Implants offer reliable and predictable long-term outcomes for restoring missing teeth. However, reestablishing esthetics can be challenging in the anterior region, where both white and pink esthetics are critical for the outcome evaluation.1,2 On one hand, as modern laboratory techniques evolve, achieving maximum similarities between artificial crowns and natural teeth is feasible. On the other hand, due to tooth loss–related keratinized gingiva recession and bone atrophy,3–6 soft tissue remodeling around the suprastructures could be difficult to predict.

Multiple parameters have been used in the assessment of soft tissue esthetics in the anterior region, among which the morphology and abundance of the gingival papilla are the focus of professional evaluation as well as patient satisfaction.7 In natural teeth, the embrasure papilla fill is mainly determined by the distance from the crestal bone level to the base of the interproximal contact point.8 In implant restorations, the papilla height of a single-tooth implant denture is also partly affected by the vertical distance from the bone crest to the contact point, which might be determined by the attachment level on the adjacent natural tooth.9–13 Nevertheless, when replacing multiple adjacent teeth with implants, it is particularly challenging to preserve and reconstruct the interproximal papilla,14,15 which could jeopardize the overall esthetics.16 Various factors might potentially influence the papilla outcome.17 However, a comprehensive understanding of the clinical features and risk factors of the papilla fill in adjacent implant crowns is still lacking.18,19

Therefore, it is of clinical importance to further elucidate the clinical characteristics as well as the risk factors of the interproximal papilla fill between single and adjacent implant crowns. To reduce clinical confounding...
effects from different tooth sites, the present work exclusively studied the maxillary central incisors. Compared with other teeth, maxillary central incisors have the greatest impact on smile esthetics, yet have not been independently studied in the literature. The aim of this study was to evaluate the esthetic outcome of interproximal papilla between implant-restored unilateral and bilateral maxillary central incisors.

MATERIALS AND METHODS

Study Design
This was a cross-sectional study of patients who had received implant restorations of unilateral or bilateral maxillary central incisors at the Department of Oral Implantology, School and Hospital of Stomatology, Tongji University, from April 2015 to January 2020. The study was conducted in accordance with the Declaration of Helsinki, revised in 2013, and was performed adhering to the STROBE statement for studies. The study was reviewed and approved by the Research Ethics Committee of the School and Hospital of Stomatology, Tongji University (approval number: [2019]-R-004). All patients provided informed consent prior to participation in the study.

Patients
The patients were retrospectively enrolled. The inclusion criteria were as follows: (1) patients who received implant treatment for unilateral or bilateral maxillary central incisor(s); (2) patients who received bone-level implant(s) and single-crown superstructure(s); and (3) patients who showed good compliance and had follow-up visits.

The exclusion criteria included: (1) patients who used medicine that may potentially induce gingiva hyperplasia; (2) patients who smoked more than 10 cigarettes per day; (3) patients with peri-implant mucositis or peri-implantitis; (4) patients who had received connective tissue graft for the purpose of soft tissue augmentation; (5) intraoral examination showed that there was no contact point between the two adjacent central incisors (implant-tooth or implant-implant site); and (6) gingival porcelain was used in the crown fabrication.

According to the number of missing incisors, patients were categorized as unilateral group (unilateral maxillary central incisor) and bilateral group (bilateral maxillary central incisors; Fig 1).

Treatment Procedure
No patient in the study received immediate implant placement. Before the surgery, patients were instructed to rinse with 0.12% chlorhexidine solution for
After local anesthesia and incisions, a mucoperiosteal flap was raised, and implants were placed based on the manufacturer’s guidelines following the principle for bone-level implant placement. Implants included Straumann bone-level implant Ø3.3 mm or Ø4.1 mm (Straumann) and Ankylos C/X implant Ø3.5 mm (Dentsply Sirona). If needed, bone substitute Bio-Oss or Bio-Oss Collagen and collagen membrane Bio-Gide were applied (Geistlich Pharma) to restore the labial alveolar contour. The full-thickness flap was repositioned and sutured tension-free. After a healing time of 3 or 6 months, depending on the performance of the bone-grafting procedure, the patients received stage 2 surgery. Incisions were placed slightly palatal without traumatizing the papilla zone. Without elevating the mucoperiosteal flap, a healing abutment was placed after removing the cover screw. After 2 to 4 weeks, the restorative procedure was initiated. Oral hygiene instruction was given after delivering the definitive restoration. All patients were recalled for clinical and radiographic assessment in the present study.

