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ORIGINAL ARTICLE

Gingival phenotype classification by visual and probe visibility assessments: Relationship with thickness and probe design

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Abstract

Background: This study investigated the agreement among dentists in classifying gingival phenotype (GP) through periodontal probe visibility (PPV) assessment with various probe types and the visual method. Additionally, the relationship between GP classifications and gingival thickness (GT) was evaluated.

Methods: Photographs were taken with standard periodontal probe (SPP), color-coded periodontal probe (CCPP) tips in white, green, and blue, as well as metal phenotype probe (MPP) tips in gray and black. Evaluators (periodontist, periodontics resident, endodontics resident, dental student) assessed the photographs and classified the GPs. GT was measured by trans gingival probing.

Results: Visual method showed poor to fair agreement to classify GP. The lowest agreement regarding PPV was noted with white-tipped CCPP. The highest agreement in singular PPV was observed with CCPP blue ($\kappa = 0.932$), followed by CCPP green ($\kappa = 0.791$), MPP black ($\kappa = 0.783$), SPP ($\kappa = 0.730$), and MPP gray ($\kappa = 0.690$). Combined PPV data revealed fair to moderate agreement with CCPP and moderate to substantial agreement with MPP in GP classification. The corresponding GT to different GP classifications based on combined PPV were comparable. The agreement between SPP and CCPP in classifying non-thin phenotypes was 89.8%, while the agreement between SPP and MPP was 75.4%. Based on PPV, no significant GT cutoff value was found to distinguish between thin and non-thin phenotypes.

Conclusion: Determining a precise GT that guarantees the visibility of a given probe can be difficult when evaluating GP. Regardless of the type of probe, the PPV method has a high potential for misclassifying GP, despite having an acceptable agreement.

KEYWORDS
gingiva, gingival thickness, periodontal phenotype

Plain Language Summary

Gingival phenotype (GP) is constituted by thickness of the gums and width of keratinized tissue around teeth. Direct visual evaluation or evaluating a periodontal probe's visibility beneath gums are established techniques to classify gingival phenotype. This study investigated how dentists classify GP using visual assessments and different types of periodontal probes, while also exploring the relationship between GP classifications and gingival thickness. Results showed varied agreement among dentists in classifying GP, with lower agreement observed when using certain types of probes, notably the white-tipped phenotype probe. The highest agreement was found with the blue phenotype probe. Data from periodontal probe visibility assessments indicated fair to moderate agreement with certain probes, suggesting some inconsistency in classification methods. Interestingly, GP classification with visual assessments or probes did not correlate with gingival thickness, which may highlight the importance of considering both factors in clinical practice. These findings underline the need for attention when relying solely on visual assessments or specific probe types for accurate GP classification.

1 | INTRODUCTION

Soft tissue characteristics around teeth and implants dictates the behavior of surrounding tissues. Despite discrepant, overlapping, and sometimes controversial descriptions of morphological characteristics of periodontal and peri-implant tissues, assessment of site-specific phenotypical features is crucial in both clinical practice and research. These features may change over time as a function of various clinical scenarios and/or therapeutic interventions.[1–6]

Determining and classifying peri-implant and gingival phenotype (GP) involves assessing soft tissue through both invasive and noninvasive methods.[7,8] GP assessment methods may involve estimating through direct visual inspection or using a periodontal probe to observe its visibility beneath the gingival sulcus followed by categorization into 2, 3, or 4 subclasses.[7–11] Gingival thickness (GT) assessment relies on direct or indirectly measuring the buccolingual dimension of the gingiva.[7,8] Among the different periodontal phenotype estimation methods, the periodontal probe visibility (PPV) method appears to be a noninvasive, cost-effective, and reproducible approach.[8,9,12,13] The PPV technique can utilize either a standard periodontal probe (SPP) or newer phenotype probes such as color-coded periodontal probe (CCPP) with changeable white, green, and blue tips, as well as the two-ended metal gray-black colored phenotype probe (MPP).[9,11–17] As the SPP has a single tip, phenotype evaluation relies on dichotomous classification (thin-thick).[3,9,12] Conversely, PPV assessment with CCPP and MPP entails sequentially inserting tips of varying diameters and/or colors until one of the tips is visible through the gingiva. Consequently, this method is based on 4 phenotype classifications (thin-medium-thick-very thick) for CCPP[18] and 3 classifications (thin-medium-thick) for MPP.[16]

Multiple methods have been described for assessing GT and GP.[8] Although the PPV technique provides a straightforward and practical approach, conflicting evidence exists regarding the consistency and reliability of GP classification data obtained through this method, especially when utilizing different probe types. Variability arises in determining the threshold GT values that enable the visibility of various probe tip designs, as well as in identifying the GT range corresponding to phenotype categories.[3,11,13,16,17,19,20] Clinical studies evaluating the effectiveness of CCPP[19,21,22] and MPP[16,17] in establishing the relationship between GP and actual GT are limited. Moreover, the efficacy of CCPP and MPP devices in classifying GP and its relationship with GT within the same study design is restricted to a single preclinical study.[17] This suggests a gap in clinical research regarding the usefulness of CCPP and MPP in accurately assessing GP through probe visibility. Hence, this study aims to assess; (1) the agreement among dentists and probe types in reproducibly classifying GP and (2) the relationship between GP classifications and GT. These assessments involve both the PPV method using probes of various designs (SPP, CCPP, and MPP) and the visual gingival phenotype assessment (VGPA) method. The underlying hypothesis is that dentists can consistently classify GP

using both the PPV and VGPA methods, as well as various probe designs.

