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Performance of zirconia abutments for implant-supported single-tooth crowns in esthetic areas: a retrospective study up to 12-year follow-up

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Abstract

Objective: The aim of this clinical study was to assess complications, success, and survival rates of zirconia abutments from different implant designs.

Material and methods: Anterior implant-supported single-tooth restorations, after 1–12 years of clinical function, were evaluated. One hundred and fifty-eight zirconia implant abutments placed in 141 patients were evaluated. Mechanical complications were observed, such as presence or absence of abutment fractures and loss of retention. In addition, the peri-implant parameters were observed. Statistical analysis was performed using Fisher's exact tests, and bone level was analyzed using the nonparametric Mann–Whitney U-test for non-normally distributed data.

Results: Sixteen restorations exhibited different complications. However, no significant difference was observed between the standard and platform switching. The standard platforms exhibited higher marginal bone loss than platform switching design followed up to 5 years. Platform switching has a potentially higher risk of fracture in some designs. In our study, one standard platform as well as two-platform switch designs seem to withstand fracture in the anterior area, regardless of the implant width. Survival and success rates were 93.8% and 81.2% (up to >7 years ≤12), respectively, for standard platform; and 90 and 84% (up to >2 years ≤5), respectively, for platform switching.

Conclusions: In general, standard platform implants restored with zirconia abutments were successful for the longest periods of observation and are a viable treatment alternative in anterior areas. Some of the studied designs of platform switching implants with zirconia abutments performed well for up to 5 years.

Zirconia implant abutments have been used for anterior esthetic restorations for over 10 years (Glauser et al. 2004; Sailer et al. 2009a; Vanlıoglu et al. 2012). The reported advantages are improved esthetics with less gingival gray–blue discoloration than titanium abutments as well as improved biocompatibility (Nakamura et al. 2010). Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is becoming the ceramic material of choice for implant abutments (Christel et al. 1989; Zarone et al. 2011). This may be explained by the fact that Y-TZP ceramics exhibit superior mechanical properties than other ceramics.

The long-term stability of Y-TZP is limited by the spontaneous tetragonal-to-monoclinic transformation. The continuing phase transformation in a humid environment (Kosmac et al. 1999) causes an aging phenomenon, referred to as low temperature degradation (LTD). LTD decreases the material strength, thereby increasing the chance of the material having catastrophic failures over time (Denry & Kelly 2008; Kim et al. 2010). However, there are no reports which identify the effect of aging on the clinical failure of zirconia implant abutments (Chevalier 2006; Denry & Kelly 2008; Sailer et al. 2009a; Gomes & Montero 2011).

Previous clinical studies performed the evaluation of zirconia implant abutments in 1 (Sailer et al. 2009b; Nothdurft & Pospiech 2010), 3 (Canullo 2007; Zembic et al. 2009), 4 (Glauser et al. 2004), and 5 (Ekfeldt et al. 2011; Vanlıoglu et al. 2012; Lops et al. 2013; Zembic et al. 2013) years in anterior and posterior regions, identifying good technical and biological performances of the zirconia abutments in a short-term period. A few studies investigated zirconia abutments after 5 years of function, observing similar performance

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with no difference between zirconia and titanium abutments in canines (Zembic et al. 2013) and posterior regions (Lops et al. 2013; Zembic et al. 2013).

The majority of data available supporting zirconia abutment loading are based on *in vitro* simulation of loading parameters (Quek et al. 2006, 2008; Seetoh et al. 2011). These *in vitro* studies suggest that zirconia abutments are suitable to withstand occlusal loading for anterior sites in normal human subjects with fractures at loads above 400 N (Adatia et al. 2009). However, most of the data presented to date for zirconia abutments are for the standard platform implants. It has been shown that regardless of the material, the standard platform abutment designs have load advantages compared to platform switching abutments due to improved material thickness in the cross-sectional dimension of the abutment (Seetoh et al. 2011).