**Clinical and Radiographic Assessment**

The primary study outcomes were the papilla index (PI) and the patient-reported esthetic satisfaction of the two study groups; the secondary study outcomes were the clinical and radiographic variables that were associated with the presence of incomplete papilla fill.

**Intraoral Photographs and Periapical Radiographs**

The intraoral photographs were taken for evaluating the papilla esthetics in the follow-up visit. All photographs were shot by the same examiner (R.L.) according to the previously published standard, with a Canon DS 126321 digital camera equipped with a Canon 100 mm 1:2.8L IS USM lens. The aperture was locked to f/32 at ISO100-125. The view was 1:1.5. A periodontal probe with calibration tail, as the measuring scale to correct the papilla height, was put parallel to the midline and in contact with the labial surface of the crown (Fig 1).

For all patients, standardized periapical radiographs were acquired using the paralleling long cone technique. An intraoral x-ray unit (Heliodent Plus, Dentsply Sirona) with an intraoral sensor was used to collect the images.

**Image Analysis**

One examiner (R.L.) performed the analysis of the intraoral photographs and radiographic images, using Adobe Photoshop CC 2017 (Adobe Systems). The analyzed variables are illustrated in Fig 2.

Two variables were measured from the intraoral photographs:

- **Papilla height (PH):** Vertical distance from the tip of the papilla to the line connecting the gingival zeniths of both central incisors, between two implants or between the implant and natural tooth.
- **Missing papilla height (MPH):** Vertical distance from the tip of the papilla to the contact point, ie, the vertical dimension of the black triangle. In the present study, incomplete papilla fill was defined when MPH > 1 mm. MPH ≤ 1 mm is not visually perceptible by laypeople because the space is mostly filled with saliva.

A computer-assisted calibration was adopted. A 5-mm length segmented from the periodontal probe

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**Figure 2** Schematic illustration of clinical and radiographic variables. IP = implant platform; T = natural tooth; B = bone crest (most coronal point); C = contact point; L = implant length; P = papilla tip; IP-IP = implant-implant distance; IP-T = implant-tooth distance; IP-B = vertical distance from implant platform (IP) to bone crest (B); B-C = vertical distance from bone crest (B) to contact point (C); PH (papilla height) = vertical distance from papilla tip to the line connecting the gingival zenith of both central incisors; MPH (missing papilla height) = vertical distance from papilla tip to contact point.
The patient was with the outcome.

10, where the greater the value was, the more satisfied answers were quantified using a 10-cm ruler, from 1 to

The visual analog scale (VAS) scored according to the PI defined by Jemt26: 0 (no papilla present), and 4 (hyperplastic papilla).

All patients received a question regarding satisfaction of the final esthetics. The visual analog scale (VAS) answers were quantified using a 10-cm ruler, from 1 to 10, where the greater the value was, the more satisfied the patient was with the outcome.

Statistical Analysis
The software SPSS version 25.0 (IBM) was used to analyze the data. Descriptive statistics are presented as frequency (n, %) or mean value (SD). The t test was used to analyze the linear variables. The chi-square test was used to analyze the categorical data. In the unilateral group, multivariate logistic regression was applied to assess the risk factors to the presence of incomplete papilla fill. In the bilateral group, as the limited patient number did not support a regression model, the non-parametric Spearman correlation test was used to compare the PI and age, gender, abutment type, implant diameter, IP-IP, IP-B, and B-C, respectively. The significance level was defined as α = .05.

RESULTS

Patient Characteristics
After preliminary screening, 62 individuals met the inclusion criteria. Two cases were excluded for gingival porcelain, and four cases were excluded because there was no contact point between central incisors. In total, 56 patients were recruited, including 40 cases in the unilateral group and 16 cases in the bilateral group. The mean follow-up time was 23.2 months (unilateral group, 23.2 months; bilateral group, 23.1 months). The two groups were not statistically different in age (P = .596), gender (P = .863), implant system (P = .064), abutment type (P = .495), or crown material (P = .372). The characteristics of enrolled cases are shown in Table 1.

Variables Between Study Groups
Table 2 shows the frequencies of PI in the two study groups. The papilla fill in the unilateral group was superior to the bilateral group (P = .002). Patients in the two groups reported equal satisfaction regarding the final esthetic outcome (P = .470), as shown in Table 3.

The comparative results of linear variables that are derived from the clinical and radiographic examination are presented in Table 4. Statistically significant differences were noted in PH (P = .000), IP-IP/IP-T (P = .002), and IP-B (P = .000) between the two study groups. For MPH (P = .554) and B-C (P = .338), no significant difference was found.

