A Multicenter Cohort Study on 301 Tissue-Level Implants: Cumulative Implant Survival Rate and Marginal Bone Level Change up to 4.5 Years

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Purpose: To retrospectively determine the cumulative survival rate (CSR) and marginal bone level change (ΔMBL) around novel hybrid design tissue-level (TL) dental implants that support multiple-screw-retained restorations. ***Materials and Methods:*** Implant CSRs were analyzed at the implant and patient level using Kaplan-Meier estimates. ΔMBL was measured by comparing the periapical loading and follow-up visit radiographs using an improved standardized digital methodology based on image gray levels. ΔMBL outcomes were subject to linear mixed regression to identify potential risk factors. ***Results:*** A total of 301 TL implants in 69 patients with an average age of 62.6 ± 11.7 years (range: 36 to 87 years) at the time of implant placement were considered for the analysis. All 301 implants were successfully restored and loaded. The 54-month CSRs at the implant and patient levels were 98.9% (95% CI: 96.7 to 99.6) and 95.3% (95% CI: 86.1 to 98.5), respectively. ΔMBL after a mean follow-up of 22 ± 10.7 months after loading was 0.00 ± 0.57 mm. None of the implant sites showed marginal bone loss exceeding 1.5 mm. Multivariate regression analysis revealed a significant association between ΔMBL and the loading protocol ($P = .027$) but not between ΔMBL and age or transgingival height. ***Conclusions:*** The high CSRs and stable peri-implant marginal bone levels support the use of recent TL implants, which have a hybrid design inherited from the bone-level implant-abutment connection, as a suitable treatment option for restoring partially or fully edentulous patients with a good mid-term prognosis. These results should be complemented by further prospective studies in a real-world multicenter private practice setup that represents the daily realities of implant treatment. *Int J Oral Maxillofac Implants 2024;39:224–234. doi: 10.11607/jomi.10141*

Keywords: dental implants, retrospective study, cumulative survival rate, marginal bone level, real-world evidence, hybrid design

Dental implants represent a well-established modality for the treatment of edentulism. Hard and soft tissue integration of dental implants can be considered key factors for the long-term clinical outcome of implant therapy.[1] The analysis of implant survival and the factors affecting it (eg, patient, surgical, and prosthetic-related characteristics) is imperative for the rational evolution of implant therapy and the associated implant designs and treatment workflows.[2–5] Among the various clinical parameters, marginal bone stability has evolved as a key indicator of implant survival and success.[6,7]

Modern dental implants have evolved from two major categories: bone-level (BL) and tissue-level (TL) implants.[8] Compared to the traditionally submerged healing BL implants, TL implants heal transgingivally and offer an alternative treatment method that requires fewer surgical interventions and less chair time for the patient.[9] TL implants have been clinically documented as equivalent to BL implants in terms of osseointegration and long-term survival.[10,11] Further, the potentially lower prosthetic flexibility of TL implants may be compensated for by its advantages in better preserving marginal bone levels, which has been attributed to the absence of surgical re-entry and the avoidance of microgaps as a potential source for bacterial colonization, as well as reduced micromechanical movements at the bone level.[12–14]

The macrodesign of the cervical implant region is another important factor that contributes to peri-implant marginal bone stability. Platform switching has been shown to effectively improve the stability of marginal bone levels around BL implants.[15] Also, the mean marginal vertical and horizontal bone loss

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Submitted June 29, 2022; accepted July 18, 2023.

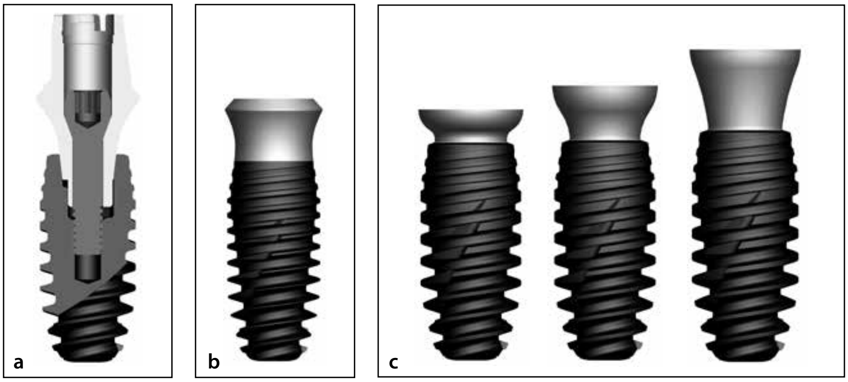

Fig 1 *(a)* Illustration of a conventional platform-switched abutment connection on a BL implant. *(b)* Illustration of a conventional TL implant design. *(c)* Schematic representation of study device—ie, hybrid design TL implants with three transgingival platform heights.

around platform-switched abutments was reported to be lower than platform-matched abutments after 3[16] and 5 years[17] of functional loading. Similar results could be expected from tissue-level implants that present a platform-switched design. However, the investigation of this specific feature for TL implants remained, to the best of our knowledge, undocumented.

The first mention of hybrid design regarding dental implants in the literature goes back to 1993, when Tarnow[18] referred to surface characteristics of implants that had a machined neck in the coronal part and a plasma-sprayed surface on the apical part to better induce osseointegration and prevent peri-implantitis. This study proposed to extend this concept to a TL implant with macroscopic design features inherited from BL implants.

A defining characteristic of this hybrid design consists of a marked change in diameter at the crestal level, similar to the platform-switched implant-abutment junction found in conical connection BL implants[19] (Fig 1). However, the long-term impact of this modification on marginal bone stability and implant survival has not been documented so far.[20] Therefore, this retrospective multicenter cohort study aimed to analyze this novel TL hybrid implant design's survival rate and marginal bone level stability in an in-practice real-world setting.

MATERIALS AND METHODS

The primary and secondary objectives of this study were to analyze the cumulative implant survival rate (CSR) of novel hybrid design TL implants at different time points and the marginal bone level change (ΔMBL) at ≥ 1 year postloading. In addition, technical complications and causes of implant failure were analyzed. Age, loading protocol, and transgingival implant height were studied as possible risk factors for marginal bone change.

