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ORIGINAL ARTICLE

Trabecular bone score, a new bone quality index, is associated with severe periodontitis

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Abstract

Background: The association between systemic bone loss and periodontitis remains unresolved; and the trabecular bone score (TBS) is a new index for assessing decreased bone quality. Therefore, this cross-sectional study investigated the association between TBS and severe periodontitis.

Methods: Eight hundred and five Thai participants, aged 30 to 82 years, underwent bone quality assessment. Their mean TBS was calculated from dual-energy X-ray absorptiometry images at the L1 to L4 lumbar spine using TBS software. Each participant was classified as normal, partially degraded, or degraded TBS. Full-mouth periodontal examinations determined plaque score, probing depth, clinical attachment level (CAL), and the number of remaining teeth. The participants were classified as non-severe or severe periodontitis. Differences in periodontal parameters between the TBS groups were analyzed using one-way ANOVA. The association between TBS and severe periodontitis was assessed with multivariate binary logistic regression. For severe periodontitis, the additive interaction between TBS and oral hygiene status was also analyzed.

Results: The mean CAL was 0.9-mm higher in the degraded TBS group compared with the normal TBS group. Degraded TBS was associated with severe periodontitis with an adjusted odds ratio (OR) of 2.10 (95% confidence interval [CI] = 1.03 to 4.26). The combination of degraded TBS and plaque score ≥80% increased the adjusted OR to 5.71 (95% CI = 1.15 to 28.43).

Conclusions: Degraded TBS is associated with severe periodontitis and has a synergistic effect with poor oral hygiene, suggesting monitoring decreased bone quality and good oral hygiene for promoting the periodontal-systemic health of these individuals.

KEYWORDS

bone, epidemiologic studies, oral hygiene, osteoporosis, periodontitis, trabecular bone

1 | INTRODUCTION

Periodontitis is a disease resulting from chronic inflammation caused by an excessive host response to dental plaque biofilm and is modified by local and systemic factors, leading to destruction of the periodontium resulting in increased periodontal probing depth (PD), clinical attachment level (CAL), and alveolar bone loss.[1] One systemic condition that is potentially associated with periodontitis is systemic bone loss or osteoporosis.[2] Elevated levels of systemic cytokines involved

in bone resorption, such as interleukin-6 and tumor necrosis factor-α found in individuals with osteoporosis,[3] may affect the skeleton and alveolar bone, thus compromising the tissue response leading to greater periodontal destruction.[4,5] In addition to advancing age, osteoporosis and periodontitis share other risk factors including sex, genetics, socioeconomic status, lifestyle, smoking, alcohol consumption, and type 2 diabetes.[4] Moreover, these two diseases affect patients' quality of life; systemic bone loss increases bone fracture risk,[2] and periodontitis is a major cause of tooth loss.[1]

Currently, the association between systemic bone loss and periodontitis is unresolved.[2] Several studies demonstrated an association between systemic bone loss and CAL,[6–11] periodontitis,[12,13] and tooth loss.[14,15] In contrast, other studies reported no association between these two diseases.[16–20] In previous studies,[6–20] the most widely-used index for measuring systemic bone loss was bone mineral density (BMD). However, BMD does not adequately determine bone strength and its resistance to fracture, because a decreased BMD only reflects a decreased cortical bone mineral content.[21] History of bone fracture was also used as a surrogate marker for systemic bone loss;[22] however, it may not be an appropriate index for disease prevention because morbidity has already occurred.

Trabecular bone score (TBS) is a newly developed index for assessing trabecular bone quality and fracture risk.[23] TBS is a bone texture parameter that quantifies cancellous bone microarchitecture, which is key in determining bone strength and resistance to fracture, by computing raw data from a dual energy X-ray absorptiometry (DXA) image of the lumbar spine.[21] Therefore, TBS was chosen in this study as a new index for assessing the association between systemic bone loss and severe periodontitis in Thai adults and elders of both sexes.

