Survival Rate and Esthetic Outcomes of 2-Piece Zirconia Dental Implants: A 1-Year Single Clinical Trial of Partially Edentulous Patients

Yaniv Mayer, DMD[1,2*]
Ofir Ginesin, DMD, MSc[1]
Daniel Rotenberg, DMD[1]
Liron Kabakov, DMD, MSc[1]
Eran Gabay, DMD, PhD[1,2]
Jacob Horwitz, DMD[1,2]
Zvi Gutmacher, DMD[2,3]
Hadar Zigdon Giladi, DMD, PhD[1,2]

Titanium dental implants, traditionally used for tooth replacement, face certain biological and esthetic limitations. Recently, zirconia has become a notable alternative, valued for its esthetics and biocompatibility. This study evaluated the efficacy of 2-piece zirconia dental implants, particularly their impact on inflammatory cytokines and their survival rate over 1 year. This study was a single-center, prospective trial and included adults aged 18 and above. From 2021 to 2022, 9 2-piece, tissue-level zirconia implants were placed in 8 patients. Following a 3-month osseointegration phase, crowns were cemented. Over a year, we assessed plaque and gingival indices, pocket depth, and tissue color and texture. Peri-apical radiographs measured bone levels, and IL-1β in peri-implant crevicular fluid was quantified using the enzyme-linked immunosorbent assay. Eight subjects (ages 31–63) participated. One implant failed after 6 months, resulting in a 1-year survival rate of 88.8%. Plaque and gingival indices rose, but peri-implant soft tissue remained stable in color and texture. At 12 months, average bone loss was minimal and insignificant compared with the baseline, and IL-1β levels were similar to those at contralateral teeth with no correlation between IL-1β, pocket depth, and bleeding on probing. Two-piece zirconia implants emerged as a viable tooth replacement option with an 88.8% 1-year survival rate. They maintained stable soft tissue and bone levels, indicating their potential as effective dental restoratives.

Key Words: zirconia implant, 2-piece zirconia, bone loss, cytokine

INTRODUCTION

For more than 40 years, titanium has been the primary material used in implant dentistry.[1] However, the search for alternatives has been spurred by esthetic concerns and the possibility of an allergic hypersensitivity reaction. The reflection of titanium through the mucosa may cause esthetic problems, mainly when thin mucosal phenotypes are present.[2] Furthermore, at least among Europeans, there is a growing demand for metal-free alternatives.[3]

Ceramic implants, especially those made of zirconia, address these concerns, offering esthetic appeal and commendable mechanical properties.[4,5] In recent years, ceramic materials have emerged as a promising alternative to traditional titanium in the fabrication of endosseous dental implants. Specifically, yttria-stabilized tetragonal zirconia polycrystal (YTZP), commonly called zirconia, has gained prominence due to its remarkable mechanical stability.[6,7] This stability is attributed to zirconia's unique ability to mitigate crack propagation by converting individual crystallites into a thermally stable allotrope, resulting in enhanced bending strength and fracture toughness. Coupled with its resistance to wear, chemical inertness, high biocompatibility, and reduced bacterial colonization, zirconia stands out as an optimal material for dental implants.[8,9]

Most recorded results concerning zirconia implants pertain to single-piece designs, primarily due to the complexities involved in integrating a screw-type connection with zirconia elements at the junction of the abutment and implant and the reduction of bone loss by eliminating the implant–abutment microgap and associated micromovements. However, single-piece implants are only helpful in situations in which immediate loading is possible, and their prosthetic adaptability is restricted.[8,10] The advent of 2-piece zirconia implants has shown encouraging results in both clinical studies and real-world applications.[11,12] Notably, the manufacturing landscape for zirconia implants is evolving

[1] Department of Periodontology, School of Graduate Dentistry, Rambam Health Care Campus, Haifa, Israel.
[2] Faculty of Medicine, Technion–Israel Institute of Technology, Haifa, Israel.
[3] Department of Prosthodontics, School of Graduate Dentistry, Rambam Health Care Campus, Haifa, Israel.
* *Corresponding author,* e-mail: yaniv.mayer@technion.ac.il
https://doi.org/10.1563/aaid-joi-D-24-00027

with ceramic injection molding offering a cost-effective method for mass production. This technique capitalizes on the implant's simultaneous molding and surface engineering, streamlining the production process.[13]

The decision to opt for 1- or 2-piece zirconia implants depends on individual cases as neither method has proven superior to the other.[14] Therefore, the absence of clinical trials examining 2-piece zirconia implants highlights the need for further research. Consequently, this study examines the performance of 2-piece zirconia implants over a year, focusing on understanding their survival rate and related tissue parameters. The research hypothesis, informed by existing literature, posits that the survival rate of zirconia implants is comparable to that of titanium implants with an estimated survival probability of around 95%. Consequently, we anticipate that the performance and longevity of zirconia implants will align with that of titanium implants, which have been used for the past 40 years.

