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Effect of internal connection type and screw channel angle on the screw stability of anterior implant-supported zirconia crowns

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Abstract

Objectives: To investigate the effect of implant–abutment connection and screw channel angle on screw stability by comparing a newly introduced and an established connection, before and after cyclic loading.

Materials and Methods: Implants ($N=44$) with Torcfit (TF) or Crossfit (CF) connection were divided to be restored with a straight (CFS and TFS) or an angled screw access channel (CFA and TFA) titanium-base abutment ($n=11$). CFA and TFA received screw-retained crowns, whereas CFS and TFS received hybrid zirconia abutments and cement-retained crowns. The initial torque value (ITV) of each complex (ITV_I) and removal torque value (RTV) after 24 h (RTV_I) were measured. Screws were replaced with new ones, ITVs were recorded again (ITV_F), and crowns were cyclically loaded (2.4 million cycles, 98 N) to measure RTVs again (RTV_F). Percentage torque loss was calculated. Data were analyzed ($\alpha=0.05$).

Results: ITVs were similar among groups ($p \geq .089$). CF led to higher RTVs ($p \leq .002$), while CFS had higher RTV_I than CFA ($p=.023$). After 24 h, CFS had lower percentage torque loss than TF, while CFA had lower percentage torque loss than TFA ($p \leq .011$). After cyclic loading, CF led to lower percentage torque ($p < .001$).

Conclusion: The implant–abutment connection affected the removal torque values. However, no screw loosening occurred during cyclic loading, which indicated a stable connection for all groups. Screw access channel angle did not affect screw stability after cyclic loading.

KEYWORDS
angled screw channel, implant–abutment connection, screw stability, torque loss

1 | INTRODUCTION

Screw-retained implant-supported prostheses have the advantage of retrievability along with the elimination of residual cement that could lead to peri-implant diseases (Rella et al., 2021). However, placing an implant in an ideal position to locate the screw access channel in a nonvisible area may not be possible in some clinical conditions such as limited bone volume (Rasaie et al., 2022). This problem may be solved by using abutments with angled screw channels (Berroeta et al., 2015). This system allows the redirection of the screw access channel to a more ideal location and eliminates the need for intermediary abutments and cement-retained crowns to rehabilitate implants placed in unsatisfactory positions (Opler et al., 2020). In addition, this system can be used with titanium-based abutments and computer-aided design and computer-aided manufacturing (CAD-CAM) technologies (Mulla et al., 2021).

Screw loosening is a commonly encountered problem with implant-supported crowns (Jacobs et al., 2022), which might lead to mechanical and biological complications (Yilmaz, Çakmak, et al., 2021). The tightening of the screw generates a clamping force between the implant fixture and the abutment that is known as preload, which pulls these two components to each other (Jörnéus et al., 1992; McGlumphy et al., 1998; Yilmaz, Gouveia, et al., 2021) and withstands any external force or load applied (Huang & Wang, 2019; Yilmaz, Çakmak, et al., 2021). Optimal preload is achieved when the stress exerted on the screw reaches 60–75% of the screw material's yield strength (Lang et al., 2003). However, when the external force exceeds the preload, mechanical complications, such as instability, micro-movement, screw loosening, and screw fracture occur (Delben et al., 2011; Yilmaz, Batak, et al., 2021; Yilmaz, Gouveia, et al., 2021). In addition, even if optimal values are reached, 2–10% of the initial preload is lost due to the embedment relaxation of the implant screw (Jaarda et al., 1994; Winkler et al., 2003), which may also lead to screw loosening (Kim & Lim, 2020). Therefore, the amount of remaining preload is a critical factor for the screw stability and can be expressed by the removal torque value (RTV), which is the amount of rotational force required to loosen the screw (Feitosa et al., 2013). Nevertheless, even without the loss of torque, RTV is lower than the initial preload due to the settling effect (Yilmaz, Gouveia, et al., 2021).

