Clinical Evaluation of the Influence of Connection Type and Restoration Height on the Reliability of Zirconia Abutments: A Retrospective Study on 965 Abutments with a Mean 6-Year Follow-Up

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This multicenter retrospective clinical study aimed to evaluate the clinical performance of zirconia abutments in anterior and posterior regions, focusing on implant-abutment connections and restoration vertical height (RVH). Six experienced prosthodontists used 965 computer-aided design/computer-assisted manufacture zirconia abutments in 601 patients. Different surgical approaches were taken according to the needs of each patient. The final restorations were all-ceramic single crowns and short-span fixed dental prostheses. Screw-retained restorations were mainly used in anterior areas, whereas cemented prostheses were chosen in cases where the implant position was not ideal. Different types of implant-abutment connections were compared: external, internal with metal components, and internal full-zirconia conical connection. All the restorations were followed up for 4 to 10 years. Technical and biologic complications were assessed in relation to several biomechanical variables, such as RVH. Differences between groups were statistically analyzed, and longevity of abutments was evaluated according to Kaplan-Meier survival analysis. Zirconia abutments resulted in overall survival and success rates of 98.9% and 94.8%, respectively. External connections reported survival and success rates of 99.7% and 94.5%, internal metal connections 99.8% and 95.5%, and internal zirconia connections 93.1% and 93.1%, respectively. Overall complication rates of 1.14%, 3.42%, and 0.62% were reported for fractures, chipping, and unscrewing, respectively. The external connection showed the longest survival while the internal zirconia connection showed the highest fracture incidence over the observation period. The clinical risk limit of RVH was identified as 14 mm. Zirconia abutments showed satisfactory clinical performance in anterior and posterior regions after 4 to 10 years. RVH and connection type influenced the clinical longevity of restorations; in particular, internal connections with secondary metallic components reduced the incidence of complications. Int J Periodontics Restorative Dent 2016;36:19–31. doi: 10.11607/prd.2974

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Due to increasing patient demand for esthetics and the development of computer-aided design/computer-assisted manufacture (CAD/CAM) technologies, the use of zirconia as a dental material has increased significantly in recent decades.[1–6] Yttrium partially stabilized tetragonal zirconia polycrystal (3Y-TZP) exhibits superior mechanical properties compared with other ceramics and is considered the strongest and most commonly used zirconia-based ceramic.[1–5,7–10] Such properties, together with the esthetic advantages due to its white color and reduced soft tissue discoloration, led to the introduction of zirconia as an alternative to metal-based prostheses. It was proposed for different types of all-ceramic dental reconstructions, including implant abutments and frameworks in both tooth- and implant-supported fixed prosthodontics.[2,4,5]

High-strength zirconia implant abutments were introduced in clinical practice to overcome the esthetic limitations correlated with titanium abutments, mainly the possible grayish or bluish appearance of peri-implant soft tissues due to the presence of metal components in relation to periodontal biotype and soft tissue thickness (Fig 1).[4,11–13] The use of titanium abutments is widely documented in the literature.[1,4,14–16] In case of soft tissue recession,

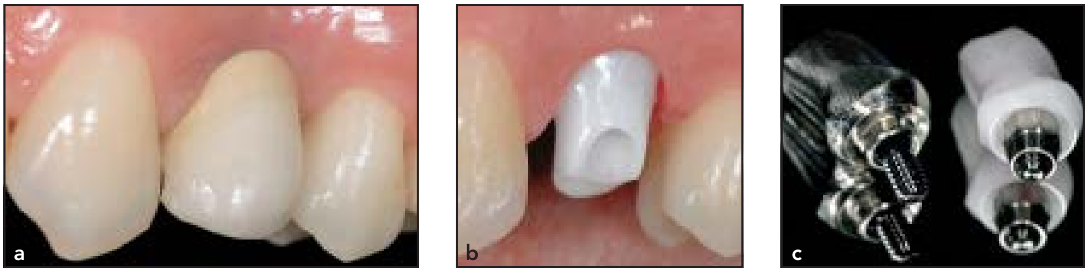

Fig 1 (a) *Porcelain-fused-to-metal crown on titanium abutment. The gray transmission through the soft tissues compromised the esthetic outcome.* (b, c) *The titanium abutment was replaced with a zirconia one.* (d) *The new all-ceramic restoration supported by a zirconia abutment. It was possible to solve the esthetic drawback simply by changing the material.*

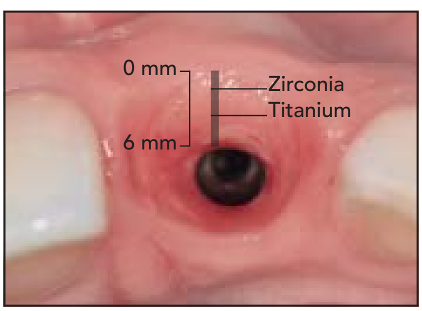

Fig 2 *Prosthetic margin placement for titanium and zirconia abutments. It is necessary to go deeper with metal to mask the material, which inevitably increases the difficulty of clinical procedures such as removing excess cement.*

exposure of the gray titanium abutment can lead to esthetic failure of restorations, particularly in anterior regions.[4,17,18] Moreover, titanium abutments require an intrasulcular placement of the prosthetic margins with consequent complications concerning clinical procedures with cement-based approaches such as impression taking, cementation, and removal of excess cement.[19,20] This aspect is paramount in posterior areas, where it is possible to keep the prosthetic margins completely extragingival to simplify the clinical procedures and ensure thorough removal of excess cement.[21,22] Another clinical limitation is a weak porcelain bond when titanium is used as substrate.[23]

The shortcomings of titanium led to the development and clinical application of zirconia abutments with esthetic and clinical advantages.[1–4] With zirconia abutments, the prosthetic margins can be placed extrasulcularly to simplify clinical procedures such as removal of excess cement[4,21,22] (Fig 2).