Materials and Methods

Study design and patients

A prospective pilot trial was conducted at a single center within Department of periodontology, School of graduate dentistry, Rambam Health care Campus. The study was approved by the [redacted for peer review] ethics committee (RMB-0382-19) and registered at ClinicalTrials.gov (identifier NCT05105113). This study meets the current World Medical Association Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects. An independent statistician reviewed and approved the study design.

Participants were sequentially enrolled if they (1) were at least 18 years of age and provided written consent before treatment; (2) had a horizontal bone width of a minimum of 6 mm and (3) implant stability above 35 N during insertion; and (4) committed to adhering to the outlined schedule for clinical, radiographic follow-ups and maintenance visits.

Individuals were disqualified from the study if they met any of the following conditions: (1) smoked more than 10 cigarettes daily; (2) exhibited active periodontal disease evidenced by probing depths exceeding 5 mm, bleeding upon probing (BOP), or suppuration; (3) were noncompliant or did not provide consent; (4) had systemic contraindications to implant procedures, such as immunodeficiency or severe systemic diseases, or were on medications such as corticosteroids or bisphosphonates; (5) were pregnant; (6) had undergone radiation therapy in the head or neck region; (7) required bone or soft-tissue augmentation; or (8) exhibited parafunctional habits.

Implants and surgery

Between 2021 and 2022, a single surgeon (HZG) placed 9 2-piece tissue levels of YTZP implants (TAV Dental, Ltd.) (Figure 1) in 8 patients. All implants had a diameter of 4.1 mm and a length of 10 or 12 mm. Before surgery, patients were administered preoperative antibiotics, either 2 g of amoxicillin or 600 mg of clindamycin. Once the flaps had been raised, drilling was carried out per the manufacturer's guidelines using all available drill diameters, followed by implant insertion. The implants were placed about 1.8 mm supracrystally (tissue-level implants), and healing abutments were placed. Postoperative instructions included antibiotics (amoxicillin 1500 mg per day or clindamycin 600 mg per day for 1 week), analgesics, and rinsing twice daily with chlorhexidine 0.2%. Sutures were removed after 1 week.

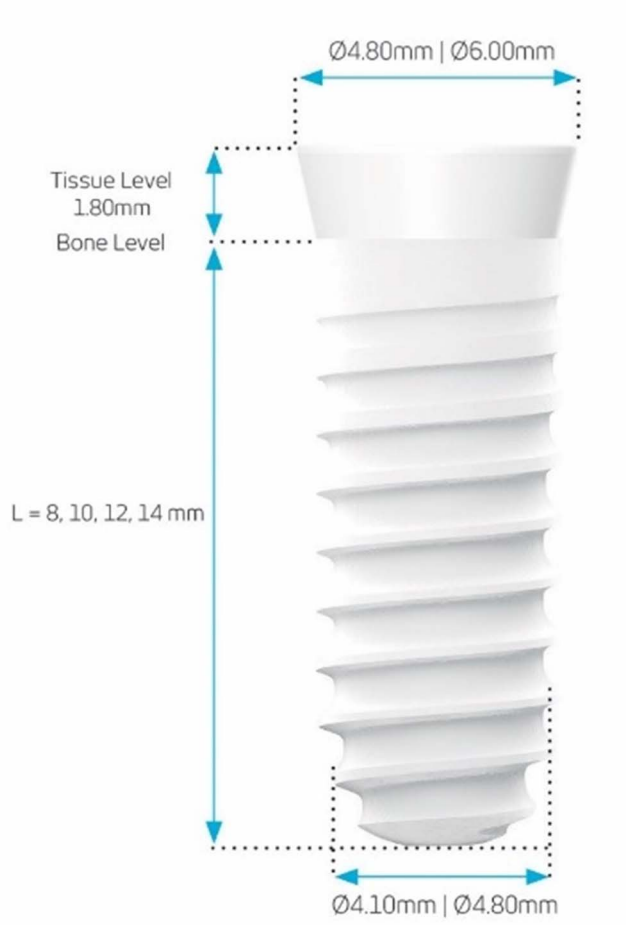

Figure 1. Schematic illustration of the 2-piece, tissue-level zirconia implant, highlighting the main components of the ceramic implant.