Implant–abutment connection (IAC) was shown to affect screw stability (Jacobs et al., 2022) and has been the main subject of interest of the manufacturers as new implant designs with different IACs are launched frequently (Kim & Lim, 2020; Pjetursson et al., 2018). Internal conical IACs are generally preferred in daily practice considering their high abutment micromovement resistance under axial and oblique forces (Coppedê et al., 2009), and high resistance to torque loss and screw loosening (Pjetursson et al., 2018). Currently available internal conical IACs differ by taper angle, abutment taper portion length, abutment surface area contacting the internal aspect of the implant, and antirotational geometry. Moreover, some of the designs include grooves, slots, or indices to prevent positional changes in the abutments (Yilmaz et al., 2018). Recently, a new IAC system called TorcFit (Straumann AG), which offers an alternative to regular IAC of the same brand (CrossFit; Straumann AG) was introduced. Even though there are studies on angled screw channel system (Drew et al., 2020; Garcia-Hammaker et al., 2021; Goldberg et al., 2019; Hu et al., 2019; Mulla et al., 2021; Rasaie et al., 2022; Rella et al., 2021; Swamidass et al., 2021), no study has ever investigated how this recently introduced IAC performs when restored with angled screw channel abutments. Therefore, the present study aimed to evaluate the effect of screw channel angle on the long-term screw stability of this new IAC (TorcFit (TF)) and to compare it with that of the conventional IAC of the same brand (CrossFit (CF)), in which stable RTVs were demonstrated (Srimurugan-Thayanithi et al., 2023). The null hypotheses were that (i) there would be no difference in initial torque values (ITVs) among tested IAC–abutment pairs, (ii) there would be no difference in reverse torque values (RTVs) among tested IAC–abutment pairs within different time intervals (after 24 h and after cyclic loading), and (iii) there would be no difference in the torque loss among tested IAC–abutment pairs within different time intervals (after 24 h and after cyclic loading).

2 | MATERIALS AND METHODS

Twenty-two bone-level implants with TF IAC (BLX RB Ø4.0 × 10 mm, Straumann AG) and 22 bone-level implants with CF IAC (BL RC Ø4.1 × 10 mm, Straumann AG) were randomly divided into two subgroups to be restored either with straight or angled screw channel titanium-base abutments. A priori power analysis (power = 95%, $f = 0.22$, $\alpha = 0.05$) based on the results of the study of Mulla et al. (2021) was performed and 10 specimens per IAC–abutment pairs were deemed sufficient. However, to increase the statistical power and compensate loss of a specimen during cyclic loading, 11 specimens per IAC–abutment pairs were prepared. TF has a 7° Morse taper, a flat top portion, a 22.5° shoulder prosthetic connection, and a six-sided star-shaped anti-rotational element, which gives abutment insertion flexibility in six different positions to allow transmission of high torques (Straumann BLX Implant Brochure). However, CF has a 15° internal cone and 4 internal grooves (Straumann BL Implant Brochure).

A previous CBCT of a patient, who had a missing maxillary right central incisor was used for virtual implant planning (coDiagnostiX, Dental Wings) to reflect 25° angulated implant position from the ideal for both implants. Then, a virtual scan body was placed on corresponding implants and the model was exported in standard tessellation language (STL) format (exocad DentalCAD, exocad GmbH) to design additively manufactured models with virtual implant analogs. The casts were additively manufactured by using a stereolithography-based 3-dimensional printer (CARES P20, Straumann AG) and model resin (P Pro Master Model, Straumann AG). After postprocessing, digital implant analogs (Repositionable Implant Analog RC and Repositionable Implant Analog RB, Straumann AG) were placed and fixed to the casts by using cyanoacrylate cement (Krazy Glue, Krazy Glue). Then, a scan body (CARES RB/WB Mono Scanbody or CARES

RC Mono Scanbody, Straumann AG) was attached to each implant analog and scanned by using a laboratory scanner (E4, 3Shape A/S). These scans were imported to a dental design software program (Dental System, 3Shape A/S).

For each IAC–abutment pair, titanium-base abutments were virtually selected in the software (RC Variobase for crown AS Ø4.7×5.5 mm, gingiva height 1 mm (CFA), RB Variobase for crown AS Ø4.5×5.5 mm, gingiva height 1.5 mm (TFA), RC Variobase for crown Ø4.5×5.5 mm, gingiva height 1 mm (CFS), and RB Variobase for crown Ø4.5×5.5 mm, gingiva height 1.5 mm (TFS), Straumann AG). For TFA and CFA, maxillary right central incisor crowns with palatal screw access were designed. For TFS and CFS, hybrid abutments to be cemented onto the straight titanium-base abutments and maxillary right central incisor crowns with buccal screw access were designed (Figure 1; Mulla et al., 2021). These designs were exported in STL format and imported to a nesting software (PrograMill CAM V4.2, Ivoclar AG) to mill 22 screw-retained crowns to be cemented on titanium-base abutments for CFA and TFA and 22 cement-retained crowns and 22 hybrid abutments for CFS and TFS

