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Original Article

The use of shear wave elastography to monitor changes in gingival elasticity associated with initial periodontal therapy in patients with advanced periodontitis: A prospective pilot study

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KEYWORDS
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Abstract *Background/purpose:* Gingival tissue firmness cannot be objectively assessed or monitored in real-time in existing examinations. This study was designed to examine the potential utility of shear wave elastography (SWE) as a means of evaluating and monitoring gingival inflammation in an effort to assess the effects of initial periodontal therapy in patients with advanced periodontitis.
Materials and methods: This pilot study included analyses of 66 sites in 6 advanced periodontitis patients. Patients underwent the SWE examination of the gingiva at the mid-labial and interdental papillae at baseline and at 2, 4, and 6 weeks following initial periodontal therapy. Measured periodontal parameters in these patients include Plaque index (PI), Gingival bleeding index (GBI), Probing depth (PD), and Clinical attachment loss (CAL).
Results: Respective baseline SWE values at the mid-labial gingiva and interdental papilla 25.68 ± 6.82 kPa and 26.78 ± 6.20 kPa, with no significant differences between these two measures. A significant negative correlation between SWE and both PI ($r = -0.350$, $P = 0.004$) and

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GBI (r = −0.287, $P = 0.020$) was observed at baseline. Initial periodontal therapy contributed to significantly higher SWE values and tougher gingiva, particularly during the first two weeks. Postoperative changes in SWE were negatively correlated with SWE values at baseline (r = −0.710, $P < 0.001$).

Conclusion: These results establish SWE as a sensitive noninvasive approach to quantitatively assessing changes in gingival elasticity in real-time.

Introduction

Periodontitis is a highly prevalent infectious inflammatory disease of the periodontal tissue that often exhibits an insidious presentation.[1,2] This condition can often result in complications including tooth loosening, alveolar bone loss, tooth migration, and potential tooth loss.[3] Given that the inflammation of the gingiva is an early step in the pathogenesis of periodontitis, regularly monitoring for such inflammation has the potential to slow or prevent the progression of this disease.

At present, the extent of gingival inflammation is primarily detected by assessing the consistency, color, texture, and bleeding on probing (BOP) of this tissue.[4] However, these analytical approaches cannot enable truly objective analyses of the firmness of gingival tissue, and simple, quantitative tools that enable the real-time visual monitoring of changes in gingival soft tissue inflammation are lacking.

Shear wave elastography (SWE) is a recently developed diagnostic technique that can provide real-time quantitative insight regarding the stiffness or elasticity of a given tissue.[5] During SWE analyses, focal ultrasound waves are directed at particular depths so as to induce a mechanical impulse that propagates shear waves perpendicular to the ultrasound axis. Ultrasound imaging equipment can then enable the visualization of this shear wave, allowing for the reconstruction of a real-time color shear wave front map in m/s or kPa.[6]

Prior reports have described the successful application of SWE as a non-invasive tool used to analyze lymph node, kidney, thyroid, breast, prostate, and fibrotic liver tissues.[6] Efforts to apply SWE in the context of dentistry, however, have been limited and primarily centered around oral and maxillofacial surgery, including the assessment of benign and malignant salivary gland tumors, Sjögren's syndrome patients, and masticatory muscle stiffness.[7–9] No prior studies to our knowledge have leveraged SWE as a tool for monitoring changes in periodontal soft tissue elasticity. Inflammation can lead to the loss of the normal firmness and resilience of the gingival tissue, with the gingiva potentially becoming either soft or firm depending on whether the primary changes are exudative or fibrotic in nature. This study was thus despited to test the potential application of SWE for use in the clinical evaluation and monitoring of gingival inflammation and the effects of initial periodontal therapy on changes in gingival elasticity in patients with advanced periodontitis.

Materials and methods

Participants

The Ethics Committee of Peking University Stomatology Hospital (PKUSSIRB-202280127) approved the present prospective observational study, which was conducted in accordance with the 2008 revision of the Declaration of Helsinki. All participants provided written informed consent.