Study Design

This retrospective study analyzed records from a cohort of patients treated with multiple screw-retained restorations who received implant treatment with commercially available REG and PX Axiom Tissue Level implants (Anthogyr, Straumann; see Fig 1c). Axiom implants consist of standard surgical grade titanium alloy (Ti-6Al-4V ELI) and a biphasic calcium phosphate surface manufactured via particle-blasting with a mixture of hydroxyapatite and tricalcium phosphate followed by nitric acid treatment.

This study was conducted according to the French regulation for health data studies under CNIL MR-004 guidance[21] and adhered to the STROBE guidelines for cohort studies.[22] It was approved by the Institutional Review Board and Ethics Committee in Lyon (Scientific and Ethical Committee of Hospices Civils de Lyon; CNIL approval number 22_5731).

Data Collection

This study considered 389 consecutive implant treatment records of 90 patients, including multi-implant-based restorations, from 23 private practices performed by 23 experienced implant surgeons from 2015 to 2018. Patient records that lacked completed follow-ups since implant placement were excluded, which reduced the number of implants and patients considered for analysis in the cohort to 301 and 69, respectively. No specific exclusion criteria were applied regarding implant placement or loading protocols.

ΔMBL of an implant subcohort that had at least a completed 1-year postloading radiographic follow-up (range: 12 ± 1 months) was analyzed as described below. The selection process for this subcohort analysis is schematically depicted in Fig 2 and was based on the availability of baseline and follow-up radiographs with sufficient quality for analysis.

The following nominal and categorical factors were recorded:

- Patient-related factors: sex, age, smoking habits, and history of periodontal disease
- Recipient site–related factors: placement and loading protocols

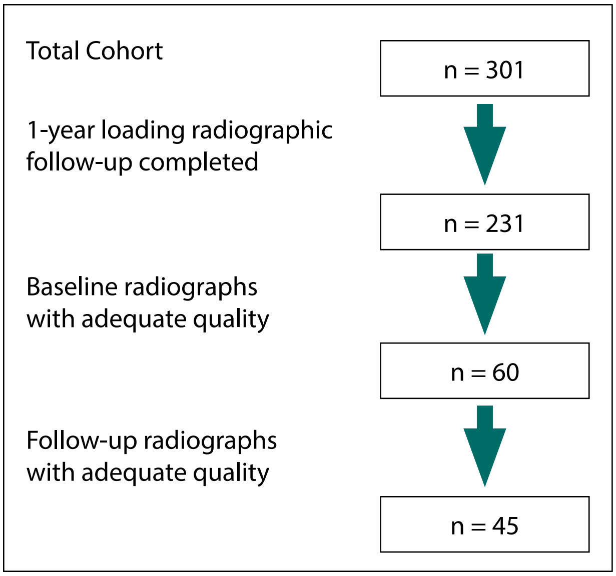

Fig 2 Election process for the subcohort of patient records used for ΔMBL analysis.

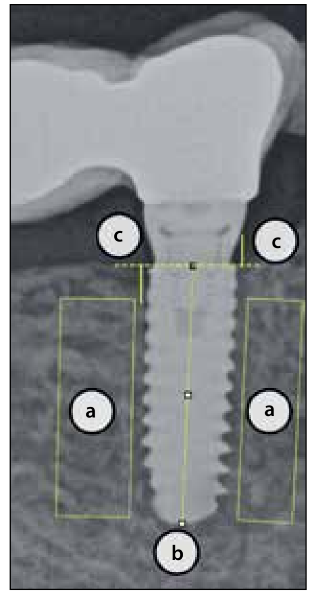

Fig 3 Methodology of measurement of marginal bone level using periapical radiographs. *(a)* Areas used to select reference gray profiles of bone at the mesial and distal aspects of the implant, excluding anatomically intrinsic radiolucent structures, eg, extraction sites. *(b)* Dimensions of the endosseous part of the implant used for dimensional image calibration. *(c)* Assessment of marginal bone level at the mesial and distal aspects using the step between the transgingival platform and the endosseous implant body as reference landmark.

- Implant-related factors: position, thread design, length, diameter, platform diameter, transgingival platform height
- Prosthetic design-related factors: type, material
- Type of prosthetic complications
- Implant survival rate

The CSR was determined using Kaplan-Meier analysis and defined the time to implant failure as the time interval between implant placement and failure. The implants were considered failed if they presented signs and symptoms that led to implant removal or were put to sleep (ie, were left in place and either were unloaded or no longer participated in prosthetic support) due to the lack of osseointegration or mechanical failure.[23]

Marginal Bone Level Change: Radiographic Assessment

ΔMBL was defined as the difference between radiographic marginal bone levels at the most recent follow-up and the time of loading (baseline) and was assessed by two independent treatment-blinded, calibrated examiners (D.C. and F.P.). The ΔMBL in milimeters measured by the two examiners was averaged and used for the statistical analysis. Examiner calibration was performed using periapical radiographs excluded from the final evaluation. The intraclass correlation coefficients (Lin coefficient of concordance) were 0.93 (36 measures) and 0.95 (36 measures) for each respective examiner. The interclass correlation coefficient (Lin coefficient of concordance) was 0.84 between the two examiners (36 measures).

As this restrospective study was multicentric, the angulation errors and radiograph capturing techniques and protocols were not standardized. To address this, a specific methodology was employed to maximize measurement reliability.

Digital periapical radiographs (> 300 dpi) were evaluated using ImageJ (NIH). Radiographs with insufficient resolution or with motion blur were excluded.

ΔMBL assessment followed the routines and definitions previously described by Weber and Buser.[24] In brief, individual vertical marginal bone levels were averaged from measurements on mesial and distal aspects using the distance between the most coronal bone to implant contact relative to the implant platform (Fig 3). Radiographs were calibrated using the implant length or, in cases of partial radiographs that did not display the entire implant, the dimensions of the transgingival platform.

