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Comparative Assessment of Primary Stability, Secondary Stability, and Marginal Bone Loss in Immediate Post-Extraction Implants: A Retrospective Study of Three Implant Macro-Geometries

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Abstract

Background: Achieving predictable primary and secondary stability while preserving crestal bone in immediate post-extraction sockets remains technically demanding. This retrospective study compared stability progression, marginal bone loss (MBL), and early complication rates across three implant systems with distinct macro-geometries placed in fresh extraction sockets. **Methods:** Records of 120 immediate post-extraction implants allocated to Group A (C-Tech; n = 40), Group B (Straumann BLT; n = 40), and Group C (BTK IS+; n = 40) were reviewed. Primary stability was evaluated at implant placement (ISQ T0, Day 0), secondary stability was assessed at impression taking at 12 weeks/3 months (ISQ T1), and final stability prior to prosthetic loading was recorded at 16 weeks/4 months (ISQ T2). MBL was measured radiographically 1 year post-loading. Comparative assessments of ISQ at T1/T2 and MBL were conducted exclusively on surviving implants. **Results:** Overall 1-year survival rates were 100% (40/40) for Group A, 97.5% (39/40) for Group B, and 87.5% (35/40) for Group C. Group A demonstrated significantly higher ISQ values across all intervals (T0: 69.8 ± 10.6, T1: 81.5 ± 5.6, T2: 84.1 ± 4.6) relative to Group B (T0: 49.3 ± 8.6, T1: 71.3 ± 4.3, T2: 72.0 ± 4.1) and Group C (T0: 44.8 ± 8.3, T1: 64.1 ± 3.1, T2: 64.1 ± 3.1; $p < 0.001$). At 1 year post-loading, mean MBL was significantly lower in Group A (0.22 ± 0.38 mm) and Group B (0.29 ± 0.44 mm) compared to Group C (0.97 ± 1.25 mm; $p < 0.001$). **Conclusions:** Significant differences in initial stability, secondary stability trajectories, and 1-year marginal bone levels were observed among the implant systems evaluated in immediate post-extraction sites. Implants featuring double-lead or tapered configurations were associated with higher initial ISQ readings and enhanced crestal bone preservation.

Keywords: dental implants; tooth extraction; osseointegration; vibration; alveolar bone loss; retrospective studies

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1. Introduction

Primary implant stability is considered a fundamental prerequisite for predictable osseointegration and for the clinical success of immediate and early loading protocols, particularly in immediate post-extraction sites, where the morphology of the fresh socket,

the limited circumferential bone support, and the need to achieve apical and/or palatal or lingual anchorage may render initial mechanical stabilization more challenging than in healed ridges [1–4]. Implant stability is a dynamic and multifactorial phenomenon influenced by host-related, site-related, surgical, and implant-related variables, including bone density, cortical engagement, implant position within the maxilla or mandible, anterior or posterior location, osteotomy preparation, and implant macro-design features such as taper, thread depth, thread pitch, and cervical configuration [5]. In this biological and biomechanical setting, resonance frequency analysis (RFA), expressed as the implant stability quotient (ISQ), has been widely adopted as a non-invasive and repeatable method for assessing implant stability over time [6,7], and previous reviews have supported its clinical usefulness for monitoring the transition from primary mechanical stability to secondary biologic stability during healing, even though ISQ values should always be interpreted in conjunction with the overall clinical context rather than as isolated predictors of outcome [8]. The temporal evolution of implant stability is known to reflect the interplay between the initial mechanical engagement of the implant and the subsequent phases of bone resorption, formation, and maturation at the implant–bone interface, and distinct stability patterns may be observed according to implant design and local bone conditions [9,10]. Immediate implant placement has been shown to represent a reliable treatment option when adequate case selection and surgical execution are achieved, with long-term reviews indicating survival rates and marginal bone level conditions broadly comparable to those reported for implants placed in healed sites, although immediate protocols may be associated with greater technique sensitivity and with site-dependent variability in primary stability and peri-implant tissue remodeling [11–13]. At the same time, implant macro-geometry appears to exert a clinically relevant influence on primary stability, since tapered implants and more aggressive thread configurations may enhance bone engagement and insertional fixation, especially in sites with reduced bone density, while differences in macro-design may also influence the subsequent pattern of stability gain and crestal bone remodeling during healing and after loading [14,15]. The relationship between insertion torque, ISQ values, and clinical performance remains complex, as systematic evidence suggests that insertion torque and RFA reflect related but non-equivalent aspects of primary stability, underscoring the importance of evaluating each parameter within a broader clinical framework [16–18]. In addition to implant stability, marginal bone level changes remain a key outcome variable in implant dentistry because early crestal remodeling may reflect the combined effects of implant design, surgical trauma, prosthetic loading, biologic width establishment, and host response, and previous clinical investigations have therefore examined marginal bone loss together with RFA-derived stability values in order to characterize the biomechanical and biologic behavior of different implant systems [19,20]. Likewise, biological and technical complications, including implant failure, implant fracture, abutment fracture, and prosthetic screw fracture, remain essential outcome measures when comparing implant systems, since such events may be influenced by insufficient primary stability, unfavorable load transfer, prosthetic biomechanics, or the interaction between implant geometry and bone support [21,22]. Patient-related factors may further modulate these outcomes, as age-related differences in cortical density and bone remodeling capacity, together with anatomical variation between maxillary and mandibular sites and between anterior and posterior regions, may affect both the magnitude of primary fixation and the subsequent evolution of implant stability and peri-implant bone maintenance [17,23,24]. Against this background, the present retrospective clinical study was designed to compare three implant groups—Group A (C-Tech), Group B (Straumann Bone Level Tapered), and Group C (BTK IS+)—placed in immediate post-extraction sites in the upper and lower jaws, across anterior and posterior regions, with an additional exploratory subgroup analysis within Group A

comparing CP and EL implant designs. This study aimed to perform a retrospective analysis of ISQ values recorded at implant insertion and at prosthetic loading after 4 months, as well as marginal bone loss at 1 year after loading in the analyzed systems and the incidence of biologic and technical complications, including implant failure, implant fracture, and fracture of prosthetic screws or abutments. In addition, the study aimed to explore the association between these outcomes, patient age, and implant system in order to clarify whether implant macro-design and patient-related variables may influence the evolution of stability, peri-implant marginal bone preservation, and complication rates in immediately placed post-extraction implants.