This study enrolled patients who underwent consultation from July to September 2022 in the Department of Periodontology of the First Clinical Division of Peking University School and Hospital of Stomatology. Eligible patients were individuals >18 years of age with severe (Stage II–III, Grade B/C) periodontitis without any missing teeth in the maxillary anterior region.[10] Patients were excluded if they exhibited any history of systemic disease, were taking antibiotics or medications known to impact the gingival tissue, were pregnant or planning to become pregnant, were smokers, had any crowns, fillings, or implant restorations within the maxillary anterior region, or had undergone periodontal or orthodontic treatment.

Periodontal evaluation and treatment

All participants underwent an examination of key periodontal clinical parameters in the maxillary anterior region both at baseline and 6 weeks following treatment. The Silness-Löe plaque index (PI), gingival bleeding index (GBI), probing depth (PD), and clinical attachment loss (CAL) were measured at the mesial, mid, and distal sites on the labial side of each tooth.[11,12] A manual periodontal probe (UNC-15 Hu-Friedy, Chicago, IL, USA) was used when measuring PD and CAL to the nearest millimeter, with the largest value being recorded when two values were evident at the interdental papilla. Initial periodontal therapy, which included full-mouth supragingival scaling, polishing, subgingival scaling, and root planning, was performed in all patients by one experienced periodontist (F.X.) who remained blinded to ultrasound examination approach.

Three-dimensional printed measurement guide preparation

The results of baseline intraoral scanning were used to design personalized extraoral measurement guides for each patient in the 3 shape CAD software with the goal of shifting the occlusal plane from intraoral to extraoral. Data in the STL format were imported into a 3D printer (D20II, Rapid Shape GmbH, Heimsheim, Germany). Participants were then directed to use these measurement guides to assess their accuracy and location.

Shear wave elastography

An experienced sonographer (N.L.) performed SWE analyses of all study participants in the Department of Ultrasound of the First Medical Center of Chinese PLA General Hospital at baseline, 2, 4 and 6 weeks following treatment. Gingival SWE values were assessed with a Philips ultrasound device (Philips Healthcare EPIQ Elite Ultrasound System Inc., Bothell, WA, USA) and an eL18-4 high-frequency probe (20 MHz) (Fig. 1). During measurements, patients were directed to remain still and to breathe steadily. The extraoral skin was coated with coupling agent (Zihui, Changyuan, China), after which the ultrasound probe was placed on the labial portion of the maxillary anterior teeth in a transverse section, and measurements were taken with the measurement guide. The image depth, focus, and gain were then adjusted to provide the clearest view of gingival morphology. The probe was maintained as steadily as possible without compressing the soft tissue to establish a stable elastogram box with even coloration. The image was then frozen, with the left screen consisting of a grayscale B-mode ultrasound image and the right screen depicting a color SWE image. When signal could not be obtained within half of the SWE box or was heterogeneously colored, repeated SWE evaluation was performed. EQI median (EQI Med, in kPa) was obtained for all teeth at the mid-labial gingival and interdental papilla (Fig. 2). Measurements were recorded as the mean of three replicate measures.

Statistical analyses

SPSS v24.0 (IBM, Armonk, NY, USA) was used to all statistical testing. Data distributions were assessed via the Shapiro—Wilk test. Differences in SWE values between groups were compared using unpaired t-tests, whereas values were compared among sites within groups via one-way ANOVAs. Relationships between gingival elasticity and baseline periodontal parameters were assessed with Spearman's correlation analyses, whereas the relationship