Correlated Variables with PI in Bilateral Group
In the bilateral group, to investigate the correlated factors with PI, the Spearman correlation test was performed. Variables, including age (P = .913), gender (P = .810), implant diameter (P = .925), abutment type (P = .224), IP-IP (P = .316), IP-B (P = .360), and B-C (P = .509), did not show significant correlation with PI.

Table 1 Characteristics of Enrolled Cases (n = 56)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unilateral (n = 40)</th>
<th>Bilateral (n = 16)</th>
<th>P value</th>
</tr>
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<tbody>
<tr>
<td>Mean ± SD age (y)</td>
<td>38 ± 13</td>
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<td>.596</td>
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<tr>
<td>Gender</td>
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<td>Abutment type</td>
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Data are reported as n (%) unless otherwise indicated. *Straumann bone-level implants and Ankylos C/X implants. PFM = porcelain fused to metal.

was transformed into pixel numbers, which were then used to calibrate the pixels of PH and MPH.

The following variables were measured in the radiographic images:

- IP-IP: Horizontal distance between adjacent implants, measured at the implant platform (IP) level
- IP-T: Horizontal distance between the implant and natural tooth (T), measured at the implant platform (IP) level
- IP-B: Vertical distance from the implant platform (IP) to the bone crest (B)
- B-C: Vertical distance from the bone crest (B) to the contact point (C)

Linear variables measured from the radiographic images were calibrated with a ratio of measured implant length/actual implant length.

Esthetic Evaluation
The papilla fill between adjacent central incisors was scored according to the PI defined by Jemt26: 0 (no papilla), 1 (< 50% papilla fill), 2 (> 50% papilla fill), 3 (full papilla present), and 4 (hyperplastic papilla).

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Risk Factors for Incomplete Papilla Fill in Unilateral Group

In the unilateral group, the risk factors that the presence of incomplete papilla fill (MPH > 1 mm) is attributed to were tested. Clinical and radiographic variables were first tested in univariate binary logistic regression, including age (P = .902), gender (P = .792), implant system (P = .232), implant diameter (P = .210), abutment type (P = .004), IP-T (P = .062), IP-B (P = .618), and B-C (P = .297). Variables that showed P < .1 in univariate models were further included in a multivariate model. B-C was also included because it is acknowledged as a decisive factor in the embrasure fill.8 The effectiveness of the model was evaluated by the Omnibus test of model coefficients (P = .000), which is meaningful. The Hosmer-Lemesho test (P = .249) showed good fitting efficiency.

In the final model, abutment type (OR = 0.019), IP-T (OR = 6.435), and B-C (OR = 4.589) showed a significant impact on incomplete papilla fill (Table 5).

**DISCUSSION**

The aim of the present study was to evaluate the esthetic outcome of interimplant papilla between implant-restored unilateral and bilateral maxillary central incisors. The results showed that the PI of the unilateral group was superior to that of the bilateral group; however, patients in the two groups reported equal esthetic satisfaction. The better papilla fill of embrasure space in the unilateral group was concomitant with higher PH, smaller horizontal interunit distance, and higher vertical distance of the implant platform to the bone crest, compared to the bilateral group. In the bilateral group, no tested clinical factor was correlated with PI. In the unilateral group, the risk of incomplete papilla fill was decreased by the customized zirconia abutment and was increased by the larger implant-tooth distance (range: 2.1 to 6.2 mm) and higher vertical distance of the bone crest to the contact point (range: 3.5 to 6.9 mm).

Previous studies assessing interimplant papilla reported unspecified tooth positions varying from central incisors to premolars.14,27 The present study focused on the tooth position of the maxillary central incisor, which has the greatest impact on the dental esthetics. The patients in the present study are homogenous from this point of view. The results showed that PI in the unilateral group was superior to that of the bilateral group. This finding agrees with literature reporting that the papilla fill and esthetics between adjacent implants were difficult to achieve compared to a single implant.15,18,27 The compromised esthetics in adjacent implants might be related to the lack of periodontal ligament integrity from the natural tooth.9 Nevertheless, the patients...
implants, which are advantageous in preserving marginal bone suggests that an interimplant distance < 3 mm is biologically prejudicial to bone remodeling and mucosal integra-
tion. In platform-switched implants, which are advantageous in preserving margin bone, and may potentially leave more space for interproximal soft tissue growth.