The present study focused on the severe periodontitis group, because these individuals are at high risk for disease progression and tooth loss.[1] This cross-sectional study was conducted to test the hypothesis that TBS status is associated with severe periodontitis. In addition, the effect of TBS and oral hygiene status on periodontitis was investigated.

2 | MATERIALS AND METHODS

This cross-sectional study recruited participants from the two surveys[24,25] on the current and former personnel of the Electricity Generating Authority of Thailand (EGAT) conducted in 2012 and 2014. The overview of the EGAT cohort surveys was previously reported.[24] The study protocol was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU 2018-111) and the Institutional Review Board and committee on Human Rights Related to Research Involving Human Participants, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Thailand (COA. No. MURA 2018/1028, protocol No. 12-61-55), and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. Before starting the surveys, all participants read and signed consent forms.

All participants answered the questionnaire and underwent a medical interview, physical examination, and laboratory blood chemistry tests performed by medical personnel from Ramathibodi Hospital. The participants' demographic, socioeconomic, and health-related characteristics of interest comprised age, sex, body mass index (BMI),[26] diabetes,[27] smoking status, alcohol consumption, education, income, menopausal status, and the use of medication related to bone were stratified and shown in Table 1.

Of the 3,948 participants from the two EGAT surveys, 848 were consecutively selected by quota sampling according to their sex and age by each age decade to receive a TBS assessment as previously reported.[28] Each participant received DXA analysis* of their lumbar spine L1 to L4 according to the standard protocol.[29] Participants with any conditions potentially affecting bone metabolism and DXA analysis were excluded.[28] TBS values of lumbar level L1 to L4 were computed from DXA images using TBS software.† The mean TBS from L1 to L4 was calculated and used to categorize the participants into three TBS groups: 1) normal: TBS score $\geq$1.35; 2) partially degraded: TBS score $>$ 1.20 and $<$ 1.35; and 3) degraded: TBS score $\leq$1.20.[30] The TBS root mean square (RMS) standard deviation (SD) was 0.026 and RMS coefficient of variation was 2.05%.[28]

The exclusion criteria for the dental examination and periodontal assessment including determination of the number of remaining teeth, PD, gingival recession (GR), and plaque score were specified in a previous EGAT study.[25] PD and GR were measured with a periodontal probe‡ on six sites per tooth,[25] and were used to calculate the CAL. The modified plaque scoring index[31] was calculated from the presence of dental plaque on two surfaces per tooth.[25] The periodontal assessment was performed by eight calibrated periodontists. As previously reported,[25] the intraclass correlation coefficient for the inter-examiner and intra-examiner agreement on the PD and GR ranged from 0.83 to 0.99, and the percent inter-examiner and intra-examiner agreement (within 1 mm) for the PD and GR was 99% to 100%. At the end of the dental examination, each participant was given a recommendation of their dental treatment needs.

Each participant's periodontal status was classified as no, mild, moderate, or severe periodontitis according to the CDC-AAP case definitions.[32] In analyzing the data, the