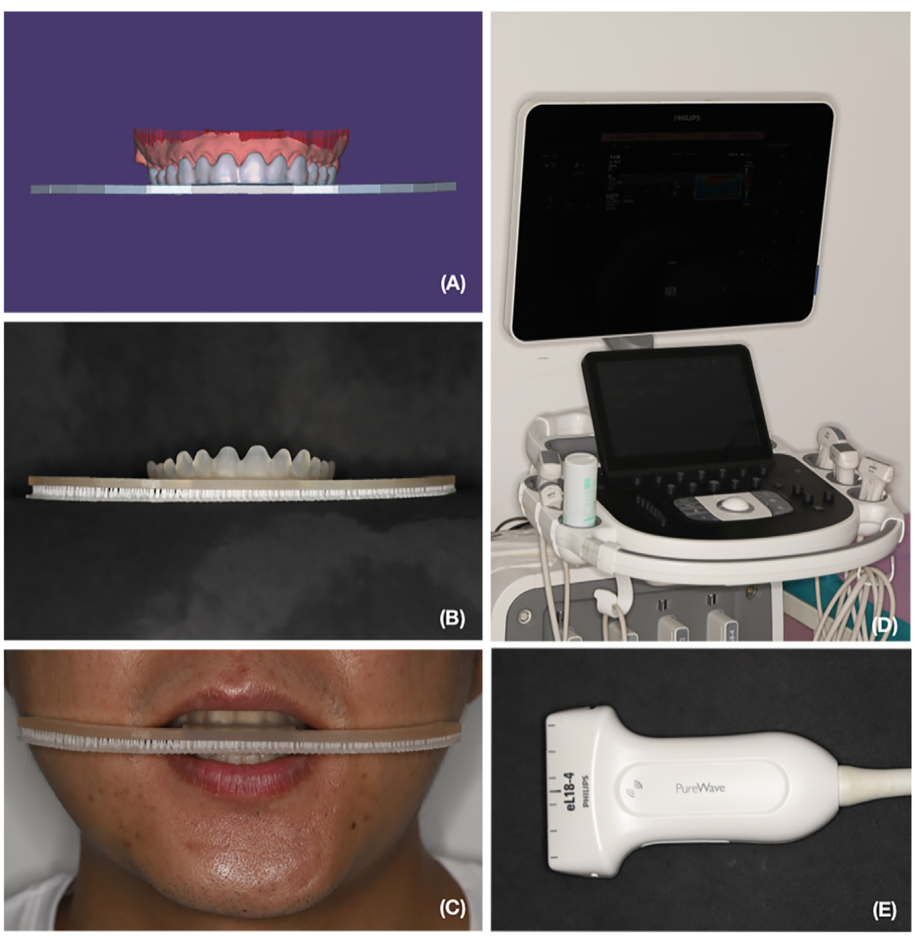

Fig. 1 Ultrasound measurement approach. (A) a digitally designed measurement guide; (B) A 3D-printed measurement guide; (C) the participant trying out the measurement guide; (D) the utilized Philips ultrasound measurement instrument; (E) an eL18-4 ultrasound probe.

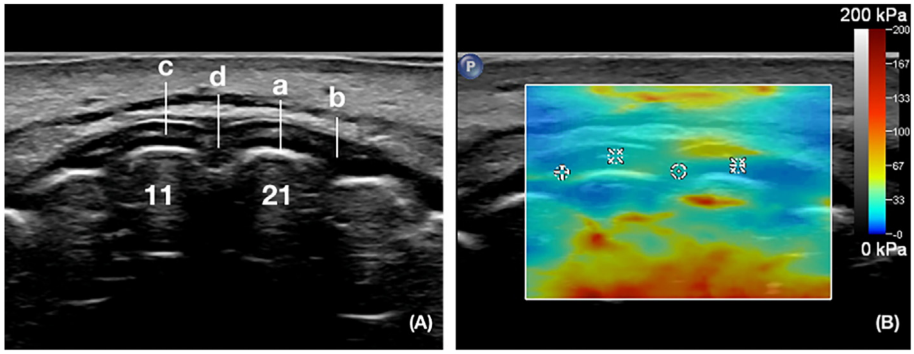

Fig. 2 Representative SWE analysis of the gingiva in the maxillary anterior region. (A) A grayscale B-mode ultrasound image; (a) the labial side of the tooth; (b) the gingiva; (c) the labial side medial gingiva of the right maxillary central incisor; (d) the gingival papillae between the bilateral maxillary central incisors; (B) a colored elastogram box image.

between baseline gingival elasticity and changes in elasticity following initial periodontal therapy were assessed using Pearson's correlation analyses. Differences in gingival SWE values between baseline and follow-up intervals were assessed via one-way ANOVAs with Tukey's post hoc test. $P < 0.05$ was the significance threshold.