Restoration

Following a 3-month osseointegration period for both the upper and lower jaws, conventional impressions were taken using polyether (Impregum NF, 3M ESPE, Seefeld, Germany). Based on these impressions, dental molds were created and then scanned. Utilizing this scanned information, all-ceramic crowns were designed and fabricated from lithium disilicate (IPS e.max CAD blocks, Ivoclar Vivadent) using the Cerec AC system from Sirona (Figure 2).

Clinical evaluation

Plaque accumulation and mucosal inflammation parameters were measured by the same calibrated examiner (DR) at 3 time points—3, 6, and 12 months—and included the following:

- Plaque index, according to Sillness and Löe (1964), is measured on the buccal and lingual surfaces. The scoring ranges from 0 (no plaque) to 3 (heavy plaque accumulation).

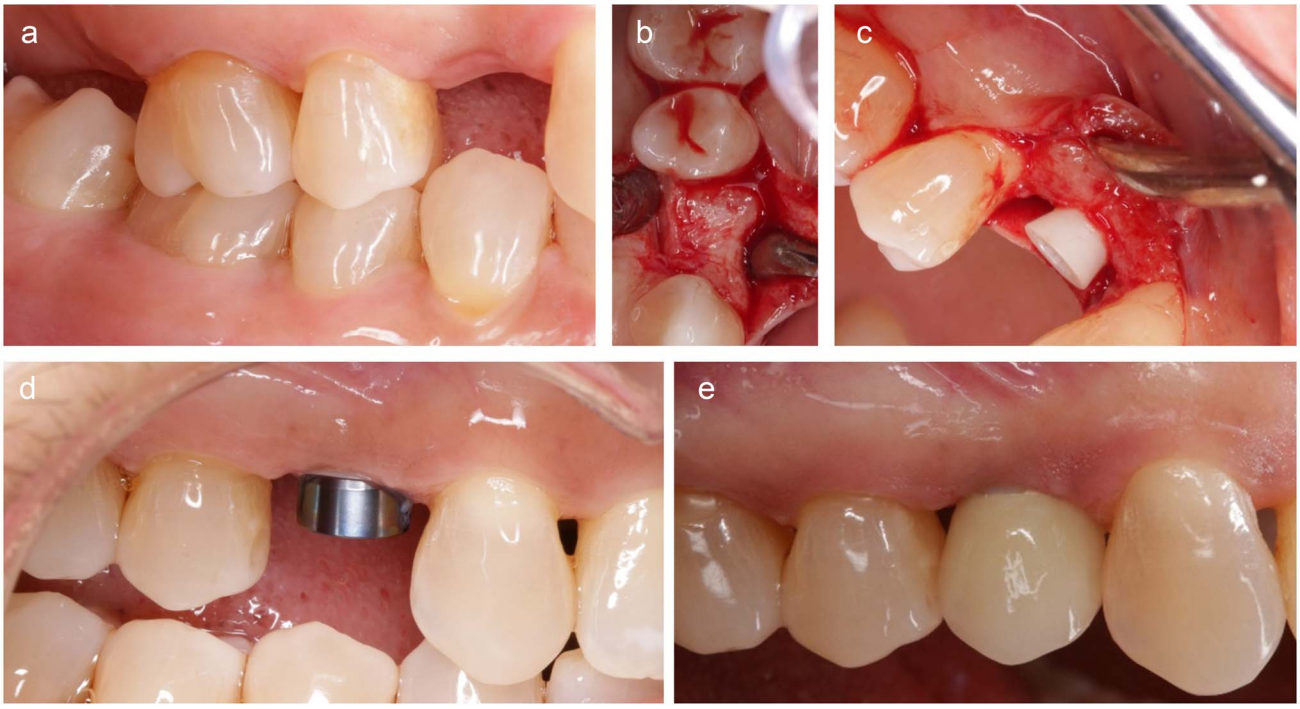

Figure 2. (a) Pretreatment. (b) Ridge after flap elevation. (c) Implant placement 1.8 mm above bone level. (d) Three months postimplantation. (e) Final restoration 1-year follow-up.

