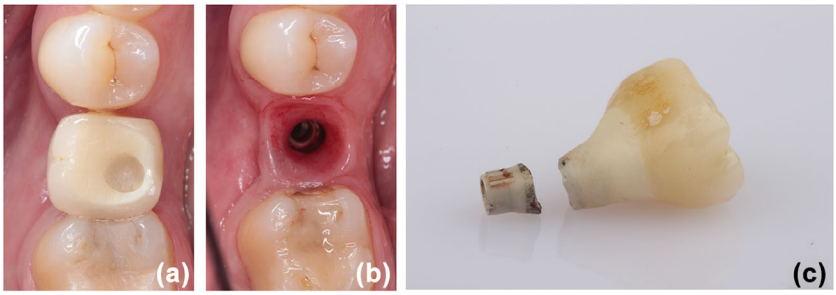


FIGURE 7 Clinical images of a mandibular fractured abutment. (a) Occlusal view of the one-piece zirconia abutment in a mandibular second premolar prior to removal. (b) Immediately after restoration removal, the fractured zirconia piece is still present inside the fixture. (c) Image of the fractured piece and zirconia abutment after removal. A common finding in fractured abutments is a dark metallic staining area in the transition zone between the abutment and the fixture, specifically, just above the engaging section of the abutment.

examination without noticeable changes throughout the rest of the investigation, loss of composite resin sealing in the screw access channel detected at the 3-year follow-up, one screw loosening detected at 4 years, and minor occlusal porcelain chipping in one patient when evaluated at 5 years.

DISCUSSION

After 5 years of clinical function, the main outcomes of the current investigation include radiological bone stability with no marginal bone loss (0.4 [0.4] vs. 0.5 [1.1] mm from 1-year follow-up to 5-year follow-up, respectively), an increase in mucosal thickness, from 3.2 (0.9) mm after 1 year to 3.3 (1.1) mm after 5 years, and a reduction in the GZP from 7.9 (1.5) mm after 1 year to 7.7 (1.5) mm at the 5-year recall examination. Implant survival rate after loading accounted for 100%, while prosthetic survival rate after 5 years was 78.9%, as 4 abutments fractured at different time points during the study. All abutment fractures occurred in the mandible, at the level of the second premolars and first molars.

Investigators indicate the need for long-term clinical studies reporting on the peri-implant soft tissues esthetic outcomes of single, implant-supported zirconia-ceramic restorations due to (1) the small number of studies assessing parameters such as the mucosal marginal level, the crown length, the thickness of the keratinized mucosa, or the level of the interproximal papilla; (2) the fact that the majority of studies reported data only at the end of the study;[18] and (3) discrepancies in gingival margin recession observed between zirconia and titanium abutments.[28] Accordingly, the current investigation aimed to report the long-term soft-tissue esthetic outcomes on veneered, one-piece, screw-retained, CAD-CAM zirconia implant-supported single crowns.

The soft tissue esthetic and restorative assessment of implant-supported single-tooth restoration outcomes with objective indexes such as PES/WES or IREI has focused on the maxillary esthetic zone.[29,30] However, these indexes do not completely comply with the clinical outcomes recommended for posterior implant-supported single-tooth restorations. In the actual investigation, considering that both anterior and posterior restorations were included, the esthetic outcomes were assessed as objectively as possible using 4 of the previously proposed parameters: ES, GZP, PIS, and thickness of the peri-implant attached gingiva (TKG).

After 5 years of clinical function, a statistically significant difference in GZP was observed between baseline (8.2 [1.4 mm]) and the 5-year clinical examination (7.7 [1.5 mm]), meaning that there was a coronal migration of the gingival margin of > 0.6 (0.7) mm and an improvement in peri-implant soft-tissue esthetic outcomes. These results are in accordance with Fenner et al.,[28] who also reported a reduction of gingival recession with single all-ceramic abutments. On the contrary, a similar prospective 5-year investigation evaluating implant-supported single all-ceramic crowns on prefabricated or CAD-CAM zirconia abutments in the maxillary esthetic zone reported no recession and stability of soft tissues.[31] While the clinical significance of the difference when

compared to the present investigation is limited, the discrepancy can be attributed to the restoration location (anterior and posterior teeth vs. only anterior teeth) and the methodology used to determine crown length and soft tissue vertical position in both studies.

Biologic complications are often evaluated and reported in a less standardized manner when compared to the way bone loss is reported, making datacomparison difficult.[32] When considering biologic complications, after 5 years of clinical function, the present investigation showed one major biological complication (peri-implantitis, detected at 4 years), and 5 minor biological complications (peri-implant mucositis detected at 2, 4, and 5 years of follow-up) for a total complication rate of 6.25%. On the contrary, previous investigations using the same abutment type and follow-up, have shown no biological complications after 5 years with screw-retained restorations, but have shown a 10.5% and 26.3% rate for major and minor biological complications, respectively, with cement-retained all-ceramic restorations.[33] The difference between the aforementioned investigations corroborates the discrepancies reported between those investigations that claim, on one hand, that there exists a significant difference in the prevalence of biological complications between screw-retained (1.08%) and cement retained (75%) restorations,[17] and those investigations that reflect no clinical and radiographic differences between both retention types.[34]