Results

In total, this pilot study included analyses of 66 sites in 6 advanced periodontitis patients (3 male, 3 female) with a mean age of 32.29 ± 8.14 years (range: 25—49 years).

Baseline gingival shear wave elastography values

No significant differences in the mean SWE values at the mid-labial gingival region (25.68 ± 6.82 kPa) and the interdental papilla region (26.78 ± 6.20 kPa) were observed. The baseline gingival SWE values in the maxillary anterior region are shown in Table 1 and Fig. 3. No significant differences were observed in gingival SWE values between sites at the mid-labial gingival or interdental papilla.

Correlations between baseline gingival shear wave elastography and periodontal parameters

Next, correlations between baseline SWE values and periodontal parameters were assessed (Table 2). Both PI ($r = -0.350$, $P = 0.004$) and GBI ($r = -0.287$, $P = 0.020$) were negatively correlated with baseline gingival SWE values, whereas PD and CAL were unrelated to these SWE values.

Post-treatment changes in gingival shear wave elastography

Changes in gingival SWE values following initial periodontal therapy are shown in Table 3 and Fig. 4. These gingival SWE values rose significantly from 26.18 ± 6.52 kPa at baseline to 33.76 ± 6.66 kPa, 39.78 ± 7.33 kPa, and 41.67 ± 5.67 kPa at 2, 4, and 6 weeks post-treatment. These results exhibit a gradual increase in SWE values following treatment, with all intervals exhibiting significant differences with the exception of the comparison between the 4- and 6-week post-treatment time points.

Table 1 Baseline SWE values in the maxillary anterior region.

Locations		n	SWE value (kPa)			*P* value
			Mean ± SD	Median (IQR)	Min, Max	
Central	CI	12	24.86 ± 4.85	24.10 (5.43)	20.00, 35.30	F = 2.230
	LI	12	23.34 ± 6.10	22.40 (8.88)	15.30, 35.30	$P_1 = 0.124$
	C	12	28.84 ± 8.34	27.40 (13.03)	16.50, 42.40	
	All	36	25.68 ± 6.82	24.75 (8.20)	15.30, 42.40	
Interdental	CI—CI	6	28.22 ± 4.52	27.65 (7.33)	23.50, 34.10	F = 0.684
	CI—LI	12	25.16 ± 5.64	25.90 (7.15)	17.60, 36.40	$P_1 = 0.513$
	LI—C	12	27.68 ± 7.44	28.45 (8.38)	15.30, 43.50	
	All	30	26.78 ± 6.20	27.00 (6.20)	15.30, 43.50	
P						$P_2 = 0.499$

Note: P_1 represents One-way ANOVA; P_2 represents Unpaired t test.
Abbreviations: SWE, shear wave elastography; n: number of sites; SD, standard deviation; IQR, inter-quartile range; Min, minimum; Max, maximum; CI: central incisors; LI: lateral incisors; C: canines; CI—CI: interdental papilla between the two central incisors; CI—LI: interdental papilla between the central incisors and lateral incisors; LI—C: interdental papilla between lateral incisors and cuspids.

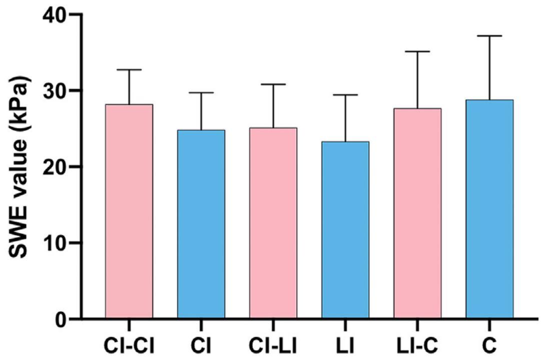

Fig. 3 Histograms representing baseline SWE values in the maxillary anterior region. Data are presented with standard deviations. Pink and blue histograms respectively correspond to SWE results for the interdental papillary and mid-labial gingival sites.