Because of the different properties of the two materials, the mechanism of zirconia abutment failure differs from that of titanium abutments.[1,3,24] Ceramics are brittle materials and therefore do not withstand tensile forces properly; usually, fractures occur when tensile forces exceed the limits of fracture toughness.[1,24] Conversely, titanium is a ductile material and this enhances its tolerance to compressive and tensile forces. Prior to metal fracture, elastic and plastic deformations occur.[1,24] This explains the excellent loading capability of metals and represents the main difference between ceramic and metal materials.[24]

Promising survival rates were reported in clinical studies on zirconia abutments, reaching 100% with single crowns (SCs) in anterior and premolar regions;[18,25] a 100% survival rate was also noticed in posterior regions after 3 years of function.[26]

Consequently, zirconia abutments were considered sufficiently stable for use with implant-supported reconstructions and were claimed as a viable alternative to metal abutments because of their satisfactory mechanical strength.[1,18,26] However, the reported clinical observation periods were shorter than those for titanium abutments. The information collected on ceramic abutments was scarce with regard to number of published studies and analyzed abutments, and the follow-up time was limited.[1,3,27] Overall, the data were not sufficient to provide conclusive evidence about indications and performance limits of zirconia abutments.[4,27]

The diameter and type of implant-abutment connection might play an important role in the reliability of ceramic abutments.[4,5,7,28–30] Implant manufacturers provide zirconia abutments with both external and internal connections; however, with the latter some companies produce abutments with metal inserts to decrease the risk of fracture. In fact, several in vitro studies suggested that two-piece zirconia abutments with secondary coupling abutments or metal inserts could withstand higher bending moments than one-piece internally or externally connected abutments.[1,31,32] An interesting parameter of the abutment-implant complex is the restoration vertical height (RVH, measured from the implant platform to the incisal portion of the prosthesis) and its potential influence on the fracture risk of abutments in relation to the type of connection. To date, no study has investigated the influence of RVH in relation to implant position, connection, and diameter.

The present multicenter retrospective clinical study aimed at evaluating the clinical performances of zirconia abutments placed either in anterior or posterior regions. The primary investigated outcomes were success and survival rates of restorations supported by zirconia implant abutments. As secondary outcomes, biomechanical and functional variables were assessed, including implant-abutment connection, RVH, and occlusal and biologic parameters. The null hypothesis was that there was no difference in cumulative survival rates of zirconia abutments in relation to implant-abutment connection.

Materials and methods

Selection of patients

Between May 2004 and December 2011, six expert prosthodontists made 965 CAD/CAM zirconia abutments in 601 patients (239 men and 362 women; age range 20 to 75 years). All the patients presented with one or more missing teeth to be replaced with implant-supported restorations. They were selected consecutively at the authors' dental offices and at a university department of fixed prosthodontics. All the patients were in good general health, and 28% were smokers (more than five cigarettes per day). Patients were selected for the study on the basis of the following inclusion criteria:[1]

- Aged 18 years or older with at least one missing tooth
- Good general health (American Society of Anesthesiologists Physical Status class I or II)
- Good oral hygiene
- Periodontally healthy
- Minimum of 20 teeth
- No signs of occlusal parafunctions (severe wear, muscular pain) or temporomandibular disorders

Subjects with uncontrolled gingival inflammation and/or periodontitis were excluded from the study. However, patients with sleep bruxism and parafunctional habits who did not show occlusal wear facets were included in the study.

All the patients underwent supportive periodontal therapy with experienced dental hygienists and were instructed to maintain proper home oral hygiene that was checked at the follow-up appointments.

Surgical procedures

Different implant surgery approaches were used according to the needs of each patient. Both one-stage and two-stage surgical techniques were performed with immediate or delayed function. In other cases, immediate postextractive implants with or without soft and/or hard tissue grafts were used.

A total of 965 implants from different manufacturers were retrospectively evaluated: 647 by Nobel Biocare, 212 by Straumann, and 106 by Biomet 3i. Different implant

Table 1 Distribution of Implant-Abutment Connections by Implant Manufacturer

	Implant manufacturer			
Abutment connection	Nobel Biocare	Straumann	Biomet 3i	Total
External	285 (Brånemark)	0	58 (Prevail N)	343
Internal metal	231 (Nobel Replace)	212 (SLA Tissue Level)	48 (Prevail Ni)	491
Internal zirconia	131 (Nobel CC)	0	0	131
Total	647	212	106	965

Table 2 Distribution of Abutments by Anatomical Location

Abutment connection	Maxilla (n [%])	Mandible (n [%])	Anterior (n [%])	Posterior (n [%])
External	232 (68)	111 (32)	76 (22)	78% (n = 267)
Internal metal	304 (62)	187 (38)	152 (31)	339 (69)
Internal zirconia	107 (82)	24 (18)	73 (56)	58 (44)
Total	643 (67)	322 (33)	301 (31)	664 (69)

lengths and diameters and different implant-abutment connections were used. No patient immediately received a final zirconia abutment. All the restored implants were fully osseointegrated with proper soft tissue health and morphology.

