

Factors associated with the appearance of gingival papillae

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Abstract

Aim: The purpose of this study was to evaluate factors associated with the fill of interdental spaces by gingival papillae.

Materials and Methods: Ninety-six adult subjects were evaluated. Papilla score (PS), tooth form/shape, interproximal contact length and gingival thickness were recorded for 672 maxillary anterior and first pre-molar interproximal sites. Statistical analyses included a non-parametric χ^2 test, ANOVA, the Mixed Procedure for SAS and Pearson's correlation coefficient (r).

Results: Papilla deficiency was more frequent in older subjects ($p < 0.05$), as papilla height decreased 0.012 mm with each year of increasing age ($p < 0.05$). Competent papillae (complete fill inter-dentally) were associated with: (1) crown width: length ≥ 0.87 ; (2) proximal contact length ≥ 2.8 mm; (3) bone crest-contact point ≤ 5 mm; and (4) interproximal gingival tissue thickness ≥ 1.5 mm. Gingival thickness correlated negatively with PS ($r = -0.37$ to -0.54) and positively with tissue height ($r = 0.23$ – 0.43). Tooth form (i.e. crown width to length ratio) correlated negatively with PS ($r = -0.37$ to -0.61). Other parameters failed to show any significant effects.

Conclusions: Gingival papilla appearance was associated significantly with subject age, tooth form/shape, proximal contact length, crestal bone height and interproximal gingival thickness.

Key words: cosmetic dentistry; cosmetic periodontal plastic surgery; gingival thickness; treatment planning

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The loss of gingival papilla height can result in open gingival embrasures, phonetic problems, food impaction and aesthetic concerns (Pradeep & Karthikeyan 2006). Clinicians must therefore understand the factors that influence papilla form in order to prevent papilla loss and to better understand the challenges of regenerating lost gingival papillae.

Studies of human skulls (Hirschfeld 1923, Becker et al. 1997) have suggested that the underlying bone anatomy dictates gingival contours. In a human clinical study, Tarnow et al. (1992) found that papillae completely filled embrasures 100% of the time when the distance from the interproximal contact point (IPC) to crestal bone was ≤ 5 mm, 56% of the time when IPC was 6 mm and only 27% of the time at 7 mm. They suggested that other factors might contribute to a complete fill, such as interproximal distance (IPD) and total embrasure space volume. Other authors also have found that IPD is a determinant of papilla form (Klassman & Zuckerman 1969, Pennel & Keagle 1977, Trossello & Gianelly 1979, Heins & Wieder 1986). A recent longitudinal study reported that sites with

IPD < 0.8 mm were 28% more likely to lose ≥ 0.5 mm of bone and 56% more likely to lose ≥ 1.0 mm over 10 years (Kim et al. 2008). Conversely, Cho et al. (2006) demonstrated that the number of papillae that filled embrasures decreased with the increasing IPD, and papillae were always lost when IPD was ≥ 4 mm. Martegani et al. (2007) also showed that increasing the IPD between roots corresponded to an increase in the distance from the interproximal contact to papilla tip. Thus, inter-dental space can affect papilla height.

Tooth form or shape is categorized frequently as ovoid, triangular or square. Empirical reports (Hirschfeld 1923, Morris 1958, Wheeler 1961, Weisgold 1977) indicate that tooth shape may affect the shape of the periodontium. Teeth with tapered, triangular-shaped

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crowns have been described as having a thin gingival ‘‘biotype’’, with highly scalloped gingival margins, thin alveolar bone and small proximal contacts located near their incisal edges. Square-shaped crowns, on the contrary, usually have a thick periodontal ‘‘biotype’’ with longer and more apically positioned contacts. As a result, square-shaped teeth tend to have a lower risk of gingival recession and require less tissue to fill the interproximal space (Olsson & Lindhe 1991, Olsson et al. 1993, Kois 2004).

Two basic types of gingival architecture have been described – ‘‘scalloped-thin’’ and ‘‘flat-thick’’ (Weisgold 1977, Kois 2004). Empirical evidence suggests areas with scalloped-thin tissue are more prone to develop recession when exposed to trauma or inflammation, while flat-thick tissues are more likely to develop deeper periodontal pockets (Weisgold 1977). It is generally agreed that thick gingival tissue allows better tissue manipulation, encourages creeping attachment, improves implant aesthetics, reduces clinical inflammation and renders predictable surgical outcomes (Matter 1980, Wennstrom & Lindhe 1983a,b, Claffey & Shanley 1986, Nelson 1987, Borghetti & Gardella 1990, Serino et al. 1994, Harris 1997, Muller et al. 2000a,b, Muller & Eger 2002, Kois 2004, Rotundo et al. 2008). To date, however, no study has evaluated the effect of gingival thickness on the appearance of dental papillae.

There is no minimum width of keratinized (KG) or attached gingival tissue (AG) necessary to maintain health, provided plaque control is adequate; however, sites with narrow KG have been associated with increased recession when exposed to mechanical trauma or poor oral hygiene (Wennstrom & Lindhe 1983b). Therefore, it is possible that KG and AG width may influence papilla appearance, particularly when inflammation is present.

