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Long-Term Clinical and Radiographic Outcomes of Ceramic Dental Implants: An 11-Year Retrospective Cohort Study

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ABSTRACT

Objective: Evidence on zirconia dental implants remains limited. This retrospective study evaluated clinical and radiographic outcomes of contemporary ceramic implant systems placed in private practice with variable follow-up of up to 11 years.

Materials and Methods: This retrospective cohort evaluation included 174 patients receiving 275 zirconia implants (one-piece systems and a two-piece tissue-level screw-retained system) placed between 2013 and 2025 with a minimum one-year follow-up. Implant survival and success rates were assessed. Standardized periapical radiographs were analyzed using ImageJ to measure marginal bone levels at placement and annually thereafter. Peri-implant soft tissue health was evaluated using the modified Plaque Index and modified Gingival Index.

Results: Kaplan–Meier cumulative implant survival was 97.6%, and overall success was 95.3%. Mean first-year marginal bone loss ranged from 0.25 to 0.74 mm, with a pooled mean of 0.49 mm. Mean annual bone loss after year 1 was low at 0.12 mm/year. Soft tissue indices remained low, and no suppuration was observed. Two implant fractures occurred (0.73%); remaining failures were associated with lack of osseointegration or aseptic loosening.

Conclusions: Within the limitations of this retrospective study, contemporary ceramic implant systems demonstrated high survival and success with stable peri-implant bone levels and favorable soft tissue conditions.

Clinical Significance: This study provides real-world clinical and radiographic data on contemporary ceramic implant systems, including one-piece ceramic implants and ATZ two-piece ceramic implants with carbon fiber screws. These findings may help clinicians contextualize the observed performance of ceramic implants in daily practice. Ceramic implants may represent a viable metal-free treatment option for appropriately selected patients, particularly in esthetically demanding situations, when careful case selection, system-specific training, and adherence to surgical and restorative protocols are applied.

1 | Introduction

Ceramic dental implants, predominantly yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) and alumina-toughened zirconia (ATZ), have been introduced as metal-free alternatives to titanium implants, driven by esthetic demands in sites with thin peri-implant mucosa and by patient preference for metal-free rehabilitation [1, 2].

Preclinical evidence indicates that zirconia and titanium implants show broadly comparable hard- and soft-tissue integration capacity, although titanium may demonstrate faster early osseointegration in some models [3, 4].

Consistent with this, clinical evidence syntheses suggest that zirconia implants can achieve survival and marginal bone level outcomes comparable to titanium, while highlighting the need for well-designed long-term comparative studies [5, 6].

Beyond osseointegration, biologic response at the transmucosal interface remains clinically relevant. Studies evaluating peri-implant or peri-abutment biomarkers have reported material-associated differences in inflammatory mediator profiles, supporting the concept that zirconia may present a distinct peri-implant immunoinflammatory response compared with titanium under certain conditions [7].

In parallel, microbial adhesion and early biofilm formation have been widely investigated. Although results vary by surface topography and experimental model, multiple studies and reviews indicate that zirconia surfaces may exhibit equal or reduced bacterial/biofilm accumulation compared with titanium, which could be relevant for peri-implant soft tissue stability [8–10].

The zirconia materials most commonly used for implant manufacturing are Y-TZP and ATZ, selected to improve fracture resistance and reduce low-temperature degradation compared with earlier zirconia generations [11–14]. Over the past decade, ceramic implant systems have evolved from predominantly one-piece (monotype) designs toward broader availability of two-piece configurations, including screw-retained restorative concepts intended to increase prosthetic flexibility [5, 15]. However, reported outcomes vary across systems and are influenced by implant design, surface characteristics, restorative protocol (cemented vs. screw-retained), and surgical/restorative experience, making direct comparisons challenging [5, 6, 15].

Recent clinical outcomes for one-piece zirconia implants are supported by prospective cohort data, including 5-year survival in the range of approximately 95%–98% with modest marginal bone changes in appropriately selected cases [16, 17]. For two-piece zirconia implants, particularly screw-retained concepts, longer follow-up data are comparatively limited and published results are heterogeneous [18–20].

Available clinical literature suggests that peri-implant soft tissue parameters around zirconia implants can remain stable over time in successfully integrated implants, although the overall evidence base – especially for newer two-piece screw-retained systems – remains smaller than for titanium [5, 6, 18, 20]. Accordingly, long-term private-practice data that include different commercially available ceramic implant systems and restorative concepts are valuable to inform real-world performance. This retrospective observational cohort study aimed to evaluate five ceramic implant systems, including one-piece and two-piece screw-retained designs, placed in a private practice setting between 2013 and 2025. The study assessed implant survival and success, radiographic marginal bone level changes, and peri-implant soft tissue health.

1.1 | Primary Objective

To evaluate the survival and success of 275 ceramic dental implants placed in 174 patients with follow-up of up to 11 years.

1.2 | Secondary Objectives

1. To quantify radiographic marginal bone level changes over time.
2. To assess peri-implant soft tissue parameters, including plaque index, gingival index, gingival inflammation, and suppuration:

2 | Materials and Methods

2.1 | Study Design

This retrospective observational cohort study evaluated the clinical and radiographic outcomes of zirconia-based ceramic dental implants placed in three private periodontal practices. A total of 275 ceramic implants were placed in 174 patients between 2013 and 2025 using five commercially available ceramic implant systems: CeraRoot, SDS, Straumann PURE, Zeramex XT, and Z-Systems. All implant systems remain commercially available except Straumann PURE, which was discontinued in 2024.

All implant systems were one-piece designs except Zeramex XT, a two-piece tissue-level, screw-retained ceramic implant system using a carbon-fiber-reinforced polymer abutment screw.

The maximum follow-up differed by system: CeraRoot (up to 11 years), Z-Systems (up to 10 years), Zeramex XT (up to 7 years), Straumann PURE (up to 7 years), and SDS (up to 6 years).

2.2 | Patient Population and Ethics

The mean patient age at implant placement was 57.4 years (range, 26–90 years). The cohort included 97 females and 77 males. Each patient received a detailed explanation of the proposed treatment and provided written informed consent prior to inclusion and data collection. All procedures complied with Health Insurance Portability and Accountability Act regulations. This retrospective study was determined by Sterling IRB to be exempt from IRB review under 45 C.F.R. §46.104(d), Category 4 Exemption (DHHS). A waiver of authorization for access to and use of protected health information was also approved.

A total of 43 patients (24.7%) presented with one or more controlled systemic conditions (Table 1), including autoimmune/inflammatory disease ($n = 27$), cardiovascular/metabolic conditions ($n = 10$), and a history of malignancy ($n = 6$). All systemic diseases were controlled at the time of implant therapy; no patient had active malignancy or uncontrolled autoimmune/inflammatory disease documented.

2.3 | Implant Systems and Distribution

The distribution of implants by system is presented in Table 2. Overall, 159 implants (58%) were placed in the maxilla and 116 (42%) in the mandible.

2.3.1 | Missing Data and Follow-Up Assessment

Clinical and radiographic records were reviewed for all included patients and implants. Surviving implants were required to have a minimum clinical follow-up of 1 year; early failures occurring before prosthetic loading or within the first year were retained in the survival analysis.

Follow-up duration varied, as patients were evaluated at available annual maintenance visits. Each implant contributed clinical and radiographic data up to the last documented recall visit or failure. Implants remaining in situ and functional at the last available follow-up were censored in the Kaplan–Meier survival analysis.

Clinical and radiographic data were complete for the visits included in the analysis. Radiographic analyses were based on available standardized periapical radiographs at baseline and documented annual follow-up visits. Follow-up duration varied among implants; therefore, the number of implants contributing data differed across follow-up intervals, as summarized in Table 6.

TABLE 1 | Patient demographics and systemic health status.