Prosthodontic procedures

All the prosthetic procedures were performed by experienced prosthodontists. Once hard and soft tissue healing was achieved, implant-level impressions were taken with elastomeric materials and screw-retained transfer copings, using an open tray technique, to fabricate screw-retained temporary restorations. These provisional prostheses were placed onto the implants about 2 weeks after impression taking. According to the needs of each patient's clinical condition, the peri-implant soft tissues were conditioned for a period ranging from 4 to 16 weeks, with periodically relining of the temporary prostheses to properly shape the emergence profile of the restorations. Final implant-level impressions with customized transfer copings were then taken as previously described.

All the patients were provided with customized zirconia abutments fabricated by means of CAD/CAM technology (558 with Procera, Nobel Biocare; 212 with CARES, Straumann; 131 with Atlantis, Dentsply; 64 with Encode, Biomet 3i). The final prostheses were all-ceramic restorations, SCs and short-span fixed dental prostheses (FDPs, three to four units) with lithium disilicate alumina, or zirconia frameworks with dedicated veneering ceramics. Screw-retained prostheses were mainly used in anterior areas, whereas cemented restorations were chosen in cases where implant position was not ideal.

The present retrospective study evaluated different types of implant-abutment connections: external connection (n = 343; 285 Brånemark, Nobel Biocare; 58 Prevail N, Biomet 3i), internal connection with metal components (n = 491; 231 Nobel Replace, Nobel Biocare; 212 SLA Tissue Level, Straumann; 48 Prevail Ni, Biomet 3i), and internal conical full-zirconia connection (n = 131; Nobel CC, Nobel Biocare) (Table 1). The anatomical distribution of the abutments is reported in Table 2.

All the zirconia abutments were torqued according to the manufacturers' instructions using dynamometric torque wrenches. The final restorations were luted with temporary or final resin-based cements according to the clinical situation. In cases of subgingival prosthetic margins, retraction cords (000 Ultrapak, Ultradent) were used, and all cement remnants were carefully removed.

Table 3 Distribution of RVH Values by Anatomical Location

Abutment connection	Anterior maxilla (mm)	Posterior maxilla (mm)	Anterior mandible (mm)	Posterior mandible (mm)
External	11–18 (mean = 14.4)	10–17 (mean = 14.1)	12–20 (mean = 16.0)	11–16 (mean = 13.6)
Internal metal	10–18 (mean = 13.7)	9–20 (mean = 13.9)	12–19 (mean = 14.2)	9–18 (mean = 13.5)
Internal zirconia	10–17 (mean = 13.7)	10–16 (mean = 13.6)	12–17 (mean = 14.3)	9–15 (mean = 12.7)
Total	10–18 (mean = 13.9)	9–20 (mean = 14.0)	12–20 (mean = 14.9)	9–18 (mean = 13.1)

Standardized radiographs of implants and restorations were taken using long-cone paralleling technique at baseline and at the yearly follow-up appointments.

Clinical evaluation

All the restorations were followed up for a minimum period of 4 years to a maximum of 10 years. No patient dropouts were recorded.

The patients were recalled yearly for follow-up appointments, and the data were recorded on individual forms reporting the following characteristics: sex, age at the time of cementation, number and type of restorations, entire observational follow-up period, implant position, implant diameter and length, type of implant-abutment connection, RVH, type of occlusal scheme, opposing dentition, presence of parafunctions, patient's self-reported satisfaction, dentist's self-reported satisfaction, and biologic and prosthodontic complications.

The RVH was measured from the implant platform to the incisal portion of the prosthesis and retrospectively evaluated on standardized radiographs; any possible dimensional distortion was corrected by comparing the real dimensions of the implants to the radiographic images. The effectiveness of this measurement technique was validated on five test retrievable, monolithic, screw-retained zirconia SCs (not considered for the present retrospective study). Their RVH was measured radiographically as previously described, and the measurements were repeated after removing the SCs, achieving the same linear results (Fig 3). Decimal values ≤ 0.5 mm were approximated by defect, while decimal values > 0.5 mm were approximated by excess (Table 3).

At the yearly follow-up examinations, success and survival of implants, abutments, and restorations were evaluated clinically and radiographically. The abutments supporting FDPs were assessed as those supporting SCs.