To improve measurement validity of the nonstandardized images, originally reported routines were modified by using digital image gray level profiles to reduce the level of bias in coronal bone level identification. Reference gray level profiles for osseous structures were determined in regions of interest located at least three implant threads apically to the implant platform, equidistant from possible neighboring implants, and under exclusion of possible anatomical radiolucent structures like extraction sockets (see Fig 3). The minimum derived gray level profile of osseous structures was selected as the reference value to determine the individual vertical marginal bone levels.

As a result of the applied selection process, 45 pairs of radiographs from four practitioners with a mean resolution higher than 1040 dpi were available. The final interclass correlation coefficients (Lin coefficient of concordance) between the two examiners (D.C. and F.P.) for

Table 1 Descriptive Factors of the Cohort at the Implant and Patient Levels

Factor type	Factor	Characteristics	Patient level % (n), n = 69	Implant level % (n), n = 301
Patient factors	Sex	Male	44.9 (31)	46.2 (139)
		Female	55.1 (38)	53.8 (162)
	Age (y)	≥ 60	59.4 (41)	66.1 (199)
		< 60	39.1 (27)	31.9 (96)
		Unknown	1.5 (1)	2.0 (6)
	Tobacco use/smoking	No	79.7 (55)	79.1 (238)
		Yes	17.4 (12)	18.9 (57)
		Unknown	2.9 (2)	2.0 (6)
	History of periodontal disease	No	59.4 (41)	53.2 (160)
		Yes	36.2 (25)	40.5 (122)
		Unknown	4.4 (3)	6.3 (19)
Recipient site factors	Implantation	Delayed implantation	N/A	62.5 (188)
		Immediate implantation	N/A	37.5 (113)
	Loading	Conventional loading	N/A	36.2 (109)
		Immediate loading	N/A	63.8 (192)
Implant factors	Position	Anterior maxilla	N/A	24.2 (73)
		Posterior maxilla	N/A	28.6 (86)
		Anterior mandible	N/A	10.3 (31)
		Posterior mandible	N/A	36.9 (111)
	Thread design	REG	N/A	38.5 (116)
		PX	N/A	61.5 (185)
	Length	Short: < 10 mm	N/A	14.0 (42)
		Conventional: ≥ 10 mm	N/A	80.7 (243)
		Missing	N/A	5.3 (16)
	Diameter	Narrow: 3.4 mm	N/A	36.9 (111)
		Conventional: 4 or 4.6 or 5.2 mm	N/A	57.8 (174)
		Missing	N/A	5.3 (16)
	Platform diameter	4	N/A	21.3 (64)
		4.8	N/A	78.7 (237)
	Platform height	1.5	N/A	14.6 (44)
		2.5	N/A	66.1 (199)
		3.5	N/A	19.3 (58)
Prosthesis	Fixed multiple prosthesis	Partial	56.5 (39)	39.9 (120)
		Full-arch	43.5 (30)	60.1 (181)
	Material	CoCr	31.9 (22)	31.6 (95)
		Ti	36.2 (25)	42.5 (128)
		Zi	23.2 (16)	15.9 (48)
		Polymer	4.3 (3)	4.7 (14)
		Missing	4.3 (3)	5.3 (16)

N/A: not applicable.

the 45 analyzed implants (90 measurements) was 1 for the gray level profiles and 0.85 for the ΔMBL.

Data and Statistical Analysis

Descriptive characteristics were reported as means, standard deviations, and frequencies (percent). CSRs were determined using Kaplan-Meier analysis and reported using 95% CIs.

The association of ΔMBL values and risk factors was analyzed by applying linear mixed univariate and multivariate regression models, considering the age of the patient (< 60 years old vs > 60 years old), transgingival height (1.5 mm vs 2.5 and 3.5 mm), and loading protocols (immediate vs conventional) as fixed effects, and the patient as a random effect. Due to the limited sample size, robust *P* values were additionally estimated using a bootstrap approach. The model assumptions (constant variance and normality of residuals) were verified.

All analyses were performed in R v4.0.2 or SAS software v9.4. A two-sided *P* value < .05 was considered statistically significant.

RESULTS

Patient and Implant Cohort Characteristics

The descriptive characteristics of the cohort at implant and patient levels are summarized in Table 1. A total of 301 TL implants in 69 patients with an average age

Table 2 Mechanical and Technical Complications Reported on Patient and Prosthesis Levels

Complication	Patient-based events	Prosthesis-based events
Total complications	15 / 59 (25.4%)	16 / 72 (22.2%)
Screw loosening	10 / 15 (66.6%)	11 / 16 (68.8%)
Ceramic chipping	1 / 15 (6.6%)	1 / 16 (6.3%)
New prosthesis	1 / 15 (6.6%)	1 / 16 (6.3%)
Screw access cover lost	1 / 15 (6.6%)	1 / 16 (6.3%)
Resin repair	1 / 15 (6.6%)	1 / 16 (6.3%)
Fractured prosthesis	1 / 15 (6.6%)	1 / 16 (6.3%)

Table 3 Kaplan-Meier Survival Probabilities at the Implant and Patient Levels

	Survival probability % (95% CI)	
Time (mo)	Implant level	Patient level
2.2	99.7 (97.5–100.0)	98.5 (89.6–99.8)
3	99.3 (97.2–99.8)	96.9 (88.2–99.2)
3.5	98.9 (96.7–99.6)	95.3 (86.1–98.5)
54	98.9 (96.7–99.6)	95.3 (86.1–98.5)

Table 4 Characteristics of Failed Implants

Failed implant	Position (FDI system)	Thread design	Diameter (mm)	Length (mm)	Platform diameter (mm)	Platform length (mm)	Implantation	Loading	Prosthesis	Removal time after implant placement (mo)	Cause of failure reported
1	25	PX	3.4	12	4.8	2.5	Delayed	Immediate	Full-arch	2.2	Non-osseointegration
2	13	PX	3.4	14	4.8	2.5	Delayed	Conventional	Partial	3	Abscess
3	36	PX	4	8	4.8	3.5	Delayed	Conventional	Full-arch	3.5	Non-osseointegration

of 62.6 ± 11.7 years (range: 36 to 87 years) at the time of implant placement were considered in the analysis. All 301 implants were successfully restored and loaded. Of these, 159 implants (52.8%) were placed in the maxilla and 142 implants (47.2%) were placed in the mandible, while 104 (34.6%) and 197 (65.4%) implants were placed in the anterior and posterior regions, respectively. Furthermore, 17.4% (12) of patients carrying 18.9% (57) of implants were smokers, and 36.2% (25) of patients affecting 40.5% (122) of implants displayed a documented history of periodontal disease.