The advent of conical platform switching implants has been promoted as beneficial to preserve crestal bone after implant placement and initial remodeling (Cappiello et al. 2008). Furthermore, the platform switching design is beneficial to increase the volume of tissue at the gingival margin by having a smaller emergence profile and hence a larger potential volume of soft tissue to provide circumferential soft tissue support (Cappiello et al. 2008). These characteristics may reduce recession and also reduce the gray shine from the metal abutment or implant. However, due to narrow cross section, when comparing standard platform to internal conical platform switching designs using similar materials there is a potential lower fracture resistance. Some platform switch designs may then be at risk from physiologic load levels for anterior teeth which are reported in the range of 90–370 N (Haraldson et al. 1979; Paphangkorakit & Osborn 1997; Mühlemann et al. 2014). In addition, the failure mode of the implant connector from conical platform switching zirconia abutments is not plastic deformation but rather fracture of the abutment at the neck of the implant. This is complicated by the narrow cross-sectional thickness of internal platform switching abutments at the neck emergence of the abutment (Seetoh et al. 2011).

Although zirconia abutments, with or without platform switching, present potential esthetic advantages, there is a potential increase in risk of load failure with both treatment concepts, and in particular, this risk may be higher in platform switch designs. Therefore, the purpose of this retrospective and clinical follow-up study was to evaluate the survival and success rates of anterior zirconia implant abutments after a clinical service of 12 years. Survival was defined as presence or absence of abutment fracture and/or screw loosening. Success was defined as no complications at all. In addition, different implant diameters and systems including 2 standard platform systems and 3 platform switching systems were compared.

Material and methods

A retrospective evaluation of patients with anterior single-tooth implant restorations using zirconia abutments was performed. Patient education including risk benefit discussion on zirconia abutment was completed; consent to implant surgery was obtained. The study is part of an ongoing long-term evaluation of dental implants associated with a University of British Columbia retrospective clinical study on dental implants. The study was approved by the Clinical Research Ethics Board at the University of British Columbia. Patients who presented with medical limitations (ASA class 3 or greater) and parafunctional activity were excluded. The patient examination, all surgeries, and typically abutment connection were completed in a single private periodontal surgery office while the crown restoration was performed by a number of different private practices in Calgary, Alberta. A total of 158 zirconia abutments in 141 patients were included in this study. Ninety-one female (106 crowns) and fifty male (52 crowns) patients with good general health were evaluated. The patients were restored with 1–4 crowns (Table 1).

The data were collected from patient's records and after performing clinical and radiographic examinations. These included the restoration location, type of implant (standard platform and platform switching), implant manufacturer (Table 2), implant diameter (narrow, regular, wide), gender, age (≤60 versus >60 years), presence or absence of abutment fractures, loose abutment screw, loss of retention and time in function according to observational period (≤2 years; >2 years ≤5; >5 years ≤7; >7 years ≤12). In addition, the periodontal status was observed by measuring bleeding on probing (i.e., mesial, buccal, distal, and palatal probing), recession and peri-implant marginal bone level.

Table 2. **Type of implant and abutment configurations**

	Implant type	Manufacturer
Standard platform implants		
EX =	3i	3i, Miami, USA
RS =	Nobel Replace	Nobel Biocare, Goteborg, Sweden
Platform switching implants		
AS =	Astra	Astra Tech AB, Mölndal, Sweden
NA =	Nobel Active	Nobel Biocare
BL =	Straumann BL	Institut Straumann AG, Waldenburg, Switzerland

Implant bone level was determined by parallelized periapical radiographs with measurement performed by one examiner (DF), using the DEXIS (Pennsylvania, USA) software program calibrated to sensor dimension. For both the standard platform and platform switching implants, the bone was measured from the fixture abutment junction (FAJ) (Piknner et al. 2009). The FAJ was chosen as the reference for bone measurement in this study as the implants are in esthetic zone and any bone loss whether normal remodeling or inflammatory related peri-implant bone loss could affect tissue volume and recession.

All implants received zirconia abutments, and all ceramic restorations were cemented. No implant fixture failures were observed among all of the implants. The crown distribution according to the implant type (EX, RS, AS, NA, BL), manufacturer, and width is listed on the Table 3. Zirconia abutments from EX were all prefabricated, lab adjusted, and custom milled for the other systems.

The primary outcome measures include zirconia abutment of implant-supported single crowns survival. The secondary outcome measures include decementation, loose abutment screw, bleeding on probing, peri-implant marginal bone level, and recession.