Statistical analysis

Analytic and descriptive statistics were performed with dedicated software (SPSS version 22, IBM). Specific and overall success, survival, and complication rates were calculated and statistically analyzed; the mechanical complications were classified as fracture, chipping, and unscrewing events. The normality of data distributions was checked using Kolmogorov-Smirnov test. Univariate analysis of variance (ANOVA)

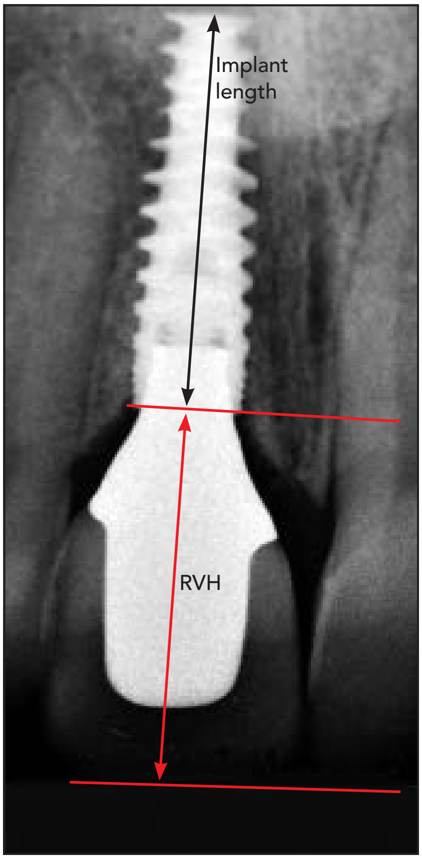

Fig 3 *Radiologic evaluation of the restoration vertical height (RVH). The radiographic distortion was evaluated on the implant length and later carried on the RVH.*

Table 4 Survival, Success, and Mechanical Complication Rates

Abutment connection	Survival rate (%)	Success rate (%)	Fracture (%)	Chipping (%)	Unscrewing (%)
External (n = 343)	99.7[a]	94.5[a,b]	0.3 (n = 1)	4.1 (n = 14)	1.2 (n = 4)
Internal metal (n = 491)	99.8[a]	95.5[a]	0.2 (n = 1)	3.9 (n = 19)	0.4 (n = 2)
Internal zirconia (n = 131)	93.1[b]	93.1[b]	6.9 (n = 9)	0 (n = 0)	0 (n = 0)
Total (n = 965)	98.9	94.8	1.1	3.4	0.6

Different superscript letters indicate statistically significant differences ($P < .05$).

Table 5 Distribution of Fractures by Anatomical Location

Abutment connection	Maxilla (% [n])	Mandible (% [n])	Anterior (% [n])	Posterior (% [n])
External	100 (1)	0 (0)	0 (0)	100 (1)
Internal metal	100 (1)	0 (0)	0 (0)	100 (1)
Internal zirconia	88.9 (8)	11.1 (1)	67 (6)	33 (3)
Total	90.9 (10)	9.1 (1)	55 (6)	45 (5)

and Tukey post hoc test for multiple comparisons were used to evaluate possible differences between the survival and success rates of different implant-abutment connection groups. The cumulative survival rates were recorded and analyzed according to Kaplan-Meier analysis; fractures of restorations needing replacement were considered as statistical events. Log-rank test was performed to compare the survival curves of different implant-abutment connections. The level of significance was set at $P = .05$ for all the statistical analyses.

Results

Zirconia abutments resulted in overall survival and success rates of 98.9% and 94.8%, respectively, over a period of 4 to 10 years (mean = 71.3 months). External connections reported survival and success rates of 99.7% and 94.5%, internal metal connections of 99.8% and 95.5%, and internal zirconia connections of 93.1% and 93.1%, respectively (Table 4).

In the external connection group, 1 fracture, 14 chippings, and 4 unscrewings were observed. In the internal metal group, 1 fracture, 19 chippings, and 2 unscrewings were seen. In the internal zirconia group, 9 fractures were observed and no chipping or unscrewing occurred (Table 4). The anatomical distribution of fractures is reported in Table 5. Overall complication rates of 1.14%, 3.42%, and 0.62% were reported for fractures, chipping, and unscrewing, respectively (Table 4).

The external connection showed the longest survival over the observation period. The fractures occurring on internal metal connections were noticed within the first year of service. The internal zirconia connection showed the highest fracture incidence occurring within 2.5 years after loading.

Regarding RVH, a total of 11 abutments fractured: 1 fracture of an external connection abutment occurred after 44 months of service (Brånemark 4-mm diameter), 1 fracture of an internal connection abutment was noticed 10 months after delivery (Biomet Prevail Ni 4-mm diameter), and 9 fractures were seen on internal zirconia abutments between 9 and 28 months of clinical use (4 Nobel Active 3.5-mm diameter and 5 Nobel Active 4-mm diameter). All the fractured abutments had a RVH between 14 and 17 mm (Fig 4). Considering the distribution of fractures between anterior and posterior abutments, slightly more events occurred on anterior restorations. However, they were noticed only in the internal zirconia group, in which 6 fractures occurred on anterior abutments and 5 on posterior ones.