Variable	*n*	%
Total patients	174	—
Female	97	55.7
Male	77	44.3
Without systemic conditions	131	75.2
With ≥ 1 systemic condition	43	24.7
Autoimmune/inflammatory	27	15.5
Cardiovascular/metabolic	10	5.7
Malignancy	6	3.4

Note: Values are presented as number (*n*) and percentage (%) of the total study population ($N = 174$). Patients with multiple systemic conditions may be included in more than 1 category.

TABLE 2 | Implant distribution by system and arch.

System	Total implants	Maxilla	Mandible
CeraRoot	29	20	9
SDS	25	14	11
Straumann PURE	63	34	29
Zeramex XT	83	52	31
Z-Systems	75	39	36
Total	275	159	116

2.4 | Eligibility Criteria

2.4.1 | Inclusion Criteria

Patients were included if they demonstrated a favorable maxillomandibular relationship and received at least 1 ceramic implant between 2013 and 2025. Patients with a minimum clinical follow-up of 1 year after implant placement were included. Early implant failures occurring before prosthetic loading or within the first year were retained in the survival analysis.

2.4.2 | Exclusion Criteria

Patients were excluded if they presented with inadequate oral hygiene, active periodontal disease, uncontrolled systemic diseases affecting bone metabolism (e.g., uncontrolled diabetes, severe osteoporosis), coagulation or leukocytic disorders, smoking > 10 cigarettes/d, or alcohol or drug abuse. Patients with uncontrolled severe parafunctional habits (e.g., severe clenching/bruxism) were excluded. Patients with documented bruxism under clinical management/control (e.g., regular night guard use) were eligible for inclusion.

TABLE 3 | Surgical timing and augmentation procedures.

System	Immediate	Crestal sinus	Lateral sinus	Ridge augmentation	Simultaneous GBR	Delayed (4-month healed)
CeraRoot	1	1	2	0	5	20
SDS	2	2	0	0	4	17
Straumann PURE	16	3	1	4	0	39
Zeramex XT	7	5	8	11	10	42
Z-Systems	1	1	1	0	9	63
Total	27	12	12	15	28	181

2.5 | Surgical Protocol and Timing

Implant placement was performed according to site-specific clinical indications and healing conditions (Table 3). Implants were placed approximately 4 months after extraction with socket grafting, approximately 6 months after lateral sinus augmentation and/or ridge augmentation, or simultaneously with crestal sinus elevation and/or guided bone regeneration (GBR). Platelet-rich fibrin (PRF) was used systematically as an adjunctive therapy in all implant placement and augmentation procedures to enhance wound healing and support tissue regeneration.

All patients receiving one-piece implants were provided an Essix protective appliance during healing until definitive restoration.

Implant placement was performed by two periodontists in three practices. Zeramex XT, Straumann PURE, and Z-Systems implants were placed by (A), whereas CeraRoot and SDS implants were placed by (D).

2.6 | Prosthetic Protocol

One-piece implants were restored with single-unit or multiunit restorations using resin cement (Panavia; Kuraray Noritake Dental Inc., Tokyo, Japan). Two-piece Zeramex implants were restored using screw-retained components according to the manufacturer's workflow.

2.7 | Radiographic Assessment of Marginal Bone Levels

Radiographic marginal bone levels were measured using ImageJ (version 1.51n; National Institutes of Health, Bethesda, Maryland). Measurements were calibrated using the implant thread pitch reported by the manufacturer or the registered implant diameter and length.

Standardized periapical radiographs were obtained with the beam oriented perpendicular to the implant long axis to enable clear visualization of fixture threads. Marginal bone level was measured at the mesial and distal aspects from the implant reference point (implant shoulder/platform) to the first bone-to-implant contact (fBIC). Marginal bone loss was calculated from baseline (implant placement) and at annual follow-up visits.

Outcome variables included the mean marginal bone level change at 1 year after implant placement and the mean annual marginal bone level change thereafter.

All clinical and radiographic measurements were performed independently by a single calibrated examiner (B), who was not involved in the clinical treatment of the patients. The examiner was blinded to the implant system and radiographic time point during image analysis to minimize assessment bias.

Prior to radiographic analysis, the examiner underwent a calibration procedure consisting of repeated measurements on a subset of radiographs not included in the final analysis. To assess intra-examiner reliability, a randomly selected 20% of the radiographs were re-evaluated after a two-week interval under identical conditions. Reliability was assessed using the intraclass correlation coefficient (ICC), which demonstrated excellent intra-examiner agreement (ICC = 0.94; 95% CI: 0.90–0.97). Measurement error was calculated using Dahlberg's formula and was found to be 0.12 mm, indicating low measurement error and high reproducibility of the radiographic measurements.

2.8 | Soft Tissue Assessment

Peri-implant soft tissue parameters were evaluated 4–6 months after implant placement and at the final follow-up visit. Soft tissue health was assessed using the modified Plaque Index (mPI) (Mombelli et al. [21]) and the modified Gingival Index (mGI) (Lobene et al. [22]). Both indices were recorded at 4 aspects per implant (mesial, distal, buccal, and lingual/palatal) using a calibrated periodontal probe. Suppuration was recorded dichotomously as present or absent.

2.9 | Outcome Measures

2.9.1 | Primary Outcomes

1. Cumulative implant survival rate over the observation period for each implant system.
2. Implant success rate for each implant system.

2.9.2 | Survival Definition

An implant was defined as surviving if it remained in situ at the last follow-up with absence of mobility and absence of infection requiring removal. Failures were defined as any implant lost or removed due to biologic or mechanical complications.

2.9.3 | Success Definition

Implant success was assessed according to the clinical criteria described by Buser et al. [23], supplemented by the radiographic marginal bone loss thresholds proposed by Albrektsson et al. [24] and Smith and Zarb [25]. An implant was considered successful if it demonstrated no persistent subjective complaints (pain, dysesthesia, foreign-body sensation), no recurrent peri-implant infection or suppuration, no clinical mobility, and absence of continuous peri-implant radiolucency. In addition, peri-implant marginal bone loss was required to remain within accepted physiologic limits, defined as ≤ 1.5 mm during the first year after implant placement and ≤ 0.2 mm annually thereafter. The first-year threshold was used to account for early peri-implant bone remodeling, whereas the annual threshold after the first year was applied to assess late progressive marginal bone loss.