2. Materials and Methods

This retrospective comparative clinical study was conducted on patients treated with immediate post-extraction implants in routine clinical practice and was designed and reported in accordance with the principles of the Declaration of Helsinki and the STROBE statement for observational studies [25]. The study was approved by the Academic Ethics Committee of the University of Genova CERA with the reference 2026/57. Due to the retrospective design of this study, data were collected a posteriori from an external clinical center, precluding randomized allocation to the treatment groups. To ensure consistency across the cohort and limit operator bias, all surgical procedures and implant placements across all three groups were performed by the same experienced surgeon during the same study timeframe using standardized clinical protocols. Clinical records and radiographic documentation of eligible patients were reviewed, and implants were allocated to three main Groups according to the implant system used: Group A (C-Tech®), Group B (Straumann Bone Level Tapered®), and Group C (BTK IS+®) (C-Tech Implant San Pietro in Casale (BO), Italy; Straumann, Basel, Switzerland; BTK Biotec srl Povolaro di Dueville (VI), Italy). These three implant systems were specifically selected to evaluate the clinical and biomechanical impact of distinct macro-geometric thread designs in immediate extraction sockets. Specifically, the C-Tech® implant features an aggressive double-lead thread geometry (double-thread design) designed for faster insertion and enhanced apical engagement with thin threads on the coronal part to preserve the cortical bone, whereas the Straumann BLT and BTK IS+ systems incorporate single-thread geometries with differing taper and pitch profiles, allowing for a comparative assessment of primary fixation and subsequent tissue stability across distinct macro-geometries.

Patients were considered eligible when they had received an immediate post-extraction implant placed in a fresh extraction socket, had complete clinical records, had implant stability measurements obtained by resonance frequency analysis at implant placement and again at the impression time and the prosthetic delivery, and had standardized radiographic follow-up including a radiograph obtained at implant insertion and a control radiograph taken 1 year after prosthetic loading. Both maxillary and mandibular sites, as well as anterior and posterior regions, were included to reflect the variability of routine clinical indications for immediate implant placement. Regarding post-extraction sites, inclusion was restricted strictly to fresh sockets demonstrating completely intact socket walls with fully preserved buccal bone integrity. Sockets exhibiting partial or total loss/defect of any bony wall (e.g., compromised buccal plate) were excluded from the study.

Exclusion criteria were as follows:

- Incomplete clinical or radiographic documentation;
- Absence of ISQ recordings;
- Follow-up shorter than 1 year after prosthetic loading;
- Delayed implant placement in healed ridges;

- Simultaneous major regenerative procedures likely to substantially affect primary stability or marginal bone remodeling;
- Uncontrolled systemic diseases contraindicating implant surgery;
- Previous head and neck radiotherapy;
- Intravenous antiresorptive therapy;
- Active untreated periodontal disease and extraction sites with acute destructive pathology preventing immediate implant stabilization;
- Cases requiring implant replacement after early failure were excluded from the comparative analysis of implant stability and marginal bone loss.

Cases requiring implant replacement after early failure were recorded for survival analysis but strictly excluded from subsequent comparative assessments of secondary stability (ISQ at T1 and T2) and 1-year marginal bone loss (MBL). Consequently, T1/T2 ISQ and 1-year MBL analyses were conducted exclusively on surviving implants.

All implants were placed immediately after tooth extraction under local anesthesia using an atraumatic surgical approach intended to preserve the socket walls, particularly the buccal plate and, when present, the interradicular septum. Whenever clinically feasible, extraction was performed flapless by means of minimally traumatic instruments, with root sectioning when required, followed by careful socket debridement to remove granulation tissue and saline irrigation. Implant osteotomy preparation was carried out according to the manufacturer's drilling sequence, with the aim of engaging native bone beyond the apex and/or along the palatal or lingual wall to maximize primary stability (Figure 1). Implants were inserted in a prosthetically driven three-dimensional position, and the peri-implant gap, when present, was managed according to defect morphology and the operator's routine clinical protocol.

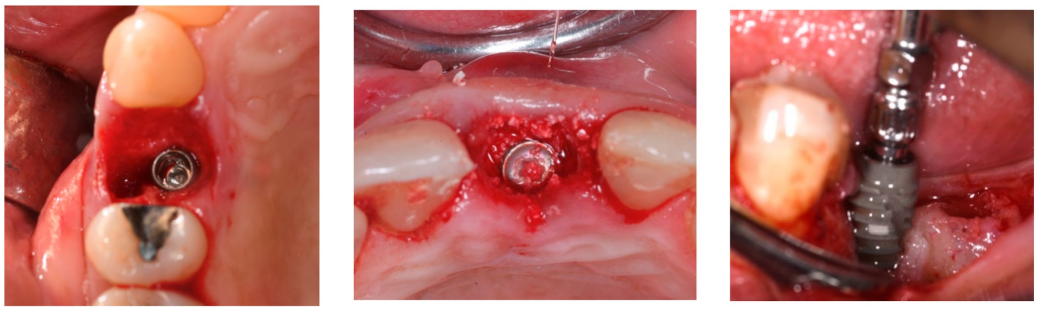


Figure 1. Three cases of immediate implantation: (**a**) C-Tech CP® implant placed in the extraction socket; (**b**) Bone Level Tapered Straumann and marginal gap filling with biomaterial; (**c**) BTK IS+® immediate implant.

All implants were inserted, ensuring an insertion torque value exceeding 35 Ncm to guarantee adequate primary stability. In all cases requiring peri-implant defect or gap grafting, bovine-derived hydroxyapatite was uniformly applied as the grafting material. A standardized delayed prosthetic loading protocol was applied for all restorations at 4 months (16 weeks) post-placement.