Table 1. **Crown distribution according to the anatomic site**

Crowns per patient	Patients	Maxilla			Mandible			Total crowns
		CI	LI	C	CI	LI	C	
1	127	94	30	1	1	–	1	127
2	12	13	10	1	–	–	–	24
3	1	2	1	–	–	–	–	3
4	1	2	2	–	–	–	–	4
Total	141	111	43	2	1	–	1	158

CI, central incisors; LI, lateral incisors; C, canines

Table 3. **Crown distribution according to implant manufacturer and width**

Implant width	Standard platform		Platform switching			Total crowns
	EX	RS	AS	NA	BL	
N	–	4	10	5	8	27
R	21	38	15	7	41	122
W	–	8	1	–	–	9
Total	21	50	26	12	49	158

N: 3.3, 3.5 mm; R: 4.0, 4.1, 4.3 mm; W: 4.5, 4.8 mm; W: 5.0 mm.

Follow-up and maintenance

The date of abutment connection was considered the baseline. The follow-up visits took place at 1 month after cementing the crowns and then about every 2 years. Among the 158 crowns evaluated, 158 crowns completed a 1- to 2-year follow-up, 107 crowns completed up to 5-year follow-up, 64 crowns completed up to 7-year follow-up, and 33 crowns completed up to 12-year follow-up. The factors investigated were presence or absence of abutment fractures, loose abutment screw, decementation, bone level, recession, and bleeding on probing (BoP). BoP that was minimal single-point bleeding was pooled with no bleeding in our comparison as there is a higher false positive bleeding on probing at implants (Gerber et al. 2009), and thus, results from this study represent significant bleeding versus trivial bleeding.

Among the 158 zirconia abutments evaluated, only 8 were not available for follow-ups. A further eight crowns were followed up for less than 1 year. Failure was defined as abutment fracture. Instances of crown decementation or loose abutment screw were recorded as complications but not considered as failures of the zirconia abutment systems. Survival was defined as no abutment fracture and no screw loosening. Success was defined as no event including any abutment fracture, screw loosening, porcelain chipping, recession, or positive bleeding score.

Statistical analysis

Each crown was statistically independent as some patients received more than one single crown. Statistical analysis was conducted using Fisher's exact tests. Bone level was analyzed using the nonparametric Mann–Whitney U-test for non-normally distributed data. The level of significance was set at $P < 0.05$.

Results

For all parameters evaluated, the unit of analysis was the implant. Bleeding on probing was evaluated at each recall, and the worst score observed was the recorded score. BoP data were then pooled for analysis on binary scale as present BoP+ (multipoint moderate bleeding, profuse rapid bleeding, or suppuration infection) versus absent or minimal BoP (no bleeding on probing or single-point minor bleeding) (Table 4). Standard platform had 12% BoP+ (9/71) compared to platform switching 4% BoP+ (4/91), but the difference was not significant ($P = 0.2744$). In addition, there was no statistical difference between standard platform designs (EX/RS; $P = 0.2643$) as well as between the platform switching designs (AS/BL, AS/NA, BL/NA; $P = 0.0875$, $P = 0.2867$ and $P > 0.99$, respectively).

Gingival recession was observed more often at standard platform implants compared to platform switching conical implants (Table 5). As regards peri-implant bone level relative to implant shoulder, the least marginal bone loss mean was observed for AS and BL designs followed up to 5 years (Table 6). The standard platforms exhibited higher marginal bone loss than platform switching design followed up to 5 years ($P < 0.000001$). After 6 years, there were insufficient data points to compare.

Mechanical complications are listed in Table 7. Among the 158 restorations evaluated in this study, 14 exhibited different complications, such as zirconia abutment fracture, loose abutment screw, decementation, or recession (Table 7). Of the 14 complications, one crown was replaced due recession in an esthetic area. In total, seven restorations showed nonrepairable failures, such as abutment fracture and loose abutment screw.