Few studies (Tarnow et al. 1992, Kurth & Kokich 2001, Wu et al. 2003, Cho et al. 2006, Chang 2008) have examined factors contributing to the presence or absence of dental papillae. Most focused on the influence of crestal bone height and/or IPD. Many other factors that might influence papillary appearance, such as tooth form/shape, gingival thickness and KG/AG width, have never been fully examined. In addition, open gingival embrasures, often termed ‘‘black triangles’’, have been reported to occur after orthodontic

correction of crowded incisors (Atherton 1970, Burke et al. 1994). Understanding how these factors affect gingival papilla appearance will aid clinicians in making better treatment decisions where aesthetics is critical. Therefore, the purpose of this study was to examine factors that may influence the appearance of inter-dental gingival papillae.

Materials and Methods

One hundred and one subjects were screened and 96 subjects, with 672 interproximal sites, were enrolled in the study from April 2006 to August 2007. Subjects were recruited from the University of Michigan School of Dentistry and included patients, dental/hygiene students, staff and faculty members. The University of Michigan’s human subject IRB approved the study protocol, and subjects gave informed consent before participation. A single calibrated examiner (YCC) performed all clinical and radiographic evaluations. For calibration before the study, the examiner performed repeated measurements of five subjects who met the same study enrollment criteria. Subjects used for calibration did not participate in the study. For all study measurements, the examiner attained a κ value of 95% agreement.

Screening examination

The calibrated examiner performed the following assessments at the initial screening visit: medical history review, dental history review, dental examination and periodontal examination. For inclusion, subjects were required to be healthy adults, ≥ 18 years old, with no history of smoking or significant systemic disease, including uncontrolled diabetes, uncontrolled hypertension, immunosuppressive diseases and other systemic diseases known to influence the papillae appearance. Each had at least eight maxillary anterior teeth with no evidence of gingivitis or periodontitis. Subjects with any of the following were excluded: history of periodontal surgery, interproximal restorations, interproximal caries, severe mal-position, absence of proximal contact and attrition score > 1 (Smith & Knight 1984). In addition, subjects with gingival overgrowth were excluded. Subjects meeting all inclusion criteria

who consented to participate were enrolled in the study and returned for an examination.

Study examination

The calibrated examiner performed all assessments and measurements. Each subject’s age, gender, ethnic background and history of orthodontic treatment were recorded. Clinical measurements were limited to the facial aspects of the maxillary first pre-molars, canines and incisors. Each inter-dental papilla was given a papilla score (PS) of 0–3 based upon Nordland and Tarnow’s classification system (Nordland & Tarnow 1998): normal (0) = inter-dental papilla fills embrasure space to the apical extent of the inter-dental contact point/area; class I (1) = the tip of the inter-dental papilla lies between the IPC and the most coronal extent of the interproximal CEJ; class II (2) = the tip of the inter-dental papilla lies at or apical to the interproximal CEJ but coronal to the apical extent of the facial CEJ; and class III (3) = the tip of the inter-dental papilla lies level with or apical to the facial CEJ. In addition, based on this score, the papilla was defined as competent (PS = 0) or deficient (PS ≥ 1).

Loss of papilla height was measured from the papilla tip to the apical terminus of the IPC using a UNC-15 periodontal probe (Hu Friedy, Chicago, IL, USA). Papilla height was then calculated by subtracting the loss of papilla height from the crestal bone height.

The examiner measured crestal bone height after administering a local anaesthesia (2% lidocaine with 1:100,000 epinephrine, Astra Pharmaceuticals/Wilmington, DE, USA) via local infiltration. For each mesio-facial or disto-facial test site, the examiner positioned a UNC-15 periodontal probe in the gingival sulcus, parallel to the long axis of the tooth and as far interproximally as possible, and then inserted it until the probe contacted bone. The distance from the crestal bone to the most apical extent of the interproximal contact area was then recorded as the crestal bone height. The incisocervical length of the inter-dental contact area was also measured.

The IPD between teeth was determined radiographically. Peri-apical radiographs were taken with a long-cone paralleling technique utilizing a film-positioning device (Rinn XCP system, Rinn Corp., Elgin, IL, USA). The width of the inter-dental space was then mea-

sured, from CEJ to CEJ of adjacent teeth, using a digital caliper (Salvin Dental Specialties Inc., Charlotte, NC, USA).

Gingival thickness was determined using an ultrasonic measuring device (SDM, Austenal Medizintechnik, Koln, Germany) as described by Muller et al. (2000a). The transducer probe with a diameter of 4 mm was moistened with either saliva or water and applied to the measurement sites. The thickness of the facial gingiva was measured at the base of the inter-dental papilla. The base of the inter-dental papilla was defined as the point of intersection between a line drawn tangent to the most apical extent of the gingival margins of two adjacent teeth, and a line perpendicular to the first line that passes through the tip of the gingival papilla.

After staining the alveolar mucosa with Schiller's iodine solution, mid-facial KG width was measured using a UNC-15 periodontal probe (Fasske & Morgenroth 1958). AG width was then determined by subtracting the mid-facial probing pocket depth from the corresponding KG width. All measurements were rounded to the nearest half-millimetre. Dental plaque and degree of gingival inflammation of the eight maxillary anterior teeth were assessed and scored according to the classifications of Loe & Silness (1963) and Silness & Loe (1964), respectively.

