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ORIGINAL ARTICLE

Relationships of social support, health-promoting lifestyles, glycemic control, and bone turnover among adults with type 2 diabetes

Mei Ha[1] | **Jun Chen**[2] | **Xiaojuan Zhang**[1] | **Hong Yang**[1] | **Changjiang Liu**[3]

[1]School of Nursing, Chongqing Medical and Pharmaceutical College, Chongqing, China

[2]Chenjiaqiao Hospital, the Affiliated Hospital of Chongqing Medical and Pharmaceutical College, Chongqing, China

[3]NHC Key Laboratory of Birth Defects and Reproductive Health, Chongqing Population and Family Planning Science and Technology Research Institute, Chongqing, China

Correspondence
Changjiang Liu, NHC Key Laboratory of Birth Defects and Reproductive Health, Chongqing Population and Family Planning Science and Technology Research Institute, 18 Honghuang Road, Chongqing 400020, China.
Email: cj_514@163.com

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Abstract

Aim: There is increasing evidence that hyperglycemia, oxidative stress, and the accumulation of advanced glycation end products in type 2 diabetes mellitus (T2DM) can lead to the deterioration of bone remodeling. The purpose of this study was to explore relationships of social support, health-promoting lifestyles, glycated hemoglobin (HbA1c) levels, and serum bone turnover markers (BTMs, including procollagen type I amino-terminal propeptide [PINP] and β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen [β-CTX]) among individuals with T2DM.

Methods: A total of 175 subjects were recruited by convenience sampling and divided into three groups based on their HbA1c levels. Statistical strategies of Spearman's correlation coefficient and multiple linear regression were used in this cross-sectional study.

Results: There was a positive association between PINP and β-CTX, whereas the HbA1c level was inversely correlated with BTMs. Moreover, scores of both PINP and β-CTX were different in genders, males having lower levels of BTMs than females after adjustment for weight. Furthermore, both social support and health-promoting lifestyles were negatively correlated with HbA1c levels, whereas they did not significantly relate to declines in PINP and β-CTX.

Conclusion: High HbA1c levels detrimentally influence bone formation and bone resorption, and males with T2DM might be more susceptible to osteoporosis because of their relatively lower levels of BTMs. However, social support and health-promoting lifestyles could contribute to better glycemic control.

KEYWORDS
bone turnover, HbA1c, health-promoting lifestyles, social support, type 2 diabetes mellitus

1 | INTRODUCTION

A healthy skeletal system with strong bones is essential to overall health and quality of life. However, a number of factors such as ageing, menopause, low body mass index, unhealthy lifestyles, and so on, could adversely affect bone health (International Osteoporosis Foundation, 2018a). Moreover, it is suggested that some diseases such as diabetes mellitus, may induce osteoporosis and further affect bone health.

Osteoporosis, a multifactorial skeletal disease characterized by painless weakening of bones, could lead to a wide

variety of clinical conditions, such as height loss, severe back pain, bone deformity, disability, fragility fracture, and even death (Abdulameer, Sulaiman, Hassali, Subramaniam, & Sahib, 2012). Osteoporosis not only detrimentally affects quality of life, but also brings about enormous socioeconomic burdens. It is reported that osteoporosis causes nearly 687,000 hip fractures in China each year and the hospital costs of treating hip fractures exceed that of treating heart disease, breast cancer, prostate cancer and ovarian cancer (International Osteoporosis Foundation, 2018b).

Strong evidence suggested that type 1 diabetes mellitus (T1DM) could impair bone formation and decrease values of peak bone mass due to the absolute deficiency of insulin and insulin-like growth factor-1 (Jackuliak & Payer, 2014). However, type 2 diabetes mellitus (T2DM) could adversely affect bone quality rather than bone mineral density (BMD), since trabecular bone score, as a measure of bone texture, had a stronger association with vertebral fractures than BMD in postmenopausal women with T2DM (Chen, Kuo, Lin, Fan, & Chen, 2019). Moreover, the study by Gilbert and Pratley (2015) found that individuals with T2DM had 10–30% higher risk of vertebral fractures and hip fractures than age-matched controls without diabetes. People with T2DM were susceptible to deterioration in bone material properties and microstructures as well as the decline in bone turnover markers (BTMs) due to hyperglycemia and accumulations of advanced glycation end products, which comprises collagen properties, increase in marrow adiposity, release of inflammatory factors and adipokines from visceral fat, and potential alterations of osteocyte functions, and so on. (Napoli et al., 2017). Furthermore, thiazolidinediones, as one of the wide anti-diabetic medications, could suppress osteoblastogenesis, thereby leading to the rise of fracture risk (Compston, 2018). According to the cross-sectional study performed in 2,671 adults, the prevalence of T2DM was inversely correlated with levels of BTMs (Lerchbaum et al., 2015).

The International Osteoporosis Foundation recommended that serum BTMs, including procollagen type I amino-terminal propeptide (PINP, a marker of bone formation) and β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen (β-CTX, a marker of bone resorption), could be considered as the standard indices in the management of osteoporosis (S. Vasikaran et al., 2011). It was also suggested that serum BTMs could be used to much faster evaluate the condition of bone loss or formation compared to the examination of BMD (Gao et al., 2017; Vasikaran, 2008). Some studies observed that the bone formation markers including osteocalcin (OC) and PINP were lower in people with T2DM compared to those without diabetes, proposing that high blood glucose levels impaired functions of osteoblasts and further suppressed bone formation (Kanazawa et al., 2011; Shu et al., 2012). Moreover, Stage et al. (2018) reported that higher blood glucose levels also suppressed bone resorption, as indicated by an inverse correlation between HbA1c and β-CTX.