2 | MATERIALS AND METHODS

2.1 | Study population

This cross-sectional study was conducted between April 2023 and July 2023 at Ege University School of Dentistry Department of Periodontology. Approval (22–9.3/48) was obtained from the Ege University School of Medicine Research Ethics Committee, and the study followed the principles of the 2013 revised Declaration of Helsinki. Volunteers were over 18 years old, systemically healthy, not taking any medication affecting marginal gingiva, not pregnant, and without gingival enlargement or recession. Additionally, they had intact and fully erupted maxillary anterior teeth without crowding, distinct angulation, filling, or prosthetic restoration on their buccal surfaces. Probing depths were $\leq$ 3 mm, keratinized tissue width was at least 2 mm, and there were no signs of gingival inflammation or excessively pigmented marginal gingiva. Volunteers who had undergone surgical intervention or orthodontic therapy in the upper anterior region were excluded. Both past and present smoking behaviors were noted and utilized in the statistical analysis. All volunteers gave their informed consent to be included in this research study.

2.2 | Intraoral photographs

Photographs were captured from maxillary centrals, laterals, and canines in the same quadrant using a digital camera (Nikon D7500, Tokyo, Japan) equipped with a ring flash (Godox, Fujifilm, Tokyo, Japan). The photographs were taken without using dental unit light, at a 1:1 magnification ratio. Photographs were initially captured without the placement of any periodontal probe. Subsequently, a SPP (UNC-15, Hu-Friedy Group, Chicago, USA) followed by white, green, and blue tips of CCPP (Colorvue Biotype Probe, Hu-Friedy Group, Chicago, USA), and then gray and black tips of MPP (DBS-12 Biotype Probe, Deppeler SA, Rolle, Switzerland) were sequentially inserted into the gingival sulcus from the mid-facial region of the teeth (Figure 1). After all photographs were taken, GT was measured by trans gingival probing (TGP) using a K-type #20 endodontic file and a silicone stopper. Following the application of 10% lidocaine anesthetic spray (Lincaine, Argis Pharmeceuticals, Ankara, Türkiye) the endodontic file was perpendicularly inserted into the gingiva at a point 2 mm apical to the gingival margin until bone contact was achieved. The silicone stopper was secured on the gingiva and was further stabilized using a flowable composite. The distance from the tip of the file to the stopper was measured 3 times using a digital caliper (Valkyrie Supplies, Pennsylvania, USA) with a precision of 1/100 mm.

2.3 | Evaluation of photographs

Photographs were transferred to an editing software (Adobe Lightroom, San Jose, California, USA). Each image was cropped to include both the papillary and keratinized gingiva and was imported into a presentation software(PowerPoint, Microsoft, Washington, USA). The coronal 0.5 mm of the marginal gingiva and the probes were masked with a rectangular shape prepared in a similar color tone to the gingiva[19] (Figure 2). Masking aimed to exclude the thinnest part of the gingiva. Photographs obtained without inserting any probe were also masked as described.

All photographs were numbered, randomized, and compiled into a presentation. Four evaluators, including 1 periodontist, 1 periodontology resident (PR), 1 endodontics resident (ER), and 1 final-year dental student (DS) previously confirmed to have no color blindness through the Ishihara test, assessed PPV and visually classified GP in all photographs. The assessment of PPV was categorized as "probe is visible/probe is not visible" (Figure 3) while the visual evaluation categorized GP as "thin/thick". Evaluators were instructed to disregard gingival wrinkles and pressure-related blanching resulting from the placement of the probe but to solely evaluate whether the probe was visible beneath the gingiva. They were also informed about the type of probes and the color of the tips. Photographic evaluations were conducted on a computer (Tulpar T5, V20.3, Monster Computer Technology Products, İstanbul, Türkiye) with the screen brightness set to the highest level and the computer screen was adjusted to display only the presentation and the assessment form.

2.4 | Statistical analysis

The sample size was calculated based on a two-sided binomial test assuming an 80% power and a 5% error level. The minimum sample size was determined to be 180 teeth (60 individuals $\times$ 3 teeth). Cochran's Q analysis was employed to compare the visual GP evaluations and PPV assessments among evaluators. McNemar's test was utilized to compare the visual GP assessments and single PPV assessments between the periodontist and other evaluators. Single PPV data collected through both CPP and MPP was combined to generate GP classifications, which were then compared with the McNemar–Bowker test. Kappa and weighted kappa were calculated to determine the intra-examiner