At the prosthetic level, 85 prosthetic restorations or 1.2 prostheses per patient were delivered, with 53 patients (76.8%) receiving 1 prosthesis and 16 patients (23.2%) receiving 2 prostheses. 42.4% (36) of the delivered prostheses were full-arch prostheses, comprising 60.1% of implants in the cohort. Of the 85 prosthetic records, 13 did not report the prosthetic follow-up, reducing the number of patients and prostheses considered for the descriptive analysis at the prosthetic level to 59 and 72, respectively. Mechanical and technical prosthetic complications are summarized in Table 2 and are reported for an average follow-up time of 22.6 ± 12.8 months postdelivery. The most frequent technical complication observed was screw loosening in 10 patients and 11 prostheses. The remaining technical complications occurred in 5 patients.

Implant Survival Rate

CSR analysis considered 301 implants in 69 patients with an average follow-up period of 22.7 ± 14.0 months after implant placement. The longest follow-up period was 54.4 months. 78.8% of the placed implants had a follow-up period of at least 1 year.

The Kaplan-Meier tables and survival plots are displayed in Table 3 and Fig 4. The CSR at 54 months was 98.9% (95% CI: 96.7 to 99.6) at the implant level and 95.3% (95% CI: 86.1 to 98.5) at the patient level. A total of three implants failed over the entire follow-up period. All failures were recorded within the first 3.5 months after implant placement. The characteristics of the failed implants are reported in Table 4 and were recorded

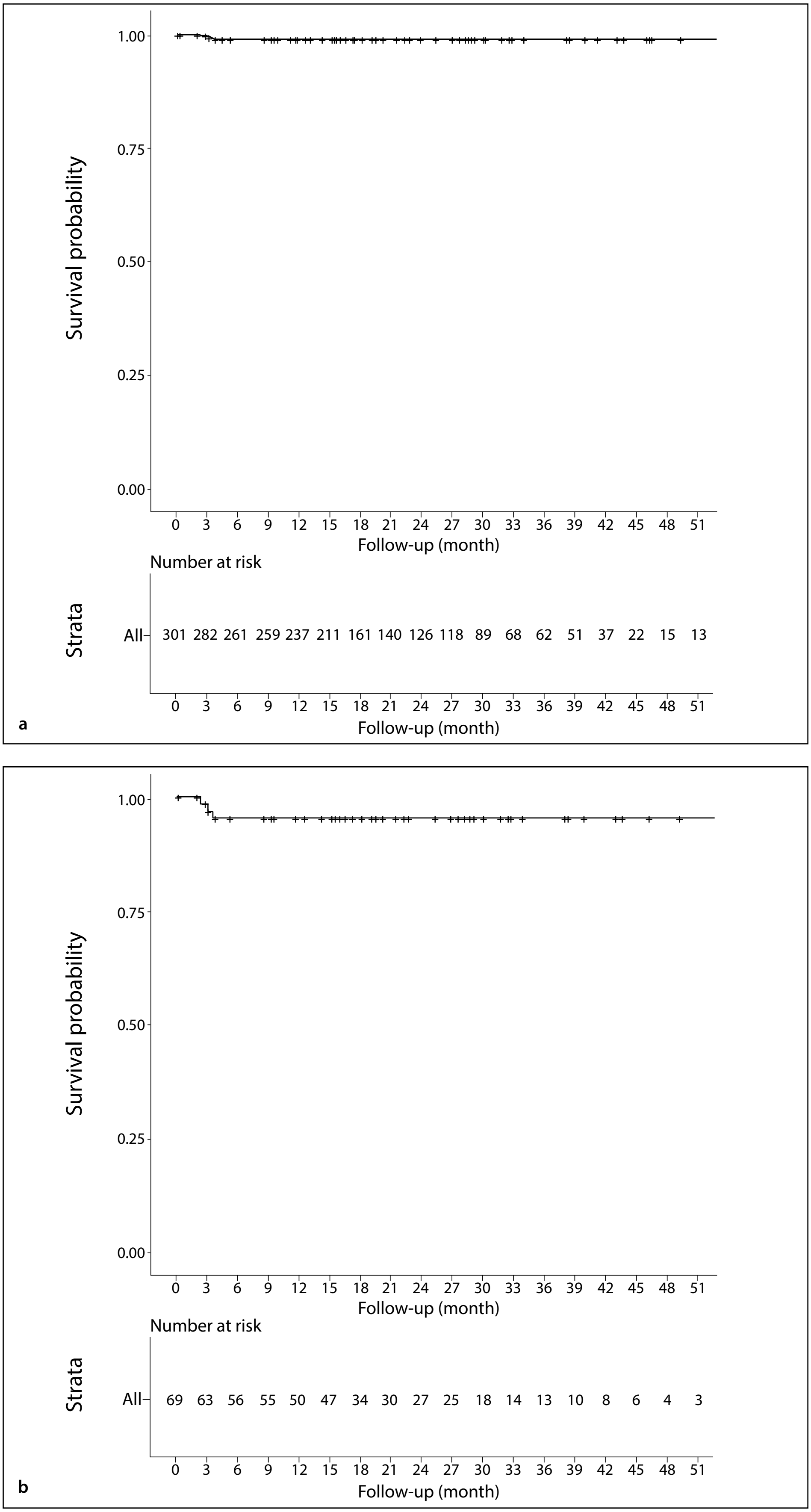

Fig 4 *(a)* Kaplan-Meier survival curves at implant level (n = 301) and the corresponding number of implants at risk. *(b)* Kaplan-Meier survival curves at patient level (n = 69) and the corresponding number of patients at risk.