- Gingival index, according to Löe and Stillness (1963), is measured on the buccal and lingual surfaces. Scoring ranges between 0 (absence of inflammation) and 3 (severe inflammation: marked redness, hypertrophy, and tendency toward spontaneous bleeding).

Other clinical parameters were recorded by the same examiner (DR) after 3 and 12 months:

- Peri-implant pocket depth (PD) was measured from the mucosal margin to the bottom of the probable pocket using a graduated manual periodontal probe (PCP-UNC 15, Hu-Friedy, Chicago, IL). Four sites per implant were evaluated (mesiobuccal, midbuccal, distobuccal, and midlingual).
- BOP in 4 sites (mesiobuccal, midbuccal, distobuccal, and midlingual) was evaluated dichotomously with either the presence or absence of bleeding within 30 seconds following probing.
- Recession depth was measured from the implant–abutment interface to the mucosal margin at the midbuccal aspect using a graduated manual periodontal probe (PCP-UNC 15, Hu-Friedy). In cases with a mucosal margin coronal to the implant shoulder, it was considered to be 0.
- Soft tissue color and soft tissue texture were based on the pink esthetic score, according to Fürhauser (2005), to assess the soft tissue esthetics around the dental implants (0 = clear difference, 1 = slight difference, 2 = no difference).

Radiographic evaluation

Peri-apical X rays were captured using the Planmeca Intra X-ray unit with an intraoral sensor set at 63 kV, 8 mA, and 0.064 s, combined with the XCP-DS FIT Universal Sensor Biteblock (Dentsply, Lancaster, PA). The implant's width served as a calibration reference for the radiographs. The bone level was measured as the distance from the top edge of the implant to the first point of bone contact on both the mesial and distal sides of the implant with 1.8 mm being deducted from this measurement. This was achieved using the Planmeca Romexis image analysis software (version 3.8.1.R, Planmeca OY, Helsinki, Finland). All radiographic evaluations were conducted twice by a single examiner (JH), who was calibrated. Measurements were performed immediately after implant insertion, after 3 months (before implant loading), and at 12 months.

Two repeated evaluations were performed to assess the consistency of the observer's measurements. The discrepancies between these measurements were analyzed using point estimates and a 95% confidence interval. The outcomes for the radiographic evaluations were as follows: mesial side difference of $d = 0.11$ mm (95% CI 0.033–0.18), $P = .006$, and distal side difference of $d =$ -0.004 mm (95% CI -0.083–0.075), $P = .914$.

IL-1 β sampling and assay

Peri-implant crevicular fluid (PICF) and gingival crevicular fluid (GCF) samples were collected from implants and contralateral teeth 12 months after implant placement. First, supragingival plaque was carefully removed using currets, after which the sample sites were isolated with cotton rolls. Four absorbent paper points no. 25 (Meta Biomed 270, Republic of Korea) were inserted into the base of the pocket around the implant and contralateral tooth for 30 seconds. Samples were wrapped in aluminum foil and stored at -20°C. Every sample was concealed before the laboratory test.

Table 1

Demographic data

	Total
Number of patients	8
Number of implants	9
Age, mean ± SD	40.8 ± 10.7
Gender	
Female (%)	6 (75)
Male (%)	2 (25)
Smokers ≤ 10 cigarettes/day (%)	2 (25)
Implant position	
Maxilla (%)	7 (75)
Mandible (%)	2 (25)

The total IL-1β level in PICF was determined using a quantitative sandwich enzyme-linked immunosorbent assay (ELISA) kit (Human IL-1 beta/IL-1F2 Quantikine ELISA Kit DLB50 human Il-1b, biotechne, R&D Systems Inc., Minneapolis, MN) as described previously by Mayer et al.[15] Briefly, filter papers were unwrapped and inserted into a sterile test tube containing 1.0 mL distilled water. The tubes were left to stand at room temperature for 30 minutes and then agitated every 5 minutes to facilitate extraction of the sample from the filter paper. A monoclonal antibody specific for IL-1β was precoated on a microplate. Standards and samples were pipetted into the wells, and the immobilized antibody bound the cytokine. After washing away any unbound substances, an enzyme-linked polyclonal antibody specific for IL-1β was added to the wells. The absorbance values were determined by using an ELISA reader at 450 nm. A standard curve was constructed using standards provided in the kit, and the cytokine concentration was calculated from this standard curve. The color intensity results were obtained using a microplate reader.[12]

Statistical analysis

The study analyses were performed by independent statisticians using SPSS software version 25.0. Microsoft Excel (Microsoft Corporation) was used for data collection. Descriptive variables were presented with mean and standard deviation. Intragroup comparisons were performed over time using a Wilcoxon signed-rank test. Differences were considered significant at $p < .05$.