* Discovery QDR 4500W, Hologic, Bedford, MA

† TBS iNsight software version 2.1, Medimaps, Mérignac, France

‡ Perio Probe PCP-UNC15, Hu-Friedy, Chicago, IL

TABLE 1 Participants' characteristics according to periodontal status

Variable	Total (n = 805)	Chronic periodontitis	
		Non-severe (n = 642, 79.8%)	Severe (n = 163, 20.2%)
Age[a] (years), mean ± SD	52.1 ± 14.3	49.7 ± 14.1	60.7 ± 11.6
<60	519 (64.5)	454 (70.7)	65 (39.9)
≥60	286 (35.5)	188 (29.3)	98 (60.1)
Sex[a]			
Female	329 (40.9)	287 (44.7)	42 (25.8)
Male	476 (59.1)	355 (55.3)	121 (74.2)
Bone quality (TBS)[a], mean ± SD	1.35 ± 0.11	1.36 ± 0.11	1.31 ± 0.10
Normal (TBS ≥1.35)	423 (52.5)	361 (56.2)	62 (38.0)
Partially degraded (1.20 < TBS < 1.35)	297 (36.9)	225 (35.1)	72 (44.2)
Degraded (TBS ≤1.20)	85 (10.6)	56 (8.7)	29 (17.8)
Plaque score[a] (%), mean ± SD	63.9 ± 22.0	61.6 ± 22.3	73.1 ± 18.2
<40%	100 (12.4)	92 (14.3)	8 (4.9)
40% to 79%	483 (60.0)	391 (60.9)	92 (56.4)
≥80%	222 (27.6)	159 (24.8)	63 (38.7)
BMI[a] (kg/m^2), mean ± SD	24.3 ± 3.6	24.2 ± 3.6	24.7 ± 3.4
Underweight (<18.5)	28 (3.5)	22 (3.4)	6 (3.7)
Normal (18.5 to 22.9)	278 (34.5)	239 (37.2)	39 (23.9)
Overweight (≥23)	499 (62.0)	381 (59.4)	118 (72.4)
Diabetes[a,b]			
No	659 (92.2)	539 (93.6)	120 (86.3)
Well controlled (HbA1C < 7%)	30 (4.2)	21 (3.6)	9 (6.5)
Poorly controlled (HbA1C ≥7%)	26 (3.6)	16 (2.8)	10 (7.2)
Smoking status[a]			
Non-smoker	610 (75.8)	515 (80.2)	95 (58.3)
Former smoker	146 (18.1)	94 (14.6)	52 (31.9)
Current smoker	49 (6.1)	33 (5.2)	16 (9.8)
Alcohol consumption[a,c]			
Non-drinker	167 (21.9)	133 (21.8)	34 (22.5)
Former drinker	313 (41.1)	266 (43.6)	47 (31.1)
Current drinker	281(37.0)	211 (34.6)	70 (46.4)
Education[a,b]			
≤High school–Diploma	174 (24.3)	104 (18.1)	70 (50.4)
Bachelor's degree or higher	541 (75.7)	472 (81.9)	69 (49.6)
Income[a,b] (USD/month)			
<600	135 (18.8)	88 (15.3)	47 (33.8)
600 to 1,499	300 (42.0)	260 (45.1)	40 (28.8)
≥1,500	280 (39.2)	228 (39.6)	52 (37.4)
Menopause, mean age ± SD	49.0 ± 4.6	48.8 ± 4.7	49.7 ± 4.4
Yes	157 (19.5)	128 (19.9)	29 (17.8)
No + males	648 (80.5)	514 (80.1)	134 (82.2)

(Continues)

TABLE 1 (Continued)

Variable	Total (n = 805)	Chronic periodontitis	
		Non-severe (n = 642, 79.8%)	Severe (n = 163, 20.2%)
Medication related to bone			
No	735 (91.3)	588 (91.6)	147 (90.2)
Yes (all drugs)	70 (8.7)	54 (8.4)	16 (9.8)
Vitamin D	6 (0.6)		
Calcium	62 (7.7)		
Hormone replacement	7 (0.9)		
Anti-resorptive drugs	4 (0.5)		

HbA1c = glycated hemoglobin.

The independence between categorical variable and periodontal status were analyzed using the Pearson Chi-square test, and differences in periodontal status for continuous variables were analyzed using the independence sample *t* test.

[a] Significant difference (P <0.05).

[b] Missing the data of 90 participants.