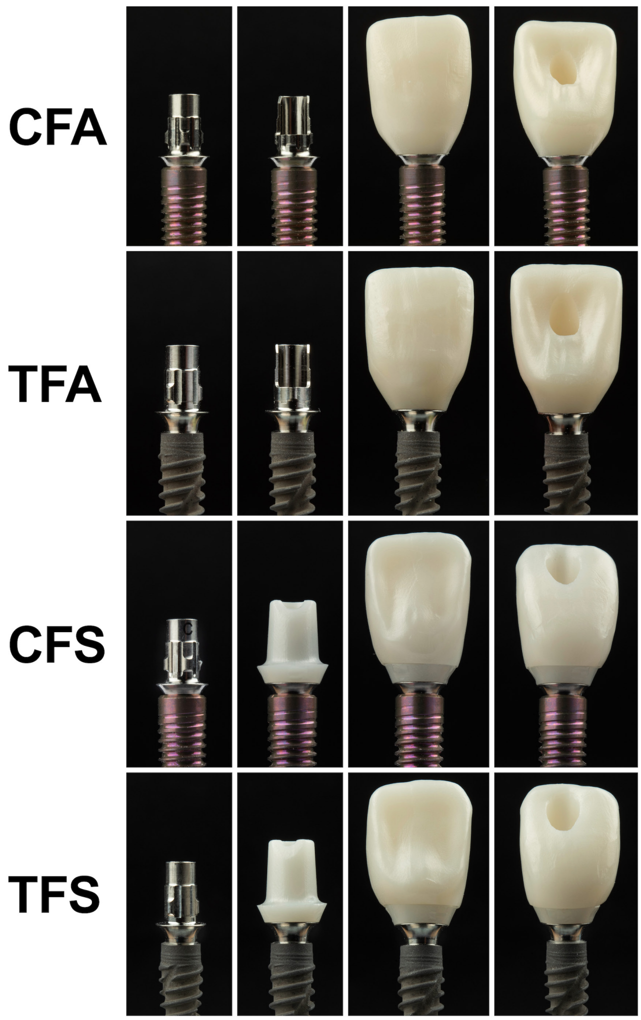

FIGURE 1 Representative images of the components of each group (CFA, CrossFit Angled; CFS, CrossFit Straight; TFA, TorcFit Angled; TFS, TorcFit Straight).

from monolithic zirconia (IPS e.max ZirCAD LT, Ivoclar AG). After milling (PrograMill PM7, Ivoclar AG) and sintering (Programat S2, Ivoclar AG), intaglio surfaces of the crowns and hybrid abutments, and titanium-base abutments were sandblasted by using 50 μm Al_2O_3 for 10 s at 1 bar from a distance of 15 mm, steam cleaned for 15 s and air dried. Intaglio surfaces of CFA and TFA crowns and hybrid abutments of CFS and TFS were treated with a universal primer (Monobond Plus, Ivoclar AG) and they were cemented onto their respective titanium-base abutments by using the manufacturer's recommended self-adhesive resin cement (Multilink Hybrid Abutment, HO 0, Ivoclar Vivadent AG). To cement CFS and TFS crowns, abutment surfaces were sandblasted as mentioned above, the same primer was applied, and the crowns were cemented with another self-adhesive resin cement (SpeedCEM Plus Abutment, Ivoclar AG). All cementation processes were performed under 24-N force (Peutzfeldt et al., 2011) and tested on the printed model.

A total of 44 glass-reinforced epoxy resin rods with dimensions of 10×15 mm (G10, McMaster-Carr) were fabricated to embed the implants. This epoxy resin has an elastic modulus (16.5 MPa) similar to that of the trabecular bone (Rho et al., 1993). By using the manufacturer's recommended implant drills, osteotomies were made to the epoxy resin rods 3 mm shorter than the lengths of the implants. A vent hole was opened at the apex of the epoxy resin by using a round drill. Then, a thin layer of a dual-polymerizing composite resin material (core-X flow, Dentsply Sirona) was applied to coat the threads of the implants and fill the spaces between the osteotomy site and the implant surface to simulate the osseointegration. All implants were embedded in their osteotomy sites with a 3-mm clearance between the implant neck and the surface of the epoxy resin (Donmez et al., 2022; ISO 14801:2007, 2007). Crown-to-implant fit was assessed by using tactile sensation and an explorer under an optical microscope at ×40 magnification (SMZ445/460 Stereoscopic Zoom Microscope, Nikon Corp).