There is no conclusive evidence regarding the risk factors of interimplant papilla fill. The present data showed that no clinical factor was correlated with PI in the bilateral group. On one hand, it is acknowledged that an interimplant distance < 3 mm is biologically prejudicial to bone remodeling and mucosal integra-
tion. In platform-switched implants, the limit could be as low as 2 mm. On the other hand, an interimplant distance > 4 mm may also negatively affect the papilla growth. In the present study, the average interimplant distance was 4.6 mm (range: 2.7 to 6.2 mm), which is around the high end of previously reported data. However, the distance of 4.6 mm is reasonable in this study considering the average width of the maxillary central incisor is 8.6 mm in the Chinese population, and all the placed implants except one were 3.5 mm in diameter. The present study did not find a correlation between horizontal distance and PI in the bilateral group. The present finding is in line with a recent systematic review, which concluded that no precise value could be suggested for the optimal horizontal distance between two adjacent implants.

Regarding the vertical distance from the bone crest to the contact point in adjacent implants, an early study demonstrated that 3 mm is ideal. Later evidence suggested that 3 to 4 mm may contribute to an optimal gingiva esthetic result with an immediate placement protocol. In the present data, the average vertical distance was 4.8 mm, which is beyond the recommended distance for complete papilla fill. Notably, the present study only included patients with maxillary central incisors missing, of which the average clinical crown length is 11.5 mm in the Chinese population. As a result, to best simulate the interproximal contour of natural teeth, the vertical distance is required to be greater than the proposed 3 to 4 mm in fabricating suprastructures, which may not be ideal for the papilla fill when promoting the harmony of white esthetics.

In evaluating the clinical factors in the unilateral group, the present study showed that compared to the stock titanium abutment, the customized zirconia abutment reduced the risk of incomplete papilla fill. Previous studies have demonstrated that various abutment materials did not affect papilla fill. Hence, the better performance of the customized zirconia abutment in the present patient cohort might be attributed to the advantages of the individualized CAD/CAM process, rather than the material per se.

As the present data suggested, in the range of 3.5 to 6.9 mm, higher vertical distance from the bone crest to the contact point may increase the risk of incomplete papilla fill. In natural teeth, a maximum 5-mm distance from the bone crest to the contact point is critical for 100% complete papilla fill. A similar pattern has been suggested in single implant restoration; ie, decreased distance is advantageous to papilla fill. The present data are in agreement with these reports.

The present results revealed that larger values of implant-tooth distance (range: 2.1 to 6.2 mm) increased the risk of incomplete papilla fill. However, in previous studies by Palmer et al (range: 1.5 to 3.7 mm) and Chang and Wennström (range: 0.4 to 4.7 mm), there was a lack of correlation between the horizontal distance and papilla level. In a study by Gastaldo et al, the horizontal distance of 3 mm showed the highest percentage of patients with complete papilla presence. In the present study, all implants were placed at a biologic safe distance (> 1.5 mm) from the natural tooth. The range of horizontal distance (4.1 mm) is relatively large, and the upper limit (6.2 mm) is greater than that of previous studies, which are favorable for achieving statistical significance. Furthermore, the present result should be explained in the context of platform-switched implants.

There are limitations in the present study that should be addressed: (1) as the present study only studied implants in maxillary central incisors, the sample size of the bilateral group was limited and insufficient for elucidating clinical risk factors for incomplete papilla fill; (2) soft tissue topography in terms of faciolingual dimensions of the papilla base may influence the papilla fill, but the present study failed to include this parameter in the analysis due to incomplete data; (3) the medical record did not include the crestal gingiva
thickness, which might contribute to the outcome of papilla fill40; (4) the PI of all patients was evaluated in a cross-sectional follow-up visit, which could not provide the information of soft tissue remodeling over time; (5) no patient from the present cohort received immediate implant placement and provisionalization, which has been suggested as a promising protocol in preserving PH41; and (6) only three cases were treated without guided bone regeneration (GBR; two in the unilateral group and one in the bilateral group), which does not support evaluating the impact of GBR on papilla fill.

CONCLUSIONS

In implant restorations, the creation of interproximal papilla in bilateral maxillary central incisors was more challenging and unpredictable than in unilateral incisors. This study showed that:

1. PI was superior in implant-restored unilateral maxillary central incisors compared to bilateral incisors. However, patients reported equal satisfaction with the final esthetic outcome.
2. In the bilateral group, no clinical variable was associated with PI. Risk factors of incomplete papilla fill were not evaluated due to limited patient number.
3. In the unilateral group, the multivariate logistic regression model indicated that the risk of incomplete papilla fill was reduced by the customized zirconia abutment and was increased by larger implant-tooth distance (range: 2.1 to 6.2 mm) and higher vertical distance from the bone crest to the contact point (range: 3.5 to 6.9 mm).

ACKNOWLEDGMENTS

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REFERENCES


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