[c] Missing the data of 44 participants.

participants were categorized into two periodontitis groups: non-severe or severe periodontitis. The participants' oral hygiene status were classified into three groups: fair, poor, or very poor oral hygiene with a plaque score of <40%, 40% to 79%, and ≥80%, respectively.[33]

The statistical analyses were performed using a standard software program[§] and the significance level was determined at P <0.05. Categorical data were described as frequency distributions and percentages; continuous data were described as mean ± one SD. The independence between categorical variables and periodontal status were analyzed using Pearson Chi-square test, and differences in periodontal status for continuous variables were analyzed using the independent sample *t* test. The differences in periodontal parameters between TBS groups were analyzed using one-way ANOVA and Games-Howell post hoc test. The degree of association between TBS and severe periodontitis was determined using binary logistic regression. Age, sex, plaque score, BMI, diabetes, smoking, alcohol consumption, education, income, menopausal status, and the use of medication related to bone were considered as covariates in the binary logistic regression. The covariates with a P value <0.1 in the univariate analysis were simultaneously considered in the multivariate analysis. Odds ratios (ORs) and their 95% confidence intervals (CIs) were calculated for covariates included in the univariate and multivariate analyses. Multivariate regression analyses using forward stepwise and disjunctive clause criterion[34] methods and a sensitivity analysis using another periodontitis case definition[35] for classifying periodontitis severity were also performed.

The interactions between TBS and oral hygiene status were determined in relationship to severe periodontitis. The multiplicative interaction between TBS and oral hygiene status was analyzed using a binary logistic regression model. For the additive interaction between TBS and oral hygiene status, three values that indicate synergistic interactions and their 95% CIs were calculated: 1) relative excess risk due to interaction (RERI); 2) attributable proportion due to interaction (AP); and 3) synergy index (S).[36] Statistically, a significantly additive interaction was considered if the 95% CIs of any of these three measures did not include a null value: RERI > 0, AP > 0, or S > 1.

3 | RESULTS

Of the 848 participants that received TBS assessment, 43 were excluded due to incomplete dental data, leaving 805 participants; 476 (59.1%) males and 329 (40.9%) females for data analysis. The participants' age ranged between aged 30 and 82 years, with a mean age of 52.1 ± 14.3 years. The participants' characteristics based on periodontal status are shown in Table 1. Based on the CDC-AAP case definitions,[32] 20.2% of the participants were classified as severe periodontitis. Comparing the two periodontitis groups, there were significant differences in all participants' characteristics, except for menopausal status and the use of medication related to bone. The severe periodontitis group had a higher mean age, higher mean plaque score, and greater percentages of participants who were overweight, diabetic, current/former smokers, current drinkers, and had low education and income levels compared with the non-severe periodontitis group.

The bone quality at lumbar spine L1 to L4 was measured as TBS. The participants' mean TBS and TBS status according to periodontal status are shown in Table 1. The L1 to L4 TBS values ranged between 1.02 and 1.68 with a mean of 1.35 ± 0.11. Comparing the two periodontitis groups, the mean TBS of the severe periodontitis group was significantly lower than that of the non-severe periodontitis group (1.31 ± 0.10 versus 1.36 ± 0.11), with a mean TBS difference of 0.05. Moreover,

[§] SPSS Statistics for Windows, Version 22.0, IBM, Armonk, NY

TABLE 2 The mean periodontal variables according to TBS status (mean ± SD)

TBS status	Plaque score (%)	PD (mm)	CAL (mm)	Remaining teeth
Normal (n = 423)	62.8 ± 22.1	2.2 ± 0.4 *	1.8 ± 0.9 *	24.9 ± 4.8 *
Partially degraded (n = 297)	66.0 ± 21.4	2.3 ± 0.7	2.5 ± 1.3	22.0 ± 6.6
Degraded (n = 85)	62.5 ± 22.4	2.3 ± 0.5 *	2.7 ± 1.0 *	21.5 ± 6.2 *
Total (n = 805)	63.9 ± 22.0	2.2 ± 0.5	2.2 ± 1.1	23.5 ± 5.9

CAL = clinical attachment level; PD = probing depth; SD = standard deviation; TBS = trabecular bone score.
Differences in periodontal parameters between TBS groups were analyzed using one-way ANOVA and Game-Howell post-hoc test.
*P <0.05.

the percentage of participants with partially degraded TBS or degraded TBS was greater in the severe periodontitis group.