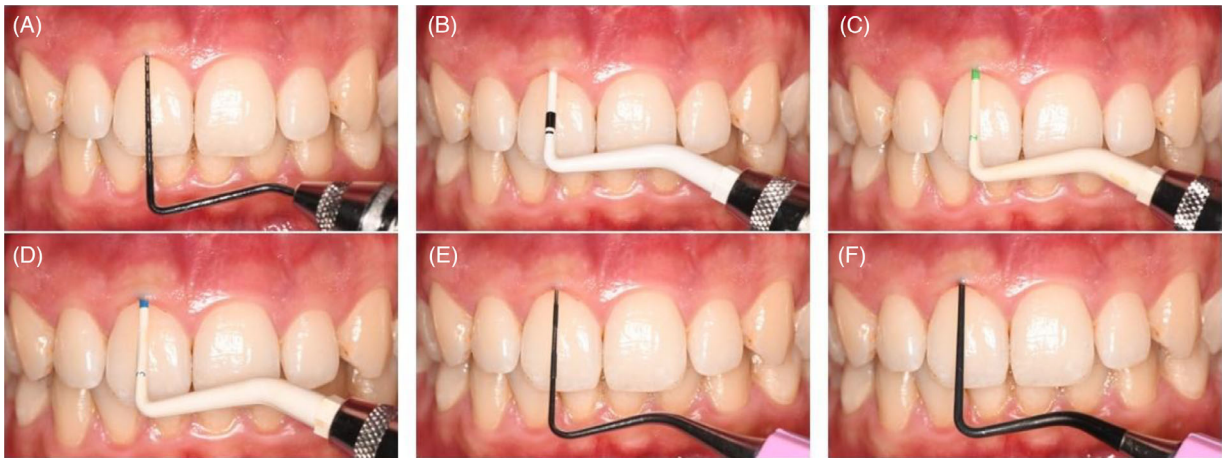

FIGURE 1 (A–F) Sequential placement of different probes into the gingival sulcus of upper central incisor for intraoral photographs. (A) SPP, (B) white, (C) green, (D) blue tips of CCPP, (E) gray/thin, and (F) black/thick ends of two-ended MPP. CCPP, color-coded phenotype probe; MPP, metal gray-black colored phenotype probe; SPP, standard periodontal probe

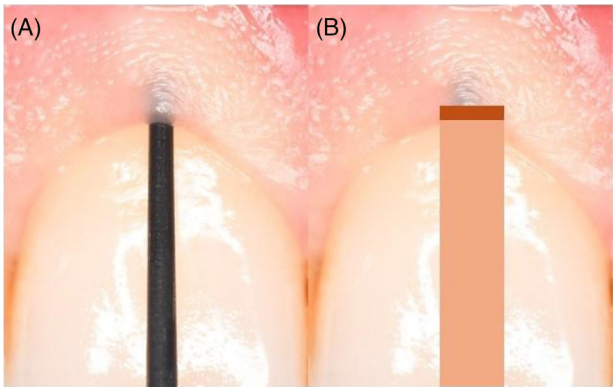

FIGURE 2 Cropped image of an upper central incisor including both the papillary and keratinized gingiva. Masking was applied to 0.5 mm coronal part of the gingival margin and to the probe inserted into the sulcus[19]. Probe tip: black end of the two-ended metal gray-black colored phenotype probe. (A) Unmasked and (B) masked

agreement and agreement between the periodontist and the other evaluators regarding visual GP and single and combined PPV data.[23]

For intra-examiner repeatability, probe visibility was judged by the evaluators at 90 sites (5 volunteers x 6 different probes x 3 tooth types) and the procedure was repeated after 1 week. For the examiner reliability, PPV judgments for photographs without any probes were analyzed. The periodontist had the highest repeatability ($k = 0.923$, 95% CI 0.837–1.000; almost perfect agreement[23]) and reliability (assessed 179 sites out of 180 sites without probes; 99.4% as "probe is not visible") among the evaluators, therefore was designated as the reference evaluator for the statistical analyses.

GT measurements by tooth type and actual GT values of the GP classifications based on visual assessment and PPV method using singular and combined PPV data were compared through analysis of variance (ANOVA). The interaction between tooth type and GT values was analyzed with factorial ANOVA. Interaction of tooth type and smoking with GP judged both by visual method and by PPV was also analyzed with factorial ANOVA. The cutoff values based on the visibility or invisibility of the probe tips were assessed using Fischer's exact test. The significance level was $\alpha = 0.05$.

3 | RESULTS

3.1 | Demographic and GT data

Sixty volunteers were enrolled (36 females and 24 males, age range:18–36 years, mean age:24.7 ± 3.5 years). Seventeen participants, comprising 9 males and 8 females, were smokers, consuming > 10 cigarettes daily. Among the volunteers, there were no former smokers. The GT range was 0.76–2.39 mm, with a mean of 1.280 mm. It was observed that 12.2% of the GT measurements were < 1 mm (22 sites) and nearly 2/3 (64.4%) fell within the range of 1.0–1.5 mm. The interaction between GT and tooth type did not yield significant results ($p > 0.05$). However, a significant difference in GT was observed across different tooth types ($p < 0.05$). Consequently, the findings were analyzed and presented separately for centrals, laterals, and canines.

GT (mean ± SE) was 1.40 ± 0.05 mm for centrals, 1.24 ± 0.05 mm for laterals, and 1.21 ± 0.04 mm for canines. GT was significantly higher in centrals compared to laterals and canines ($p < 0.001$). However, there was no significant difference in GT between laterals and canines ($p > 0.05$).