Results

Eight subjects (6 females and 2 males) were recruited for this pilot study. The demographic data is shown in Table 1. The age of the participants ranged from 31 to 63 years with a mean of 40.8 ± 10.7 years. Two participants were current smokers (<10 cigarettes per day). Nine implants were included in the study, 2 in the mandible and 7 in the maxilla.

One implant failed 6 months after restoration. This implant was placed in the second mandibular molar. The patient arrived at the clinic with symptoms of a peri-implant abscess. The implant was mobile, and peri-implant bone loss was observed. The implant was removed from the jaw.

The clinical parameters are described in Table 2. The plaque index and gingival index were less than 1 for all the observatory times, and the mean pocket depth was 3.18 ± 1.28 mm at the 1-year follow-up. Soft tissue color and texture were 1.85 ± 0.38 and 1.88 ± 0.35 after 12 months with a nonsignificant change compared with 3 months.

Table 2

Clinical measurements at baseline, 3 months, and 12 months

Variable	Time point (months)*	Mean (SD)	N†	*p*-value
Plaque index	1	0.36 (0.51)	8	
	3	0 (0)	8	
	12	0.43 (0.53)	7	
	T1–T3	0.375 (0.52)	8	.284
	T1–T12	0 (0.58)	7	>.9999
	T3–T12	−0.43 (0.53)	7	.195
Gingival index	1	0.5 (0.53)	8	
	3	0 (0)	8	
	12	1 (0.82)	7	
	T1–T3	0.5 (0.53)	8	.2198
	T1–T12	−0.428 (0.97)	7	.7316
	T3–T12	−1 (0.82)	7	**.0113**
Pocket depth	T12	3.18 (1.28)	7	
BOP	T12	0.17 (0.39)	7	
Soft tissue color	T3	2 (0)	8	
	T12	1.85 (0.38)	7	
	T3–T12	0.14 (0.38)		.5567
Soft tissue texture	T3	1.88 (0.35)	8	
	T12	1.71 (0.48)	7	
	T3–T12	0.14 (0.38)		>.9999

*T1 = baseline, T3 = 3 months, T12 = 12 months.
†N indicates number of participants.

Figure 3 demonstrates radiographic marginal bone level changes in the mesial and distal aspects. The zirconia implants were associated with a mesial mean bone loss of 0.65 mm (SD: 0.37) after 3 months and 0.91 mm (SD: 0.59) after 12 months. On the distal side, the values were 0.59 mm (SD: 0.37) after 3 months and 0.87 mm (SD: 0.4) after 12 months.

IL-1β was examined in the PICF and GCF of the contralateral tooth at 12 months. Results showed an average level of 24.86 pg/ml of IL-1β in the PICF and 22.68 pg/ml in the GCF. The difference between the sites was not statistically significant ($p > .05$) (Figure 4).

Discussion

In this prospective pilot cohort study, we scrutinized the performance of 2-piece zirconia implants, primarily in the context of

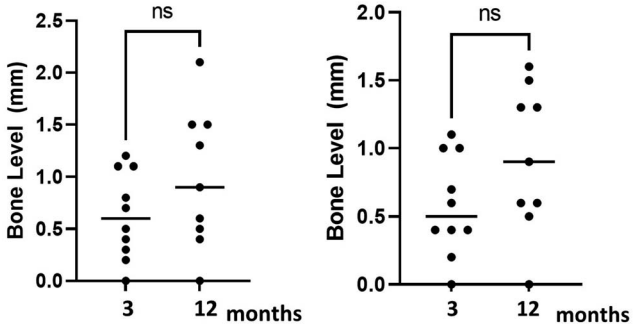

Figure 3. Radiographic mean bone level after 3 and 12 months on the mesial (left) and distal (right) aspects.