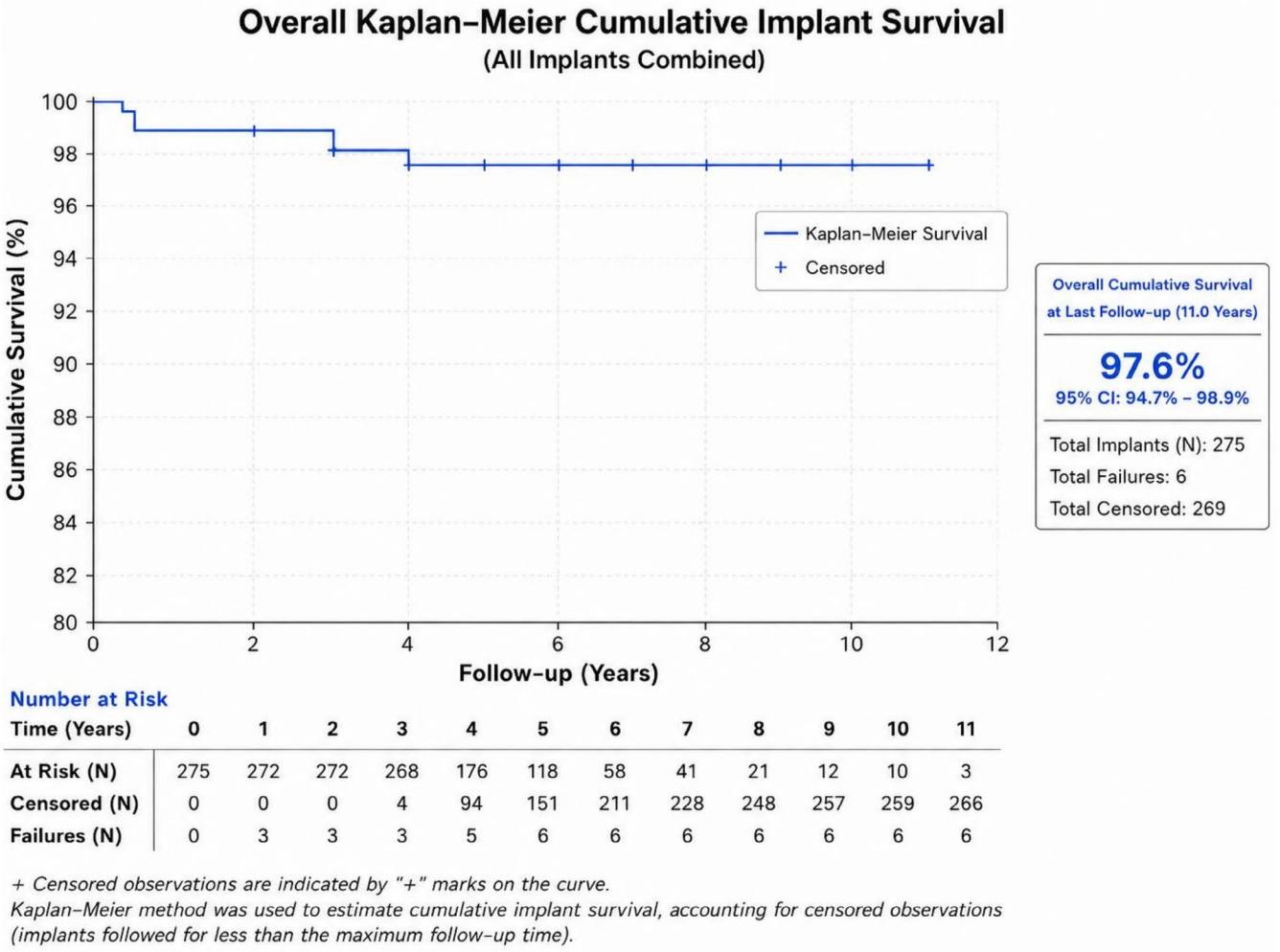

FIGURE 1 | Overall Kaplan–Meier cumulative implant survival curve. Kaplan–Meier cumulative survival curve for the overall implant cohort ($n = 275$). Censored observations are indicated by tick marks. The overall cumulative survival rate was 97.6% during the observation period.

2.9.4 | Secondary Outcomes

1. Mean changes in radiographic marginal bone levels from baseline (implant placement) to the last follow-up visit.
2. Longitudinal trends in soft tissue indices (mPI, mGI) and suppuration frequency.

2.10 | Statistical Analysis

Implant survival was analyzed using the Kaplan–Meier method with IBM SPSS Statistics to account for unequal follow-up durations and censored observations. Implant failure was defined as implant loss or removal during the observation period. Implants remaining functional at the last follow-up visit were treated as censored observations. Cumulative survival probabilities with 95% confidence intervals (CI) were calculated. Owing to substantial heterogeneity in implant design and geometry, no comparative survival analyses were conducted between implant systems.

Follow-up duration was summarized descriptively using mean, median, and range.

All other statistical analyses were descriptive in nature. Continuous variables were summarized using mean, standard deviation, median, and range, while categorical variables were summarized using frequencies and percentages. Implant success rates were calculated descriptively for each implant system. No inferential statistical comparisons between implant systems were performed because of differences in sample size and implant characteristics.

3 | Results

3.1 | Overall Implant Performance

A total of 275 implants were evaluated. Mean follow-up duration for the overall cohort was 4.6 years (median: 4 years; range: 4 months–11 years). Kaplan–Meier analysis demonstrated an overall cumulative implant survival of 97.6% during the observation period, with follow-up extending to 11 years (95% CI: 94.7%–98.9%). Censored observations represented implants that remained functional at their last recorded follow-up and contributed survival data up to that time point. The Kaplan–Meier cumulative survival curve for the overall implant cohort is presented in Figure 1, with censored observations indicated by tick marks.

The overall success rate was 95.3%. System-specific success rates, calculated using the clinical criteria described by Buser et al. [25] and supplemented by the radiographic marginal bone loss thresholds proposed by Albrektsson et al. [24] and Smith and Zarb [25], are presented in Table 4.

Follow-up duration and survival outcomes for each implant system are summarized in Table 5. Detailed follow-up distributions for each implant system are presented in Table 6. Six implant failures occurred during the observation period. All failures were observed in medically healthy patients with no documented systemic disease and no history of periodontitis.

Follow-up duration varied across implant systems and ranged from 4 months to 11 years. The 4- and 6-month observations corresponded to early implant failures that occurred before completion of the first year and were retained in the survival analysis. Among surviving implants, clinical and radiographic data were available through the last documented annual follow-up visit. Implants that remained functional at their last available recall but did not have longer-term follow-up were treated as censored observations in the Kaplan–Meier analysis. No imputation was performed. The number of implants contributing data at each follow-up duration is presented in Table 6.

3.2 | Surgical Timing and Augmentation Procedures

Across all systems, delayed placement following a 4-month socket graft healing period was the most frequent approach (181 implants; 65.8%). Immediate placement was performed in 27 implants (9.8%). Simultaneous GBR accompanied implant placement in 28 implants (10.2%), crestal sinus augmentation in 12 implants (4.4%), and placement following lateral sinus augmentation in 12 implants (4.4%). Ridge-augmented sites accounted for 15 implants (5.5%) (Table 3).

System-specific trends were observed: CeraRoot implants were predominantly placed in delayed, healed grafted sites (~69% delayed); SDS implants showed a similar distribution (~68% delayed) with a higher proportion performed with simultaneous GBR (~16%); Straumann PURE demonstrated the highest proportion of immediate placement (~25%); Zeramex XT implants were frequently associated with augmentation procedures (crestal and lateral sinus elevation, GBR, and ridge augmentation) in addition to delayed placement; and Z-Systems implants were placed predominantly in healed, grafted sites (~84% delayed).

3.3 | Radiographic Marginal Bone Level Changes

3.3.1 | First-Year Marginal Bone Loss

Mean first-year marginal bone loss (MBL) varied by implant system: CeraRoot, 0.57 ± 0.29 mm (range, 0–1.20); SDS, 0.63 ± 0.26 mm (0.30–1.20); Straumann PURE, 0.33 ± 0.23 mm (0–0.80); Zeramex XT, 0.74 ± 0.30 mm (0.20–1.50); and Z-Systems, 0.25 ± 0.44 mm (0–1.40). The pooled weighted mean first-year MBL across systems was 0.49 mm (overall range, 0–1.50 mm) (Table 4).

TABLE 4 | Marginal bone loss, survival, and success.

System (*n*)	First-year MBL, mean ± SD (range), mm	Annual MBL after year 1, mean ± SD (range), mm/y	Kaplan–Meier Survival, %	Success, %
CeraRoot (29)	0.57 ± 0.29 (0–1.20)	0.12 ± 0.06 (0.10–0.30)	96.6	93.1
SDS (25)	0.63 ± 0.26 (0.30–1.20)	0.12 ± 0.05 (0–0.30)	96.0	95.8
Straumann PURE (63)	0.33 ± 0.23 (0–0.80)	0.10 ± 0.06 (0–0.20)	98.4	96.7
Zeramex XT (83)	0.74 ± 0.30 (0.20–1.50)	0.11 ± 0.05 (0–0.30)	98.8	95.1
Z-Systems (75)	0.25 ± 0.44 (0–1.40)	0.14 ± 0.10 (0–0.30)	96.4	94.6

Abbreviation: MBL, marginal bone loss.