The mean periodontal variables according to TBS status are shown in Table 2. As the TBS status worsened, the mean PD and CAL increased, and the mean number of remaining teeth decreased; however, there was no significant difference in mean plaque score between the TBS groups. ANOVA and Game-Howell post hoc tests were used to compare the differences in the mean periodontal variables between the TBS status groups. The results indicated that the mean PD, CAL, and number of remaining teeth were different between the normal and partially degraded TBS groups, and between the normal and degraded TBS groups, but not between the degraded and partially degraded TBS groups. The mean CAL difference between the normal and partially degraded TBS groups was 0.7 mm and between the normal and degraded TBS groups was 0.9 mm.

The degree of association between TBS and severe periodontitis was determined using binary logistic regression (Table 3). In the univariate model, partially degraded and degraded TBS were associated with severe periodontitis with an unadjusted OR of 1.86 (95% CI = 1.28 to 2.72) and 3.02 (95% CI = 1.79 to 5.09), respectively. Alcohol consumption, menopausal status, and the use of medication related to bone were not associated with severe periodontitis, thus these variables were not included in the multivariate regression analysis. In the multivariate model, after adjusting for covariates, which were age, sex, plaque score, BMI, diabetes, smoking, education, and income, degraded TBS was associated with severe periodontitis with an adjusted OR of 2.10 (95% CI = 1.03 to 4.26). A sensitivity analysis performed using another periodontitis case definition (see Supplementary Table 1 in online *Journal of Periodontology*) also found an association between degraded TBS and severe periodontitis with an adjusted OR of 2.35 (95% CI = 1.14 to 4.86). In the multivariate models (see Supplementary Table 2 in online *Journal of Periodontology*), using forward stepwise and disjunctive clause criterion methods with all covariates, the ORs for the association between degraded TBS and severe periodontitis were 2.27 (95% CI = 1.13 to 2.54) and 1.91 (95% CI = 0.92 to 3.95), respectively.

The degree of association between oral hygiene status and severe periodontitis was also determined using binary logistic regression (Table 3). In the multivariate analysis, after adjusting for age, sex, TBS, BMI, diabetes, smoking, education, and income, poor and very poor oral hygiene were associated with severe periodontitis with an adjusted OR of 2.48 (95% CI = 1.03 to 5.97) and 2.81 (95% CI = 1.12 to 7.02), respectively. Therefore, the multiplicative interaction between TBS and oral hygiene status on severe periodontitis was analyzed using binary logistic regression (Table 4). The results demonstrated a significant interaction between TBS and oral hygiene status on severe periodontitis after adjusting for covariates. The combination of degraded TBS and poor to very poor oral hygiene increased the odds of having severe periodontitis to 4.96 (95% CI = 1.20 to 20.24) and 5.71 (95% CI = 1.15 to 28.43), respectively. Moreover, a significant additive interaction between degraded TBS and oral hygiene was revealed, because the 95% CIs of the AP value did not include the null value (AP > 0) (Table 5). When combining degraded TBS with poor or very poor oral hygiene, the calculated AP value was 0.67 with the 95% CI = 0.20 to 1.14 for poor oral hygiene and the 95% CI = 0.15 to 1.19 for very poor oral hygiene, respectively.

4 | DISCUSSION

This study demonstrates that degraded TBS is associated with severe periodontitis. After adjusting for other covariates, individuals with degraded TBS were ≈2-fold more likely to have severe periodontitis than those with normal TBS. This finding was confirmed by performing a sensitivity analysis using criteria advocated by Albandar[35] in classifying periodontitis severity where degraded TBS was also found to be associated with a 2.4-fold increase in the likelihood of having severe periodontitis.