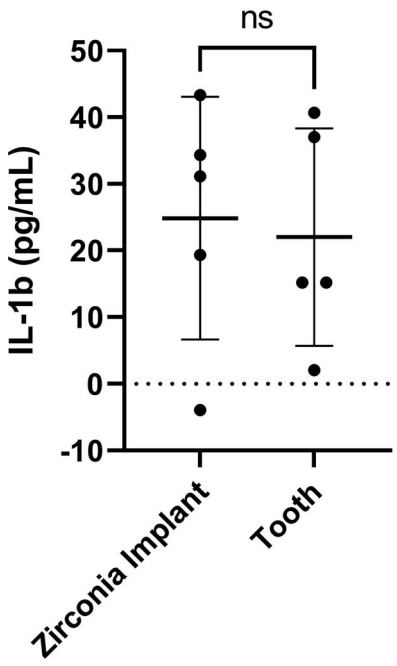

Figure 4. IL-1β levels in peri-implant crevicular fluid and gingival crevicular fluid samples from implants and contralateral teeth.

replacing individual missing teeth. A year postimplantation, the observed survival rate was 88.8%. This rate, especially after 1 year, is marginally lower than those reported in certain existing studies comparing ceramic and titanium implants.[13,14] The overall documented survival rates for zirconia implants, considering both types (1- and 2-piece), fluctuate between 87% and 95%. Considering a year of functional use, the average survival rate is 92%.[11,13,16,17]

Comparatively, a recent retrospective analysis highlights that zirconia endosseous implants potentially match titanium implants in terms of survival rate while preserving the health of soft and hard tissues alike.[18,19] Specifically, Brull et al[20] examined 121 zirconia implants (66 2-piece and 55 1-piece) placed in 74 subjects. After an average monitoring span of 18 months, they reported a robust implant survival rate of 96.5%. This aligns with the findings from the Cionca et al[12] prospective study on 32 patients, in which they documented a cumulative survival rate of 87% after 1 year of loading with all failures attributed to aseptic loosening, which is a process of bone resorption due to a noninfectious cause. Variations in connection systems, implant designs, and implant manufacturing processes may cause discrepancies across the studies. The current study's sample size is extremely small: just 1 implant failure out of 9.

Our investigation included a critical measurement of bone loss on both the mesial and distal sides. More than 1 year after implant surgery, we observed a distal bone recession averaging 0.87 ± 0.4 mm. The mesial side exhibited a slightly more pronounced decrease, averaging 0.91 ± 0.59 mm. For context, a systematic review and meta-analysis by Elnayef et al[4] documented an average marginal bone loss of 1.46 ± 9.57 mm associated with 2-piece zirconia implants. Correspondingly, Borges et al[21] reported in their systematic review that marginal bone remodeling around zirconia implants resulted in average losses of 0.8 mm (95% CI: 0.60 to 1.00 mm) and 1.01 mm (95% CI: 0.72 to 1.29 mm) at 1 and 2 years after loading, respectively.

It is essential to notice that, according to several previous studies that examined tissue-level titanium implants, the average marginal bone loss during the first year was 0.2–0.61 mm, which is less than the results in our study.[22–25] Bone loss is generally found to be lower in 1-piece implants compared with 2-piece implants.[26,27] A systematic review comparing 1- and 2-piece titanium implants found no significant differences in marginal bone loss between the 2 options.[28]

Interleukin-1's role is paramount in the sphere of immune-inflammatory responses, essentially ensuring the maintenance of periodontal equilibrium. Elevated levels of the inflammatory cytokine interleukin-1 (IL-1) in the crevicular fluid around diseased implants play an important role in the pathogenesis and severity of peri-implantitis.[29] Over the years, myriad research undertakings have delved deep into understanding the intricate relationship between prevalent polymorphisms of IL-1 (specifically IL-1A and IL-1B) genes and the heightened risk factors associated with peri-implant ailments and implant failures. However, the verdict remains clouded with ambiguity. Notably, in the existing corpus of research, an endeavor had yet to be made to decipher the potential link between IL-1 and zirconia implants.[30] A previous study that examined 130 titanium implants found significantly higher levels of IL-1β in patients with peri-implant diseases such as mucositis (325.89 ± 235.17 pg/mL) and peri-implantitis (439.89 ± 182.67 pg/mL) compared with healthy implants (67.51 ± 62.9 pg/m).[31]

A focal point of our research revolved around analyzing the concentration of IL-1β levels in PICF and GCF samples extracted from the implants and control teeth. Surprisingly, the data amassed in the subsequent 12 months did not indicate any momentous deviations. Further, the ELISA results failed to draw any parallels with PD and BOP measurements. A similar absence of correlation was also evident between the marginal bone loss recorded during the subsequent monitoring phase and the 12-month ELISA results.