Table 5 Descriptive Characteristics of the Study Subcohort Used for the Analysis of ΔMBL at the Implant and Patient Levels

			Patient level % (n) for ΔMBL, n = 16	Implant level % (n) for ΔMBL, n = 45
Patient factors	Sex	Male	56.25 (9)	57.8 (26)
		Female	43.75 (7)	42.2 (19)
	Age (y)	≥ 60	43.75 (7)	51.1 (23)
		< 60	56.25 (9)	48.9 (22)
		Unknown	0.0 (0)	0.0 (0)
	Tobacco use/smoking	No	81.25 (13)	80.0 (36)
		Yes	18.75 (3)	20.0 (9)
		Unknown	0.0 (0)	0.0 (0)
	History of periodontal disease	No	68.75 (11)	68.9 (31)
		Yes	31.25 (5)	31.1 (14)
		Unknown	0.0 (0)	0.0 (0)
Recipient site factors	Implantation	Delayed implantation	N/A	53.3 (24)
		Immediate implantation	N/A	46.7 (21)
	Loading	Conventional loading	N/A	42.2 (19)
		Immediate loading	N/A	57.8 (26)
Implant factors	Position	Anterior maxilla	N/A	26.7 (12)
		Posterior maxilla	N/A	35.5 (16)
		Anterior mandible	N/A	8.9 (4)
		Posterior mandible	N/A	28.9 (13)
	Thread design	REG	N/A	57.8 (26)
		PX	N/A	42.2 (19)
	Length	Short: < 10 mm	N/A	20.0 (9)
		Conventional: ≥ 10 mm	N/A	80.0 (36)
		Missing	N/A	0.0 (0)
	Diameter	Narrow: 3.4 mm	N/A	28.9 (13)
		Conventional: 4, 4.6, or 5.2 mm	N/A	71.1 (32)
		Missing	N/A	0.0 (0)
	Platform diameter	4	N/A	44.4 (20)
		4.8	N/A	55.6 (25)
	Platform length	1.5	N/A	17.8 (8)
		2.5	N/A	77.8 (35)
		3.5	N/A	4.4 (2)
Prosthesis	Fixed multiple prosthesis	Partial	75 (12)	55.6 (25)
		Full-arch	25 (4)	44.4 (20)
	Material	CrCo	31.25 (5)	37.8 (17)
		Ti	6.25 (1)	4.4 (2)
		Zi	62.5 (10)	57.8 (26)
		Polymer	0.0 (0)	0.0 (0)
		Missing	0.0 (0)	0.0 (0)

N/A = not applicable.

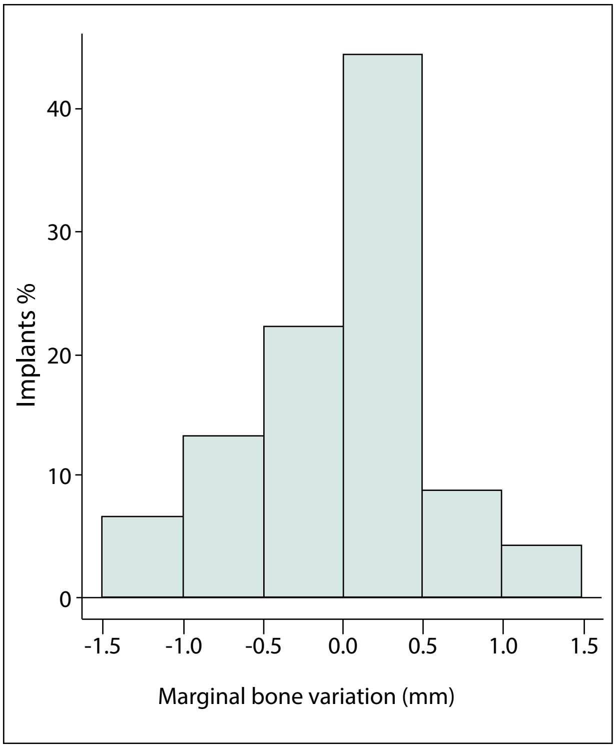

Fig 5 Distribution of the marginal bone level change (mm) over the 45 implants in the ΔMBL subcohort.

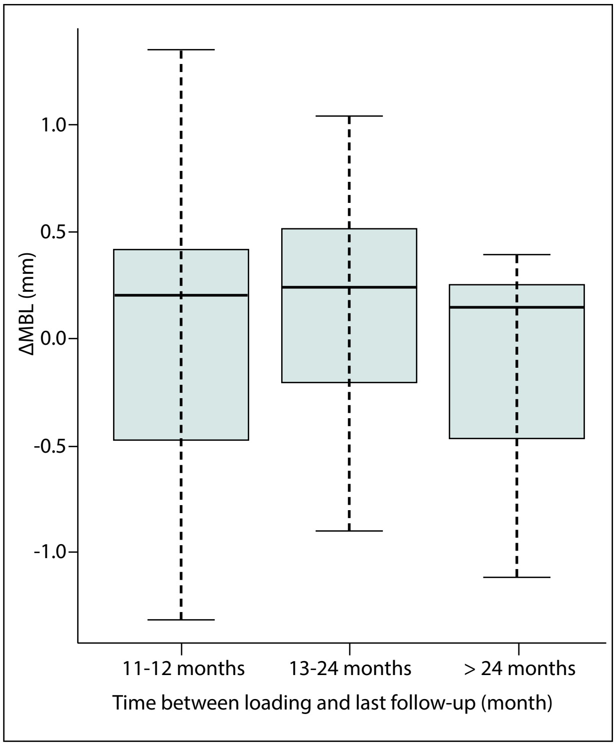

Fig 6 Box plot diagram of ΔMBL per analyzed time interval subcohort. Horizontal bars designate medians. Boxes represent the second and third quartiles, and upper and lower whiskers designate the first and fourth quartiles, demarking minimum and maximum values, respectively.