Because this was the first study to explore an association between TBS status and periodontitis, no similar findings have been reported. However, the odds of having severe periodontitis in participants with degraded TBS was consistent with previous cross-sectional studies in postmenopausal women[6,13] that demonstrated a decreased lumbar spine BMD was associated with periodontitis with an adjusted OR of 2.24 (95% CI = 1.24 to 4.06)[13] and osteoporosis was associated with periodontitis with an adjusted OR of 2.45 (95% CI = 1.38 to 4.34).[6]

TABLE 3 Association between variables and severe periodontitis

Variable	Unadjusted OR (95% CI)[a]	Adjusted OR (95% CI)[a]
Bone quality (TBS)[b]		
Normal (TBS ≥ 1.35)[d]		
Partially degraded (1.20 < TBS < 1.35)	1.86 (1.28 to 2.72)*	0.97 (0.59 to 1.58)
Degraded (TBS ≤ 1.20)	3.02 (1.79 to 5.09)*	2.10 (1.03 to 4.26)*
OH (plaque score %)[c]		
Fair (plaque score < 40%)[d]		
Poor (plaque score 40% to 79%)	2.71 (1.27 to 5.77)*	2.48 (1.03 to 5.97)*
Very poor (plaque score ≥80%)	4.56 (2.10 to 9.93)*	2.81 (1.12 to 7.02)*

OH = oral hygiene status.
[a] Odds ratios and 95% confidence intervals were obtained using binary logistic regression analysis using participants with non-severe periodontitis as the reference group.
[b] Adjusted by age, sex, plaque score, BMI, diabetes, smoking, education, and income.
[c] Adjusted by age, sex, TBS, BMI, diabetes, smoking, education, and income.
[d] Reference group.
*P <0.05.

TABLE 4 Multiplicative interaction between TBS and oral hygiene status on severe periodontitis

Odds ratio	Oral hygiene status	Normal TBS (TBS ≥ 1.35)	Partially degraded TBS (1.20 < TBS < 1.35)	Degraded TBS (TBS ≤ 1.20)
Unadjusted OR(95% CI)[a]	Fair OH (Plaque < 40%)	Reference	2.99 (0.62 to 14.35)	1.70 (0.16 to 17.86)
	Poor OH (Plaque 40% to 79%)	2.98 (0.89 to 1.06)	4.97 (1.47 to 1.78)*	11.31 (3.12 to 40.99)*
	Very poor OH (Plaque > 80%)	5.21 (1.50 to 18.12)*	9.49 (2.75 to 32.76)*	12.44 (2.87 to 53.91)*
Adjusted OR(95% CI)[a,b]	Fair OH (Plaque < 40%)	Reference	1.12 (0.19 to 6.72)	0.66 (0.06 to 7.80)
	Poor OH (Plaque 40% to 79%)	1.97 (0.56 to 6.92)	1.95 (0.56 to 7.07)	4.96 (1.20 to 20.24)*
	Very poor OH (Plaque > 80%)	2.25 (0.61 to 8.31)	2.36 (0.62 to 9.02)	5.71 (1.15 to 28.43)*

OH = oral hygiene status.
[a] Odds ratios and 95% confidence intervals were obtained using binary logistic regression analysis using participants with normal TBS and fair oral hygiene as the reference group.
[b] Adjusted by age, sex, BMI, diabetes, smoking, education, and income.
*P value <0.05.

Age, sex, plaque score, BMI, diabetes, smoking, alcohol consumption, education, and income were considered as covariates in the binary logistic regression because they were reported to be associated with periodontitis in another epidemiologic survey[37] and previous EGAT studies.[25,33] Because the use of medication related to bone was reported to be associated with improved periodontal status and menopause was associated with systemic bone loss,[10,38] these two variables were also initially considered. In this study, menopause was identified in female participants based on their age at their last menstruation, whereas andropause could not be defined in the male participants; therefore, male and non-menopausal female participants were combined into the same group.