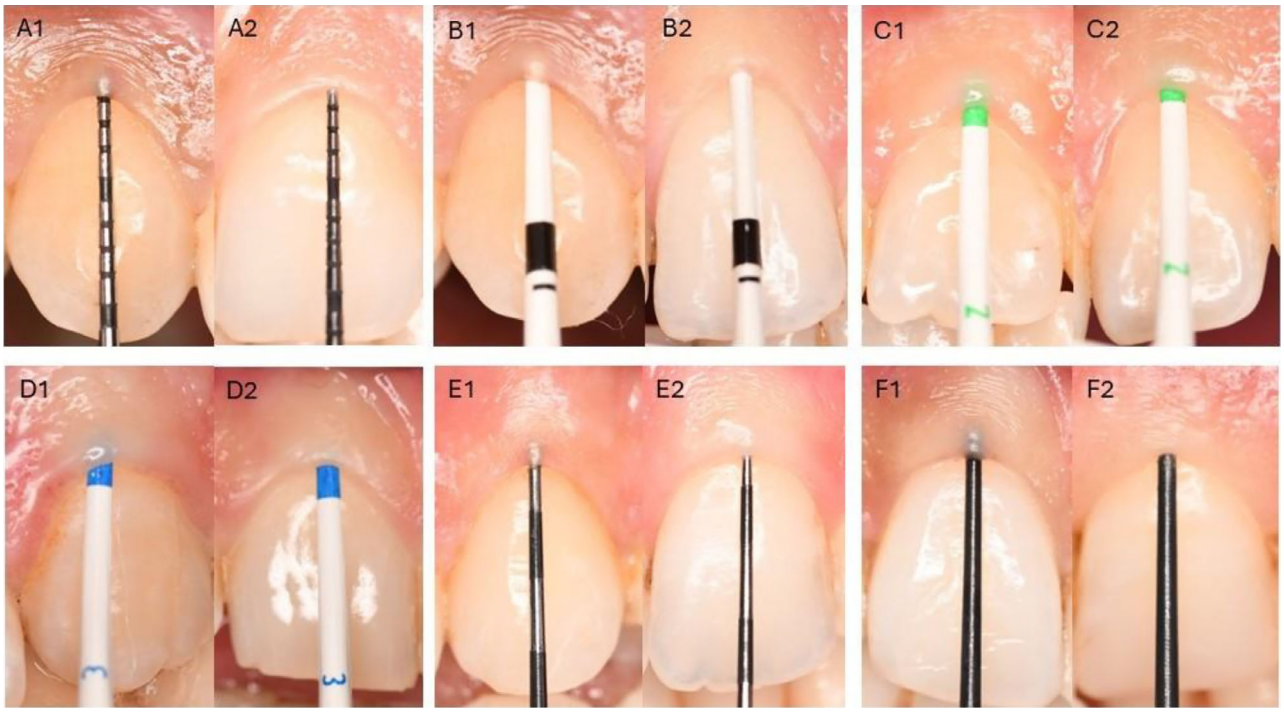

FIGURE 3 Assessment of gingival phenotype by periodontal probe visibility method with various periodontal probes. (A) SPP, (B) white, (C) green, (D) blue tips of plastic CCPP, (E) gray/thin, and (F) black/thick ends of two-ended MPP. Subgroups 1: "probe is visible", 2: "probe is not visible". (Rectangular-shaped colored masks are removed for better visibility). CCPP, color-coded phenotype probe, MPP, metal gray-black colored phenotype probe; SPP, standard periodontal probe

Periodontists visually judged 156 (86.7%) teeth as having thick and 24 teeth (13.3%) as having thin GP. The VGPA of PR, ER, and DS were 134, 75, and 140 for thick GP, respectively. Agreement of "thick" GP judgments of PR, and DS with periodontist exceed 80% for laterals and 70% for centrals and canines. The "thin" GP judgments of ER reached to more than 60% for centrals, 70% for laterals, and 80% for canines. It was found that the VGPAs of the periodontist and the ER differed significantly for centrals, laterals, and canines ($p < 0.0001$). Low agreement scores were observed with a maximum kappa value of 0.357. Additionally, GT values were similar among the evaluators' VGPA judgments. For sites categorized as "thin," by periodontist, PR, ER, and DS corresponding GT values were 1.24 ± 0.24 mm, 1.27 ± 0.27 mm, 1.28 ± 0.28 mm and 1.26 ± 0.27 mm, respectively. Similarly, for sites categorized as "thick," by periodontist, PR, ER, and DS the GT values were 1.29 ± 0.29 mm, 1.32 ± 0.30 mm, 1.28 ± 0.28 mm, and 1.29 ± 0.28 mm, respectively ($p > 0.05$) (Table 1). No interaction was found between smoking and visually classified GP ($p > 0.05$).