Tooth form/shape was determined by measuring the ratio of the width of each crown to its length (CW/CL) from study models of each subject's maxillary teeth (Olsson & Lindhe 1991). CL was defined as the distance from the gingival margin or, if discernible, the CEJ to the incisal edge or cusp tip of the crown. Crown width (CW) was determined by measuring the distance from the most apical extent of the proximal contact on the mesial surface to the similar point on the distal surface of each tooth. A Trubyte[®] Millimeter Rule (Dentsply International Inc., York, PA, USA) was used to make measurements.

Data analysis

Statistic analysis was performed using the SAS statistical program (Statistical Analysis System, SAS Institute, Cary, NC, USA). Intra-examiner repeatability was assessed using Kappa statistics. We used the patient as the unit of analysis for all calculations. The papilla competence/deficiency frequencies in different

age, gender, ethnic and orthodontic groups were calculated using χ^2 tests for contingency tables. The mean value of each clinical parameter (CW/CL, contact length, crestal bone height, IPD, gingival thickness and KG and AG width) at each inter-dental site was determined for each group, papilla competent and papilla deficient, and compared with a two-way analysis of variance (ANOVA). The Mixed Procedure for SAS was used to analyse relationships between the demographic variables (age, gender and ethnicity), clinical measurements (CW/CL, contact length, crestal bone height, IPD, gingival thickness and KG and AG width) and papilla appearance. In addition, Pearson's correlation coefficients were used to assess the associations between clinical variables and PSs/heights, and between CW/CL and contact length. Statistical significance was recognized at a p value <0.05 .

Results

The mean age of the 96 subjects was 31.1 ± 11.5 years and the median age was 27 years with an inter-quartile range of 9.5 years. Age ranged from 18–73 years (Table 1). There were 55 females and 43 males. Most of the subjects were either Caucasians (54%) or Chinese (34%). The remaining subjects were African-Americans (9%) and Hispanics (2%). All subjects had good oral hygiene with no sign of active periodontal disease. Mean attachment levels ranged from 0.3 to 0.6 mm apical to CEJ, except maxillary first pre-molars, which averaged a 1 mm mid-facial attachment loss. None of the sites had a mean probing depth >3 mm. All

mean PI (Loe & Silness 1963) and GI (Silness & Loe 1964) scores were <1 .

The site most susceptible to having a deficient papilla was at the midline, between the two central incisors, where 69.75% had $PS >0$. Other sites had complete papilla fill ($PS = 0$), ranging from 61.1% to 81.9%. The vertical height of inter-dental papilla ranged from 3.8 mm between lateral and central incisors to 4.3 mm at the pre-molar-canine area (Table 2). PS and papilla heights did not differ on the right and left sides.

Impact of age, gender and ethnicity on the appearance of papillae

The 96 subjects were divided into three age groups: <35 years (74 subjects), 35–49 years (11 subjects) and ≥ 50 years (11 subjects). Regardless of inter-dental site, the older group always had a higher incidence of papilla deficiency than the younger one (Table 3). In addition, the incidence of papilla deficiency was always the greatest between the central incisors regardless of age group. Overall, the papillary tissue height decreased by 0.012 mm/year of age ($p < 0.05$). See Fig. 1.

The incidence of deficient papillae was greater in males than females, but this was statistically significant only between teeth 14 and 13. Additionally, papilla height was greater for males than females (4.2 versus 3.9 mm, $p < 0.01$).

African-American and Hispanic subjects were excluded from the statistical analysis of the association of ethnicity with the papillary appearance because of small sample sizes (i.e. <10 subjects). When the incidence of competent papilla was compared between Caucasians and Chinese, no significant difference

Table 1. Subject demographics and history of orthodontic treatment

	Male (N = 43, 44.8%)	Female (N = 53, 55.2%)	All subjects	
Age (years)				
Median, inter-quartile range	26, 10	28, 9.5	27, 9.5	
Mean \pm SD	32.1 ± 11.4	30.2 ± 11.6	31.1 ± 11.5	
Range	22–66	18–73	18–73	
	Caucasian	Asian (Chinese)	African-American	Hispanic
Ethnicity				
N (%)	52 (54.2%)	33 (34.4%)	9 (9.4%)	2 (2.1%)
		Yes		No
Orthodontic treatment				
N (%)		52 (54.2%)		44 (45.8%)

Table 2. Papilla score and height in the maxillary anterior region

Inter-dental	Papilla score (PS) N (%)		Papilla height (mean \pm SD mm)
	PS = 0	PS \geq 1	
14-13	64 (74.4)	22 (25.6)	4.18 \pm 0.83
13-12	75 (79.8)	19 (20.2)	3.97 \pm 0.85
12-11	58 (61.1)	37 (38.9)	3.78 \pm 0.87
11-21	27 (30.3)	62 (69.7)	4.04 \pm 0.99
21-22	61 (63.5)	35 (36.5)	3.86 \pm 0.82
22-23	77 (80.2)	19 (19.8)	4.09 \pm 0.82
23-24	68 (81.9)	15 (18.1)	4.27 \pm 0.70

Table 3. Frequency of the seven interproximal sites with PS = 0 (i.e. complete papilla fill, or competence) in the three age groups: <35 years (74 subjects), 35-49 years (11 subjects) and \geq 50 years (11 subjects)

Inter-dental Site by tooth number	Age (years)	Papilla competent (%)	χ^2
14-13	<35	82	$p < 0.05$
	35-49	70	
	≥ 50	22	
13-12	<35	90	$p < 0.0001$
	35-49	55	
	≥ 50	36	
12-11	<35	71	$p < 0.05$
	35-49	45	
	≥ 50	9	
11-21	<35	39	$p < 0.05$
	35-49	9	
	≥ 50	0	
21-22	<35	77	$p < 0.0001$
	35-49	27	
	≥ 50	9	
22-23	<35	89	$p < 0.05$
	35-49	55	
	≥ 50	45	
23-24	<35	92	$p < 0.0001$
	35-49	60	
	≥ 50	25	

PS, papilla score.