Six abutment fractures were observed after 3 months, 1, 3, 4, 5, and 6 years. AS and EX presented 4 and 2 abutment fractures, respectively. There was no statistical difference between standard platform and platform switching ($P = 0.6963$). The location of the fracture failures was different for internal connection compared to standard platform connection implants. In the standard platform design (EX), failures were due to wall fracture of the abutment adjacent to the screw access hole and were related to thin wall dimensions (Fig. 1). All four internal abutment platform switch designs (AS) failed at the neck of the implant (Fig. 2). In these cases, all failures occurred when the final crowns were in function, with two cases failing early within 3 months of loading and two cases failing over 4 years of loading. Statistically, a significant difference in abutment fracture was only observed between AS and BL ($P = 0.01$). There was a trend to more abutment fractures in males and younger patients; however, gender and age factors were not statistically significant, $P = 0.0901$

Table 4. **Implant type distribution according to bleeding on probing (BoP) evaluation**

Index*	Standard platform		Platform switching			Total crowns
	EX	RS	AS	NA	BL	
BoP-	20	42	22	12	47	143
BoP+	1	8	4	0	2	15
Total	21	50	26	12	49	158

BoP-: no bleeding on probing or single-point minor bleeding; BoP+: multi point moderate bleeding, profuse rapid bleeding or suppuration infection.
*BoP was evaluated at each recall.

Table 5. **Implant type distribution according to gingival recession (mm)**

Gingival recession (mm)	Standard platform		Platform switching			Total crowns
	EX	RS	AS	NA	BL	
0	15	34	21	9	39	118
1	6	15	4	3	7	35
2	0	1	1	0	3	5
Total	21	50	26	12	49	158

Table 6. **Implant type distribution according to mean of peri-implant marginal bone level from the prosthetic connection (mm)**

Bone level from the prosthetic connection (mm)	Standard platform		Platform switching		
	EX	RS	AS	NA	BL
3 months	3.2	3	0.2	0.4	0.1
Year 1	1.8	1.9	0.4	0.6	0.2
Year 2–3	2.0	1.9	0.4	1.3	0.2
Year 4–5	1.9	2.0	0.6	0.7	0.5
Year 6–7	1.8	1.8	0.5	NA	NA
Year 8–12	2.0	NA	NA	NA	NA

NA, No data available: peri-implant marginal bone level relative to implant shoulder was not evaluated in those observational periods for those specific implants.

Table 7. **Distribution of mechanical complications according to patient gender and age, implant type and time in function**

	Crowns (n = 158)	Abutment fracture (%)	Loose abutment screw (%)	Decementation (%)	Total (%)
Gender					
Male	52	4 (7.7)	0	3 (5.8)	7 (13.5)
Female	106	2 (1.9)	1 (0.9)	4 (3.8)	7 (6.6)
Age					
≤60 years old	143	5 (3.5)	1 (0.7)	7 (4.9)	13 (9.1)
>60 years old	15	1 (6.7)	0	0	1 (6.7)
Standard platform implants					
EX	21	2 (9.5)	0	0	2 (9.5)
RS	50	0	0	4 (8)	4 (8)
Platform switching implants					
AS	26	4 (15.4)	0	2 (7.7)	6 (23.1)
NA	12	0	0	0	0
BL	49	0	1 (2)	1 (2)	2 (4.1)
Implant width					
N	27	0	0	0	0
R	122	6 (4.9)	1 (0.8)	6 (4.9)	13 (10.7)
W	9	0	0	1 (11.1)	1 (11.1)
Time in function					
≤2 years	158	2 (1.3)	1 (0.6)	1 (0.6)	4 (2.5)
Up to 5 years	107	3 (2.8)	0	3 (2.8)	6 (5.6)
Up to 7 years	64	1 (1.6)	0	0	1 (1.6)
Up to 12 years	33	0	0	3 (9.1)	3 (9.1)

and $P = 0.4471$, respectively. Regarding implant width relative to abutment fracture, no difference was observed when narrow and regular ($P = 0.5913$), and regular and wide ($P > 0.99$) were compared.

As showed in Table 7, the rate of screw loosening overall was very low exhibiting only 1 abutment loosening of the 150 followed over 1 or more years. Loss of retention occurred in seven restorations. The overall survival and success rates are shown in Table 8.