Primary implant stability was assessed at placement by resonance frequency analysis measured with the Osstell device and recorded as implant stability quotient (ISQ) at baseline (T0) (Figure 2).



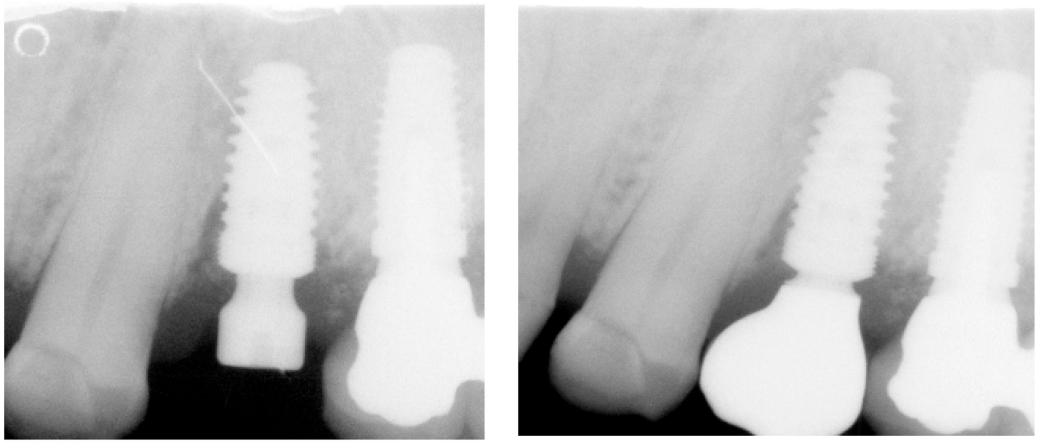
Figure 2. The RFA pin is inserted into the implant, and the ISQ reading is measured with the Osstell® device.

Implant stability quotient (ISQ) values were recorded at three specific time points: T0 (implant insertion), T1 (impression taking at 3 months post-surgery), and T2 (definitive prosthetic loading at 4 months post-surgery). The primary outcome measure was implant stability, expressed as ISQ at different time intervals. Secondary outcome measures were marginal bone loss at 1 year after loading and the incidence of biological and technical complications, including implant failure, implant fracture, fracture of prosthetic screws, and fracture of abutments.

Marginal bone loss was assessed radiographically by comparing the radiograph obtained immediately after implant placement with the radiograph taken 1 year after prosthetic loading. Mesial and distal bone levels were measured by an independent examiner with ImageJ software (https://imagej.net/ij/) from a reproducible reference point at the implant platform or shoulder to the most coronal bone-to-implant contact, and image calibration was performed using the known implant length or diameter to compensate for radiographic distortion. The mean of the mesial and distal measurements was used for the analysis of peri-implant marginal bone changes (Figure 3).

To assess the early mechanical engagement provided by the different thread geometries, the micromotor insertion torque was standardized and capped at 30 Ncm; at this preliminary threshold, insertion was momentarily paused to record the exposed length of the implant body remaining above the socket margin using a calibrated periodontal probe (PCP UNC 15, Hu-Friedy). Subsequently, implant seating was always manually completed using a surgical torque wrench until reaching the intended prosthetically driven position while ensuring that final insertion torque values remained within safe clinical limits (Figure 4).

For each implant, the following variables were retrieved from the records: patient age at surgery, sex, implant system, implant site, jaw, region (anterior/posterior), ISQ T0, ISQ at T1, ISQ at T2, mm of implant at 30 Ncm, radiographic marginal bone loss at 1 year after loading, and occurrence of complications during follow-up.



(**a**) (**b**)

Figure 3. A case of C-Tech CP: (**a**) periapical X-ray at the implant placement; (**b**) periapical X-ray 12 months after loading. MBL was measured as *the level of bone 12 months after loading minus the level of bone at the implant placement*.

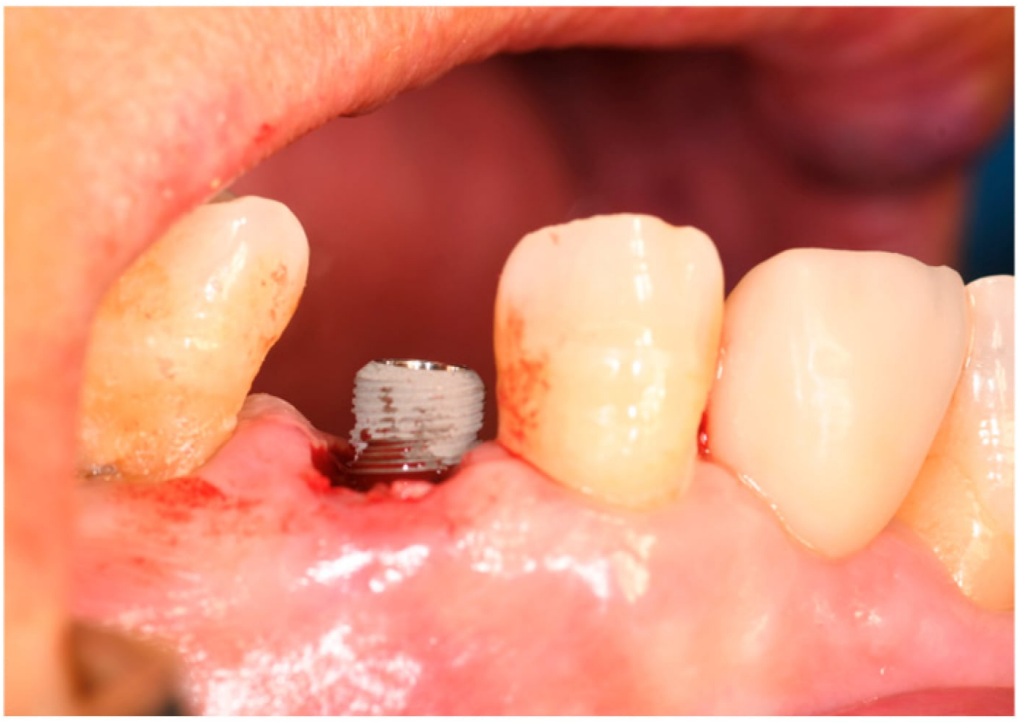


Figure 4. The amount of implant body that remains out of the extraction socket after setting the insertion torque at 30 N was measured with a periodontal probe (PCP UNC 15 Hu Friedy®).