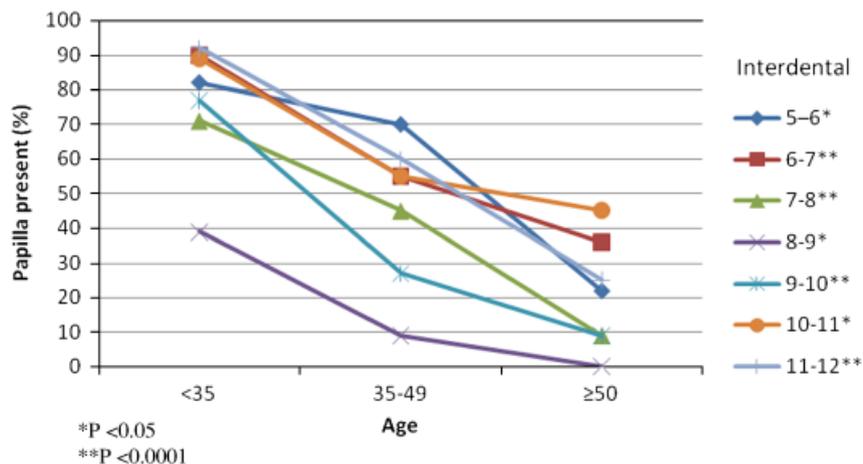


Fig. 1. Impact of age on the appearance of papilla. * $p < 0.05$, ** $p < 0.0001$. Frequency of the seven inter-dental sites with PS = 0 (competent papilla) in the three age groups. Within each inter-dental site, the older group always showed a lower frequency of competent papillae than the young one. PS, papilla score.

was found. Chinese had slightly greater papilla height than Caucasians, but not statistically significant (4.2 versus 4.0 mm, $p = 0.14$).

Impact of orthodontic treatment on appearance of papillae

Orthodontically treated patients had a similar gingival fill to non-orthodontically treated patients, except at teeth #12-13 and 23-24, where papilla deficiency was significantly less ($p < 0.05$) for orthodontically treated patients. More than half of the subjects (54.2%) had orthodontic treatment in the past (Table 1).

Impact of tooth form/shape on the appearance of papillae

The competent papilla group always illustrated significantly greater CW/CL ratios on adjacent teeth than the papilla-deficient group (Table 5a). The CW/CL ratio in the competent papilla group (PS = 0) was ≥ 0.87 ($p < 0.05$). Mean tooth shape (CW/CL) ranged from 0.84 at the lateral incisors, which corresponds to a long-narrow shape, to 0.92 at the pre-molars, which is a short-wide shape (Table 4a, Fig. 2).

Impact of contact length on the appearance of papillae

Teeth with competent papillae had significantly longer interproximal contacts with only two exceptions, the #14-13 and 13-12 sites (Table 5b). Also, the overall mean IPC length was significantly greater in the competent papilla group than the deficient group (2.8 versus 2.2 mm, $p < 0.01$). Contact length was the shortest between the pre-molars and canines (2.15 \pm 0.47 and 2.12 \pm 0.55 mm for 14-13 and 23-24 sites, respectively), and gradually increased towards the midline, where it was the longest between the central incisors (3.08 \pm 1.14 mm).

Impact of crestal bone level on the appearance of papillae

Table 5c and Fig. 3 illustrate that papillae always filled the inter-dental space when the distance from proximal contact to bone crest was ≤ 5 mm. The average distance from contact point to bone crest was ≤ 5 mm for all sites except between teeth 12-21, which measured approximately 6 mm.

Table 4. Crown width to crown length (CW/CL) ratios of maxillary anterior teeth

Tooth	CW/CL ratio (mean ± SD)	Minimum	Maximum
14	0.92 ± 0.11	0.72	1.33
13	0.88 ± 0.09	0.64	1.13
12	0.85 ± 0.11	0.61	1.17
11	0.86 ± 0.08	0.72	1.06
21	0.86 ± 0.09	0.68	1.13
22	0.84 ± 0.10	0.60	1.13
23	0.86 ± 0.08	0.65	1.12
24	0.92 ± 0.11	0.70	1.25