A notable limitation of this study is the small number of implants included in our analysis. This constraint might influence the perceived survival rates and serves as a primary restriction on the breadth of our research. Another challenge is the relatively short observation period. Unfortunately, long-term research in this field is still emerging with most studies chiefly centered on the 1-piece zirconia implant designs.[12,31,32]

During the research, we did not encounter any noticeable prosthetic complications. A common issue with zirconia implants is that the connecting parts can break. However, the 2-piece design usually makes it easy to swap out any broken parts.[14]

In summary, zirconia dental implants demonstrated minimal bone loss 1 year following their placement (0.6–0.9 mm) with a single implant failing to osseointegrate. However, given the limited sample size, this translates to an 88% survival rate at the 1-year mark.

Conclusion

The findings suggest that 2-piece ceramic implants may yield positive clinical results during the follow-up period. Their survival

rates and bone loss metrics are on par with titanium and other ceramic implants. These implants may provide a viable and practical choice for individuals looking for metal-free options, especially those who prefer to avoid metal in their treatments. Extended studies encompassing various edentulous morphologies are required to validate the current data.

Note

The study was approved by the Rambam Health Care Campus Ethics Committee (RMB-0382-19) and registered at ClinicalTrials.gov (identifier NCT05105113). The study was supported by TAV Dental Company, Ltd. Informed consent was obtained from all subjects involved in the study. The authors declare no conflict of interest. Author contributions are as follows: validation—Y.M. and E.M.; data curation—Y.M. and O.G.; writing original draft—Y.M. and L.K.; visualization—Y.M. and E.G.; software—O.G. and J.H.; investigation—D.R., J.H., and Z.G.; methodology—Z.G.; resource—H.Z.G.; conceptualization—H.Z.G.; supervision—H.Z.G.; writing, review, and editing—H.Z.G.

References

1. Adell R, Lekholm U, Rockler B, Branemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg*. 1981;10:387–416.

2. Jung RE, Sailer I, Hämmerle CH, Attin T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. *Int J Periodontics Restorative Dent*. 2007;27:251–257.

3. Cionca N, Hashim D, Mombelli A. Zirconia dental implants: where are we now, and where are we heading? *Periodontology 2000*. 2017;73:241–258.

4. Elnayef B, Lazaro A, Suarez-Lopez Del Amo F, et al. Zirconia implants as an alternative to titanium: a systematic review and meta-analysis. *Int J Oral Maxillofac Implants*. 2017;32:e125–e134.

5. Noronha Oliveira M, Schunemann WVH, Mathew MT et al. Can degradation products released from dental implants affect peri-implant tissues? *J Periodontal Res*. 2018;53:1–11.

6. Kohal R-J, Finke HC, Klaus G. Stability of prototype two-piece zirconia and titanium implants after artificial aging: an in vitro pilot study. *Clin Implant Dent Relat Res*. 2009;11:323–329.

7. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. *Biomaterials*. 1999;20:1–25.

8. Tschernitschek H, Borchers L, Geurtsen W. Nonalloyed titanium as a bioinert metal—a review. *Quintessence Int*. 2005;36:523–530.

9. Apratim A, Eachempati P, Krishnappa Salian KK, Singh V, Chhabra S, Shah S. Zirconia in dental implantology: a review. *J Int Soc Prev Community Dent*. 2015;5:147–156.

10. Payer M, Arnetzl V, Kirmeier R, Koller M, Arnetzl G, Jakse N. Immediate provisional restoration of single-piece zirconia implants: a prospective case series—results after 24 months of clinical function. *Clin Oral Implants Res*. 2013;24:569–575.

11. Koller M, Steyer E, Theisen K, Stagnell S, Jakse N, Payer M. Two-piece zirconia versus titanium implants after 80 months: clinical outcomes from a prospective randomized pilot trial. *Clin Oral Implants Res*. 2020;31:388–396.

12. Cionca N, Müller N, Mombelli A. Two-piece zirconia implants supporting all-ceramic crowns: a prospective clinical study. *Clin Oral Implants Res*. 2015;26:413–418.

13. Formas K, Kurowska A, Janusz J, Szczygieł P, Rajzer I. Injection molding process simulation of polycaprolactone sticks for further 3D printing of medical implants. *Materials* 15:7295.

14. Rodriguez AE, Monzavi M, Yokoyama CL, Nowzari H. Zirconia dental implants: a clinical and radiographic evaluation. *J Esthet Restor Dent*. 2018;30:538–544.