TABLE 5 | Follow-up duration and survival outcomes by implant system.

Implant system	Number of implants (*n*)	Mean follow-up (years)	Median follow-up (years)	Range	Failure (*n*)	Kaplan–Meier survival
CeraRoot	29	6.90	7	3–11 years	1	96.6%
SDS	25	4.00	4	6 months–6 years	1	96.0%
Straumann PURE	63	4.12	4	4 months–7 years	1	98.4%
Zeramex XT	83	4.20	4	3–7 years	1	98.8%
Z-Systems	75	4.64	4	4 months–10 years	2	96.4%
Overall	275	4.60	4	4 months–11 years	6	97.6%

TABLE 6 | Distribution of implants according to last available follow-up duration by implant system.

Follow-up duration	CeraRoot (*n*)	SDS (*n*)	Straumann (*n*)	Zeramex XT (*n*)	Z systems (*n*)
4 months[a]			1		1
6 months[a]		1			
2 years		1			3
3 years	2	4	26	31	27
4 years	5	12	10	14	17
5 years	2	4	17	30	7
6 years	2	3	6	4	3
7 years	5		3	4	8
8 years	6				3
9 years	2				
10 years	2				6
11 years	3				
Total	29	25	63	83	75

Note: Values represent the number of implants whose last documented clinical and radiographic follow-up occurred at the indicated time point. Implants that remained functional at the last available follow-up were treated as censored observations in the Kaplan–Meier survival analysis.
[a]The 4- and 6-month observations represent early implant failures that occurred before completion of 1 year of follow-up and were retained in the survival analysis.

TABLE 7 | Peri-implant soft tissue parameters.

System (*n*)	mGI baseline, mean ± SD (range)	mGI final, mean ± SD (range)	mPI baseline, mean ± SD (range)	mPI final, mean ± SD (range)	Suppuration
CeraRoot (29)	0.24 ± 0.44 (0–1)	0.17 ± 0.38 (0–1)	0.07 ± 0.26 (0–1)	0.14 ± 0.35 (0–1)	None
SDS (25)	0.08 ± 0.28 (0–1)	0.17 ± 0.38 (0–1)	0.00 (0)	0.13 ± 0.34 (0–1)	None
Straumann PURE (63)	0.11 ± 0.14 (0–1)	0.13 ± 0.34 (0–1)	0.15 ± 0.36 (0–1)	0.05 ± 0.22 (0–1)	None
Zeramex XT (83)	0.04 ± 0.19 (0–1)	0.06 ± 0.24 (0–1)	0.10 ± 0.30 (0–1)	0.02 ± 0.15 (0–1)	None
Z-Systems (75)	0.08 ± 0.27 (0–1)	0.05 ± 0.23 (0–1)	0.11 ± 0.31 (0–1)	0.04 ± 0.20 (0–1)	None

3.3.2 | Annual Marginal Bone Loss After the First Year

Mean annual MBL after the first year was low across all systems: CeraRoot, 0.12 ± 0.06 mm/y (0.10–0.30); SDS, 0.12 ± 0.05 mm/y (0–0.30); Straumann PURE, 0.10 ± 0.06 mm/y (0–0.20); Zeramex XT, 0.11 ± 0.05 mm/y (0–0.30); and Z-Systems, 0.14 ± 0.10 mm/y (0–0.30). The pooled weighted mean annual bone loss was 0.12 mm/y (Table 4).

3.4 | Peri-Implant Soft Tissue Parameters

All implant systems demonstrated favorable peri-implant mucosal conditions, and no suppuration was documented at any implant site (Table 7). Baseline mean mGI values ranged from 0.04 to 0.24 and final follow-up mean values ranged from 0.05 to 0.17. Baseline mean mPI values ranged from 0.00 to 0.15 and final follow-up mean values ranged from 0.02 to 0.14. Pooled weighted means across systems were 0.09 for mGI at baseline and final follow-up, and 0.10 (baseline) and 0.05 (final) for mPI.

4 | System-Specific Outcomes and Complications

4.1 | CeraRoot

A total of 29 implants were followed for a mean duration of 6.9 years (median: 7 years; range: 3–11 years), yielding a survival rate of 96.6%.

One implant fracture occurred 2 years after definitive restoration. The fractured implant (CeraRoot 16) was placed at site #3 in a previously grafted socket using corticocancellous particulate allograft and had been inserted with a high insertion torque of 55 N·cm. Optical and scanning electron microscopy analysis demonstrated a chipping defect at the fracture origin (Figure 2). The patient was a medically healthy 45-year-old male.

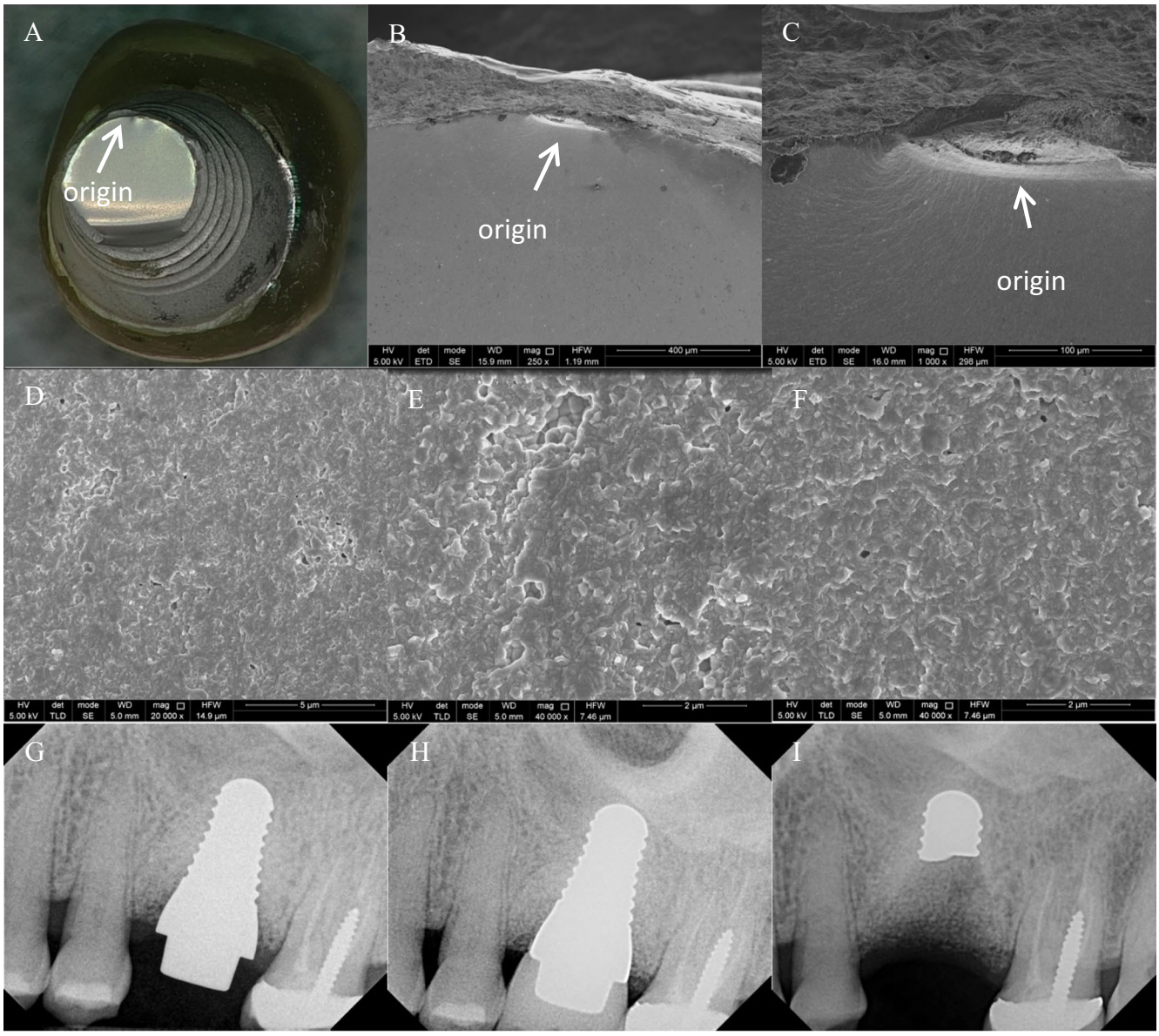

FIGURE 2 | Fracture analysis of the CeraRoot implant. (A) Optical image of the fractured surface. (B) Chipping defect at the fracture origin. (C) Higher magnification of the chipping defect. (D–F) Fracture origin from high to low magnification demonstrating intergranular and transgranular fracture modes with visible pores. (G–I) Periapical radiographs at placement, at final restoration, and at removal.