A friction-style torque-controlling device (TCD) was used to tighten each crown to its respective implant. Before tightening the crowns, the reliability of the TCD was assessed by using a digital torque gauge (M5I, Mark-10) and calculating the mean values obtained by recording 10 observations for 35 Ncm (Mulla et al., 2021), which was 35.1 N. Each implant was inserted into the holder of the digital torque gauge and specific screwdrivers of straight (SCS Screwdriver, Straumann AG) and angled screw channel (AS Screwdriver, Straumann AG) abutments were connected to TCD to tighten each restoration to the manufacturer's recommended torque value of 35 Ncm to achieve the optimal preload. Applied torque was standardized with the duration of 4 s from 0 to 35 Ncm and the initial torque values (ITV_I) were recorded in Ncm for each abutment screw (NC/RC Basal Screw AS 7.9 mm in length for CFA, RB/WB Basal Screw AS 6.5 mm in length for TFA, RC Basal Screw 7.9 mm in length for CFS, and RB/WB Basal Screw 6.1 mm in length for TFS, Straumann AG; Figure 2). The screws and inner surface of all implants were washed with 1 mL saline to simulate the oral environment (Sun et al., 2022). After 24 h, peak removal torque values (RTVs) were recorded (RTV_I) to calculate the embedment relaxation

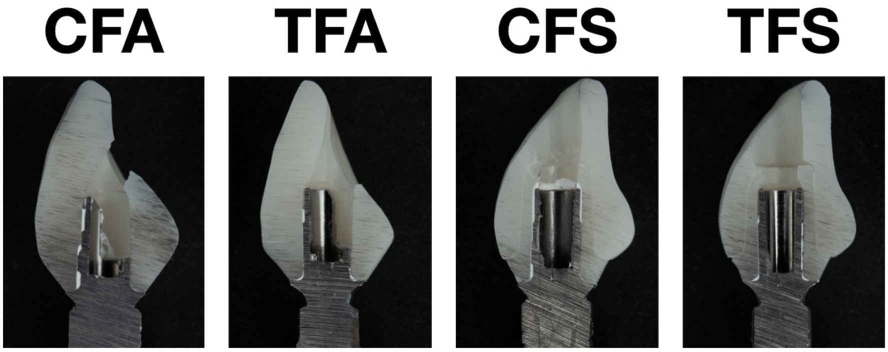

FIGURE 2 Cross-sectional view of one specimen from each group.

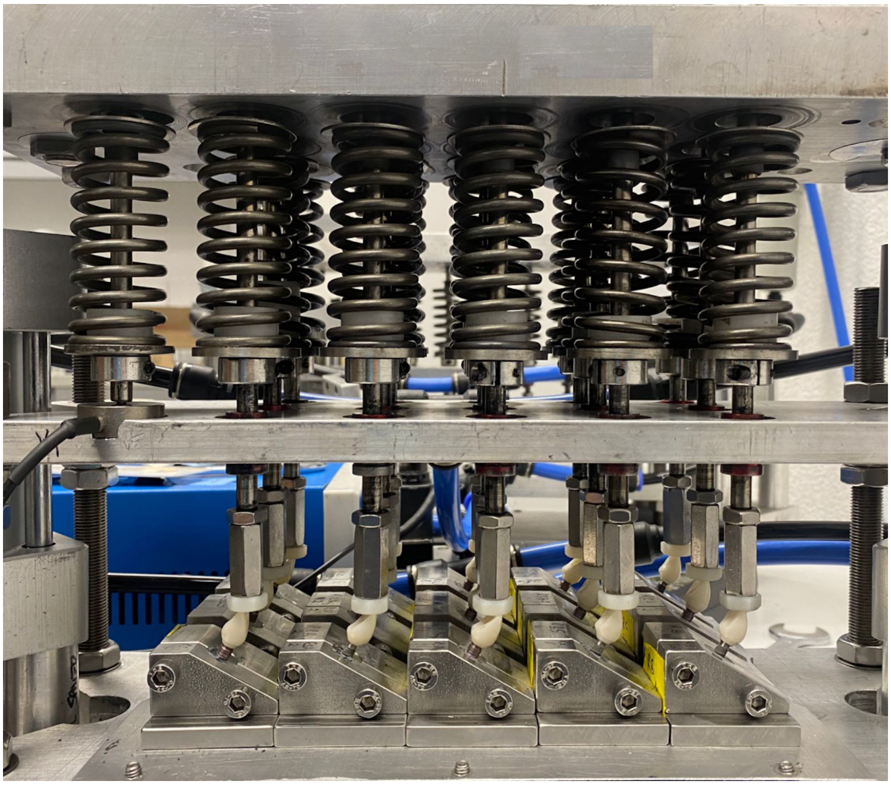

FIGURE 3 Mastication simulator used for cyclic loading.

that occurred in the mating surfaces of newly manufactured components. Screws were changed with the new ones, and the ITVs were recorded again (ITV_F).