15. Mayer Y, Balbir-Gurman A, Machtei EE. Anti-tumor necrosis factor-alpha therapy and periodontal parameters in patients with rheumatoid arthritis. *J Periodontol*. 2009;80:1414–1420.

16. Hashim D, Cionca N, Courvoisier DS, Mombelli A. A systematic review of the clinical survival of zirconia implants. *Clin Oral Investig*. 2016;20:1403–1417.

17. Becker J, John G, Becker K, Mainusch S, Diedrich, G, Schwarz F. Clinical performance of two-piece zirconia implants in the posterior mandible and maxilla: a prospective cohort study over 2 years. *Clin. Oral Implants Res*. 2017;28:29–35.

18. Payer M, Heschl A, Koller M, Arnetzl G, Lorenzoni M, Jakse N. All-ceramic restoration of zirconia two-piece implants—a randomized controlled clinical trial. *Clin. Oral Implants Res*. 2015;26:371–376.

19. Roehling S, Schlegel KA, Woelfler H, Gahlert M. Zirconia compared to titanium dental implants in preclinical studies—a systematic review and meta-analysis. *Clin Oral Implants Res*. 2019;30:365–395.

20. Brüll F, van Winkelhoff AJ, Cune MS. Zirconia dental implants: a clinical, radiographic, and microbiologic evaluation up to 3 years. *Int J Oral Maxillofac Implants*. 2014;29:914–920.

21. Borges H, Correia ARM, Castilho RM, de Oliveira Fernandes GV. Zirconia implants and marginal bone loss: a systematic review and meta-analysis of clinical studies. *Int J Oral Maxillofac Implants*. 2020;35:707–720.

22. Taheri M, Akbari S, Shamshiri AR, Shayesteh YS. Marginal bone loss around bone-level and tissue-level implants: a systematic review and meta-analysis. *Ann Anat*. 2020;231:151525.

23. Fernández-Formoso N, Rilo B, Mora MJ, Martínez-Silva I, Díaz-Afonso AM. Radiographic evaluation of marginal bone maintenance around tissue level implant and bone level implant: a randomised controlled trial. A 1-year follow-up. *J Oral Rehabil*. 2012;39:830–837.

24. Kumar VV, Sagheb K, Kämmerer PW, Al-Nawas B, Wagner W. Retrospective clinical study of marginal bone level changes with two different screw-implant types: comparison between tissue level (TE) and bone level (BL) implant. *J Maxillofac Oral Surg*. 2014;13:259–266.

25. van Eekeren P, Tahmaseb A, Wismeijer D. Crestal bone changes in macrogeometrically similar implants with the implant-abutment connection at the crestal bone level or 2.5 mm above: a prospective randomized clinical trial. *Clin. Oral Implants Res*. 2016;27:1479–1484.

26. Balmer M, Spies BC, Kohal RJ, Hämmerle CH, Vach K, Jung RE. Zirconia implants restored with single crowns or fixed dental prostheses: 5-year results of a prospective cohort investigation. *Clin. Oral Implants Res*. 2020;31:452–462.

27. Kohal RJ, Spies BC, Vach K, Balmer M, Pieralli S. A prospective clinical cohort investigation on zirconia implants: 5-year results. *J Clin Med*. 2020;9:2585.

28. de Oliveira Limírio JPJ, Lemos CAA, de Luna Gomes JM, Minatel L, Alves Rezende MCR, Pellizzer EP. A clinical comparison of 1-piece versus 2-piece implants: a systematic review and meta-analysis. *Prosthet Dent*. 2020;124:439–445.

29. Berglundh T, Armitage G, Araujo MG, et al. Peri-implant diseases and conditions: consensus report of workgroup 4 of the 2017 world workshop on the classification of periodontal and peri-implant diseases and conditions. *J Clin Periodontol*. 2018;45:S286–S291.

30. Andreiotelli M, Koutayas SO, Madianos PN, Strub JR. Relationship between interleukin-1 genotype and peri-implantitis: a literature review. *Quintessence Int*. 2008;39:289298.

31. Casado PL, Canullo L, de Almeida Filardy A, Granjeiro JM, Barboza EP, Leite Duarte ME. Interleukins 1β and 10 expressions in the periimplant crevicular fluid from patients with untreated periimplant disease. *Implant Dent*. 2013;22:143–150.

32. Mohammadi H, Roochi MM, Sadeghi M, et al. Association between interleukin-1 polymorphisms and susceptibility to dental peri-implant disease: a meta-analysis. *Pathogens*. 2021;10:1600.