Table 6 Associations Between Risk Factors and ΔMBL

	Univariate (n = 45)			Multivariate (n = 45)		
	ΔMBL (mm)	*P*	*P* value bootstrap	ΔMBL (mm)	*P*	*P* value bootstrap
Age group (60 vs ≥ 60)	0.21 (–0.13 to 0.55)	.174	.212	0.33 (–0.14 to 0.80)	.164	.082
Loading (immediate vs conventional)	–0.21 (–0.55 to 0.13)	.358	.225	–0.47 (–0.95 to 0.01)	.054	.027
Transgingival height (1.5 vs 2.5 and 3.5 mm)	–0.01 (–0.46 to 0.45)	.641	.976	–0.18 (–0.63 to 0.28)	.446	.223

in one male and two female patients (range: 66 to 75 years). Two of the patients experiencing implant loss were smokers and displayed a history of periodontitis.

ΔMBL

ΔMBL was analyzed on a cohort of 45 implants and 16 patients and reported for an average follow-up time of 24.1 ± 11.1 months postplacement and 22 ± 10.7 months postloading. The descriptive characteristics of the cohort are reported in Table 5. Specifically, treatments of this cohort were provided by four clinicians and with an average loading time of 2.2 ± 2.5 months postplacement.

The average ΔMBL was 0.00 ± 0.57 mm, with a distribution displayed in Fig 5. Corresponding values after 11 to 12 months (12 ± 0.6), 13 to 24 months (21.2 ± 2.8), and > 24 months (32.9 ± 8.4) postloading were 0.03 ± 0.62 mm (18 implants), 0.16 ± 0.56 mm (10 implants), and –0.14 ± 0.52 mm (17 implants), respectively (Fig 6).

Individual univariate models did not reveal any significant association between ΔMBL and age (*P* = .212), loading (*P* = .225), or transgingival height (*P* = .976).

Multivariate regression analysis did reveal a significant association between ΔMBL and the loading protocol (*P* = .027), but not between ΔMBL and age (*P* = .082) or transgingival height (*P* = .223) (Table 6). Specifically, immediately loaded implants displayed on average a 0.47 mm negative difference in ΔMBL compared to conventionally loaded implants.

Associations were derived by mixed multivariate regression models with the age of the patient, transgingival height, and loading protocol as a fixed effects, and the patient as random effect.

DISCUSSION

The current study documented the clinical performance of a hybrid TL implant that displayed a specific platform-switched design at the crestal level of the implant. This implant design was expected to support crestal bone stability and implant survival. The retrospective analysis of patient records reported herein found a 54-month cumulative survival rate of 98.9% for the analyzed average follow-up of 20.7 months. A radiographically stable marginal bone level was measured after an average follow-up of 24.1 months postloading.

Considering the limited average follow-up time of 20.7 months, the 54-month CSRs of 98.9% at the implant level and 95.3% at the patient level observed herein are in good agreement and comparable to other studies on TL implants: 5 year-CSRs of 98.76% and 98.13% at implant and patient levels, respectively, for Kim et al[11]; a 5 year-CSR of 97.9% and a survival rate of 99.4% between 4 to 5 years at the implant level for Buser et al[25]; and a survival rate of 99% at 3 years at the implant level for French et al.[26] The three failed implants were lost early after implant placement, and no implant fracture was reported.

Furthermore, despite this study's limited observation time and sample size, the fact that the observed ΔMBL was close to 0 mm suggests that the transgingival implant design has a positive effect on marginal bone levels. Overall, the observed values were consistent with other retrospective studies reporting on the ability of TL implants to support crestal bone stability. Specifically, Kumar et al[8] reported a ΔMBL derived from panoramic radiographs of –0.61 ± 1.13 mm and –0.93 ± 0.42 mm at 1 (79 implants) and 3 years (43 implants) after implant placement, respectively. Wallner et al[27] reported a ΔMBL of –0.15 ± 0.53 mm on periapical radiographs for 20 implants after a mean follow-up time of 4.9 years, and Kang et al[28] reported a ΔMBL between –0.05 ± 0.17 mm after 1 year (1,585 implants) and –0.17 ± 0.45 mm after 9 years (198 implants), as derived from periapical and panoramic radiographs analysis. Finally, in a prospective cohort study, Bornstein et al[29] reported an average change of 0.15 mm observed between 3 months and 5 years after early loading. Despite the obvious limitation brought by the reduced ΔMBL cohort size as a result of the selection process, the final sample size of 45 remains in the same order of magnitude as these previous works.

In agreement with other reports, the most prominent mechanical or technical complication observed herein was screw loosening.[30] The restriction to screw-retained restorations as the sole connection type analyzed within this study was particularly relevant to the outcomes, as factors like cement pollution, subgingival platform positioning, and compromised access for maintenance that may negatively impact ΔMBLs and implant survival when applying alternative connection types could be excluded for the analyzed cohort.[31]

The current study further suggested a negative impact on ΔMBL after immediate loading compared to delayed loading protocols, with the immediately loaded implants showing an average of 0.47 mm less bone gain or more bone loss compared to conventionally loaded counterparts. These results contrasted with recent systematic reviews by Suarez et al[32] and Sommer et al,[33] who have failed to identify a systematic effect of the timing of restoration on marginal bone level[32] and reported a significantly higher marginal bone loss for conventional loading protocols compared to immediate, immediate nonocclusal, early loadings 1 year after implant placement.[33]

Also, the current study failed to show an effect of age or transgingival height on ΔMBL, which is contrary to previous preliminary results studying the same implant type.[20] These differences may be attributed to the radiographic assessment methodology used and different baseline settings for the studies. Specifically, Fillion et al[20] assessed marginal bone levels during a period of 2 to 6 months after implant placement, while this study reported on the ΔMBL after significantly longer periods by using the time of loading as the baseline timepoint. Therefore, the results presented here may better represent the possible postloading physiological changes of marginal bone levels around this specific implant type after being put into function.