3.2 | GP classification with PPV

The agreement of "probe is visible" and "probe is not visible" judgments of PR, ER, and DS with periodontist for SPP, white, green, and blue tips of CCPP, thin gray and thick black tips of MPP are shown in Table 2. The agreement between the periodontist and other evaluators regarding PPV scores varied between 46.7% and 100% for "probe is visible" and 42.9% and 100% for "probe is not visible" judgment with all probe tips excluding the white tip of CCPP. Agreement coefficient ranged from fair to almost perfect ($\kappa = 0.318–0.932$). The highest level of agreement between the periodontist and the other evaluator's assessments was achieved with the blue tip of the CCPP (almost perfect agreement, $\kappa = 0.932$) followed by the green tip of the CCPP (substantial agreement, $\kappa = 0.791$), the black tip of the MPP (substantial agreement = 0.783), SPP (substantial agreement, $\kappa = 0.730$) and the gray tip of the MPP (substantial agreement, $\kappa = 0.690$). The least agreement between the periodontist and other evaluators was noted with the white tip of the CCPP. While the agreement for the "probe is not visible" interpretation with the white probe ranged from 90.7% to 100.0%, the agreement for the "probe is visible" interpretation varied from 0.0% to 25.0%. Dependably, kappa values were extremely low in the majority of the teeth subgroups for white tip of CCPP (Table 2).

The visibility scores of all 3 tips of CCPP were merged to generate a phenotype classification based on the first visible probe in the sequence to simulate clinical decision process. Sites were predominantly classified as having a

TABLE 1 Visual gingival phenotype assessments, their agreement with reference evaluator, and corresponding gingival thickness values (mean ± SD mm)

Parameter	Visual gingival phenotype assessments						Gingival thickness of sites described as thick versus thin	
	Centrals $n = 60$		Laterals $n = 60$		Canines $n = 60$		Total $n = 180$	
Evaluators	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Periodontist	54	6	53	7	49	11	1.29 ± 0.29	1.24 ± 0.24
Periodontology resident	43	17	48	12	43	17	1.32 ± 0.30	1.27 ± 0.27
Agreement % with periodontist	74.1	50.0	84.9	57.1	79.6	63.6		
Kappa	$\kappa = 0.133$ $p = 0.214$		$\kappa = 0.321$ $p = 0.009$		$\kappa = 0.357$ $p = 0.004$			
Endodontics resident	17	43	34	26	24	36	1.28 ± 0.28	1.28 ± 0.28
Agreement % with periodontist	27.8	66.7	60.4	71.4	44.9	81.8		
Kappa	-0.15 $p < 0.0001$		0.146 $p < 0.0001$		0.142 $p < 0.0001$			
Dental student	48	12	52	8	40	20	1.29 ± 0.28	1.26 ± 0.27
Agreement % with periodontist	83.3	50.0	86.8	14.3	71.4	54.5		
Kappa	0.231 $p = 0.053$		0.010 $p = 0.937$		0.197 $p = 0.099$			

medium GP by all evaluators. Agreement of phenotype assessments of PR, ER, and DS with periodontist was the lowest (3.6%) for thin phenotypes (see Table S1 in online *Journal of Periodontology*).

The periodontist classified 28 sites as having a thin phenotype. Due to differences in interpretation of the visibility of white probe PR, ER, and DS classified only 1 site as "thin" out of the 28 sites (see Table S1 in the online *Journal of Periodontology*). Owing to the very low agreement for the visibility of white probe, 85.2% to 96.3% of the remaining 27 sites were interpreted as having "medium" phenotype by the PR, ER, and DS (23, 26, and 25 sites out of 27 sites, respectively) as the first visible probe was the green CCPP for these evaluators (Figure 4). This disparity in interpretations among evaluators regarding thin and medium phenotype judgments through CCPP, decreased the overall agreement, resulting in moderate agreement (weighted κ = 0.456-0.542) (see Table S1 in the online *Journal of Periodontology*).

The visibility scores of all gray and black tips of MPP were also combined in sequence to generate a phenotype classification based on the first visible probe. The most frequently categorized GP was medium by 3 of the evaluators. Agreement was moderate to substantial (weighted κ = 0.578-0.662) (see Table S1 in the online *Journal of Periodontology*).

Smoking did not show a significant interaction with GP classified through SPP, CCPP, or MPP at central incisor and canine sites ($p > 0.05$). Although smoking had no significant interaction with GP assessed by SPP and MPP at lateral sites, its interaction with GP judged with CCPP was significant ($p = 0.04$).

3.3 | Agreement among periodontal probe types in classifying gingival phenotypes

The agreement of SPP to classify thin phenotype was 25.8% and 50% while it was 89.8% and 75.4% to classify nonthin phenotypes with CCPP and MPP, respectively. The agreement of CCPP and MPP to classify thin, medium, and thick/very thick phenotypes were 67.9%, 48.1%, and 58.3%, respectively.