Discussion

The majority of implant manufacturers offer zirconia abutments for use despite the lack of long-term clinical data to 5 years in particular for most recent platform switching implant designs. Several new ceramic abutment designs are available, and differences in their clinical performance should be identified. Many factors can affect the survival of zirconia abutments, such as the implant-abutment connection (Sailer et al. 2009c; Leutert et al. 2012; Truninger et al. 2012), the abutment wall thickness (Wang et al. 2008; Nguyen et al. 2009), the fabrication process (Chevalier 2006), and the material's aging. The relationship between the effect of aging on the clinical failure of zirconia implant abutments is still not well understood (Chevalier 2006; Denry & Kelly 2008; Sailer et al. 2009a; Gomes & Montero 2011); however, it is related to zirconia types and manufacturers (Chevalier 2006). At present, the observational period for zirconia abutment is limited as there are few reports with medium-term follow-up (Ekfeldt et al. 2011; Vanlıoglu et al. 2012; Lops et al. 2013; Zembic et al. 2013) and only one report following zirconia abutments long-term over 5 years, and this included only 11 implants restored with zirconia abutments (Döring et al. 2004).

The present investigation evaluated a significant number of abutments (n = 158). Thirty-three abutments were followed between 7 and 12 years after insertion. According to the results of this study, the zirconia abutments performed well after evaluation up to 12 years. Previous studies reported good performance of zirconia abutments as

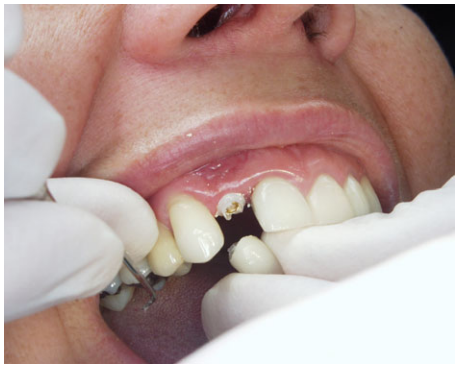

Fig. 1. External hex standard platform zirconia abutment fracture.

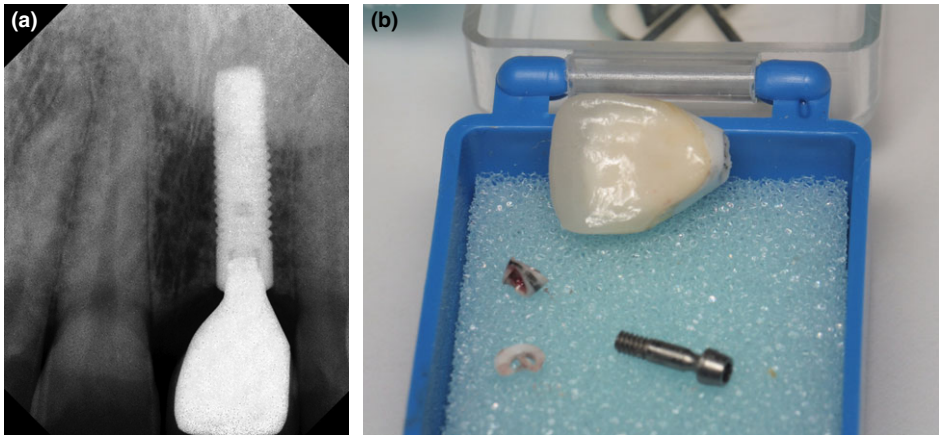

Fig. 2. Platform shift abutment. (a) Note excessively narrow neck and (b) after fracture.

Table 8. **Survival and success rates of the crown complications according to the implant design used**

	≤2 years		Up to >2 years ≤5		Up to >5 years ≤7		Up to >7 years ≤12	
Implant design	Survival rate (%)	Success rate (%)	Survival rate (%)	Success rate (%)	Survival rate (%)	Success rate (%)	Survival rate (%)	Success rate (%)
Standard platform	100	98.6	98.2	96.5	96	94	93.8	81.2
Platform switching	96.6	96.6	90	84	NA*	NA*	NA*	NA*

NA, no data available.
*Not a significant number of crowns were evaluated. However, the number was included in the total survival and success rates for both implant designs.