Age was additionally analyzed as an explanatory variable to investigate its possible association with implant stability and marginal bone remodeling. In addition to the main comparison among the three implant groups, a secondary subgroup analysis was planned within Group A in order to compare CP and EL implant designs; given the unequal subgroup distribution, this analysis was considered exploratory in nature.

A sample size justification was performed for the primary comparison among the three implant groups. With 40 implants per group, the study was considered adequately sized to detect a moderate-to-large difference in ISQ values for the principal comparative analysis at a two-sided alpha level of 0.05 and 80% statistical power. However, no formal power was assumed for the CP versus EL subgroup comparison within Group A, owing

to the unequal distribution of 26 and 14 implants, and findings from this analysis were therefore interpreted with caution.

Sample size calculation was performed prior to statistical analysis using G-Power software (version 3.1) for a one-way Analysis of Variance (ANOVA) among three independent groups. Based on primary outcome differences in ISQ values, assuming a medium effect size (f = 0.29), an alpha error rate of 0.05, and a statistical power of 80% (0.80), a minimum sample size of 38 implants per group (114 total) was calculated as necessary to detect statistically significant intergroup differences. A total cohort of 120 implants (40 per group) was ultimately analyzed, ensuring adequate statistical power. However, no formal power was assumed for the exploratory CP versus EL subgroup comparison within Group A.

Descriptive statistics were calculated for all variables. Continuous variables are expressed as mean and standard deviation, whereas categorical variables are presented as absolute frequencies and percentages. Normality of distribution was assessed using the Shapiro–Wilk test. Intragroup changes in ISQ between baseline and 4 months were analyzed using paired tests, while intergroup comparisons among the groups were performed using one-way analysis of variance or the Kruskal–Wallis test according to data distribution. When appropriate, post hoc pairwise comparisons with adjustment for multiple testing were performed. Marginal bone loss at 1 year was analyzed similarly, and complication rates were compared using the chi-square test or Fisher's exact test, as appropriate. The exploratory comparison between the three groups was performed separately using independent-samples testing according to variable distribution. Correlation or regression analysis was used to assess the association between age and the principal study outcomes. Statistical significance was set at $p < 0.05$.

To evaluate stability trends over time, intragroup temporal progression was analyzed across time points (T0, T1, and T2) alongside intergroup comparisons at each specific interval. While separate time-point analyses demonstrate distinct baseline fixation and secondary stability patterns for each macro-geometry, longitudinal stability trajectories reflect the dynamic transition from mechanical to biological integration across systems.

3. Results

3.1. Sample Characteristics

A total of 120 immediate post-extraction implants were analyzed, with 40 implants initially placed in each group. Within Group A, 26 implants used the CP design and 14 the EL design, as reported in Table 1.

No implant failures were recorded in Group A (C-Tech) during the healing period or within the first year after loading. In Group B (Straumann BLT), 1 implant was lost, whereas in Group C (BTK IS+), 5 implants were classified as early failures. No implant fracture, abutment fracture, or prosthetic screw fracture occurred in any group during the observation period. Overall 1-year cumulative implant survival rates were 100% for Group A (40/40), 97.5% for Group B (39/40), and 87.5% for Group C (35/40).

The overall mean age of patients in Group A was 61.5 ± 10.6 years, with a similar age distribution across Group B (60.2 ± 11.1 years) and Group C (59.8 ± 10.4 years) ($p = 0.742$).

Implant stability over time (ISQ): Across all groups, mean ISQ values showed a statistically significant increase from implant placement (T0) to prosthetic loading (T2) ($p < 0.001$ for intragroup temporal progression in all three systems), confirming progressive osseointegration.

Statistically significant differences in ISQ values were detected among the three implant groups at all observation time points (intergroup $p < 0.001$). In Group A, mean ISQ was 69.8 ± 10.6 at T0, 81.5 ± 5.6 at T1, and 84.1 ± 4.6 at T2. Group B exhibited significantly lower primary stability at placement (49.3 ± 8.6, $p < 0.001$ vs. Group A), reaching 71.3 ± 4.3

at T1 and 72.0 ± 4.1 at T2 ($p < 0.001$ vs. Group A). Group C demonstrated the lowest ISQ values across all time points: 44.8 ± 8.3 at T0, 64.1 ± 3.1 at T1, and 64.1 ± 3.1 at T2 ($p < 0.001$ compared to both Group A and Group B).

Table 1. Baseline demographic and implant characteristics across the study groups.