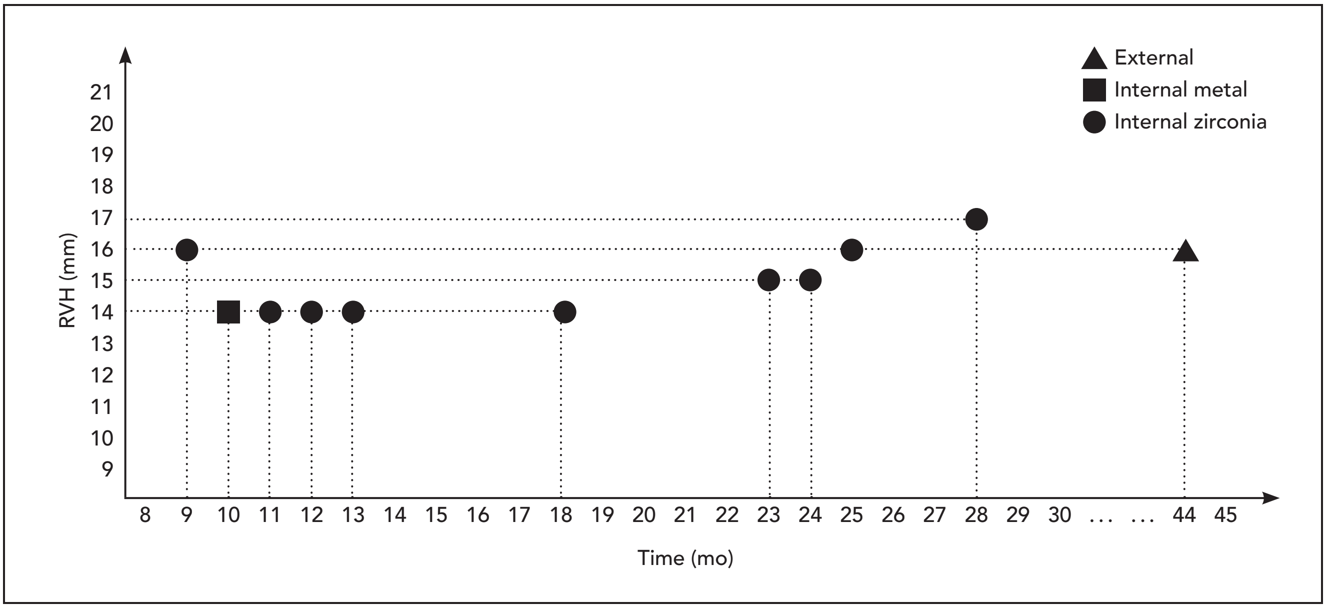

Fig 4 *Incidence of fracture of zirconia abutments over time in relation to RVH and implant-abutment connection.*

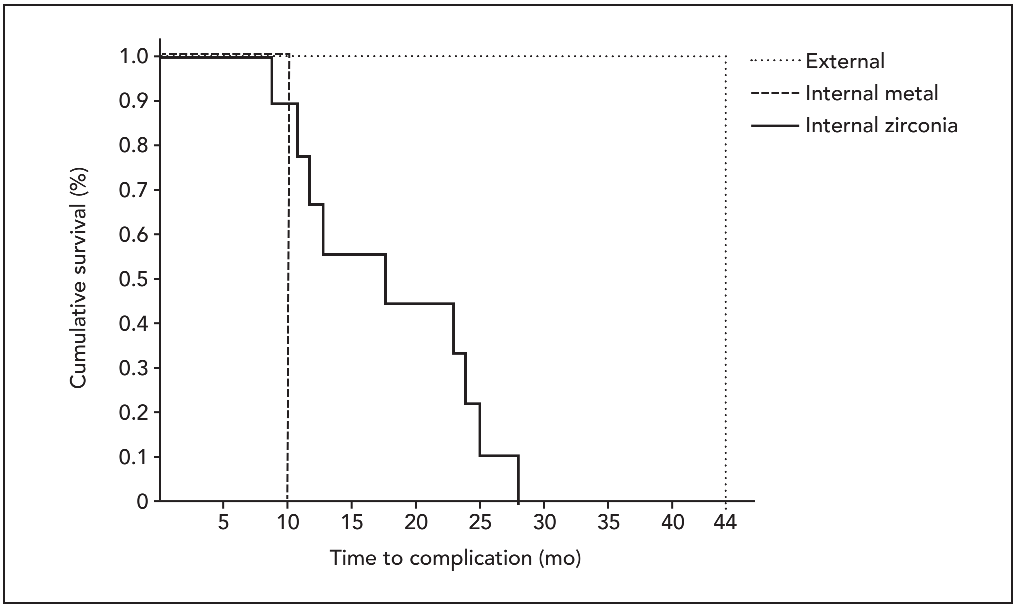

Fig 5 *Kaplan-Meier graph of complication onset in relation to time for zirconia abutments with different connection geometries.*

As to the statistical analyses, Kolmogorov-Smirnov test pointed out normal data distribution ($P > .05$). The ANOVA and Tukey post hoc test showed statistically significant differences between groups ($P < .05$). Regarding the survival rates, the internal zirconia connection demonstrated worse clinical outcomes ($P < .05$) than the other experimental groups ($P > .05$). For success rates, statistically significant differences were seen between the internal metal and the internal zirconia connections ($P < .05$) but not between the external connection and the other groups ($P > .05$) (Table 4). The Kaplan-Meier survival analysis and the log-rank test comparing the survival curves of the different implant-abutment connections found statistically significant differences only for the full-zirconia internal connection ($P < .05$) (Fig 5).