3.4 | GT in relation to PPV and GP classifications

PPV scores based on singular probes by the periodontist and corresponding GT values were not significantly different for SPP, white, green, and blue tips of CCPP, and black tip of MPP ($p > 0.05$). GT values corresponding to the "probe is visible" assessment compared to values corresponding to the "probe is not visible" assessments by the periodontist with a gray tip of MPP were found to

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TABLE 2 PPV assessments and their agreement with the reference evaluator

Probes	Evaluators	Teeth	Absolute agreement %		Kappa
			Probe is visible	Probe is not visible	
Standard periodontal probe UNC-15	Periodontology resident	Central	46.7	84.4	0.318
		Lateral	75.0	91.7	0.681
		Canine	52.2	83.8	0.375
	Endodontics resident	Central	80.0	77.8	0.500
		Lateral	91.7	83.3	0.730
		Canine	82.6	64.9	0.442
	Dental student	Central	53.8	91.1	0.476
		Lateral	83.3	77.8	0.595
		Canine	73.9	78.4	0.514
Color-coded phenotype probe white tip	Periodontology resident	Central	0.0	92.9	-0.071
		Lateral	0.0	94.3	-0.075
		Canine	5.9	90.7	-0.043
	Endodontics resident	Central	1.0	100	0.384
		Lateral	0.0	98.1	-0.030
		Canine	0.0	97.7	-0.033
	Dental student	Central	25.0	96.4	0.242
		Lateral	0.0	96.2	-0.055
		Canine	0.0	97.7	-0.033
Color-coded phenotype probe green tip	Periodontology resident	Central	76.9	90.1	0.626
		Lateral	79.5	87.5	0.589
		Canine	73.9	64.3	0.325
	Endodontics resident	Central	97.4	76.2	0.770
		Lateral	95.5	56.3	0.574
		Canine	97.8	42.9	0.429
	Dental student	Central	96.3	81.0	0.741
		Lateral	93.2	87.5	0.791
		Canine	80.4	71.4	0.461
Color-coded phenotype probe blue tip	Periodontology resident	Central	71.1	86.4	0.533
		Lateral	74.5	88.9	0.409
		Canine	88.0	70.0	0.518
	Endodontics resident	Central	100	59.1	0.647
		Lateral	100	88.9	0.932
		Canine	100	60.0	0.714
	Dental student	Central	97.4	72.7	0.736
		Lateral	94.1	77.8	0.688
		Canine	98.0	70.0	0.739
Metal phenotype probe thin gray tip	Periodontology resident	Central	55.0	95.0	0.548
		Lateral	46.7	95.6	0.487
		Canine	68.0	82.9	0.514
	Endodontics resident	Central	75.0	87.5	0.625
		Lateral	73.3	80.0	0.480
		Canine	96.0	71.4	0.641
	Dental student	Central	55.0	95.0	0.548
		Lateral	66.7	91.1	0.591
		Canine	80.0	88.6	0.690

(Continues)

TABLE 2 (Continued)

Probes	Evaluators	Teeth	Absolute agreement %		Kappa
			Probe is visible	Probe is not visible	
Metal phenotype probe thick black tip	Periodontology resident	Central	64.9	78.3	0.405
		Lateral	89.2	87.0	0.755
		Canine	79.5	81.3	0.543
	Endodontics resident	Central	86.5	60.9	0.490
		Lateral	100	56.5	0.616
		Canine	93.2	81.3	0.744
	Dental student	Central	86.5	73.9	0.609
		Lateral	89.2	78.3	0.680
		Canine	95.5	81.3	0.783

Note: Kappa values are categorized as: Poor agreement (< 0.00, blue); slight agreement (0.00 to 0.20, not applicable); fair agreement (0.21 to 0.40, green); moderate agreement (0.41 to 0.60, yellow); substantial agreement (0.61 to 0.80, orange) and almost perfect agreement (0.81 to 1.00, red).[23]
Abbreviation: PPV, periodontal probe visibility.