Characteristic/Parameter	Overall Cohort (n = 120)	Group A (n = 40)	Group B (n = 40)	Group C (n = 40)
Total Implants (n)	**120**	**40**	**40**	**40**
Age (years)				
Mean ± SD	48.0 ± 10.5	48.3 ± 10.8	47.8 ± 10.2	47.9 ± 10.6
Min–Max	24–72	25–71	24–70	26–72
Sex (n, %)				
Male	70 (58.3%)	23 (57.5%)	24 (60.0%)	23 (57.5%)
Female	50 (41.7%)	17 (42.5%)	16 (40.0%)	17 (42.5%)
Jaw (n, %)				
Maxilla	60 (50.0%)	20 (50.0%)	20 (50.0%)	20 (50.0%)
Mandible	60 (50.0%)	20 (50.0%)	20 (50.0%)	20 (50.0%)
Region (n, %)				
Anterior (Incisors & Canines)	45 (37.5%)	15 (37.5%)	15 (37.5%)	15 (37.5%)
Posterior (Premolars & Molars)	75 (62.5%)	25 (62.5%)	25 (62.5%)	25 (62.5%)
Tooth Region (n, %)				
Incisors	24 (20.0%)	8 (20.0%)	8 (20.0%)	8 (20.0%)
Canines	21 (17.5%)	7 (17.5%)	7 (17.5%)	7 (17.5%)
Premolars	45 (37.5%)	15 (37.5%)	15 (37.5%)	15 (37.5%)
Molars	30 (25.0%)	10 (25.0%)	10 (25.0%)	10 (25.0%)
Implant Diameter (mm)				
Mean ± SD	4.0 ± 0.4	4.0 ± 0.4	4.0 ± 0.4	4.0 ± 0.4
Min–Max	3.3–5.1	3.3–5.1	3.3–5.1	3.3–5.1
Implant Length (mm)				
Mean ± SD	10.0 ± 1.2	10.0 ± 1.2	10.0 ± 1.2	10.0 ± 1.2
Min–Max	8.0–13.0	8.0–13.0	8.0–13.0	8.0–13.0
Implant Dimensions (n, %)				
Narrow (≤3.5 mm)	24 (20.0%)	8 (20.0%)	8 (20.0%)	8 (20.0%)
Standard (3.8–4.3 mm)	72 (60.0%)	24 (60.0%)	24 (60.0%)	24 (60.0%)
Wide (≥4.8 mm)	24 (20.0%)	8 (20.0%)	8 (20.0%)	8 (20.0%)

In the exploratory subgroup analysis of Group A, C-Tech CP implants showed mean ISQ values of 69.0 ± 3.5 at T0, 81.0 ± 1.4 at T1, and 84.0 ± 1.4 at T2. C-Tech EL implants showed mean values of 67.0 ± 2.1 at T0, 83.0 ± 7.0 at T1, and 84.0 ± 7.0 at T2. No statistically significant differences were observed between CP and EL designs at T0 ($p = 0.062$) or T2 ($p = 0.981$) (Table 2).

Patient age evaluated as a continuous variable showed no statistically significant correlation with baseline ISQ at T0, secondary stability at T2, or 1-year MBL across the study cohort ($p > 0.05$).

Table 2. Implant stability quotient (ISQ) values recorded at baseline/insertion (T0, Day 0), impression taking (T1, 12 weeks/3 months), and prosthetic loading (T2, 16 weeks/4 months) across study groups.

Implant Group	n	ISQ T0 (Mean ± SD)	ISQ T1 (Mean ± SD)	ISQ T2 (Mean ± SD)	*p*-Value (Intragroup Temporal Change)
Group A (C-Tech) overall	40	69.8 ± 10.6	81.5 ± 5.6	84.1 ± 4.6	<0.001
Group B (Straumann BLT)	39	49.3 ± 8.6	71.3 ± 4.3	72.0 ± 4.1	<0.001
Group C (BTK IS+)	35	44.8 ± 8.3	64.1 ± 3.1	64.1 ± 3.1	<0.001
p-value (Intergroup comparison)		<0.001	<0.001	<0.001	
Subgroup Analysis:					
C-Tech CP	26	69.0 ± 3.5	81.0 ± 1.4	84.0 ± 1.4	<0.001
C-Tech EL	14	67.0 ± 2.1	83.0 ± 7.0	84.0 ± 7.0	<0.001

3.2. Marginal Bone Loss at 1 Year

Statistically significant differences in 1-year MBL were detected among the three systems ($p < 0.001$). Group A demonstrated a mean MBL of 0.22 ± 0.38 mm, while Group B showed a mean MBL of 0.29 ± 0.44 mm; post-hoc pairwise comparison revealed no significant difference between Group A and Group B ($p = 0.812$). Conversely, Group C presented a significantly higher mean MBL of 0.97 ± 1.25 mm compared to both Group A ($p < 0.001$) and Group B ($p < 0.001$). MBL was not significantly influenced by age stratification in any group ($p > 0.05$) (Table 3).

Table 3. Marginal bone loss (MBL) at 1-year follow-up. Sample sizes for T1, T2, and MBL evaluations represent surviving implants only (Group A: n = 40; Group B: n = 39; Group C: n = 35).

Implant Group	n (Surviving Implants)	MBL, Mean ± SD (95% CI) [mm]	*p*-Value (Intergroup Comparison)
Group A (C-Tech)	40	0.22 ± 0.38 (0.09–0.34)	< 0.001
Group B (Straumann BLT)	39	0.29 ± 0.44 (0.15–0.43)	*(Group A vs. B: p = 0.812)*
Group C (BTK IS+)	35	0.97 ± 1.25 (0.57–1.37)	*(Group C vs. A/B: p < 0.001)*

3.3. Implant Position Relative to Bone (mm at 30 N)

The mean length of the implant remaining outside the bone margin at the standardized motor torque of 30 Ncm differed significantly among systems ($p = 0.038$). Group A presented a mean unengaged length of 1.79 ± 2.03 mm, Group B averaged 1.41 ± 1.20 mm, and Group C averaged 1.23 ± 1.15 mm. Post hoc analysis showed a significant difference between Group A and Group C ($p = 0.029$), whereas no significant difference was observed between Group A and Group B ($p = 0.415$). No correlation was found between exposed length at 30 Ncm and 1-year MBL ($r = 0.11$, $p = 0.235$) (Table 4).

Table 4. Mean implant length remaining outside bone at 30 Ncm.

Implant Group	n (Total Placed)	mm Outside Bone at 30 Ncm (Mean ± SD)	*p*-Value (Intergroup Comparison)
Group A (C-Tech)	40	1.79 ± 2.03 (1.14–2.45)	0.038
Group B (Straumann BLT)	40	1.41 ± 1.20 (0.81–1.54)	*(Group A vs. B: p = 0.415)*
Group C (BTK IS+)	40	1.23 ± 1.15 (0.81–1.54)	*(Group A vs. C: p = 0.029)*

3.4. Summary of Main Findings

Taken together, these results indicate that Group A implants achieved the highest ISQ values at both placement and 4 months, with very limited marginal bone remodeling and no failures in the first year. Group B implants showed lower primary stability but a pronounced increase in ISQ during healing, minimal MBL, and only one failure, while Group C implants, although reaching sufficient secondary stability at 4 months, exhibited lower initial ISQ, higher mean MBL, and a higher number of failures. Age appeared to influence primary stability, with older patients generally showing higher ISQ at placement, whereas secondary stability at 4 months and marginal bone changes at 1 year did not demonstrate clinically relevant differences between younger and older patients across the three implant systems.