Our results from the final regression model concurred with previous reports,[25,33,39,40] that aside from degraded TBS, age, oral hygiene status, smoking, overweight, low socioeconomic status, and education level were associated with periodontitis severity. Improvements in periodontal status were reported in previous studies[10,38] of postmenopausal women who received anti-resorptive agents. However, in our study, the use of medication related to bone was not protective against severe periodontitis. These findings may be due to the small percentage (<1%) of participants who received anti-bone resorptive drugs or hormone replacement therapy.

In individuals with systemic bone loss, increased systemic cytokines involved in bone resorption may modify the host response to the dental plaque biofilm and enhance periodontal destruction.[4,5] Accordingly, TBS and oral hygiene status were combined for analyzing their interactions on severe periodontitis. Although the multiplicative interaction reflects a statistical interaction, analysis on the additive scale reflects

TABLE 5 Additive interaction between bone quality (TBS) and oral hygiene status in relationship to severe periodontitis

TBS status and OH	RERI (95% CIs)	AP (95% CIs)	S (95% CIs)
Partially degraded TBS			
Poor OH	−0.41 (−2.96 to 2.13)	−2.21 (−1.40 to 0.98)	0.68 (0.14 to 3.51)
Very poor OH	−0.01 (−2.59 to 2.58)	0.00 (−1.10 to 1.09)	0.99 (0.15 to 6.61)
Degraded TBS			
Poor OH	3.33 (−1.58 to 8.24)	0.67 (0.20 to 1.14)[a]	6.32 (0.08 to 534.84)
Very poor OH	3.81 (−3.37 to 10.99)	0.67 (0.15 to 1.19)[a]	5.23 (0.17 to 158.66)

AP = attributable proportion due to interaction; OH = oral hygiene status; RERI =relative excess risk due to interaction; S = synergy index.
[a] Significant additive interaction between degraded TBS and oral hygiene status (RERI > 0 or AP > 0 or S > 1).

a synergistic effect and a mechanistic interaction. Thus, reporting results on both multiplicative and additive scales is recommended.[36] The findings of significant interactions between degraded TBS and oral hygiene status after adjusting for other covariates, suggests that degraded TBS synergizes with poor to very poor oral hygiene with an ≈5-fold increase in the likelihood of having severe periodontitis in this study population. Because the AP value represents the proportion of the effect due to interaction, the calculated AP value of 0.67 for additive interactions found between degraded TBS and poor/very poor oral hygiene in relationship to severe periodontitis indicates that in 100 participants with severe periodontitis and degraded TBS and poor/very poor oral hygiene, 67 participants had an additive effect of these two factors. The clinical implication of this preliminary finding is that oral hygiene maintenance, along with bone health monitoring, may be beneficial for preventing periodontal deterioration associated with systemic bone loss in these individuals. The relatively wide CIs of the adjusted ORs for multiplicative interactions between oral hygiene and TBS status may partly be due to the small sample size in each group (very poor OH – degraded TBS: n = 20 and poor OH – degraded TBS: n = 53). Therefore, the additive effect of these two variables needs to be confirmed in a larger population.

In this study, increases in mean PD, CAL, and number of remaining teeth correlated with worsening TBS status. As the cause of tooth loss in our study population was unknown and PD may not truly reflect the incremental destruction related to periodontitis, CAL is a more appropriate clinical variable for assessing cumulative alveolar bone loss and periodontal destruction during an individual's life-time period.[1] The mean CAL difference of 0.9 mm found between the degraded and normal TBS groups is clinically relevant because the average mean CAL loss of the general population reported in a meta-analysis of prospective studies on progression of periodontitis was only 0.1-mm per year.[41] Moreover, the inverse association between TBS and CAL found in our study concurred with a systematic review and meta-analysis on the association between systemic bone loss and periodontitis in postmenopausal women[42] that reported a mean CAL difference of 0.34 mm between the osteoporosis and normal BMD groups.