The success rate for CeraRoot was 93.1%. Three implants did not meet the strict marginal bone loss threshold of ≤0.2 mm/y, although no clinical signs of inflammation or bleeding were observed.

4.2 | SDS

Twenty-five implants were followed for a mean duration of 4.0 years (median: 4 years; range: 6 months–6 years). One implant failed at 6 months after placement, resulting in an overall implant survival rate of 96.0%. The failed implant was a 4.6×8 mm one-piece SDS ceramic implant placed at site #3 in conjunction with simultaneous crestal sinus augmentation. The sinus floor was elevated to 6 mm, and graft material was placed using the osteotome technique. Primary stability at placement was 35 N·cm. The patient was a medically healthy 43-year-old male. Clinical mobility was detected 6 months after placement, consistent with loss of osseointegration, and the implant was subsequently removed.

The system success rate was 95.8%, with one additional implant exceeding the strict annual bone loss threshold. Figure 3 presents the clinical and radiographic sequences of a 43-year-old medically healthy male patient with up to 6 years of follow-up.

4.3 | Straumann PURE

Sixty-three implants were followed for a mean duration of 4.12 years (median: 4 years; range: 4 months–7 years). One implant failed because of lack of osseointegration and was removed at 4 months resulting in a survival rate of 98.4%. The failed implant was a 3.3×10 mm one-piece implant placed at site #25, 5 months after extraction and socket grafting. The

FIGURE 3 | Clinical sequence of extraction and immediate placement of SDS one-piece implants at sites #8 and #9 in a 43-year-old medically healthy male patient. (A) Preoperative clinical photograph. (B) Clinical view following extraction and immediate implant placement. (C) Post-extraction periapical radiograph following immediate implant placement. (D) Four-month postoperative clinical photograph at the time of impression. (E) Definitive restoration. (F) Six-year follow-up demonstrating stable peri-implant tissues. (G) Six-year radiographic follow-up demonstrating stable peri-implant bone levels.

patient was a healthy 46-year-old male who was noncompliant with the protective Essix appliance and demonstrated poor oral hygiene.

The success rate was 96.7%, with two implants exceeding the strict annual bone loss threshold. Figure 4 presents a clinical case in a 39-year-old medically healthy female patient with 5 years of follow-up.

4.4 | Zeramex XT

Eighty-three implants were followed for a mean duration of 4.20 years (median: 4 years; range: 3–7 years). One implant failed due to aseptic loosening at 3 years in a 51-year-old medically healthy male with documented but clinically managed and controlled bruxism/attrition patterns. The patient reported regular night guard use and did not meet the exclusion criterion for uncontrolled severe parafunctional habits. The overall survival rate was 98.8%.

Three implants did not meet strict radiographic success thresholds (annual bone loss > 0.2 mm/y and/or excessive first-year loss), resulting in a success rate of 95.1%. No implant fractures were observed.

One restorative complication occurred: a crown at site #4 became loose 1 year after delivery. The carbon-fiber-reinforced polymer screw had been torqued to 30 N·cm, and subsequent screw wear/delamination was observed. The screw was replaced, and the restoration was remade without further complication. Figures 5 and 6 present two clinical cases with 6- and 4-year follow-ups.

4.5 | Z-Systems

Seventy-five implants were followed for a mean duration of 4.64 years (median: 4 years; range: 4 months–10 years). One implant fracture occurred 3 years after restoration: a one-piece Z5m implant (4.0 mm diameter) placed at site #30 in a medically healthy 37-year-old male. One additional implant failed because of lack of osseointegration and was removed at 4 months in a medically healthy 40-year-old female. This implant had been placed at site #15 in a previously grafted site following a lateral sinus augmentation procedure. These two failures resulted in a