4. Discussion

The present retrospective study evaluated primary and secondary implant stability, marginal bone loss, and early complications among three implant systems placed in immediate post-extraction sites. Overall, all systems showed an increase in ISQ values from implant placement to prosthetic loading, confirming that resonance frequency analysis can effectively document the transition from primary mechanical stability to secondary biologic stability during healing. This finding is consistent with previous clinical and retrospective studies reporting that ISQ values generally increase over time as osseointegration progresses, although the magnitude and pattern of change may vary according to implant design, bone quality, and implant site [3,26–28].

Among the investigated systems, Group A implants (C-Tech®) showed the highest ISQ values at all observation times, with mean values increasing from about 69.8 at placement to 84.1 at 4 months. Group B implants (Straumann BLT®) showed lower initial values but a clear increase during healing, whereas Group C implants (BTK IS+®) showed the lowest mean ISQ values both at placement and at 4 months. These findings suggest that distinct performance patterns were associated with the different macro-geometries evaluated. While taper and thread geometry are known to contribute to initial mechanical engagement and insertion behavior, observational differences across groups should be interpreted cautiously, as other clinical and anatomical variables inherent to a retrospective design may also contribute to these findings. At the same time, the progressive increase in ISQ observed in all groups supports the concept that lower primary stability does not necessarily preclude successful secondary stability, provided that healing is uneventful and adequate biologic integration occurs [29].

The internal comparison within the C-Tech® Group further suggests that implant design may influence the early stability profile without necessarily affecting final stability at loading. In the present study, CP implants showed slightly higher ISQ values at insertion, whereas EL implants reached similar values by 4 months despite greater variability during the healing phase. This pattern is clinically relevant because repeated ISQ measurements over time appear to be more informative than a single absolute baseline value, particularly when comparing implants with different macro-geometries or placed under different anatomic conditions [28].

Age stratification showed that older patients tended to present slightly higher ISQ values at insertion, whereas younger patients showed similar or slightly higher values at later time points. Although this observation should be interpreted cautiously, it may suggest that age alone is not a decisive determinant of secondary stability once osseointegration proceeds normally. Previous literature has shown that implant stability is influenced by multiple interacting variables, including implant location, bone density, implant diameter, and healing pattern, and that these factors may have a stronger effect on ISQ evolution

than chronological age per se [26]. In addition, the absence of a marked divergence in final ISQ values between age groups in the present cohort suggests that immediate implant placement may remain predictable across different age categories when adequate primary fixation is achieved [30].

Marginal bone loss at 1 year was limited in Groups A and B, whereas Group C showed higher mean MBL values. The mean MBL values recorded for A and B were low and compatible with favorable peri-implant bone maintenance during the first year of function. This result is broadly in line with previous studies showing that immediate implants can maintain satisfactory crestal bone levels when primary stability is adequate and the restorative protocol is appropriately timed [31,32]. Although the mean MBL in Group C was higher compared to the other groups, the values remained within the range clinically reported as acceptable for the first year of function. These differences may reflect complex interactions between macro-geometry and local tissue responses, alongside well-established clinical confounders such as socket anatomy, buccal plate integrity, and surgical approach.

An important point emerging from the present findings is that the relationship between ISQ and marginal bone loss appears to be indirect rather than linear. Although the group with the lowest mean ISQ values also showed the highest MBL, previous retrospective evidence has shown that a statistically significant direct correlation between longitudinal changes in ISQ and MBL is not always demonstrable [27]. This supports the view that resonance frequency analysis and radiographic bone level assessment describe different but complementary aspects of implant performance: the former reflects the stiffness of the implant-bone complex, whereas the latter captures crestal remodeling over time.

The analysis of implant threads remaining outside bone at 30 Ncm also provides clinically relevant information. In the present cohort, mean exposure was relatively limited in all groups, although slightly greater in Group A. In immediate post-extraction implants, a certain amount of exposed coronal implant surface may be expected because implant positioning is often prosthetically driven and primary fixation is frequently sought beyond the apical portion of the socket. Nevertheless, within the range observed in the present study, greater coronal exposure did not appear to translate into increased marginal bone loss in the best-performing groups, suggesting that modest thread exposure alone may not be detrimental when stability and healing conditions are favorable.

The complication profile also deserves attention. No failures were reported in Group A, one failure was recorded in Group B, and five failures occurred in Group C. These findings are clinically consistent with the lower stability and higher MBL observed in the BTK group and with the broader concept that low baseline stability may be associated with a greater risk of early failure. Previous retrospective analyses have similarly shown that failed implants tend to present lower ISQ values at surgery than surviving implants, even though no single ISQ threshold can be considered universally predictive in every clinical setting [33].

The present results should be interpreted in light of some limitations. First, the retrospective design limits control over confounding variables and does not allow causal inference. Second, although the groups were numerically balanced, other relevant determinants of implant stability and bone remodeling, such as jaw distribution, local bone quality, socket morphology, and prosthetic loading conditions, were not fully explored in the present analysis. Third, because ISQ is influenced by multiple biologic and technical variables, comparisons across implant systems should not rely exclusively on absolute values but rather on temporal trends and associated clinical outcomes. A further limitation is the retrospective nature of the study, relying on a posteriori data collection from an external center, which represents an inherent limitation, as patient assignment to specific implant systems could not be randomized. However, potential operator-dependent variability was

minimized because all procedures were carried out by a single surgeon over the same observation period. Furthermore, although baseline characteristics such as jaw location, region, and implant dimensions were homogeneously distributed across groups, local anatomical bone variations (e.g., precise bone density according to Lekholm & Zarb classification) and specific local grafting responses could not be fully adjusted for in a multivariate statistical model due to the retrospective collection of data. These local baseline factors may independently influence both primary stability (ISQ) and marginal bone level dynamics. Consequently, caution is advised when interpreting minor performance differences between macro-geometries, and future prospective trials should incorporate multivariate adjustments for all baseline anatomical covariates. Additionally, age was evaluated as a continuous demographic parameter rather than through arbitrary categorical subgroupings, as no established biological threshold exists for ISQ evolution. Future prospective studies with larger samples could further investigate age-related bone density nuances.