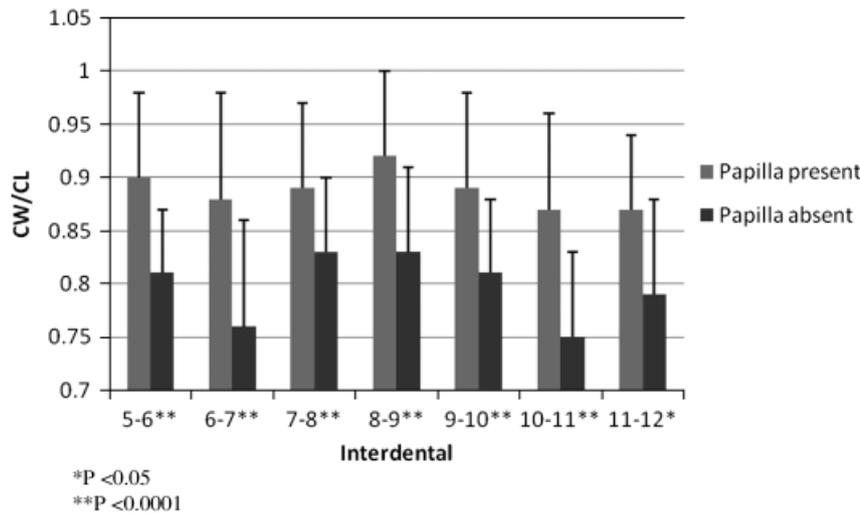


Fig. 2. Impact of tooth form/shape on the appearance of papilla. * $p < 0.05$, ** $p < 0.0001$. (a) Mesial CW/CL of the seven inter-dental sites in the competent papilla (present) (i.e. PS = 0) and deficient (absent) (i.e. PS ≥ 1) groups. The competent papilla group always displayed a higher CW/CL ratio ($p < 0.05$). PS, papilla score; CW/CL; crown width to crown length.

Table 5a. Mesial and distal crown width to crown length (CW/CL) ratios of the seven inter-dental sites in the papilla competent (i.e. PS = 0) and deficient (i.e. PS ≥ 1) groups in the maxillary anterior region

Inter-dental	Mesial CW/CL (mean ± SE)		<i>p</i>	Distal CW/CL (mean ± SE)		<i>p</i>
	PS = 0	PS ≥ 1		PS = 0	PS ≥ 1	
14–13	0.90 ± 0.01	0.81 ± 0.01	<0.0001	0.95 ± 0.01	0.82 ± 0.01	<0.0001
13–12	0.88 ± 0.01	0.76 ± 0.02	<0.0001	0.90 ± 0.01	0.80 ± 0.02	<0.0001
12–11	0.89 ± 0.01	0.83 ± 0.01	<0.0001	0.91 ± 0.01	0.77 ± 0.01	<0.0001
11–21	0.92 ± 0.02	0.83 ± 0.01	<0.0001	0.92 ± 0.01	0.83 ± 0.01	<0.0001
21–22	0.89 ± 0.01	0.81 ± 0.01	<0.0001	0.89 ± 0.01	0.76 ± 0.01	<0.0001
22–23	0.87 ± 0.01	0.75 ± 0.02	<0.0001	0.87 ± 0.01	0.80 ± 0.02	<0.05
23–24	0.87 ± 0.01	0.79 ± 0.02	<0.05	0.94 ± 0.01	0.81 ± 0.02	<0.0001

The analysis of variance showed a significant interval (between inter-dental sites) effect ($p \leq 0.0001$), a significant group (relating to CW/CL ratios) effect ($p \leq 0.0001$) and a significant interaction effect ($p = 0.0089$). PS, papilla score.

Impact of IPD on the appearance of papillae

The IPD between central incisors was significantly wider in the deficient papilla group than the competent group (1.6 versus 1.4 mm, $p < 0.05$). Conversely, the IPD between teeth 21 and

22 was significantly narrower for the deficient papilla group (1.0 versus 1.2 mm, $p < 0.05$). At other sites, there were no significant differences between groups with regard to IPD. The average IPD varied from 1.1 to 1.5 mm.

Impact of KG/AG tissue on the appearance of papillae

Overall, when the papilla was competent, the KG/AG tended to be wider; however, the difference was not statistically significant at any site ($p > 0.05$). The mean width of KG ranged from 3.6 to 5.1 mm, and the width of AG ranged from 2.3 to 4.0 mm. Widths of KG and AG were the narrowest over pre-molars and the widest over lateral incisors.

Impact of gingival thickness on the appearance of papillae

In general, mean gingival thickness was significantly greater when the papilla was competent than when deficient (1.5 versus 0.9 mm, $p < 0.01$). This was also true for all individual sites (Table 5d). The average gingival thickness ranged from 1.2 to 1.5 mm. Gingiva tended to be the thickest between the central incisors (1.47 ± 0.68 mm).

Correlation between papillary appearance and clinical variables

Out of the six clinical parameters assessed, only tooth form (CW/CL), crestal bone level and gingival thickness were significantly associated with papilla appearance in all inter-dental sites (Table 6). Tooth form was negatively associated with the PS ($r = -0.37$ to -0.61), meaning that teeth with a higher CW/CL would be more likely to have a lower PS (i.e. presence of papilla). Bone height showed a positive correlation with both PS ($r = 0.67-0.79$) and papilla height ($r = 0.12-0.32$). Gingival thickness was positively correlated with papilla height ($r = 0.23-0.43$). The PS had a negative correlation with tissue thickness ($r = -0.37$ to -0.54), meaning that thicker tissue was associated with an increased likelihood of having a complete papilla fill.

Correlation between tooth form/shape and contact length

For each inter-dental site, the correlation between tooth form/shape and contact length was assessed. There was no correlation between these two variables ($p > 0.05$).

Discussion

This study evaluated factors that may be associated with dimensions of the papil-

Table 5b. Contact lengths of the seven inter-dental sites in the papilla competent (i.e. PS = 0) and deficient (i.e. PS \geq 1) groups in maxillary anterior region.