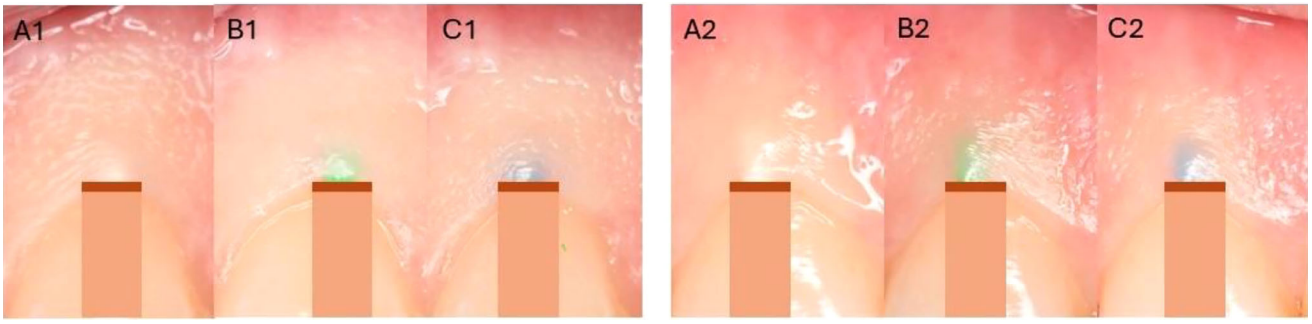

FIGURE 4 All probe tips were separately judged as "probe is visible" and "probe is not visible" by all the evaluators on randomized photos in the present study. When the singular PPV evaluations from photos captured from the same site with CCPP were combined, 28 sites were assessed as having "thin" GP (white, green, and blue probes are visible) by the reference evaluator (periodontist). Due to differences in the interpretation of PPV scores with white probe, periodontology resident, endodontics resident, and dental student classified only 1 site as "thin" out of the 28 sites. The remaining sites were interpreted as having a "medium" phenotype (white probe is not visible, green and blue probes are visible) by the PR, ER, and DS (23, 26, and 25 sites out of the remaining 27 sites, respectively). The below photos show 2 samples (A1-C1& A2–C2) out of these sites. A1 was judged as "probe is visible" only by the periodontist and A2 was judged as "probe is visible" by the periodontist and the periodontology resident. Sample site 1 (A1–C1) was classified as "thin" by the periodontist and as "medium" by other evaluators. Sample site 2 (A2–C2) was classified as "thin" by the periodontist and the periodontology resident. and as "medium" by the other evaluators. The gingival thickness of site 1 and site 2 are 1.26 mm and 1.27 mm, respectively. (A1 & A2: White, B1 & B2: Green, C1 & C2: Blue tips of CCPP). CCPP, color-coded phenotype probe; DS, dental student; ER, endodontics resident; GP, gingival phenotype; PPV, periodontal probe visibility; PR, periodontology resident

be significantly thicker ($p = 0.02$) (see Table S2 in online *Journal of Periodontology*).

No difference was found in terms of GT corresponding to the GP classification made based on the combined PPV data of evaluations conducted by the periodontist using the CCPP ($p > 0.05$). GT of different GP classifications based on the assessments of the periodontist with MPP was also similar ($p > 0.05$). Comparisons were similar as distributed by tooth type for both CCPP and MPP ($p > 0.05$) (see Table S2 in the online *Journal of Periodontology*).

Several cutoff values ranging from 1 to 1.5 mm were used to discriminate thin and nonthin phenotypes based on the visibility/invisibility of the 6 probe tips judged by the reference evaluator. At sites with GT < 1.2 mm, about 80% of the green and blue tips of CCPP were visible, and these sites showed the highest percentage of PPV when compared to other threshold values in the same probe group. Nevertheless, no cutoff value for any of the probes revealed noticeably different PPV rates ($p > 0.05$) (seeTable S3 in online *Journal of Periodontology*).

4 | DISCUSSION

The most suitable anatomical location for both clinical and radiological GT measurements is suggested to

be 2 mm apical to the free gingival margin (FGM).[24] Additionally, it was emphasized that GT measurements made on CBCT images at a point 2 mm apical to the FGM were compatible with the PPV method.[25] Based on these assumptions, the reference anatomical point for GT measurement was determined as 2 mm apical to the FGM. One can assume that, if GT was measured at a point more coronal, our study sites would include more thin GP percentage since GT is reported to increase in the apical direction.[7,24] However, according to a systematic review GT at 1 and 2 mm apical to FGM only show slight differences which may be interpreted as clinically insignificant (mean:1.126 mm versus 1.170 mm and range:0.87 –1.37 mm versus 0.82 –1.56 mm), respectively.[24]

In this study, no clearly discriminative mean GT values were reached for different GP classifications based on probe visibility. Numerous mean values and various specific thresholds have been suggested for GT measurements in the discrimination of GP categories using the PPV technique with different types of periodontal probes including SPP, CCPP, and MPP. In this regard threshold values of 0.5 to 1 mm [3,13,16,17,21,22] for thin vs thick discrimination, 0.5 to 0.85 mm[16,17,21,22] for thin vs medium discrimination, and 0.75 to 1.23 mm[16,17,21,22] for medium vs thick discrimination were suggested. For the discrimination of thick from very thick gingiva 1.24 and 1.53 mm threshold values were reported.[21,22] Additionally, mean GT was reported to be between 0.41 and 0.83 mm for thin; 0.53 and 1.14 mm for medium; 0.62 and 1.40 mm for thick, and 0.76 and 1.98 mm for very thick GP.[14,15,22,26] In this study, sites with a GT of less than 1.2 mm could be identified with high accuracy, nearly 80%, by observing the visibility of the green tip of the CCPP. This finding aligns with a previous clinical study that employed the CCPP and reported more than 90% specificity and sensitivity and a 1.23 mm cutoff value where the green tip needed to be visible.[22] Discrepancy between our study and aforementioned studies may be associated with heterogeneous methodologies regarding different probe types and classification categories, the lack of standardization of the GT measurement points relative to FGM, and the higher percentage of thick GP sites (> 1 mm GT) compared to thin GP sites (< 1 mm) in this study. This suggests that consensus has yet to be reached regarding the metric values for classifying distinctive GPs by the PPV method.

Frost et al.[11] reported gradually decreasing sensitivity for the visibility of SPP as the GT increased. The authors stated that there is no specific GT value at which the probe becomes invisible beneath the gingiva. Similarly, low agreement of PPV and GT was reported (50%, kappa = 0.19), particularly for the GT range of 0.6–1.2 mm.[27] In a study comparing SPP and CCPP, low specificity of both probes for thick GP was reported.[20] Additionally, Kim et al.[28] did not find a significant relation between GT and PPV. In another study utilizing SPP and CCPP, Bertl et al.[19] reported that the CCPP did not accurately distinguish between GP categories and exhibited low repeatability. These findings may suggest that probe visibility is not solely dependent on GT, but may also be influenced by epithelial thickness, degree of keratinization, amount of pigmentation, and collagen density in the connective tissue.[17]