Finally, implants that failed prior to prosthetic loading were included in the overall survival analysis but excluded from subsequent longitudinal ISQ (T1 and T2) and marginal bone loss evaluations, leaving 40, 39, and 35 implants in Groups A, B, and C, respectively. This introduces a degree of survivorship bias, as the longitudinal stability and bone level changes described reflect exclusively the implants that achieved successful osseointegration and survived to functional loading. Furthermore, baseline ISQ values for the failed implants were not available for retrospective extraction.

5. Conclusions

Within the limitations of this study, all three evaluated implant macro-geometries demonstrated favorable primary and secondary stability, as well as satisfactory short-term clinical outcomes. While distinct thread designs influence initial mechanical engagement and early stability trajectories, all systems achieved high stability values by the time of definitive prosthetic loading.

Although preliminary observations show high short-term survival rates across all groups, these findings should be interpreted with caution. Long-term prospective studies with extended follow-up periods are required to fully confirm the longitudinal survival rates and peri-implant tissue stability associated with each macro-geometry.

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References

1. Meredith, N. Assessment of Implant Stability as a Prognostic Determinant. *Int. J. Prosthodont.* **1998**, *11*, 491–501. [PubMed]

2. Cehreli, M.C.; Karasoy, D.; Akca, K.; Eckert, S.E. Meta-Analysis of Methods Used to Assess Implant Stability. *Int. J. Oral Maxillofac. Implants* **2009**, *24*, 1015–1032.
3. Sennerby, L.; Meredith, N. Implant Stability Measurements Using Resonance Frequency Analysis: Biological and Biomechanical Aspects and Clinical Implications. *Periodontol. 2000* **2008**, *47*, 51–66. [CrossRef] [PubMed]
4. Quesada-Garcia, M.-P.; Prados-Sanchez, E.; Olmedo-Gaya, M.-V.; Munoz-Soto, E.; Gonzalez-Rodriguez, M.-P.; Vallecillo-Capilla, M. Measurement of Dental Implant Stability by Resonance Frequency Analysis: A Review of the Literature. *Med. Oral Patol. Oral Cir. Bucal* **2009**, e538–e546. [CrossRef] [PubMed]
5. Roberts, E.W.; Poon, L.C.; Smith, R.K. Interface Histology of Rigid Endosseous Implants. *J. Oral Implantol.* **1986**, *12*, 406–416. [PubMed]
6. López, A.B.; Martínez, J.B.; Pelayo, J.L.; García, C.C.; Diago, M.P. Resonance Frequency Analysis of Dental Implant Stability during the Healing Period. *Med. Oral Patol. Oral Cir. Bucal* **2008**, *13*, 244.
7. Rasmusson, L.; Stegersjö, G.; Kahnberg, K.; Sennerby, L. Implant Stability Measurements Using Resonance Frequency Analysis in the Grafted Maxilla: A Cross-Sectional Pilot Study. *Clin. Implant Dent. Relat. Res.* **1999**, *1*, 70–74. [CrossRef] [PubMed]
8. Lages, F.S.; Douglas-de Oliveira, D.W.; Costa, F.O. Relationship between Implant Stability Measurements Obtained by Insertion Torque and Resonance Frequency Analysis: A Systematic Review. *Clin. Implant Dent. Relat. Res.* **2018**, *20*, 26–33. [CrossRef] [PubMed]
9. Albrektsson, T.; Brånemark, P.I.; Hansson, H.A.; Lindström, J. Osseointegrated Titanium Implants. Requirements for Ensuring a Long-Lasting, Direct Bone-to-Implant Anchorage in Man. *Acta Orthop. Scand.* **1981**, *52*, 155–170. [CrossRef] [PubMed]
10. Albrektsson, T.; Zarb, G.; Worthington, P.; Eriksson, A.R. 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.
11. AlKudmani, H.; AL Jasser, R.; Andreana, S. Is Bone Graft or Guided Bone Regeneration Needed When Placing Immediate Dental Implants? A Systematic Review. *Implant Dent.* **2017**, *26*, 936–944. [CrossRef] [PubMed]
12. Simunek, A.; Kopecka, D.; Brazda, T.; Strnad, I.; Capek, L.; Slezak, R. Development of Implant Stability during Early Healing of Immediately Loaded Implants. *Int. J. Oral Maxillofac. Implants* **2012**, *27*, 619–627.
13. de Oliveira, G.B.; Rebello, I.M.C.; Montanha Andrade, K.; Araujo, N.S.; Dos Santos, J.N.; Cury, P.R. Evaluation of Alveolar Process Resorption after Tooth Extraction Using the Socket Shield Technique without Immediate Installation of Implants: A Randomised Controlled Clinical Trial. *Br. J. Oral Maxillofac. Surg.* **2021**, *59*, 1227–1232. [CrossRef] [PubMed]
14. Winter, W.; Klein, D.; Karl, M. Micromotion of Dental Implants: Basic Mechanical Considerations. *J. Med. Eng.* **2012**, *2013*, 265412. [CrossRef] [PubMed]
15. Chrcanovic, B.R.; Albrektsson, T.; Wennerberg, A. Tilted versus Axially Placed Dental Implants: A Meta-Analysis. *J. Dent.* **2015**, *43*, 149–170. [CrossRef] [PubMed]
16. Godoy-Reina, I.; Moreu-Burgos, G.; González-Jaranay, M. Stability and Marginal Bone Loss in Implants Placed Using Piezoelectric Osteotomy versus Conventional Drilling: Systematic Review and Meta-Analysis. *Med. Oral Patol. Oral Cir. Bucal* **2021**, e226–e237. [CrossRef] [PubMed]
17. Pérez-Pevida, E.; Monteagudo-Villalobos, I.; Chávarri-Prado, D.; Estrada-Martínez, A.; Beltrán-Guijarro, M.; Diéguez-Pereira, M.; Brizuela-Velasco, A. The Relationship Between Peri-Implant Marginal Bone Loss and Resonance Frequency Analysis. *J. Funct. Biomater.* **2025**, *16*, 71. [CrossRef] [PubMed]
18. Charoenniwassakul, R.; Aruncharoensuk, S.; Subbalekha, K.; Mattheos, N.; Jiaranuchart, S.; Pimkhaokham, A. Effect of Dental Implant Design on Stability During Early Healing: A Randomised Controlled Trial. *J. Clin. Periodontol.* **2026**, *53*, 256–267. [CrossRef] [PubMed]
19. Scarano, A.; Degidi, M.; Iezzi, G.; Petrone, G.; Piattelli, A. Correlation Between Implant Stability Quotient and Bone-Implant Contact: A Retrospective Histological and Histomorphometrical Study of Seven Titanium Implants Retrieved from Humans. *Clin. Implant Dent. Relat. Res.* **2006**, *8*, 218–222. [CrossRef] [PubMed]
20. Chen, M. Clinical Significance of the Use of Resonance Frequency Analysis in Assessing Implant Stability: A Systematic Review. *Int. J. Prosthodont.* **2018**, *32*, 51–58. [CrossRef] [PubMed]
21. Sailer, I.; Karasan, D.; Todorovic, A.; Ligoutsikou, M.; Pjetursson, B.E. Prosthetic Failures in Dental Implant Therapy. *Periodontol. 2000* **2022**, *88*, 130–144. [CrossRef] [PubMed]
22. Kim, S.-J.; Kahm, S.H. Time- and Cost-Efficient, Minimally Invasive Comparative Assessment of Implant Stability: Reliability and Inter-Examiner Agreement of IST Versus ISQ Across Different Bone Quality Models. *Bioengineering* **2026**, *13*, 86. [CrossRef] [PubMed]
23. Trisi, P.; Berardi, D.; Paolantonio, M.; Spoto, G.; D'Addona, A.; Perfetti, G. Primary Stability, Insertion Torque, and Bone Density of Conical Implants with Internal Hexagon. *J. Craniofac. Surg.* **2013**, *24*, 841–844. [CrossRef] [PubMed]
24. Medina-Madrid, R.; Boquete-Castro, A.; Martín-Vacas, A.; Aragoneses-Lamas, J. Influence of Implant Macrodesign on Isq Values Placed in Bone Defects with Different Configurations. An In Vitro Experimental Study. *Int. J. Oral Maxillofac. Implants* **2026**, *41*, s89–s99. [CrossRef] [PubMed]