The crown–implant pairs were then mounted on mastication (Hernandez et al., 2008; Jacobs et al., 2022; Mulla et al., 2021; Nasrin et al., 2018; Yilmaz, Batak, et al., 2021; Yilmaz, Çakmak, et al., 2021; Yilmaz, Gouveia, et al., 2021) simulator at a 30-degree off-axis from the loading direction (ISO 14801:2007, 2007; Figure 3). A software program (Excel, Microsoft Corp) was used to randomize the specimen positions on the mastication simulator. The crowns were cyclically loaded at 1.6 Hz for 2.4 million cycles under 98 N load, to simulate 10 years of functional loading (Kohal et al., 2011). The load was applied through a flat nylon tipped indenter, which contacted the incisal surface of the crowns. To simulate a 6-month recall appointment, the mastication simulator was stopped every 120,000 cycles (Kohal et al., 2011) to check crown stability by using cotton pliers, observe screw and/or abutment fracture, and screw loosening and retighten any loose screws. One specimen from the TFS group failed during cyclic loading (≈ 1,257,000 cycles) and was defined as a catastrophic fracture of the prosthetic component. However, the remaining specimens did not get loose during cyclic loading, and no screw retightening was performed. After cyclic loading, the crowns were checked again and peak RTVs were recorded (RTV_F). Percentage torque loss after 24 h (ITV_I and RTV_I) and after cyclic loading (ITV_F and RTV_F) was calculated by using the formula (Swamidass et al., 2021):

$$(ITV - RTV / ITV) \times 100$$

RTV recording of the failed specimen from the TFS group was not possible; thus, this specimen was not included in the statistical analysis of RTV_F and percentage torque loss after cyclic loading data. Also, the threshold value for the probability of screw stability was determined by using the average torque value of 15 Ncm obtained by manual tightening (Alikhasi et al., 2017). Any value below 15 Ncm was considered loosening prone. Scanning electron microscopy (SEM) (LEO 440, Zeiss) images of one screw from each group were taken after cyclic under ×30 and ×200 magnification at 14 kV.

Shapiro–Wilk tests were used to analyze the distribution of data. ITV_I and ITV_F values were compared among test groups by using one-way analysis of variance (ANOVA) tests. RTV_I values were compared using Kruskal–Wallis, whereas RTV_F values were compared by using one-way ANOVA and Scheffé tests. Either Kruskal–Wallis (after 24 h) or one-way ANOVA followed by the Scheffé test (after cyclic loading) were used to evaluate the percentage of torque loss among test groups. All analyses were performed by using a statistical analysis software program (IBM SPSS Statistics v22.0, IBM Corp; $\alpha = .05$).

3 | RESULTS

Table 1 lists the mean and standard deviation ITVs for each group. No significant differences were found among test groups when ITV values were considered ($p = .089$ for ITV_I and $p = .421$ for ITV_F).

RTVs of each group are listed in Table 2. Significant differences were observed among tested IAC–abutment pairs for RTV_I and RTV_F ($p < .001$ for both RTV_I and RTV_F). When RTV_I was considered, CFS had higher values than TFs ($p \leq .002$), while CFA had higher values than TFA ($p = .018$). When RTV_F was considered, CF groups had higher values than TF groups ($p < .001$). However, the differences between groups with the same IAC were nonsignificant ($p \geq .870$).

Significant differences were observed among test groups when percentage torque loss was concerned ($p < .001$ for both after 24 h and after cyclic loading). When torque loss after 24 h was considered, CFS had lower percentage than TFA and TFS ($p \leq .002$), while CFA had lower percentage than TFA ($p = .011$). Every other pairwise comparison was nonsignificant ($p \geq .189$). When torque loss after cyclic loading was considered, CFA and CFS had similar percentages ($p = .893$) that were lower than those of TFA and TFS ($p < .001$). In addition, the difference between TFA and TFS was nonsignificant ($p = .838$; Table 3). All CFA specimens had a percentage torque loss less than 10% and all TFA specimens had a percentage torque loss higher than 50%. While nine CFS specimens had a percentage torque loss between 10% and 30%, seven TFS specimens had had a percentage torque loss higher than 50%. Figure 4 shows the representative SEM images of each IAC-abutment pair. Even though abrasion was not evident on the screw head, scratches and powder-like accumulations were visible on the neck and shaft of the screws. In addition, those scratches were more prominent on TF screws. When screw threads were evaluated, the abrasion was evident for all groups.