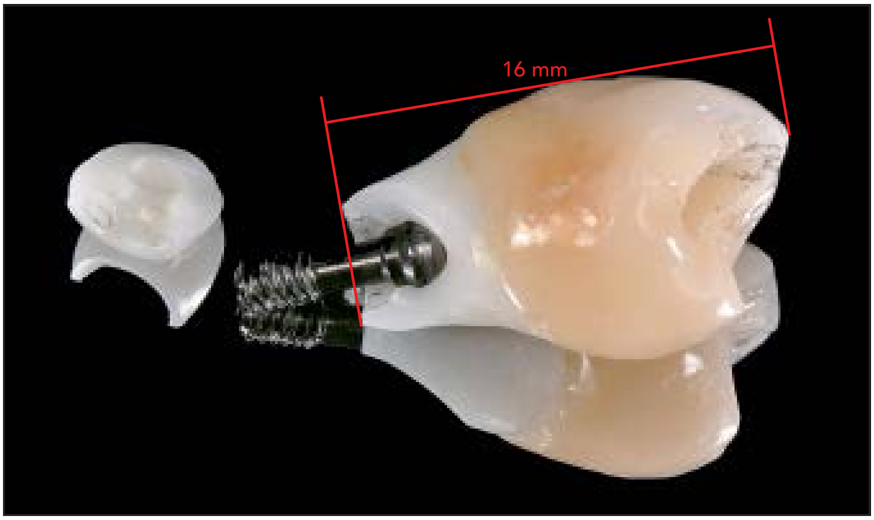

Fig 6 *Fractured zirconia abutment with external connection regular platform after an intraoral traumatic event. The RVH was 16 mm.*

Fig 7 *Zirconia abutment with internal connection combined with metal component.*

External connection

A total of 343 zirconia abutments with external connection were retrospectively evaluated. Overall, 208 abutments (60.7%) supported SCs and 135 (39.3%) supported FDPs.

The RVH ranged from 10 to 19 mm. The highest and lowest values were recorded at the level of mandibular central incisors and mandibular molars, respectively. The abutment distributions were reported in Table 3. Parafunctional habits were present in 17% of patients.

Only one fracture was observed, in a maxillary first premolar with a RVH of 16 mm and a regular platform after 44 months of service (Fig 6). The failure was not due to parafunctional habits but to a traumatic event while chewing; the zirconia abutment was replaced with a titanium one and a new crown was delivered.

Chipping occurred in 4.1% of the population (n = 14) and was mainly observed in layered zirconia in patients with parafunctional habits. Cohesive fractures did not impair function; consequently, restorations were thoroughly polished and remained in situ.

Screw loosening occurred in 1.2% of patients (n = 4) and only on SCs. The abutments were torqued again according to the manufacturers' instructions, and the restorations were left in situ.

Buccal recessions were observed in 19% of the restorations, but none compromised the esthetic outcome due to the natural tooth-like appearance of zirconia.

Abnormal bone resorption (> 1 mm in the first year of loading and > 0.2 mm in each subsequent year[33]) was detected by standardized radiographs in 9.5% of implants.

Internal connection with metal components

A total of 491 zirconia abutments with internal connection and metal components were retrospectively evaluated. Overall, 426 abutments (86.7%) supported SCs and 65 (13.3%) supported FDPs (Fig 7).

The RVH ranged from 9 to 21 mm. The highest values were recorded at the level of mandibular central incisors and maxillary molars, while the lowest values were found at the level of mandibular premolars and molars. The abutment distributions are reported in Table 3. Parafunctional habits were seen in 18% of patients.

Only one fracture was observed, in a maxillary second premolar with a RVH of 14 mm and regular platform after 10 months of service. The failure was due to overload in a parafunctional patient. The zirco-

Fig 8 *Zirconia abutment with full-zirconia internal conical connection.*

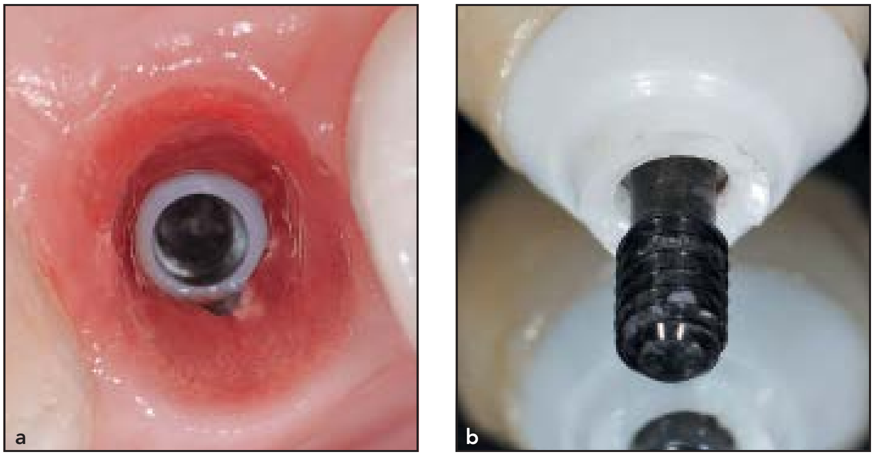

Fig 9 (a) *Abutment fracture on regular platform implant in patient with parafunctional habit. The abutment fragment inside the implant was removed and a new titanium abutment was produced. The RVH was 15 mm.* (b) *Abutment fracture. Typically with this kind of solution, the fracture involves the internal walls of the abutment.*

nia abutment was substituted with a titanium one, and a new crown was fabricated.