Inter-dental	Contact length (mean \pm SE mm)		<i>p</i>
	PS = 0	PS \geq 1	
14–13	2.17 \pm 0.08	1.97 \pm 0.13	0.18
13–12	2.43 \pm 0.07	2.22 \pm 0.14	0.16
12–11	3.08 \pm 0.08	2.50 \pm 0.10	<0.0001
12–21	4.25 \pm 0.12	2.56 \pm 0.08	<0.0001
21–22	3.25 \pm 0.08	2.29 \pm 0.10	<0.0001
22–23	2.41 \pm 0.07	2.10 \pm 0.14	<0.05
23–24	2.16 \pm 0.08	1.75 \pm 0.15	<0.05

The average contact length of papilla competent group (2.8 mm) was significantly longer than the deficient group (2.2 mm) ($p < 0.0001$). The analysis of variance showed a significant interval (between inter-dental sites) effect ($p \leq .0001$), a significant group (relating to contact length) effect ($p \leq 0.001$) and a significant interaction effect ($p \leq 0.001$).

PS, papilla score.

Table 5c. Clinical bone heights of the seven inter-dental sites in the papilla competent (i.e. PS = 0) and deficient (i.e. PS \geq 1) groups in the maxillary anterior region

Inter-dental	Bone height (mean \pm SE mm)		<i>p</i>
	PS = 0	PS \geq 1	
14–13	4.66 \pm 0.13	5.07 \pm 0.18	<0.05
13–12	4.35 \pm 0.12	5.08 \pm 0.19	<0.0001
12–11	4.36 \pm 0.13	5.45 \pm 0.15	<0.0001
12–21	4.85 \pm 0.16	6.43 \pm 0.13	<0.0001
21–22	4.37 \pm 0.13	5.66 \pm 0.15	<0.0001
22–23	4.40 \pm 0.12	5.16 \pm 0.19	<0.0001
23–24	4.58 \pm 0.12	4.95 \pm 0.20	0.068

The average bone height in the papilla competent group was 4.5 mm while the deficient group was 5.4 mm ($p < 0.0001$). The analysis of variance showed a significant (between inter-dental sites) interval effect ($p \leq 0.0001$), a significant group (relating to bone height) effect ($p \leq 0.0001$) and a significant interaction effect ($p \leq 0.0001$).

PS, papilla score.

Table 5d. Gingival thicknesses of the seven inter-dental sites in the papilla competent (i.e. PS = 0) and deficient (i.e. PS \geq 1) groups in the maxillary anterior region

Inter-dental	Gingival thickness (mean \pm SE mm)		<i>p</i>
	PS = 0	PS \geq 1	
14–13	1.41 \pm 0.06	0.85 \pm 0.10	<0.0001
13–12	1.54 \pm 0.06	0.78 \pm 0.10	<0.0001
12–11	1.45 \pm 0.06	0.82 \pm 0.08	<0.0001
12–21	1.94 \pm 0.09	1.22 \pm 0.06	<0.0001
21–22	1.45 \pm 0.06	0.80 \pm 0.08	<0.0001
22–23	1.50 \pm 0.06	0.80 \pm 0.10	<0.0001
23–24	1.31 \pm 0.06	0.83 \pm 0.11	<0.0001

The average thickness in the papilla competent group (1.5 mm) was significantly greater than the deficient group (0.87 mm) ($p < 0.0001$). The analysis of variance showed a significant interval (between inter-dental sites) effect ($p \leq 0.0001$) and a significant group (relating to gingival thickness) effect ($p \leq 0.0001$). Interaction effect was not significant ($p = 0.5825$).

PS, papilla score.

lary gingiva in the maxillary anterior teeth in 96 subjects. The results showed that subject age, tooth shape, inter-dental contact length, gingival thickness and distance from contact point to the alveolar crest were associated with papilla dimensions. Other factors, such

as gender, race and previous orthodontic treatment and KG/AG width had minimal impact. Papilla height decreased 0.012 mm/year of age, which agrees with a recent report by Chang (2008).

In this study, the embrasure between central incisors was the most frequent

site for deficient papillae (69.7%). Long-narrow tooth form and incisally positioned interproximal contacts may contribute to an increased incidence of incompetent papillae between maxillary central incisors.

Associations of gender and ethnic background with gingival recession have been reported (Gorman 1967, Albandar & Kingman 1999, Susin et al. 2004, Collins et al. 2005, Abrahamsen et al. 2006). Our data revealed no association of either factor on inter-dental papilla appearance, with the following exception: papilla height was greater for males than females ($p < 0.05$), which may have been due to larger tooth size in the males.

We found that CW/CL ratios of teeth adjacent to competent papillae were significantly greater than those adjacent to deficient papillae, which indicates that teeth with a square form were less likely to have deficient papillae. When CW/CL was ≥ 0.87 , papillae always filled the inter-dental space. Our results agree with previous reports that the square tooth shape favours papilla competence more than the triangular tooth shape (LaSota 1988, Kokich 1996, Kois 2004). Kois (2004) explained that square teeth have longer proximal contacts and more tooth structure to fill the inter-dental area, which reduces the risk of ‘black triangles’ compared with a triangular-shaped tooth. Our data however failed to demonstrate a correlation between proximal contact length and tooth shape for most inter-dental sites. Despite this, our findings showed that the IPC length in the competent papilla group was 0.6 mm longer than the deficient papilla group, leading to the conclusion that a long contact appears beneficial for papilla competence.