TABLE 1 Descriptive statistics (mean ± SD) of initial torque values (ITV) of each group.

	ITV_I (Ncm)	ITV_F (Ncm)
CFA	34.9 ± 0.5^a	35.2 ± 0.4^a
TFA	35.1 ± 0.2^a	35.1 ± 0.2^a
CFS	35.3 ± 0.2^a	35.3 ± 0.3^a
TFS	35.3 ± 0.3^a	35.2 ± 0.2^a

Note: Different superscript lowercase letters indicate significant differences among test groups within each column ($p < .05$).
Abbreviations: CFA, CrossFit Angled; CFS, CrossFit Straight; TFA, TorcFit Angled; TFS, TorcFit Straight.

4 | DISCUSSION

The present study evaluated the effect of IAC and screw access channels on the screw stability of implant-supported anterior crowns. No significant differences among the ITVs of test groups were observed. Therefore, the first null hypothesis was accepted. This result contradicts those reported in a previous study (Mulla et al., 2021) in which significant differences between ITVs of different angled screw channel systems and a straight screw channel system were reported. This difference may be related to the fact that the manufacturer's proprietary titanium-base abutments were tested in the present study, whereas in Mulla et al.'s (2021) study, titanium-base abutments from third-party manufacturers were also tested. Therefore, it can also be stated that a more compatible and stable implant–abutment connection can be expected when proprietary components are used.

When comparing the RTV_I values among test groups, CFS had higher values than TF groups and CFA had higher values than TFA. In addition, when RTV_F values were considered, CF led to significantly higher RTVs than those of TF. Therefore, the second null hypothesis was rejected. A possible explanation for significantly or nonsignificantly higher RTVs with CF may be the screw seat angles. CF screws have a 30° angle, whereas TF screws have a 45° angle that leads to a smaller support surface, which can reverse-turn the screw with relatively lower torque values. Morse taper angle is another factor that may have contributed to the lower RTVs of the TF connection; the taper with TF is 7°, which is 15° with CF. Results of a previous study substantiate this interpretation as CF was shown to have higher RTVs when compared with an IAC (synOcta, Straumann AG) that had an 8° Morse taper angle (Srimurugan-Thayanithi et al., 2023). The length of the abutment screws may also be associated with the higher RTVs of CF as the difference between the length of the screws of tested IACs was 1.8 mm for straight and 1.4 mm for angled screw access channel titanium-base abutments. However, a previous study on the effect of screw length on anterior implants showed that abutment screws did not affect RTVs before and after cyclic loading (Lee & Cha, 2018); therefore, this speculation needs to be supported. Another factor that might have contributed to the lower RTVs of TF is the gingival height of the titanium-base abutments. Even though the proprietary titanium-base abutments of the manufacturer were used for each IAC, the gingival height of the titanium-base abutments of TF was 0.5 mm higher than those of CF. Previous studies have shown that increased gingival height results in higher

TABLE 2 Descriptive statistics of removal torque values (RTV) after 24 h (RTV_I) and after cyclic loading (RTV_F) for each group.

	RTV_I (Ncm)		RTV_F (Ncm)	
	Mean ± SD	Median (Min–Max)	Mean ± SD	Median (Min–Max)
CFA	29.3 ± 3.4	28.5^{bc} (22.3–34.6)	26.5 ± 2.4^{b}	26.4 (23.6–31.3)
TFA	25.1 ± 1.4	25.2^{a} (22.8–27.4)	13.6 ± 2.7^{a}	14.2 (8.6–17.4)
CFS	33.8 ± 6.4	32.4^{c} (28.4–52)	27.6 ± 2.5^{b}	27.2 (23.5–33.5)
TFS	26.4 ± 1.9	26.1^{ab} (24.1–29.3)	14.8 ± 4.8^{a}	14.1 (7.2–23.8)

Note: Different superscript lowercase letters indicate significant differences in columns (Kruskal–Wallis test was used for after 24 h data, and one-way ANOVA and Scheffé tests were used for after cyclic loading data; $p < .05$).

Abbreviations: CFA, CrossFit Angled; CFS, CrossFit Straight; TFA, TorcFit Angled; TFS, TorcFit Straight.

TABLE 3 Descriptive statistics of torque loss of each group.