Chipping occurred in 3.9% of patients (n = 19) and was prevalent in layered zirconia in patients with parafunctional habits. Cohesive fractures did not interfere with function; consequently, the chipped areas were thoroughly polished and the prostheses remained in situ.

Screw loosening occurred in 0.4% of the population (n = 2) and only on SCs. The abutments were torqued again according to the manufacturers' instructions and restorations were left in situ.

Buccal recessions were recorded in 9.8% of the restorations, but no esthetic failure was reported because of the white color of the zirconia.

Abnormal bone resorption[33] was seen in radiographs in 7.3% of implants.

Internal full-zirconia conical connection

A total of 131 zirconia abutments with internal full-zirconia conical connection were retrospectively evaluated. Overall, 118 abutments (90%) supported SCs and 13 (10%) supported FDPs (Fig 8).

The RVH ranged from 9 to 17 mm. The highest values were reported at the level of maxillary and mandibular central incisors, while the lowest values were seen at the level of mandibular premolars. The abutment distributions are reported in Table 3. Parafunctional habits were present in 26% of patients.

A total of 9 fractures was observed, mainly at the maxillary arch, and they all occurred in parafunctional patients (Fig 9). The distribution and characteristics of the fractured abutments with internal full-zirconia conical connection are reported in Table 6. All the fractured zirconia abutments were substituted with titanium ones, and new prostheses were delivered.

Neither chipping nor screw loosening were observed in restorations supported by zirconia abutments with internal full-zirconia connection.

Buccal recessions were recorded in 4.5% of the restorations, but none compromised the esthetic success due to the white appearance of the zirconia.

Abnormal bone resorption[33] was seen in standardized radiographs in 2.7% of implants.

Discussion

According to the results of the present study, the null hypothesis was rejected because the implant-abutment connection influenced the survival rates of the restorations.

Table 6 Distribution and Characteristics of Fractured Abutments with Internal Full-Zirconia Conical Connection

Location	Follow-up (mo)	RVH (mm)	Notes
Maxillary central incisor	9	16	Regular platform
Maxillary lateral incisor	13	14	Narrow platform, abutment of FDP 1.2–2.2
	18	14	Narrow platform
	23	15	Narrow platform
Maxillary canine	25	16	Regular platform
Maxillary premolar	11	14	Regular platform
	12	14	Regular platform
	24	15	Regular platform
Mandibular central incisor	28	17	Narrow platform

The survival and success rates were calculated for all experimental groups. Survival was represented by the number of abutments still in place after the entire follow-up period, including those that experienced mechanical complications that did not impair function. Conversely, success was defined as the number of abutments that did not show any kind of mechanical complication. In other words, the clinical events that differentiated success and survival were fractures of the restorations needing replacement.[4]

Technical complications were few and were mainly limited to patients with slight occlusal parafunctions (sleep bruxism) and/or adverse biomechanical conditions (ie, unfavorable crown-to-implant ratio).

The reported clinical evidence agreed with the results of in vitro investigations, suggesting that two-piece zirconia abutments with secondary coupling components or metallic inserts could withstand higher bending moments than one-piece internally or externally connected zirconia abutments.[1,32]

This topic remains controversial in the literature. In vitro studies have focused on the mechanical strength of zirconia abutments, but results are heterogenous due to different loading conditions.[1,31,34] Moreover, the clinical behavior of zirconia abutments at 3 to 5 years of follow-up was comparable to that of titanium abutments.[18,25,26,35]

Several factors might influence the stability and survival of zirconia abutments, including the manufacturing process, clinical handling, implant location, implant-abutment connection, crown-to-implant ratio, RVH, and occlusal scheme. These variables were evaluated retrospectively in the present study. RVH in particular is paramount in clinical practice as it can strongly influence stress concentration and dissipation and, consequently, the biomechanics of implant-supported restorations. To the best of the authors' knowledge, this study is the only clinical investigation to date focusing on the influence of RVH on the survival of zirconia abutments.

During occlusal loading of implant-supported restorations, the region around the abutment screw head is the area of highest torque and stress concentration, and this was demonstrated to be the most critical area for the integrity of ceramic abutments.[28–30] As a consequence, biomechanical variables such as direction and intensity of loads have a major influence on the stability and predictability of zirconia implant abutments.[4,5,7,24]

All fractures occurred in restorations with RVH ≥ 14 mm. These failures were mainly recorded in anterior areas, where nonaxial loads are common due to the anatomical shape of incisors, the volume of anterior bone crests, and the finalized position of implants to achieve optimal esthetics. No fractures for values ≤ 13 mm were observed.

Since all the fractured abutments had a RVH between 14 and 17 mm, 14 mm can be considered the clinical risk limit for restoration height in the presence of zirconia abutments irrespective of implant-abutment connection type. It can be speculated that, in the presence of restorations with a high RVH, such as in periodontal patients, the biomechanical stress at the level of the implant connection is higher than that occurring in prostheses with a reduced RVH.