It would be interesting to mention that some of the studies reporting lower diagnostic accuracy, including ours, are standardized clinical photograph assessment studies.[10,19] From this perspective, one might argue that this design has some limitations, may not accurately reflect clinical practice, and is susceptible to variations. On the other hand, standardizing confounding factors may not always be feasible in a clinical study setting. Photographic assessment studies may offer advantages such as generalizability of assessments, practicality, and increased patient comfort especially when comparing several probes. In addition, masking of the probes and the 0.5 mm coronal part of the gingival margin first described by Bertl et al.[19] may be a key factor in excluding the most transparent part of the gingiva, thus reducing bias and erroneous PPV assessments. Another recent diagnostic reproducibility study used standardized photographs for the investigation of variables related to gingival recession and GP.[29] Among all variables, authors noted the lowest inter-examiner agreement for probe visibility when tested with UNC-15 probe (kappa = 0.41, range: 0.05–0.89, moderate agreement). This finding is in line with our findings regarding UNC-15 and gray end of MPP resembling a standard PCP-12 probe. Our VGPA results also support the evidence that visual inspection has low inter-examiner reproducibility.[10,12,27]

In our study, GT was measured following placement of probes. To enhance patient comfort and to minimize time spent in the dentist's chair, probes were sequentially inserted into the gingival sulcus without waiting intervals. In this regard, it is conceivable that the GT may have been overestimated due to edema and bleeding resulting from the trauma caused by the consecutive placement of probes into the gingival sulcus.[17] Some precautions were taken to minimize the unwanted effects on GT measurements. Considering that local anesthesia can affect GT measurements by altering tissue volume after injection[30] topical anesthesia was used instead. In addition, the probing sequence was designed to place the thickest probe (black thick tip of MPP, Ø = 0.7 mm) as the final probe in order to reduce trauma. However, our GT findings (Range:0.76–2.39, mean:1.28 mm) were

slightly higher than the values reported for anterior teeth 2 mm apical to FGM (Range:0.82–1.56, mean:1.17 mm).[24] However, the clinical importance and its effect on PPV of this nearly 0.1 mm difference remains to be determined.

Sites where the gray tip of the MPP probe was visible showed 0.1 mm thicker measurements compared to sites where the probe was not visible. This unexpected outcome may be discussed on the basis of statistical versus clinical significance of a minute difference. Moreover, considering the moderate to substantial agreement of evaluators on GP classifications with this probe tip this unanticipated finding may provide additional support to the idea that probe visibility could be influenced by factors beyond GT. For instance, the presence or absence of black markings on a silver-gray metal probe's shaft could also play a role.

In the present study, the lowest agreement between evaluators was observed with the white tip of CCPP. While the agreement between the periodontist and other evaluators for the "probe is not visible" interpretation with the white probe was over 90%, the agreement for the "probe is visible" interpretation hardly reached 25.0%. The clustering of agreement data in this manner may be attributed to the high percentage of thick GP observed in our study, as defined by the threshold of 1 mm. In this context, low percentage of sites with thin gingiva might be assumed as a major limitation. However, decrease in recruitment of patients with thin GP may be related to exclusion of gingival recession cases and inclusion of sites with at least 2 mm width of keratinized gingiva. It may be worth to note that this artificially created cut-off value is frequently employed but remains one of the most unspecified aspects in this context.[3,12,31] Our findings for the white probe align with a previous study[19] reporting low accuracy in diagnosing thin GP which included similar percentage of sites having GT < 1 mm (12.2% vs. 18.0%).

Our study revealed that the agreement between GP categorizations based on combined PPV findings with CCPP were moderate to substantial. The lower agreement of combined PPV data compared to single PPV data may be attributed to the differences between the PPV assessments with the white CCPP. Periodontists seem to distinguish white probe's silhouette beneath the gingiva more frequently than other clinicians. This may have led to the interpretation of almost all sites by other clinicians as "medium" which are judged as "thin" by the periodontist. Furthermore, the lower agreement coefficients regarding the white probe may stem from the fact that the PPV method is being conducted not in a clinical setting but on photographs enlarged beyond their original dimensions. Additionally, the illumination from a flashlight could complicate probe visibility through the gingiva. Furthermore, the influence of gingival texture and blood flow characteristics and variations in probing force exerted by manual phenotype probes on the PPV still requires clarification.

5 | CONCLUSIONS

Clinicians can categorize different GPs with moderate to substantial agreement using SPP, CCPP, and MPP by assessing the gingival translucency. When judging GP based on clinical photographs and the research sites primarily display GT > 1 mm, defining a specific GT that ensures the visibility of a particular probe may be challenging. This may highlight the significance of considering both PPV scores and GT in clinical settings. Although the PPV method has an acceptable reproducibility, there is a high risk of misclassifying GP regardless of the type of probe used. These findings may underline the need for attention when relying solely on visual assessments or specific probe types for accurate GP classification.

AUTHOR CONTRIBUTIONS

Conception and design: Ali Gürkan. *Clinical interventions*: Burak Fatih Uysal. *Statistical analysis and data interpretation*: Timur Köse, Ali Gürkan. *Manuscript preparation*: Ali Gürkan.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest and no commercial relations to declare.

DATA AVAILABILITY STATEMENT

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

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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