Our results indicated that contact position is more likely to affect papilla fill than contact length. For example, a square-shaped tooth may have a more apically positioned contact than a triangular-shaped tooth. Kurth & Kokich (2001) also found that patients with open gingival embrasures after orthodontic treatment had a significantly reduced CW/CL ratio (i.e. 0.78) and shorter interproximal contacts that were located 1 mm more incisally than patients with normal gingival embrasures. In addition, they found that open embrasures were associated with an increased embrasure area (8.16 *versus* 5.09 mm²). Based on anthropologic and forensic data regarding maxillary inci-

sors, a fair number of patients have triangular-shaped central incisors (Taylor 1969). Hence, to minimize the occurrence of deficient papillae in the maxillary anterior, clinicians should assess tooth shape with care before performing restorative, orthodontic or surgical treatment.

Results from this study showed that papillary appearance is significantly associated with the vertical distance from the alveolar bone crest to the interproximal contact (BC/IPC), which confirms findings from previous studies

(Tarnow et al. 1992, Wu et al. 2003). The bone crest level displayed a strong positive correlation with the PS and moderate positive correlation with papilla height. The papilla almost always filled the interproximal embrasure when the vertical distance was ≤ 5 mm. In contrast, the papillae usually did not fill the interproximal spaces when the distance was > 5 mm. BC/IPC between the two central incisors was 5.6 mm, which may explain the high prevalence of papilla deficiency in this specific area. Our findings agree

with Tarnow et al. (1992), who reported that 44% of gingival embrasures were open when BC/IPC was 6 mm, increasing to 73% as the distance increased to 7 mm. In addition, Kurth & Kokich (2001) demonstrated that a 1 mm increase in BC/IPC increases the odds of an open gingival embrasure by 78–97%. Chang (2008) also reported that each 1 mm increase in BC/IPC increases the risk of papilla recession by 3.04-fold, and the bone crest to CEJ distance is the strongest predictor of the probability of papillary loss. Based on these data, the interproximal soft tissue usually extends ≤ 5 mm from the alveolar crest to the contact.

Other studies have reported that the IPD between roots influences gingival papilla appearance (Cho et al. 2006, Martegani et al. 2007). Cho et al. (2006) reported that papilla fill decreased as the distance between roots increased, ranging from 80% when the IPD was 1 mm to 0% filled when the distance was ≥ 4 mm. Martegani et al. (2007) also found a relation between IPD and papilla fill between maxillary incisors. Using digital photographs and peri-apical radiographs, they found that when the inter-radicular distance was ≤ 2.4 mm, an increase in BC/IPC corresponded to a marked increase in interdental black triangle dimensions. When the distance was > 2.4 mm, BC/IPC lost its influence on the papillary appearance. Our results, however, showed that the IPD was similar for both com-

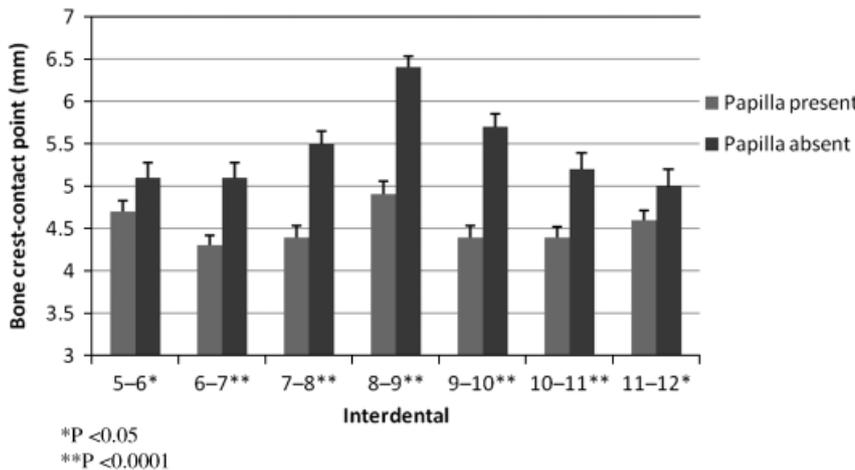


Fig. 3. Impact of crestal bone level on the appearance of papilla. * $p < 0.05$, ** $p < 0.0001$. (a) Clinical bone level of the seven inter-dental sites in the papilla present (competent) (i.e. PS = 0) and absent (deficient) (i.e. PS ≥ 1) groups. The distance from the bone crest to the contact point was significantly smaller in the papilla competent group than the deficient group ($p < 0.05$). The average bone height in the papilla competent group was 4.5 mm while the deficient group was 5.4 mm ($p < 0.0001$). PS, papilla score.