	After 24 h (%)		After cyclic loading (%)	
	Mean ± SD	Median (Min–Max)	Mean ± SD	Median (Min–Max)
CFA	16 ± 9.7	17.7^{ab} (2–36.3)	24.6 ± 6.6^{a}	25 (11.1–32.8)
TFA	28.6 ± 4	28.3^{c} (21.7–35)	61.2 ± 7.7^{b}	59.5 (50.7–75.7)
CFS	4.1 ± 18.7	8^{a} (−49–19.5)	21.9 ± 7^{a}	22.3 (5.6–33.4)
TFS	25.3 ± 5.2	26^{bc} (17.5–32.5)	57.9 ± 13.5^{b}	60.1 (32.8–79.7)

Note: Different superscript lowercase letters indicate significant differences in columns (Kruskal–Wallis test was used for after 24 h data, and one-way ANOVA and Scheffé tests were used for after cyclic loading data; $p < .05$).

Abbreviations: CFA, CrossFit Angled; CFS, CrossFit Straight; TFA, TorcFit Angled; TFS, TorcFit Straight.

stresses on both the abutment and the screw (Bordin et al., 2019) along with lower RTVs (Siadat et al., 2015) as increased gingival height leads to increased crown to implant ratio. Even though it was nonsignificant, CFS had higher RTV values than CFA, which may be related to the angle between the screwdriver and the screw in CFA that resulted in a different preload value at the screw head (Opler et al., 2020; Pitman et al., 2022).

When the torque loss after 24 h was considered, CFS had lower percentage torque loss than TFA and TFS, whereas CFA had lower percentage torque loss than TFA. In addition, when the torque loss after cyclic loading was considered, CF had lower percentage torque than TF. Therefore, the third null hypothesis was also rejected. In a previous study, it was reported that screw head design had a significant effect on torque loss and conical-headed screws had a lower percentage of torque loss compared with flat-headed screws and were more effective in preserving screw preload during cyclic loading (Coppedê et al., 2013). In the present study, the head and the neck of CF screws had a more conical-shaped geometry (Figure 4), which may have strengthened the connection between the abutment and the implant, which resists micromovements, due to additional friction. TF's susceptibility to screw loosening was evident when torque loss values were further evaluated based on the survival probability threshold value of 15 Ncm (Alikhasi et al., 2017), which is approximately 43% when the ideal torque value is considered as 35 Ncm, as the 18 TF specimens (11 TFA and 7 TFS) had torque loss over 50% while remaining three TFS specimens had a torque loss between 30% and 50%. However, only 3 specimens from CF (2 CFA and 1 CFS) had a torque loss between 30% and 50%, and most of the CF specimens (9 CFA and 10 CFS) had a torque loss below 30% (Figure 4). However, it should be emphasized that significantly lower RTVs and higher percentage torque loss of TF may not lead to complications and loose crowns in clinical situations as none of the crowns got loose during cyclic loading, which indicates the integrity of TF connection, and the proprietary removal tool of the manufacturer that was specifically designed for implants with TF connection (Removal tool for BLX Basal Screw, Straumann AG) had to be used to remove some of the TFA and TFS crowns after cyclic loading. Nevertheless, this hypothesis needs further in vivo support as the results of the present study highlight the long-term screw stability of CF and abutment stability of TF (need for removal tool) and clinical situations may lead to different results.

Even though the present study was the first on the newly introduced IAC TF, it was only compared with the established IAC of the same brand. Therefore, the fact that the present study focused on only one implant system and two IACs was a limitation and these results should not be generalized to other implant systems and IACs. In addition, the cyclic loading methodology of the present study did not involve any liquid medium, and a nylon-tipped indenter was used. Future studies that involve enamel antagonists and artificial saliva medium