The association between gingival shear wave elastography values at baseline and 6 weeks after treatment

The baseline SWE values were strongly negatively correlated with the change in SWE values at 6 weeks post-treatment ($r = -0.710$, $P < 0.001$), suggesting that smaller baseline gingival SWE values were associated with greater treatment-related increases in these values (Fig. 5).

Discussion

SWE has recently emerged as a popular clinical imaging modality, offering insight into the elasticity of soft tissues based upon the measurement of shear wave velocity and the calculation of the degree of deformation in these tissues in conventional B-mode ultrasound images. After a reliable, stable elastogram box has been established, the elasticity of the soft tissue in a given region of interest can be monitored in real time.[6] This SWE approach has been successfully leveraged to monitor the stiffness of many oral and maxillofacial soft tissues including the submandibular gland, temporomandibular joint disc, and masticatory muscles.[13–16] Despite the promise of this technique, however, its application in the field of dentistry and periodontology has been limited. This study is the first to our knowledge to have utilized an SWE-based approach to quantify gingival soft tissue elasticity and to assess the impact of initial periodontal therapy on gingival elasticity in advanced periodontitis patients.

Table 2 Correlation between periodontal parameters and baseline SWE values.

Variables	Grades	n (%)	SWE value (kPa)			*P* value
			Mean ± SD	Median (IQR)	Min, Max	
PI	0	8 (12.12)	31.56 ± 5.59	30.60 (7.15)	25.90, 42.40	$r = -0.350$
	1	23 (34.85)	27.66 ± 6.07	27.10 (4.70)	20.00, 43.50	$P = 0.004$
	2	7 (10.61)	25.04 ± 5.52	25.90 (4.15)	17.60, 34.10	
	3	28 (42.42)	23.71 ± 6.34	22.05 (9.38)	15.30, 36.50	
GBI	0	0 (0)	/	/	/	$r = -0.287$
	1	7 (10.61)	32.13 ± 6.64	30.60 (7.90)	23.10, 42.40	$P = 0.020$
	2	15 (22.73)	27.73 ± 7.55	27.10 (7.95)	16.50, 43.50	
	3	11 (16.67)	26.08 ± 5.35	25.90 (4.10)	15.30, 34.10	
	4	29 (43.94)	24.65 ± 5.72	24.70 (8.20)	15.30, 36.50	
	5	4 (6.06)	21.33 ± 4.12	20.30 (3.73)	17.60, 27.10	
PD			5.39 ± 1.91	5.00 (3.00)	3.00, 10.00	$r = 0.778$ $P = 0.535$
CAL			5.64 ± 2.41	5.00 (3.75)	2.00, 10.00	$r = 0.660$ $P = 0.599$

Abbreviations: SWE, shear wave elastography; n: number of sites; SD, standard deviation; IQR, inter-quartile range; Min, minimum; Max, maximum; PI: plaque index; GBI: gingival bleeding index; PD: probing depth; CAL: clinical attachment loss.

Table 3 Changes in gingival SWE values following initial periodontal therapy.

Periods	Mean ± SD (kPa)	*P*		
		Compared to baseline	Compared to 2 weeks	Compared to 4 weeks
Baseline	26.18 ± 6.52			
2 weeks	33.76 ± 6.66^{a}	$P < 0.001$		
4 weeks	39.78 ± 7.33^{ab}	$P < 0.001$	$P = 0.001$	
6 weeks	41.67 ± 5.67^{ab}	$P < 0.001$	$P < 0.001$	$P = 0.509$

Note: [a] represents a statistically significant difference compared to baseline; [b] represents a statistically significant difference compared to 2 weeks post-operative.
Abbreviations: SD, standard deviation.