Table 6. Pearson's correlation coefficients between dependent[†] and independent[‡] variables for seven inter-dental sites in the maxillary anterior region

Inter-dental		CW/CL ratio		Contact length	Crestal bone level	Interproximal distance	KG/AG		Gingival thickness
		mesial	distal				mesial	distal	
14-13	Papilla score	-0.45***	-0.46***	-0.17	0.70***	0.075	-0.17/-0.18	-0.22**/-0.23**	-0.40***
	Papilla height	0.17	0.35**	-0.046	0.24**	0.071	0.052/0.014	0.23**/0.20	0.43***
13-12	Papilla score	-0.42***	-0.45***	0.033	0.73***	0.024	-0.090/-0.079	-0.075/-0.093	-0.39***
	Papilla height	-0.082	-0.047	-0.016	0.37**	-0.065	0.17/0.099	0.12/0.043	0.23**
12-11	Papilla score	-0.40***	-0.59***	-0.24**	0.79***	-0.12	-0.22**/-0.28**	-0.15/-0.17	-0.51***
	Papilla height	-0.014	0.066	0.21**	0.18	0.0067	0.17/0.18	0.091/0.068	0.34**
11-21	Papilla score	-0.41***	-0.47***	-0.55***	0.67***	0.093	-0.044/-0.20*	-0.14/-0.18	-0.49***
	Papilla height	-0.064	-0.0076	0.093	0.33**	-0.053	0.13/0.12	0.23**/0.20*	0.35**
21-22	Papilla score	-0.37**	-0.61***	-0.38**	0.79***	0.33**	-0.061/-0.14	-0.19*/-0.24**	-0.54***
	Papilla height	-0.11	0.094	0.30**	0.17	0.22**	-0.043/-0.048	0.039/0.041	0.25**
22-23	Papilla score	-0.47***	-0.43***	-0.13	0.72***	-0.049	-0.18/-0.22**	-0.19*/-0.19*	-0.47***
	Papilla height	-0.047	-0.048	0.080	0.36**	-0.11	-0.018/-0.024	-0.049/-0.082	0.29**
23-24	Papilla score	-0.40**	-0.41**	-0.18	0.76***	-0.16	-0.21*/-0.25**	-0.16/-0.16	-0.37**
	Papilla height	-0.11	-0.010	0.083	0.38**	0.17	0.14/0.13	0.13/0.075	0.34**

[†]Dependent variables – papilla score, papilla height.

[‡]Independent variables – crown width to crown length (CW/CL) ratio, contact length, bone level, interproximal distance, KG/AG and gingival thickness.

* $p \approx 0.05$.

** $p < 0.05$.

*** $p < 0.0001$.

petent and deficient papilla groups. Our study differed from the studies by Martegani and colleagues and Cho and colleagues, which may account for the contradictory findings. Our study focused on seven periodontally healthy maxillary anterior inter-dental sites, and the IPD was determined radiographically. Martegani et al. (2007) also measured IPD radiographically, but they only assessed three inter-dental sites between the maxillary incisors. In addition, they did not report the periodontal status of their subjects. Cho et al. (2006) made direct measurements of periodontally healthy and diseased anterior and posterior sites after elevating full-thickness flaps. These differences in methods make direct comparisons between studies difficult.

We report a positive correlation between gingival thickness and papilla fill in this study. Limited blood supply is believed to be one of the major reasons why papilla preservation and regeneration are difficult. Thicker tissue may resist collapse and contraction due to increased vascularity and extracellular matrix volume. In addition, thicker KG epithelium may be more resistant to physical damage and bacterial ingress. Therefore, thick gingival biotype has been considered more favourable for achieving optimal aesthetics. Interestingly, in each group, the papilla gingiva between central incisors was always thicker than other sites. We speculate that maxillary frenulae might have contributed to this thicker tissue and papilla deficiency between the central incisors.

In this study, we found no significant difference between the competent and deficient papilla groups with regard to KG and attached gingiva. These are consistent with Wennstrom's finding that the lack of an "adequate" zone of attached gingiva did not result in an increase in soft tissue recession in patients who maintained good plaque control (Wennstrom 1987). Kennedy et al. (1985) also determined that there was no minimum zone of AG necessary to prevent recession in well-maintained patients. It is, therefore, reasonable to expect that patients with abundant KG/AG might experience less papillary recession in the presence of inflammation; however, we could not confirm this with this study.

The present study has several limitations. As a cross-sectional study, causal relationships cannot be established. Owing to small sample sizes, the Afri-

can-American and Hispanic groups were not included in the analysis of the association of ethnicity with the papillary appearance. Finally, other potential factors such as smoking, frenum attachment and traumatic habits were not evaluated in this study.

In summary, the present study found that the appearance of the gingival papilla is significantly associated with age, tooth form/shape, proximal contact length, crestal bone height and interproximal gingival thickness. Within the limits of the present study, the following clinical conditions were found to favour a gingival papilla that fills the interproximal embrasure space:

- (1) Young subject.
- (2) Crown width/length ≥ 0.87 .
- (3) Long proximal contact ≥ 2.8 mm.
- (4) Bone crest-contact point ≤ 5 mm.
- (5) Thick interproximal gingival tissue ≥ 1.5 mm.

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Clinical Relevance

Scientific rationale for the study: Crestal bone level and IPD are known to affect inter-dental fill by gingival papillae. Factors such as tooth form, gingival thickness, KG gingival width, age and gender, have not been investigated fully.

Principal findings: Complete interdental fill by papillary gingiva was associated with younger age, crown width: length ≥ 0.87 , proximal contact ≥ 2.8 mm, interproximal contact to bone crest distance ≤ 5 mm and interproximal tissue distance ≥ 1.5 mm.

Practical implications: Tooth form, proximal contact length, interproximal contact to bone crest distance and interproximal tissue thickness should all be considered when managing inter-dental papilla aesthetics.