This study was performed in a population subgroup of a previous EGAT study[25] where BMD was not associated with periodontitis in the whole study population. In contrast, the present study found an association between degraded TBS and severe periodontitis. Although TBS and BMD are both generated from a DXA image, these two indexes reflect different bone properties. Unlike BMD measurement, the TBS value is not affected by bony degenerative changes. Inconsistent lumbar spine BMD and TBS results were found in individuals with degenerative changes with calcification including osteoarthritis, osteophytes, scoliosis, and aortic calcification,[43,44] where BMD increased in elder patients with calcific degenerative changes, whereas the TBS continuously declined with increasing age regardless of any calcific degeneration. Moreover, a cross-sectional study[45] showed that decreased TBS was associated with increased odds of having a vertebral fracture in the osteopenia or normal BMD groups. Thus, TBS is an index that can be used independently or combined with BMD in predicting osteoporotic fractures.[46–48]

In this study population, the mean TBS was greater than those reported in a meta-analysis of other cohort surveys worldwide (1.35 ± 0.11 versus 1.27 ± 0.10).[49] This finding may be due to the young age group (30 to 49 years) and a high proportion of male participants included in our study, while most studies focused on female participants aged >50 years. However, the mean TBS of our female participants aged 50 to 80 years was 1.26 ± 0.09, which was consistent with the results of other studies.[49] Moreover, the mean TBS difference of 0.05 found between the non-severe and severe periodontitis groups in our study is clinically relevant because according to a case control study,[50] each incremental decrease of 0.01 in TBS value was associated with a 2.5-fold increase in the likelihood of having a vertebral fracture.

The strengths of this study include a relatively large number of participants covering both sexes and wide age ranges. Full-mouth periodontal examinations were performed by calibrated periodontists. The CDC/AAP case definition[32]

recommended for surveillance and population-based research was used. The TBS was calculated from high quality DXA images with a standard quality scanner. Moreover, the effects of several covariates were adjusted in the data analyses. However, the present study has some limitations. Since periodontitis and systemic bone loss are multifactorial diseases, unknown factors may influence the association between these diseases. This study was conducted in only the EGAT population; therefore, the results of this study need to be confirmed in other population groups. Furthermore, this was a cross-sectional study, thus longitudinal studies are required to confirm a causal effect of degraded TBS and periodontitis. Additionally, analysis in the opposite direction using periodontitis as a predictor for decreased bone quality and fracture risk would result in new information in another aspect of the association between systemic bone loss and periodontitis.

5 | CONCLUSIONS

This study revealed that degraded TBS at lumbar spine L1 to L4 was associated with severe periodontitis and there was a synergistic interaction between degraded TBS and poor to very poor oral hygiene in severe periodontitis. Therefore, early detection and monitoring of decreased bone quality along with good oral hygiene maintenance would be beneficial in preventing periodontitis progression and lead to an overall improvement of a patient's quality of life. Multidisciplinary approaches by dentists and physicians should be established to encourage patients to have a healthy lifestyle that promotes overall health.

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AUTHOR CONTRIBUTIONS

All authors have made substantial contributions to the study. Dr. Mongkornkarn and Dr. Sritara conceived the study concept and design. Dr. Niramitchainon, Dr. Lertpimonchai, and Dr. Udomsak contributed by arranging the field survey, calibration and data collection. Dr. Niramitchainon, Dr. Mongkornkarn, and Dr. Lertpimonchai contributed to data analysis, interpretation of the results, and wrote the first draft. Dr. Niramitchainon, Dr. Mongkornkarn, Dr. Sritara, Dr. Lertpimonchai, and Dr. Udomsak have revised and approved the final version of the manuscript.

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SUPPORTING INFORMATION

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

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