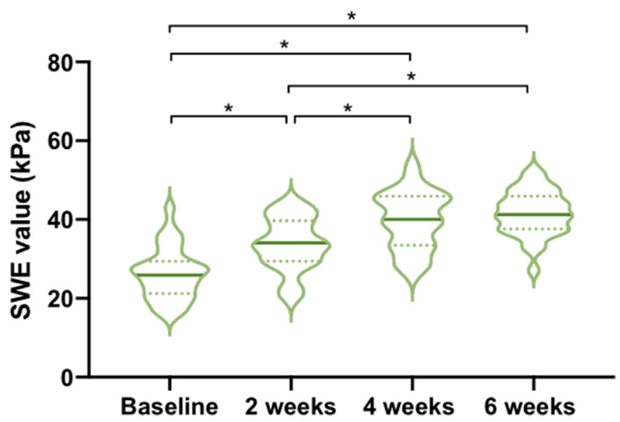

Fig. 4 Violin plots representing changes in gingival SWE values following initial periodontal therapy. Data are presented as the median with quartiles respectively represented by a solid line and dashed lines.

Ultrasonography is an advantageous approach to assessing the morphological characteristics of soft tissue, as it enables the delineation of boundaries between bony surfaces and soft tissues while generating accurate, detailed cross-sectional images. Ultrasound-based approaches have been previously used to assess palatal mucosal thickness and the dimensions of soft tissues surrounding the teeth.[17] In one prior report that analyzed seven fresh cadaver head samples using three different techniques including 25 MHz ultrasonography, cone beam computed tomography (CBCT), and transgingival probing with digital vernier calipers, the ultrasound technique was found to yield favorable results that were comparable to these two other analytical strategies.[18] Given that ultrasonography enables real-time monitoring without the need for ionizing radiation exposure or tissue trauma while also avoiding the potential for CBCT-related reconstruction errors, it offers certain clear advantages when used to assess soft tissues.

The gingiva consists of both epithelial and connective tissues. Many efforts to monitor gingival status rely on visual examination findings based on the observation of gingival surface texture and stippling on dry gingival surfaces, including the Root Surface Coverage Aesthetic Score (RES) and the Pink Aesthetic Score/White Aesthetic Score Index (PES/WES Index) systems.[19,20] These visual strategies, however, fail to provide any insight into the status of the underlying connective tissue layer. Healthy gingival tissue is firm and resilient, but increases in permeability, reduced vascular flow, and fluid accumulation associated with ongoing inflammation can give rise to soft and edematous gingiva.[21] Here, a negative correlation was detected between baseline gingival SWE values and both PI and GBI in patients with untreated advanced periodontitis. When significant plaque accumulation and substantial BOP are evident, SWE values tend to be small, consistent with clinical observations of soft and edematous gingival tissue and poor oral hygiene in individuals exhibiting a high level of ongoing inflammation. Using SWE values thus provides a valid approach to assessing gingival consistency, including the consistency of the underlying connective tissue, highlighting the clinical promise of this analytical strategy. No significant correlations were observed between gingival SWE values and either PD or CAL in this study, potentially owing to the fact that all included patients had already been diagnosed with advanced periodontitis, and high PD and CAL values have a limited impact on measurement sites proximal to the gingival margin.

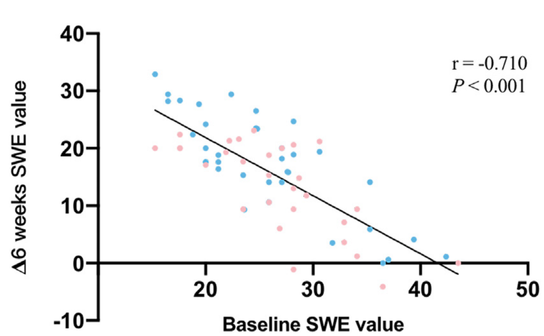

Fig. 5 The association between baseline SWE values and changes in SWE values at 6 weeks after treatment. Pink and blue dots respectively correspond to SWE results for the interdental papillary and mid-labial gingival sites.