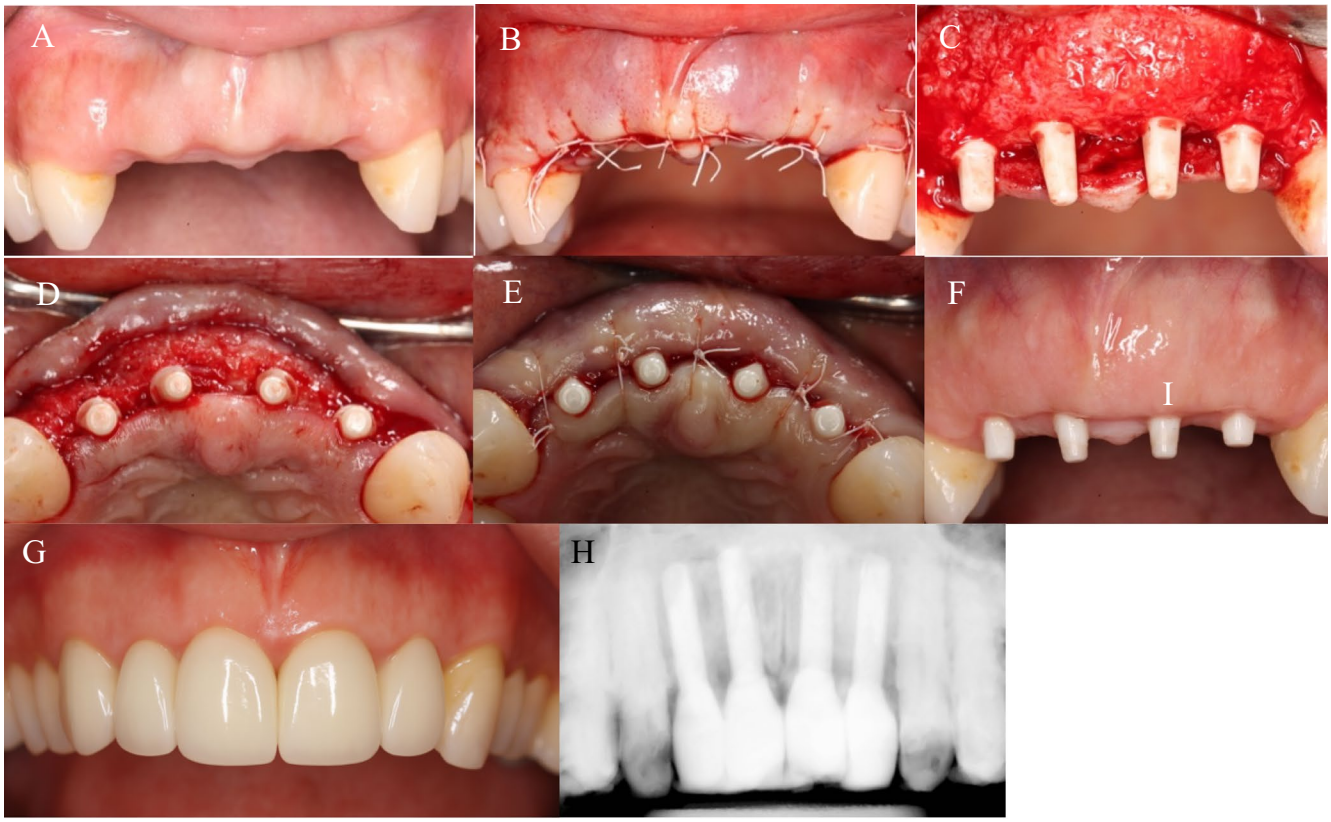

FIGURE 4 | Clinical sequence of placement of one-piece Straumann PURE Ceramic implants at sites #7–10 in a 39-year-old medically healthy female patient. (A) Preoperative clinical view demonstrating pronounced horizontal ridge resorption and partial edentulism in the anterior maxilla (#7–10). (B) Postoperative clinical view following ridge augmentation. (C–E) Implant placement sequence demonstrating insertion of one-piece Straumann PURE Ceramic implants at sites #7–10. (F) Clinical view at the 6-month follow-up demonstrating soft tissue maturation around the ceramic implants. (G) Clinical view at the 5-year follow-up demonstrating stable and harmonious peri-implant soft tissue contours with favorable esthetic integration. (H) Five-year postoperative radiographic follow-up demonstrating stable peri-implant bone levels.

survival rate of 96.4%. Four implants exceeded the strict annual bone loss threshold, resulting in a success rate of 94.6%. Figure 7 presents a clinical case with 10 years of follow-up.

5 | Discussion

This retrospective study evaluated radiographic marginal bone level changes and peri-implant soft tissue outcomes associated with five ceramic dental implant systems. Kaplan–Meier survival analysis demonstrated a favorable cumulative implant survival rate of 97.6% during the observation period between 2013 and 2025, with follow-up extending to 11 years. The use of Kaplan–Meier methodology allowed survival estimation while accounting for censored observations and unequal follow-up intervals, thereby providing a more robust assessment of observed implant performance over time. The low number of failures observed across the cohort suggests favorable medium- to long-term clinical performance within the documented follow-up distribution. A substantial proportion of implants were censored because they remained functional at the final available follow-up visit or had not yet reached long-term follow-up at the time of analysis. This is expected in retrospective longitudinal studies with ongoing patient follow-up.

The overall success rate (95.3%) was likewise consistent with recent reports describing favorable clinical performance of contemporary zirconia-based implant systems [20, 26–28].

No statistical comparison between implant systems was performed. The included implant systems differed substantially in implant design, geometry, and follow-up distribution, limiting the validity of direct comparative analysis.

The fracture rate in the current study was 0.73% (2/275), aligning with the 0.65% rate reported in a large evaluation of 4017 ceramic implants and reflecting improvement compared with early-generation ceramic implant designs [5, 27].

Peri-implant soft tissue parameters were favorable across all systems, supporting the biocompatibility of zirconia and its ability to promote mucosal healing and stable peri-implant tissue architecture [29, 30].

Marginal bone level analysis showed that the two-piece Zeramex XT implants demonstrated mean first-year crestal bone remodeling of 0.74 mm (range, 0–1.50 mm), comparable to previously reported outcomes [20].

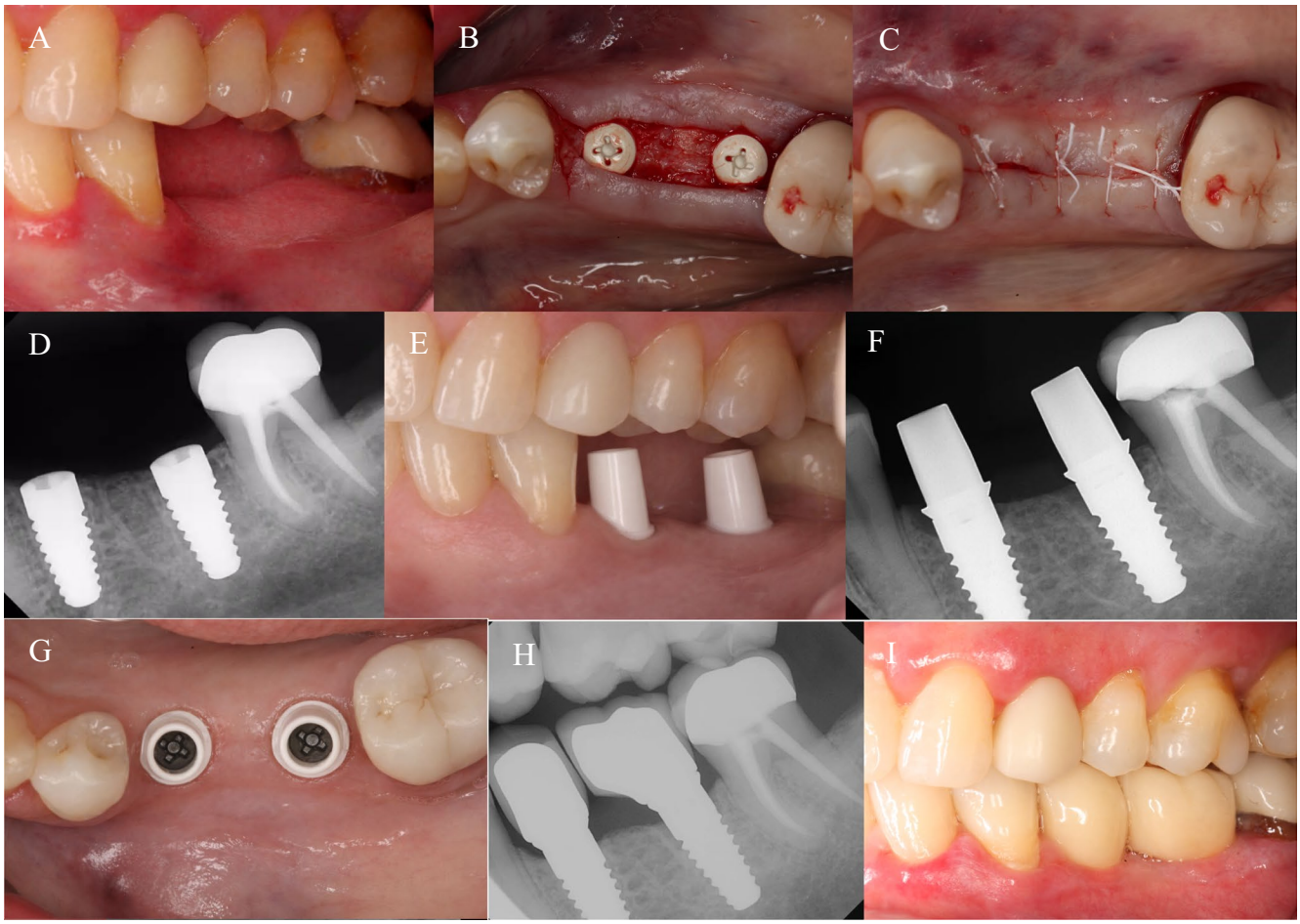

FIGURE 5 | Clinical sequence of implant treatment at sites #19 and #20 in a 51-year-old medically healthy female patient treated with Zeramex XT two-piece implants. (A) Preoperative clinical view of the edentulous sites #19 and #20 prior to implant placement. (B, C) Clinical views of Zeramex XT implants placed at sites #19 and #20 with platelet-rich fibrin (PRF). (D) Periapical radiograph obtained at the time of surgical placement. (E) Clinical view at the 4-month follow-up demonstrating soft-tissue healing and abutment placement secured with carbon-fiber screws. (F) Periapical radiograph showing the implants with abutments prior to occlusal adjustment and final impression. (G) Occlusal view at the 4-month follow-up. (H) Periapical radiograph at the 6-year follow-up. (I) Six-year clinical follow-up demonstrating stable peri-implant soft tissues with well-contoured and esthetically favorable mucosal architecture.