A further important aspect of this study was the use of an improved methodology for ΔMBL assessment, which was based on strictly selected periapical radiographs with sufficient resolution. Specifically, the ΔMBL analysis was based on 45 implants placed by four implantology specialists as part of partial to full-arch prosthetic restorations. In contrast to traditional methods, the applied methodology determined the first bone contact based on software digital radiographic gray level profiles. This addressed a major source of error related to the capability to distinguish neighboring gray levels via visual observation (law of simultaneous contrast[34]). Compared to the original methodology introduced by Weber et al,[24] the presented methodology used standardized calibrated gray level profiles and was, unlike human visual evaluation, not biased by intrinsic differences between individual radiographs, like the visual acuity, lighting, and magnification. Further, the applied method compensated for the angulation error of the radiographic images or the absence of bone walls as much as possible by identifying the presence of four bone walls based on calibrated radiographic gray level values. Finally, substantial efforts were put into the calibration of the examiners to prepare for the radiographic assessment, and future research may address the robustness of the presented methodology towards angular variations during the radiography.

Finally, although the methodology for measuring ΔMBL on two-dimensional images has certain known limitations,[35] the high radiographic resolution and the absence of artifacts on periapical radiographs, unlike three-dimensional CBCT or CT measurements, confirm its usefulness as a technique of choice. Future improvements in the methodology may automate the evaluation process or apply machine learning algorithms to analyze the bone level around implants more quickly and easily, as demonstrated in similar applications around teeth.[36]

Another important aspect of the presented study was related to retrospectively analyzing the patient records of real-world routine treatment outcomes, which differs from the standardized set-up encountered in long-term or large retrospective cohort studies traditionally reported in the scientific literature.[11,25,37,38] French et al[39] recently re-emphasized the importance of these real-world implantology data to document the "real life" performance of dental implants over time. Although retrospective designs may be classically limited in determining the direct cause and effect relationship between treatment outcomes and interventions, they may be well suited to determine the event rates in conventional dental implant therapies. This retrospective multicenter cohort study collected patient records from 23 private practices and analyzed real-world data, overcoming potential biases of more controlled setups.[40]

One of the limitations of the presented study of ΔMBL may be related to the small number of implants. This number only allowed for consideration of the impact of age, transgingival height, and loading procedure as potential risk factors as part of the univariate and multivariate analysis, while immediate implantation[41] (representing 46.7 % of the cases herein), additional bone surgery,[42] or the angulation of abutments[30] may represent other potentially interesting characteristics reported to impact ΔMBL. Prospective studies with large samples and long-term observational periods may complement the presented real-world retrospective data.

CONCLUSIONS

The high cumulative survival rates and stable marginal peri-implant bone levels found in the current study support recent TL implants with a hybrid design as a suitable treatment option for restoring partially or fully edentulous patients, with a good mid-term prognosis. The retrospective design and the small sample size for the evaluation of the ΔMBL outcome reported herein should be complemented by future prospective studies, ideally in a multicentric real-world setup.

ACKNOWLEDGMENTS

The experienced implant surgeons who contributed to this study were Francis Bailly, Guillaume Becker, Philippe Boghanim, Pierre Bruet, Damien Carrotte, Olivier Chabadel, Philippe Colin, Loic David, Christophe Foresti, Richard Garrel, Thomas Guillaumin, Philippe Heraud, Georges Khoury, Franck Sayac, Jean-Baptiste Verdino, Jacques Vermeulen, and Mathieu Fillion.
The authors would like to thank Fanny Paris and Lucas Rocher for the help with the radiographic retrieval and assessment, and Delphine Maucort-Boulch for reviewing the statistics.

Conceptualization: D.C., L.L., C.L., K.G., and B.G.; investigation: D.C.; statistics: CL..; writing—original draft preparation: D.C.; writing—review and editing: L.L., M.D., C.L., K.G., and B.G;. supervision: K.G. and B.G.

M.D. is an employee of Institut Straumann, Basel, Switzerland. The other authors reported no conflicts of interest related to this study.

REFERENCES

1. Lago L, da Silva L, Gude F, Rilo B. Bone and soft tissue response in bone-level implants restored with platform switching: A 5-year clinical prospective study. Int J Oral Maxillofac Implants 2017;32:919–926.
2. Sakka S, Baroudi K, Nassani MZ. Factors associated with early and late failure of dental implants. J Investig Clin Dent 2012;3:258–261.
3. De Angelis F, Papi P, Mencio F, Rosella D, Di Carlo S, Pompa G. Implant survival and success rates in patients with risk factors: Results from a long-term retrospective study with a 10 to 18 years follow-up. Eur Rev Med Pharmacol Sci 2017;21:433–437.
4. Kandasamy B, Kaur N, Tomar GK, Bharadwaj A, Manual L, Chauhan M. Long-term retrospective study based on implant success rate in patients with risk factor: 15-year follow-up. J Contemp Dent Pract 2018;19:90–93.
5. Schoenbaum TR, Moy PK, Aghaloo T, Elashoff D. Risk factors for dental implant failure in private practice: A multicenter survival analysis. Int J Oral Maxillofac Implants 2021;36:388–394.
6. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
7. Misch CE, Perel ML, Wang H-L, et al. Implant success, survival, and failure: The International Congress of Oral Implantologists (ICOI) Pisa Consensus Conference. Implant Dent 2008;17:5–15.
8. 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.
9. Buser D, Mericske-Stern R, Dula K, Lang NP. Clinical experience with one-stage, non-submerged dental implants. Adv Dent Res 1999;13:153–161.