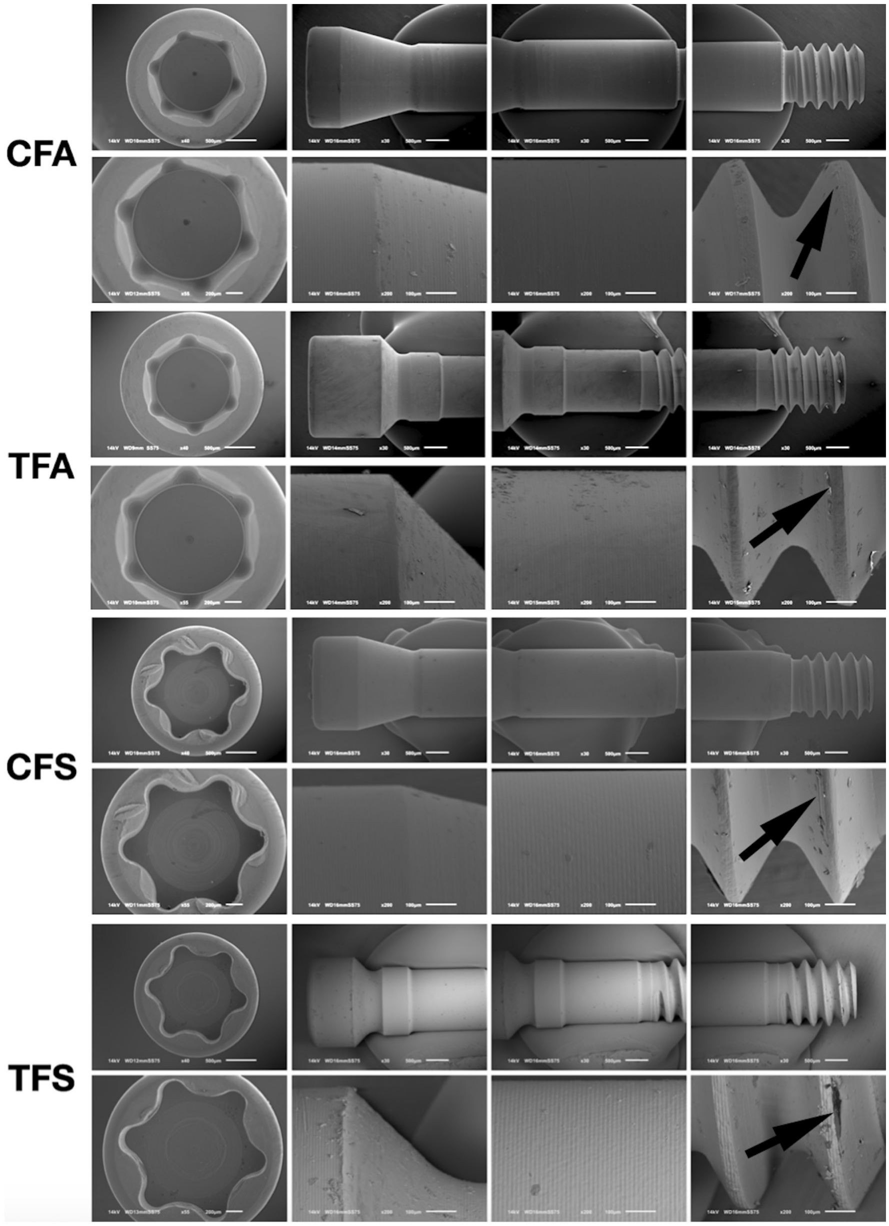

FIGURE 4 SEM images of the screw head, neck, shank, and threads after cyclic loading (CFA, CrossFit Angled; CFS, CrossFit Straight; TFA: TorcFit Angled; TFS, TorcFit Straight). Black arrows indicate worn areas on screw threads.

along with longer cyclic durations with increased loads are needed to corroborate and approximate the present study's findings to clinical situations. In addition, the internal surface of TF implants after long-term cyclic loading and how multiple tightening and loosening affect ITVs and RTVs should be evaluated to broaden the knowledge on this new IAC when abutments of different screw channel angles are used.

5 | CONCLUSIONS

Based on the limitations of the present study, the following conclusions could be drawn:

1. Initial torque values were similar among test groups. However, reverse torque values were affected by the implant–abutment connection and screw access channel angle.
2. Cross-fit implant-abutment connection led to higher reverse torque values along with lower percentage torque loss, both before and after cyclic loading. Nevertheless, no screw loosening was observed during cyclic loading, which indicated a stable implant–abutment connection for all groups.
3. Screw access channel angle did not affect reverse torque values and percentage torque loss after cyclic loading within each implant–abutment connection.

AUTHOR CONTRIBUTIONS

Conceptualization: G.Ç., S.A.-A, and B.Y.; methodology: G.Ç., M.S., and B.Y.; software: M.E.G.; validation: G.Ç., M.B.D., and B.Y.; formal analysis: Ç.K.; investigation: G.Ç., M.E.G., and M.B.D.; data curation: M.B.D. and S.A.-A.; writing—original draft preparation, M.B.D., M.E.G., and S.A.-A.; writing—review and editing, M.B.D., S.A.-A., and B.Y.; visualization: G.Ç.; supervision: M.S. and B.Y.;

project administration: G.Ç. and B.Y.; funding acquisition: G.Ç. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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