well, but for shorter observational periods (Glauser et al. 2004; Canullo 2007; Sailer et al. 2009a,c; Zembic et al. 2009, 2013; Nakamura et al. 2010; Nothdurft & Pospiech 2010; Ekfeldt et al. 2011; Vanlıoglu et al. 2012; Lops et al. 2013). In this study, standard platform implant-supported restorations were observed up to 12 years in function and the platform switching conical implant-supported restorations were observed up to 6 years. The shorter follow-up for platform switching implants is attributed to the fact that the historic standard platform implant designs have been available longer. The overall survival and success rates of the standard platform implant-supported restorations were higher than the platform switching implant-supported restorations (Table 8). According to a systematic review (Sailer et al. 2009a), the survival rates of ceramic abutments up to 5 years were estimated in 99.1%. In addition, a recent systematic review reported that the mean failure of ceramic abutments among the selected studies was 1.15% in short-term reports (Döring et al. 2004). In the present evaluation, the survival rates of abutments for standard platform and for platform switching were 93.8% (up to >7 years ≤12) and 90% (up to >2 years ≤5), respectively. Survival rates for titanium abutments were 97.4% up to 5 years (Sailer et al. 2009a) and 90% up to 6.3 years (Zembic et al. 2013). In the present study, survival rates were 98.2% for standard platform and 90% for platform switching up to 5 years.

Among 158 crowns observed in this investigation, six zirconia abutments fractured. In comparing platform switch designs, a significantly higher number of fractures were observed for AS compared to BL, while the NA had no fractures due to low numbers; there was no statistical difference between other platform switch designs. The higher fracture rate observed for AS abutments is consistent with the research of Muhllemann on bending moments of aged zirconia and titanium abutments supported by all ceramic crowns where the AS abutment had a significantly lower bending moment than the other implant systems tested (Mühlemann et al. 2014). Two crowns were replaced due to excessive recession or loose abutment screw. In a systematic review (Sailer et al. 2009a), ceramic abutment screw loosening was the most frequent technical complication among the studies, showing an estimated incidence of 5.1%. In contrast, only one loose abutment screw was observed in the current study. This finding is in agreement with a previous study which evaluated 185 implant-supported restorations up to 5 years (Ekfeldt et al. 2011).

The use of zirconia abutments has been reported to be advantageous for esthetics at gingival margin as ceramic abutments may cause less soft tissue discoloration than metal abutments (Jung et al. 2008; Bidra & Rungruanganunt 2013). However, the potential fracture risk of zirconia abutments is generally greater than the comparable design in titanium as ceramics are brittle materials, fatigue over time can cause fracture (Rekow & Thompson 2007). For that reason, long follow-up times are essential to identify the mechanical performance and the aging effect of these materials. It is known that different implant systems do not distribute stress equally on the zirconia abutments. Among the six implant systems evaluated in the present study, only one was externally connected to the abutments (EX). Most of the clinical studies to date have investigated mainly externally connected zirconia abutments (Glauser et al. 2004; Canullo 2007; Sailer et al. 2009a,c; Zembic et al. 2009; Nakamura et al. 2010; Nothdurft & Pospiech 2010; Ekfeldt et al. 2011).

In the present study, 2 abutment fractures were observed for the EX standard platform implants and 4 abutment fractures from platform switching (AS). The fractures in the EX system could be explained by laboratory adjustments after milling. It is worth noting that the EX zirconia abutments were in the early adoption of zirconia and the fractures were in the wall of the abutment. It is probable that laboratory modification after milling was a factor in the breakage of these designs. This is supported by the fact that all the other abutments, standard and platform switching, that were used later and delivered with instructions not to adjust the abutment had no wall fractures in this study. Of the platform switch design, 4 abutments (AS) fractured; one after 6 months, one after 9 months, and two after 4 years.