As expected for two-piece implant systems, most remodeling occurred during the initial healing phase and subsequently stabilized. First-year bone loss in the two-piece system was slightly greater than that observed in one-piece implants, a plausible finding attributable to the presence of an implant-abutment junction and associated microgap.

Vertical positioning of the implant platform influenced early bone remodeling. Implants placed at the crestal level exhibited greater first-year bone loss (up to 1.6 mm) compared with implants positioned 0.6–1.6 mm supracrestally. This finding is consistent with prior reports and classical titanium implant data indicating that marginal bone remodeling is influenced by the location of the implant-abutment microgap [20, 31].

Although subcrestal positioning is frequently recommended in esthetic titanium implant therapy, the current observations suggest that this approach may be less favorable for ceramic implant systems. Controlled studies are warranted to clarify optimal vertical positioning of ceramic implants, particularly in esthetically demanding scenarios.

One failure in the Zeramex XT group occurred because of aseptic loosening without clinical or radiographic signs of peri-implant inflammation. A restorative complication, involving loosening of the final restoration, was observed in a patient with a documented history of clinically managed and controlled bruxism. The single-use carbon-fiber screw required replacement after being torqued to 30 N·cm, which exceeded the manufacturer's recommendation. This finding underscores the importance of strict compliance with system-specific restorative protocols and risk management in patients with bruxism [32, 33].

Among one-piece ceramic implant systems, first-year and annual marginal bone level changes were favorable. These findings correspond with prospective cohort studies reporting 95%–97% survival over 5 years for one-piece zirconia implants, with stable marginal bone levels and low complication rates [34–36].

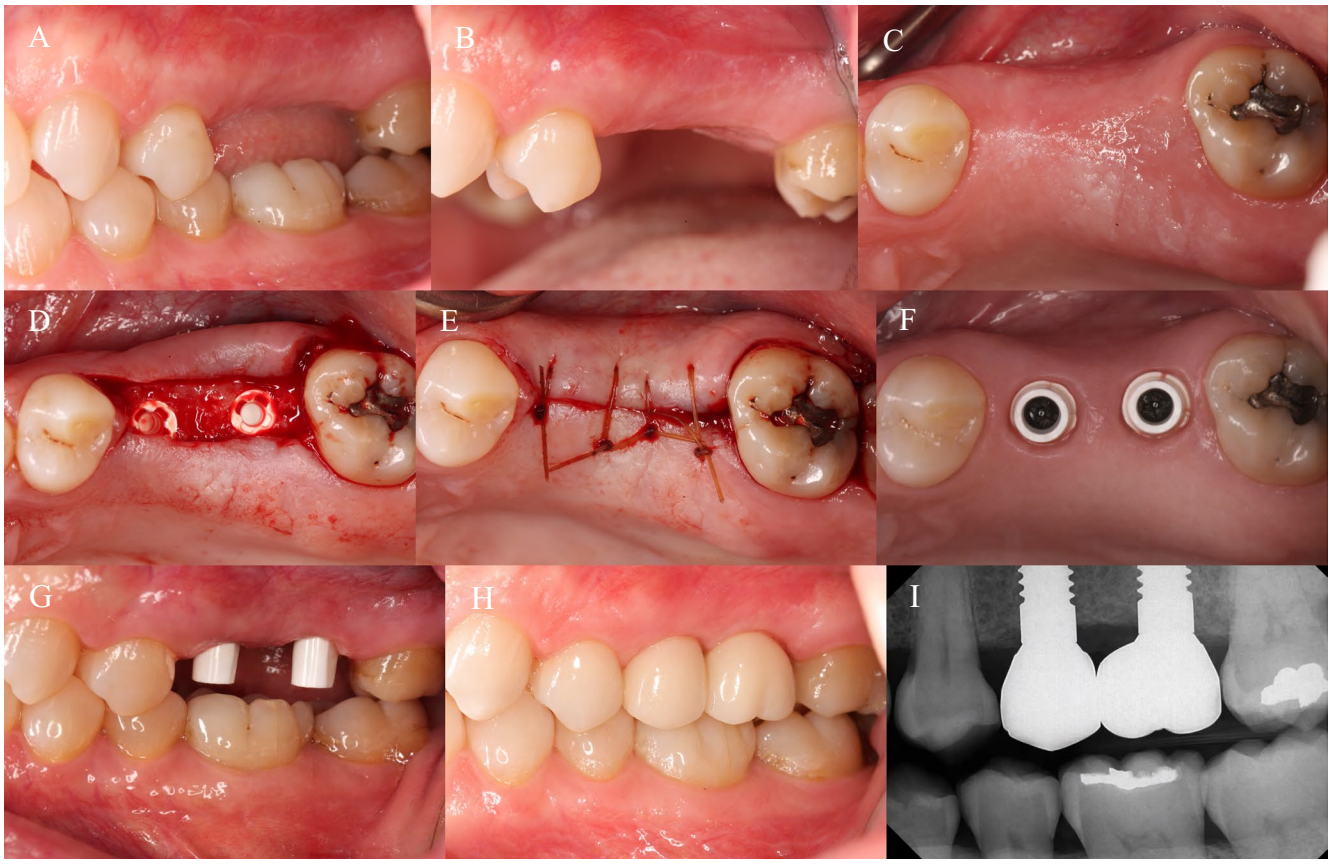

FIGURE 6 | Clinical sequence of implant treatment at sites #13 and #14 in a 62-year-old medically healthy female. (A–C) Preoperative clinical photographs of the edentulous sites #13 and #14 prior to implant placement. (D, E) Clinical views of the Zeramex XT implants placed at sites #13 and #14 with platelet-rich fibrin (PRF). (F, G) Clinical photographs at the 4-month follow-up demonstrating soft-tissue healing and abutment placement secured with carbon-fiber screws. In panel (G), the abutments have been occlusally reduced prior to the final impression. (H) Clinical image of the definitive prosthesis at the 4-year follow-up. (I) Radiographic image of the Zeramex XT restoration at the 4-year follow-up.

In this cohort, failures attributed to lack of osseointegration occurred under clinically compromised conditions (e.g., simultaneous sinus augmentation, placement in posterior maxillary sites previously augmented using a lateral sinus approach, and noncompliance with protective appliances). These scenarios highlight the relevance of bone quality and primary stability for one-piece ceramic implants.

Two one-piece implants failed because of fracture. In the CeraRoot implant, excessive insertion torque likely contributed to chipping at the fracture origin, compromising structural integrity and initiating crack propagation. Microscopic evaluation revealed internal porosities, emphasizing the importance of manufacturing quality control. The fracture of the Z-Systems implant occurred in a 4-mm diameter implant placed in a molar region, again highlighting the need for adequate implant diameter selection in high-load areas and avoidance of excessive insertion torque [37].

Overall, these observations are consistent with favorable performance of contemporary zirconia implant systems, as reported in systematic reviews and meta-analyses describing high survival rates, stable bone levels, and low mechanical complication rates [5, 27].

Clinician experience and protocol adherence appear to be important determinants of success. Ceramic implant placement is technique-sensitive and may be associated with a steeper learning curve than conventional titanium implant therapy. This is related to the reduced intraoperative flexibility of ceramic materials, system-specific drilling and insertion protocols, limitations in prosthetic compensation, and the need for precise three-dimensional implant positioning.

In particular, the high elastic modulus and limited plastic deformation capacity of ceramic implants, together with their limited tolerance for excessive insertion torque, off-axis loading, or unfavorable restorative emergence profiles, require careful surgical execution and prosthetic planning. Each ceramic implant system also requires adherence to its specific surgical and restorative workflow. Applying titanium-based techniques to ceramic systems may increase the risk of mechanical or biologic complications. Dedicated training and system-specific education in case selection, surgical placement, prosthetic planning, and restorative guidelines are therefore recommended prior to routine use.