A large body of evidence supports the value of scaling and root planning as a means of removing plaque and calculus from the tooth surface, thereby leading to marked improvements in local periodontal tissue inflammation.[22] As this inflammation abates, the gingival tissue volume decreases and rates of BOP and depth of probing both decrease. Periodontal re-evaluation is generally conducted at 4—8 weeks after the final scaling and root planning visit with the goal of assessing the efficacy of this treatment and the oral hygiene habits of the patient, allowing for the formulation of future treatment plans as appropriate.[23] Here, significant hardening of the elastic consistency of the gingival tissue was observed following initial periodontal therapy, with significant increases in gingival SWE values between baseline and 2 weeks post-treatment, as well as between 2 and 4 weeks post-treatment. This suggests that improvements in gingival texture occur continuously and gradually following treatment, with the majority of these changes occurring within 2 weeks and remaining stable by 4 weeks after treatment such that no further significant changes were detected at 6 weeks post-treatment. It is also important that the time of new attachment formation be considered when establishing the timing of periodontal re-examination, and altered gingival texture is just one of several potentially important parameters that warrant evaluation. These results highlight a significant correlation between baseline SWE values and the change in these values at 6 weeks post-treatment, with smaller baseline SWE values corresponding to greater increases following treatment such that the benefits of this intervention were greatest at sites exhibiting the highest levels of inflammation, in line with accepted clinical practice.

BOP is among the earliest signs of gingival inflammation, and the percentage of BOP on clinical examination can thus be used to gauge overall periodontal status and the progression of disease. Patients exhibiting BOP at 16% or more sites are more likely to exhibit loss of attachment.[24] The recommended level of force to use when probing for BOP is 0.25 N (25 g) in order to ensure that any observed bleeding is the result of gingival inflammation and not due to trauma. The force of probing that is applied can thus have a direct impact on the results of this examination approach, and many patients express anxiety associated with the pain induced by such probing.[25] The present study outlines the use of commercially available ultrasonography equipment, together with 3D-printed guides, to enable the quantitative assessment of gingival consistency. This approach can complement more conventional clinical approaches to periodontal and peri-implant evaluation. Using B-mode ultrasonography, gingival soft tissue thickness can be measured, as previously reported.[26] Additionally, it provides objective, quantitative, non-invasive assessment of changes in gingival elasticity without compromising patient comfort. Importantly, no patients in the present pilot study reported any side effects associated with undergoing these ultrasound examinations.

This pilot study is subject to several limitations. For one, the sample size was small, and no correlation analyses were performed exploring the associations between elastography results and the soft tissues exhibiting varying degrees of inflammation. There may be differences among individuals, ethnicities, or even regions of the dental arch within a given individual.[27] This preliminary study focused only on the maxillary anterior region for quality control purposes. It should be noted that the size and shape design of the existing ultrasound probe is not yet able to complete lingual-palatal measurements. It would be great to design a smaller probe that is more suitable for oral use in the future. In addition, clinical promotion of SWE techniques has a certain learning curve and is technically dependent on the operator. Prospective studies with larger sample sizes are warranted to further analyze the differences in gingival tissue consistency across diverse populations, or various treatment interventions. With the accumulation of data from the study, new models may be developed to predict future treatment outcomes. The SWE offers the potential for detecting early gingival inflammation or preventing periodontitis from recurring.[28]

In conclusion, this study demonstrate the promise of shear wave elastography as a noninvasive strategy that can allow for the objective, quantitative assessment of gingival consistency in real time. The use of SWE-based monitoring is thus clinically feasible and a promising means of assessing gingival inflammation. Here, a significant negative correlation was observed between gingival consistency and both PI and GBI, whereas it was unrelated to PD or CAL. Following initial periodontal therapy, gradual improvements in gingival consistency were observed in parallel with reductions in inflammation, and these improvements were greater when the baseline elasticity was poorer.

Declaration of competing interest

The authors do not have any financial interest in the companies whose materials are included in this article.

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