Most of the fractures involved internal full-zirconia connections, in which the thickness of the internal walls represents a critical variable, particularly in narrow-platform implants. Scanning electron microscope analyses of clinically fractured one-piece zirconia abutments suggested that failures of internal full-zirconia connections may occur because of friction stresses generated by fixation screws or overpreparation and thinning of the lateral walls of abutments;[36,37] a minimum thickness of 0.5 mm should be kept to prevent fractures.[18] This phenomenon could explain the higher number of abutment fractures compared with ceramic chipping in internal full-zirconia connections, since the zirconia connection can be considered the weak link of the prosthetic system.

To overcome this problem, some implant manufacturers produce zirconia abutments with metal inserts at the thinnest part of the connection. The retrieval of fractured fragments at the level of the implant-abutment connection is difficult and could damage the inner implant components.[31,38] Only two fractures were reported in external and internal metal connections, one per group; they both were secondary to occlusal traumas while chewing.

An overall screw-loosening rate of 0.62% was recorded (Table 4). According to a recent systematic review,[31] loosening of abutment screws was the most frequent technical complication in single-implant restorations. The type of connection was reported to be a primary factor in screw loosening, as unscrewing more frequently occurred in external connections. To minimize such a drawback, abutment and prosthetic screws should always be tightened at the torque level recommended by the manufacturer, using dynamometric torque wrenches and screws with surface treatments finalized to achieve higher preload values with the same torque, as performed in the present investigation.

Cohesive fractures (ie, chipping) of the veneering ceramics were recorded in 3.42% of the restorations (Table 4). According to previous investigations,[39–41] they were mainly observed in parafunctional patients and occurred on supporting cusps and connectors of FDPs. None of the chippings impaired function; consequently, the veneering ceramic was thoroughly polished and the restorations remained in situ.

The entire observational period ranged from 4 to 10 years (mean = 71.3 months). No significant differences in terms of technical complications were reported between restorations with different follow-up times.

As to the biologic outcomes, the well-documented biocompatibility of zirconia[2] allows more superficial placement of the prosthetic margins than with metal abutments.[4] This represents a paramount advantage to preserve peri-implant soft tissue health and simplify clinical procedures, especially in cases of cement-retained prostheses. In the present investigation, 70.8% of the restorations were treated with circumferential juxta- or extragingival prosthetic margins; in the remaining 29.2%, subgingival margins were used. No inflammatory reactions were observed in the former group, while moderate soft-tissue inflammation due to cement remnants was noticed in a few restorations belonging to the latter group. Slight plaque accumulation was reported on 33% of the restorations.

The juxta- or extragingival placement of prosthetic margins could lead to abutment exposure in case of soft tissue recession. Buccal recessions occurred in 13.2% of the restorations treated with juxta- or extragingival margins after a mean observational period of 82.7 months. This did not represent a major esthetic concern because of the toothlike color of zirconia abutments,[4] and no restoration was replaced (Fig 10).

In terms of soft tissue integration, no significant differences were found comparing different types of implant-abutment connection. As to marginal bone, 6% of patients presented with abnormal bone resorption evidenced clinically and radiographically. The two-dimensional radiographic examination showed less bone resorption in full-zirconia conical connections with implant platform switching.

Nine implants were lost due to peri-implantitis and removed. However, the prostheses were considered successful until the time of implant removal.

Fig 10 (a) *Challenging esthetic treatment on teeth and implants. Zirconia abutments allow idealization of the soft tissues appearance and maintenance of the juxtagingival prosthetic margin.* (b) *Final outcome 6 months after cementation of the all-porcelain crowns.* (c) *Prosthetic outcome 8 years after the final restoration. The unperceivable recession on the implant-supported crowns doesn't compromise the esthetic outcome thanks to the zirconia esthetic abutment.*

This investigation was a clinical, retrospective, multicenter study. Although the same rigorous approach was adopted, different operators and several clinical variables (ie, restoration type, intraoral distribution, multiunit prostheses in single patients) may have acted as confounders in the clinical and statistical results. On the basis of such limitations, further in vivo investigations are needed to validate the clinical reliability of the reported results.

Conclusions

The rates of technical and biologic complications were low, and in general the patients were extremely satisfied with the implant-supported all-ceramic restorations. With the limitations of this study, the following conclusions can be drawn:

- The performances of zirconia abutments were clinically satisfactory in both anterior and posterior regions after a mean follow-up period of 6 years.
- The connection type and RVH influenced the clinical longevity of restorations.
- Internal connections with secondary metallic components reduced the incidence of complications over the entire observation period.
- RVH ≥ 14 mm presented greater risk of failure, particularly in the presence of full-zirconia internal connections.
- RVH can be considered a critical parameter concerning the predictability of zirconia abutments.
- In the presence of parafunctional habits and unfavorable biomechanical parameters, external or internal zirconia abutments with metal components should be considered the first choice to reduce the risk of clinical failures.

Further prospective randomized clinical trials are necessary to validate the present results and overcome the limits of the present investigation.

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