Limitations of the present study include its retrospective design, heterogeneity among implant systems and restorative protocols, use of a single examiner for radiographic measurements, and potential selection and attrition bias related to follow-up patterns. The retrospective nature of the study may have introduced selection and information bias because of reliance on existing

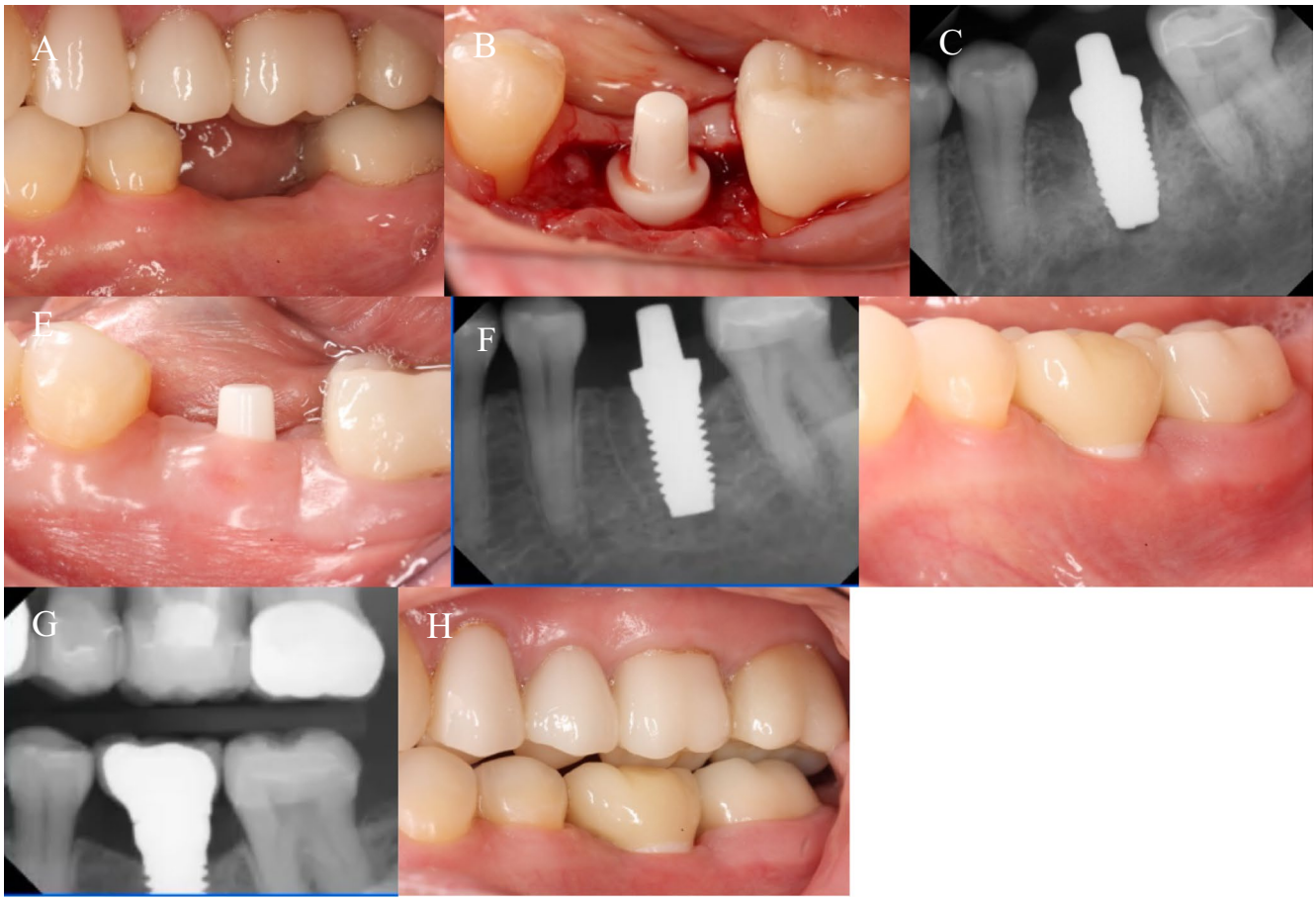

FIGURE 7 | Clinical sequence of implant placement at site #19 using the Z-systems implant system in a 57-year-old female patient. (A) Preoperative clinical photograph. (B) Clinical photograph following implant placement. (C) Periapical radiograph obtained at surgical placement of the implant. (D) Four-month postoperative clinical photograph obtained at the final impression visit. (E) Four-month postoperative periapical radiograph. (F) Clinical photograph of the definitive crown restoration. (G) Periapical radiograph at the 10-year follow-up visit demonstrating stable crestal bone levels and long-term peri-implant stability. (H) Clinical photograph at the 10-year follow-up visit showing long-term stability of the peri-implant soft tissues with no significant changes.

clinical and radiographic records, while the limited availability of covariates precluded comprehensive adjustment for potential confounding factors. In addition, derivation of the cohort from patients attending annual maintenance visits in private practice may have introduced attrition bias, as patients lost to follow-up may have differed systematically from those who remained under maintenance, and failures or complications managed outside the study practices may not have been captured. Although Kaplan–Meier analysis accounted for unequal follow-up duration through censoring, the survival estimates should be interpreted as outcomes among patients with documented follow-up rather than as population-level estimates for all treated patients. Therefore, the findings should be interpreted descriptively and should not be used to infer causal relationships or comparative effectiveness between implant systems.

Furthermore, the heterogeneity of the included implant systems, treatment indications, and restorative protocols may limit the generalizability of the results. Peri-implant marginal bone levels were assessed using two-dimensional periapical radiographs. Although standardized periapical radiographs are widely accepted in implant dentistry because of their high resolution and relatively low radiation exposure, they do not permit evaluation of buccal or lingual bone remodeling. Minor variations in radiographic angulation may also influence linear measurements despite calibration and standardization procedures. Therefore, the reported marginal bone level changes should be interpreted as two-dimensional estimations rather than true volumetric bone alterations. Additionally, some patients received multiple implants, which may have introduced clustering effects and reduced statistical independence between observations. Nevertheless, the large sample size and extended follow-up period provide valuable real-world data regarding the clinical performance of contemporary ceramic implant systems.

6 | Conclusion

Within the limitations of this retrospective study, both one-piece Y-TZP and two-piece ATZ ceramic implant systems demonstrated high survival and success rates, stable marginal bone levels, and favorable peri-implant soft tissue outcomes in the evaluated cohort. Contemporary zirconia-based implants may therefore represent a clinically relevant treatment option for appropriately selected patients, particularly those seeking metal-free rehabilitation or enhanced esthetic outcomes. However,

given the retrospective design, heterogeneity of implant systems and restorative protocols, and limited control of potential confounding variables, the findings should be interpreted cautiously as descriptive cohort data rather than evidence of comparative superiority or equivalence. Favorable outcomes remain contingent upon accurate treatment planning, system-specific training, appropriate case selection, precise three-dimensional implant positioning, and adherence to established surgical and restorative protocols. Further long-term prospective controlled studies with standardized protocols are warranted to validate these findings and refine evidence-based recommendations for vertical implant positioning and risk management in high-load and grafted sites.

Author Contributions

Concept and design: Mona Monzavi. Data Analysis and Interpretation: Mona Monzavi, Al Manesh, Ayman Zraiqat. Drafting of the manuscript: Mona Monzavi. Critical Revision of the manuscript: Mona Monzavi, Medis Masnavi, Al Manesh, Ayman Zraiqat. Final Approval of the Manuscript: Mona Monzavi, Medis Masnavi, Al Manesh, Ayman Zraiqat. Statistical analysis: Mona Monzavi. Data Collection: Medis Masnavi.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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