Narrow diameter implant-abutment arrangements have been shown to have lower fracture resistance than wider diameters (Truninger et al. 2012), and there is a lack of clinical data to date for zirconia abutments on narrow implants. For that reason, different abutment widths were evaluated in this study. Twenty-seven narrow implants (eight central incisors and 19 lateral incisors) were evaluated. Narrow zirconia abutments were not different relative to fracture in this study, but only small numbers were included; for that reason, results should be interpreted cautiously. There is one previous clinical study (AS system) with a small number of narrow diameter implants ($N = 10$) which reported no abutment fractures after 5 years in function (Vanlıoglu et al. 2012). Similarly, in our study, there were no fractures observed in the 10 abutments with narrow diameter of 3.5 mm from AS design at 6 years in function. However, there were four abutment fractures from AS system in 4.0 mm implants and one in the 4.5 width. The relatively better performance of narrow implants may be due to the fact that the 3.5 narrow implants were used only in lateral incisors with inherently smaller crowns dimensions, whereas 4.0 implant was typically used on central incisors with larger crowns, and at the time of the study, the 4.0 AS implants had the same narrow connection as 3.5 mm implants so may offer less material thickness of the zirconia.

Although gender was not statistically significant, there was a trend noted to more fractures in younger male patients. In the 6 abutment fractures, most of them (4/6) occurred in male patients despite the fact that there were nearly two times more females were treated with zirconia abutments than males. As for age of patient, only one abutment fracture occurred in a patient over 60 years old. This is likely due to higher forces potentially generated in male patients under age 60.

The implant design is a factor which may affect abutment fracture as it has been reported that zirconia abutments are not as good for platform switching due to rotational and tensile stress (Guess et al. 2011). This remains true according to the results of this investigation as the reliable mechanical performances of the standard platform implants combined with zirconia abutments in anterior regions were confirmed by previous studies (Glauser et al. 2004; Sailer et al. 2007; Chen et al. 2008; Lee & Hasegawa 2008; Vanlıoglu et al. 2012). However, one of the major findings based on this study is that the performance of platform switch conical implant-abutment connections varied significantly according to the system. In particular, in the present investigation, high survival rates in a large number of cases were observed for the BL design and high survival in NA design albeit in smaller numbers. This finding is in agreement with an *in vitro* study on angle cyclic load testing to point of fracture which reported that BL design had better results compared among the two other conical platform switching designs evaluated as well the BL exhibited similar performance to the titanium abutment of equal dimension under (Seetoh et al. 2011).

Regarding periodontal parameters investigated in this study, no significant difference was observed when BoP was investigated. However, there was a trend to more inflammation in standard platform with 12.7% BoP+ (9/71) compared to 6.9% BoP+ (6/87) for platform switching. The platform switching implants also exhibited less tendency to gingival recession with 19.7% (18/87) sites showing recession of 1–2 mm compared to than the standard platform implant designs which had 30.9% (22/71) sites with 1–2 mm recession (Figs 3 and 4). Although the difference was not significant in our study, the trend to less recession may relate to the bone-preserving principle of platform switching offers on thin buccal bone. Furthermore, platform switching implants have more volume of soft tissue as a result of a narrower abutment profile in cross section with more soft tissue volume at the neck of the abutment. This may have benefit of less gray shine through, although gingival coloration was not evaluated in this study.

There was less bone remodeling with platform switching design relative to the FAJ, and this is in agreement with previous studies that report less crestal bone loss for platform switching implants (Cappiello et al. 2008; Vigolo & Givani 2009; Atieh et al. 2010; Canullo et al. 2010a,b, 2011). That platform switching design showed less bone loss suggests they may provide better esthetic results with less potential for related recession. The bone loss relative to FAJ was greater for standard platform designs with combined totals ranging from 1.8 to 3.2 mm for RS and EX implants. However, bone was measured from FAJ (implant shoulder) as such for standard platform designs we must also account for 1.5 mm "normal" remodeling from smooth collar on RS or from microgap on EX design. Thus, for example, the 3-year average bone loss of 1.9 mm on relative to FAJ on the RS implants actually only reflects an exposed rough surface of 0.3 mm indicating minimal peri-implantitis-related loss. One limitation of bone level measurements that have to be considered is that periapical radiographs were used and with this measurement method and radiographic technique which in a review by Sanz & Chapple (2012) has been shown to have an range of error of about 1 mm.