From the restorative point of view, abutment fracture was the main reason for restoration loss, leading to an implant-supported restoration survival rate of 78.9%. Investigations using the same abutment type and connection design have reported similar survival rates after 3[35] and 5 years[33] of clinical follow-up, both in anterior and posterior teeth. However, other clinical studies[36] and recent systematic[34,37] reviews have reported considerably higher survival rates (100% and an estimated 5-year survival rate [93.0%–99.1%], respectively) for zirconia abutments after 5 years. In addition, other systematic reviews also show significant differences in success and survival rates of zirconia abutments, varying from 1.08% to 17.86%.[38]

Differences in clinical outcomes have been attributed mainly to abutment materials, follow-up extension, and implant-abutment connection design. Regarding abutment materials, Ferrari et al.[35] found significantly higher success rates for titanium and titanium nitride abutments compared to zirconia abutments. In all the failed zirconia abutments, fractures occurred at the transition zone between the abutment and the fixture (stem level). The authors speculated that a possible explanation for the zirconia abutment failures could be related to the geometry and dimensions of the zirconia abutment connection and reduced thickness of zirconia at the transition zone, as well as milling discrepancies and micromotion, leading to internal deformation of the implant and abutment fracture. In the present investigation, the fracture line, as shown by the metallic debris observed in Figure 7, is also located in the transition zone between the abutment and the fixture (stem level), but more specifically, just above the engaging zone of the abutment. This fact, in accordance with the above investigations, could indicate this area to be the thinnest and weakest section of the abutments.

Considering the extension of the follow-ups, it has been reported that most zirconia abutment fractures occur within 3 years of clinical function[38] due to the limited observation times of most clinical investigations. The actual investigation, with a 5-year follow-up, is intended to provide additional long-term clinical data in this sense, reporting abutment fractures at 2, 4, and 5-year follow-ups, respectively. Therefore, the current investigation only partially corroborates this data considering the fracture interval previously reported.

Implant-abutment connection design is considered one of the main influencing factors leading to these discrepancies, although it still remains a controversial factor.[38] While clinical studies using zirconia abutments with an external implant-abutment connection design have reported no or few abutment fractures,[15,39] other systematic reviews[38] and clinical studies [33,35] suggest that the combination of one-piece zirconia abutments with internal-connection implants increases abutment fracture risk. On the contrary, a systematic review of in vitro investigations evaluating different types of implant abutments and abutment-connection types after cyclic loading, demonstrated a significantly higher fracture strength after cyclic loading for both titanium and zirconia internal-connection abutment materials, when compared to external-connection abutment materials.[40]

Chipping of the veneering porcelain has been reported as one of the main minor technical complications with veneered all-ceramic implant-supported single crowns (1.65%) when compared to a 0.39% ceramic chipping incidence for implant-supported monolithic all-ceramic single crowns.[32] In the current investigation, at 1-year follow-up, no patients showed porcelain chipping, and only one patient showed minor ceramic chipping (polished within the same clinical visit), detected at the 5-year recall examination. In the present investigation, each implant reconstruction was planned and manufactured following a prosthetically-driven concept, where a full-contour, screw-retained, diagnostic wax-up was designed prior to the fabrication of each CAD-CAM zirconia reconstruction; this may have reduced the number of technical complications, such as chipping.

Limitations of the present investigation include the incorporation of both anterior and posterior teeth, due to their different clinical behavior, which could be interpreted as a confounding factor since a comparison between these groups of teeth may not be representative when analyzed separately. In addition, the small sample size and the fact that only one type of ceramic abutment was used, represent additional limitations. Therefore, extrapolation of data to different implant systems, abutment designs, and reconstruction types must be cautious. Moreover, due to the high prevalence of zirconia abutment fractures and the associated permanent damage to the implant's connection shown in the present study, as well as in previous investigations, prefabricated titanium-base abutments (Ti-base) combined with different CAD-CAM materials constitute the most popular

solution nowadays due to the titanium-titanium contact interface. In addition, monolithic zirconia restorations have also been introduced in order to reduce the chipping incidence of veneering material. Nevertheless, the 5-year follow-up evaluation, to a certain extent, could have compensated for these limitations.

CONCLUSION

Within the limitation of the present prospective case series investigation, it can be concluded that after 5-years clinical function, Atlantis one-piece, screw-retained, internally connected CAD-CAM veneered zirconia implant-supported single crowns resulted in a relatively low survival rate, mainly associated with posterior single implant-supported reconstructions. However, due to the fact that the present clinical investigation used only one abutment design and reconstruction type, extrapolation of data to different implant systems, abutment designs, and reconstruction types must be considered with caution. Additional randomized controlled clinical trials with longer observation periods are needed to validate the results of the present investigation.

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CONFLICT OF INTEREST STATEMENT

Pablo Galindo-Moreno is a frequent speaker for Dentsply Sirona Implants. Regardless, the authors declare no conflicts of interest, either directly or indirectly, in any of the products listed in the manuscript.

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