25. Cuschieri, S. The STROBE Guidelines. *Saudi J. Anaesth.* **2019**, *13*, 31. [CrossRef] [PubMed]
26. Huang, H.; Wu, G.; Hunziker, E. The Clinical Significance of Implant Stability Quotient (ISQ) Measurements: A Literature Review. *J. Oral Biol. Craniofac. Res.* **2020**, *10*, 629–638. [CrossRef] [PubMed]
27. Chen, M.; Lyons, K.; Tawse-Smith, A.; Ma, S. Resonance Frequency Analysis in Assessing Implant Stability: A Retrospective Analysis. *Int. J. Prosthodont.* **2019**, *32*, 317–326. [CrossRef] [PubMed]
28. Karl, M.; Graef, F.; Heckmann, S.; Krafft, T. Parameters of Resonance Frequency Measurement Values: A Retrospective Study of 385 ITI Dental Implants. *Clin. Oral Implants Res.* **2008**, *19*, 214–218. [CrossRef] [PubMed]
29. Lang, N.P.; Pun, L.; Lau, K.Y.; Li, K.Y.; Wong, M.C. A Systematic Review on Survival and Success Rates of Implants Placed Immediately into Fresh Extraction Sockets after at Least 1 Year. *Clin. Oral Implants Res.* **2012**, *23*, 39–66. [CrossRef] [PubMed]
30. Malchiodi, L.; Balzani, L.; Cucchi, A.; Ghensi, P.; Nocini, P. Primary and Secondary Stability of Implants in Postextraction and Healed Sites: A Randomized Controlled Clinical Trial. *Int. J. Oral Maxillofac. Implants* **2016**, *31*, 1435–1443. [CrossRef] [PubMed]
31. Slagter, K.W.; den Hartog, L.; Bakker, N.A.; Vissink, A.; Meijer, H.J.A.; Raghoebar, G.M. Immediate Placement of Dental Implants in the Esthetic Zone: A Systematic Review and Pooled Analysis. *J. Periodontol.* **2014**, *85*, e241–e250. [CrossRef] [PubMed]
32. De Angelis, N.; Sorrenti, E.; Modena, C.; Benedicenti, S.; De Angelis, N.; Sorrenti, E.; Modena, C.; De Angelis, N.; Sorrenti, E.; Modena, C.; et al. Evaluation of Primary Stability of Single Implants Placed in Fresh Extraction Sockets: A Clinical Trial Sockets: A Clinical Trial. *Biotechnol. Biotechnol. Equip.* **2016**, *30*, 354–359. [CrossRef]
33. Haseeb, S.A.; Rajendra, K.; Manual, L.; Kochhar, A.S.; Dubey, D.; Dang, G.S. Comparative Evaluation of Implant Stability, Insertion Torque, and Implant Macrogeometry in Different Bone Densities Using Resonance Frequency Analysis. *J. Contemp. Dent. Pract.* **2021**, *22*, 665–668. [CrossRef]

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