10. Cosola S, Marconcini S, Boccuzzi M, et al. Radiological outcomes of bone-level and tissue-level dental implants: Systematic review. IJERPH 2020;17:6920.
11. Kim S, Jung U-W, Cho K-S, Lee J-S. Retrospective radiographic observational study of 1692 Straumann tissue-level dental implants over 10 years: I. Implant survival and loss pattern. Clin Implant Dent Relat Res 2018;20:860–866.
12. Cochran DL. The scientific basis for and clinical experiences with Straumann implants including the ITI Dental Implant System: A consensus report. Clin Oral Implants Res 2000;11(suppl 1):33–58.
13. Hermann JS, Schoolfield JD, Schenk RK, Buser D, Cochran DL. Influence of the size of the microgap on crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged implants in the canine mandible. J Periodontol 2001;72:1372–1383.
14. Sasada Y, Cochran DL. Implant-abutment connections: A review of biologic consequences and peri-implantitis implications. Int J Oral Maxillofac Implants 2017;32:1296–1307.
15. Strietzel FP, Neumann K, Hertel M. Impact of platform switching on marginal peri-implant bone-level changes. A systematic review and meta-analysis. Clin Oral Implants Res 2015;26:342–358.
16. Pan YH, Lin HK, Lin JC-Y, et al. Evaluation of the peri-implant bone level around platform-switched dental implants: A retrospective 3-year radiographic study. Int J Environ Res Public Health 2019;16:E2570.
17. Messias A, Rocha S, Wagner W, et al. Peri-implant marginal bone loss reduction with platform-switching components: 5-year post-loading results of an equivalence randomized clinical trial. J Clin Periodontol 2019;46:678–687.
18. Tarnow DP. Dental implants in periodontal care. Curr Opin Periodontol 1993:157–162.
19. Esposito M, Salina S, Rigotti F, et al. Multicentre withinperson randomised controlled trial of 0.5 mm versus 1.5 mm subcrestal placement of dental implants with internal conical connection: Five-year post-loading results. Clin Tri Dent 2020;2:77.
20. Fillion M, Fauxpoint G. Preliminary results of bone level around a new shape of tissue level implant. Clinical Oral Implants Research 2019;30:312–312.
21. Recherches n'impliquant pas la personne humaine, études et évaluations dans le domaine de la santé Méthodologie de référence MR-004 | CNIL. Accessed 6 January 2022. https://www.cnil.fr/fr/declaration/mr-004-recherches-nimpliquant-pas-la-personne-humaine-etudes-et-evaluations-dans-le
22. von Elm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: Guidelines for reporting observational studies. Lancet 2007;370:1453–1457.
23. Albrektsson T, Zarb GA. Current interpretations of the osseointegrated response: Clinical significance. Int J Prosthodont 1993;6:95–105.
24. Weber HP, Buser D, Fiorellini JP, Williams RC. Radiographic evaluation of crestal bone levels adjacent to nonsubmerged titanium implants. Clin Oral Implants Res 1992;3:181–188.
25. Buser D, Mericske-Stern R, Bernard JP, et al. Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants. Clin Oral Implants Res 1997;8:161–172.
26. French D, Larjava H, Ofec R. Retrospective cohort study of 4591 Straumann implants in private practice setting, with up to 10-year follow-up. Part 1: multivariate survival analysis. Clin Oral Implants Res 2015;26:1345–1354.
27. Wallner G, Rieder D, Wichmann MG, Heckmann SM. Peri-implant bone loss of tissue-level and bone-level implants in the esthetic zone with gingival biotype analysis. Int J Oral Maxillofac Implants 2018;33:1119–1125.
28. Kang M-H, Jung U-W, Cho K-S, Lee J-S. Retrospective radiographic observational study of 1,692 Straumann tissue-level dental implants over 10 years. II. Marginal bone stability. Clin Implant Dent Relat Res 2018;20:875–881.
29. Bornstein MM, Schmid B, Belser UC, Lussi A, Buser D. Early loading of non-submerged titanium implants with a sandblasted and acid-etched surface. 5-year results of a prospective study in partially edentulous patients. Clin Oral Implants Res 2005;16:631–638.
30. Omori Y, Lang NP, Botticelli D, Papageorgiou SN, Baba S. Biological and mechanical complications of angulated abutments connected to fixed dental prostheses: A systematic review with meta-analysis. J Oral Rehabil 2020;47:101–111.
31. Wittneben J-G, Millen C, Brägger U. Clinical performance of screw-versus cement-retained fixed implant-supported reconstructions—A systematic review. Int J Oral Maxillofac Implants 2014;29:84–98.
32. Suarez F, Chan H-L, Monje A, Galindo-Moreno P, Wang H-L. Effect of the timing of restoration on implant marginal bone loss: A systematic review. J Periodontol 2013;84:159–169.
33. Sommer M, Zimmermann J, Grize L, Stübinger S. Marginal bone loss one year after implantation: A systematic review of different loading protocols. Int J Oral Maxillofac Surg 2020;49:121–134.
34. Soranzo A. Simultaneous color contrast. In: Luo MR (ed). Encyclopedia of Color Science and Technology. New York: Springer, 2016:1149–1152.
35. Saleh MHA, Ravidà A, Suárez-López Del Amo F, Lin G-H, Asa'ad F, Wang H-L. The effect of implant-abutment junction position on crestal bone loss: A systematic review and meta-analysis. Clin Implant Dent Relat Res 2018;20:617–633.
36. Krois J, Ekert T, Meinhold L, et al. Deep learning for the radiographic detection of periodontal bone loss. Sci Rep 2019;9:8495.
37. Simonis P, Dufour T, Tenenbaum H. Long-term implant survival and success: A 10-16-year follow-up of non-submerged dental implants. Clin Oral Implants Res 2010;21:772–777.
38. Lini F, Poli PP, Beretta M, Cortinovis I, Maiorana C. Long-term retrospective observational cohort study on the survival rate of stepped screw titanium implants followed up to 20 years. Int J Oral Maxillofac Implants 2019;34:999–1006.
39. French D, Ofec R, Levin L. Long term clinical performance of 10,871 dental implants with up to 22 years of follow-up: A cohort study in 4,247 patients. Clin Implant Dent Relat Res 2021;23:289–297.
40. Dard M. The standardised in-line clinical case series: A new concept for real-world evidence in dentistry. 2017;3:6.
41. Chappuis V, Engel O, Reyes M, Shahim K, Nolte L-P, Buser D. Ridge alterations post-extraction in the esthetic zone: A 3D analysis with CBCT. J Dent Res 2013;92:195S–201S.
42. Kuchler U, Chappuis V, Gruber R, Lang NP, Salvi GE. Immediate implant placement with simultaneous guided bone regeneration in the esthetic zone: 10-year clinical and radiographic outcomes. Clin Oral Implants Res 2016;27:253–257.