Overall, BL and NA platform switch designs exhibited positive results regarding abutment fracture and were equal to the standard platform design RS. The AS abutments had higher fracture rates, but this may relate to the narrow prosthetic connection on the 4-mm implant (AS) that was used at the time of our study. The AS system was recently redesigned with new abutment to implant neck dimension. Therefore, the results from the present study do not reflect the system currently offered.

Platform switching designs may have esthetic and biologic benefits, but the clinician should weigh the mechanical considerations before selection of any implant system, connection type, or abutment material. Further clinical studies with greater number of patients observed in a long-term period are necessary.

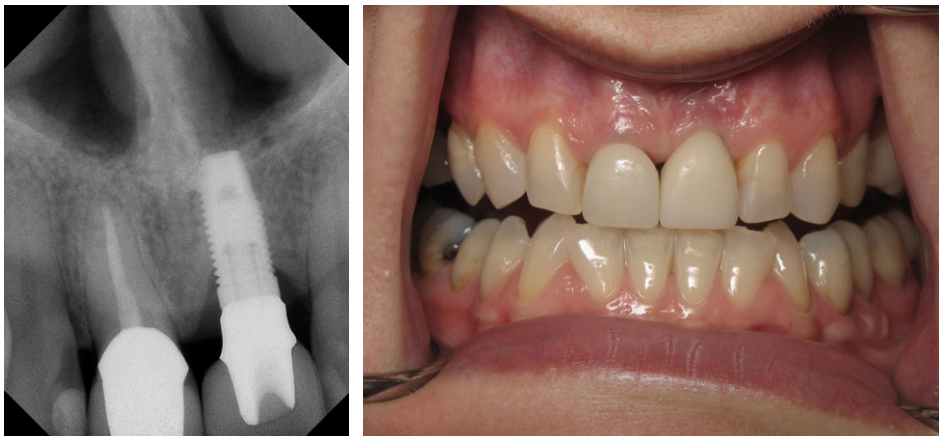

Fig. 3. Standard platform implant. Site# 21 after 3 years in function.

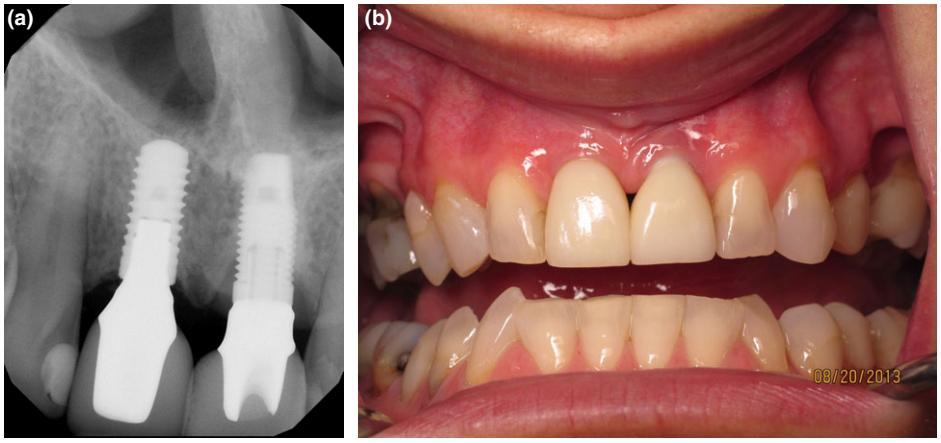

Fig. 4. (a) Standard platform (21) compared to platform switch (11). Site# 11 after 1 year in function and site# 21 after 11 8 years in function. (b) Note recession common in standard platform designs.

Conclusions

- In general, standard platform implants combined zirconia abutments were successful for the longest periods of observation and can be considered a viable treatment alternative in incisor anterior

areas for single unit crowns in patients with no parafunction;
- The load fatigue performance of Zr conical platform switching abutments varied and seemed to be system dependent with BL and NA performing well in anterior area regardless the implant width at up to 5-year follow-up;
- Regarding biologic parameters, the BoP levels were similar between standard platform and platform switch designs; however, platform switching designs had significantly less bone remodeling relative to FAJ and also trended to less recession; and
- Survival and success rates were 93.8% and 81.2% (up to >7 years ≤12) for standard platform, and 90 and 84% (up to >2 years ≤5) for platform switching.

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