Owing to close relationships between hyperglycemia and osteoporosis and skeletal deterioration, it is imperative to explore effective measures to control HbA1c levels and promote bone remodeling. Among various measures, optimal glycemic control, positive social support, and health-promoting lifestyles are associated with better health outcomes of people with T2DM. It was reported that HbA1c levels were more likely decreased in people with T2DM who received family support or had close relationships with their physicians (Badedi et al., 2016; Nicklett, Michele Heisler, Spencer, & Rosland, 2013). Furthermore, health-promoting lifestyles such as exercises were frequently used to evaluate functional fitness maintenance and glycemic control (Ades, 2015; Gregg et al., 2012). However, the relationships of social support, health-promoting lifestyles, and BTMs still remained unknown.

The PRECEDE Model consisting of predisposing factors, reinforcing factors, enabling factors, behaviors, and health was used in the present study (Green & Kreuter, 2005). It is comprehensive to distinguish the potential factors of health outcome. Predisposing factors consist of demographic variables such as age, gender, weight, and so on. The reinforcing factor refers to social support. According to the Medical Outcomes Study Social Support Survey (Sherboume & Stewart, 1991), the social support in this study contains four dimensions, including tangible support, affectionate support, positive social interaction, and emotional information support. The enabling factor mainly includes economic status (income). Behaviors mainly mean health-promoting lifestyles, including interpersonal relationship, health responsibility, physical activity, stress management, spiritual growth, and nutrition (Walker, Sechrist, & Pender, 1995). Health includes glycemic control and BTMs (Figure 1).

The purpose of the current study was to examine relationships between glycemic control (HbA1c) and BTMs (PINP and β-CTX), to further explore the influence of gender on those relationships, and then reveal effects of social support and health-promoting lifestyles on glycemic control and BTMs. Our study answered the research questions as follows.

1. What are relationships between HbA1c and BTMs (PINP and β-CTX)?
2. How does gender influence the relationship between HbA1c and BTMs?
3. What are relationships among social support, its subscales, HbA1c, and BTMs?

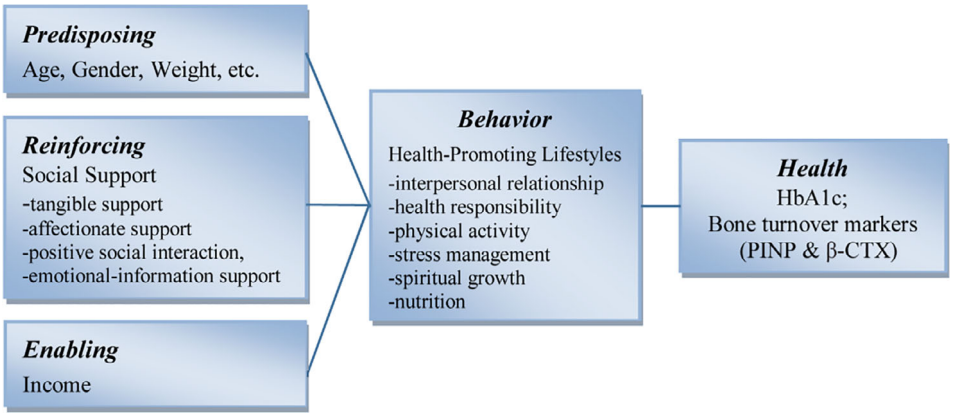

FIGURE 1 Components of the PRECEDE Model applied in this study

4. What are relationships among health-promoting lifestyles, their subscales, HbA1c, and BTMs?

2 | METHODS

2.1 | Study design, setting, and participants

A cross-sectional correlational design was used to study relationships between glycemic control (HbA1c) and BTMs (PINP and β-CTX), and further reveal effects of social support and health-promoting lifestyles on glycemic control and BTMs.

Study participants with T2DM were recruited by convenience sampling from a diabetes clinic of the local hospital. The hospital provides health services for a population of approximately 54.8 thousand, including 12 villages and six communities. Participants without T2DM in the control group were recruited from local communities. Inclusion criteria were as follows: (a) older than 30 years; (b) patients had a diagnosis of T2DM for at least 1 year or above with recent HbA1c more than 6.0% (affinity chromatography); and (c) participants in the control group had HbA1c between 4–6%. Exclusion criteria were as follows: (a) patients with T2DM had their glycemic control within normal range; and (b) diagnosis of severe diabetes complications, fracture, rickets, multiple myeloma, cancer, celiac or inflammatory bowel disease, current glucocorticoid or anticonvulsant use, current hormone replacement therapy, and current or past treatment of osteoporosis. A power analysis was performed to determine the sample size. A regression analysis with 12 independent variables, a medium effect size of 0.15 (Cohen, 1988), a *P* value of .05, and a power of 0.80 indicated that a sample size of 127 was required (GPower, version 3.1). A final sample of 175 was recruited for the study.

Given that HbA1c level below 8.0% is associated with the lowest mortality risk in the management of diabetes (Mácsai, Rakk, Miléder, & Fulcz, 2014), all participants were divided into three groups, including two diabetes groups with different HbA1c levels and one control group. Group A consisted of 66 participants with HbA1c levels above 8.0% (affinity chromatography); group B of 64 participants with HbA1c levels between 6.1 and 8.0%; and group C consisted of 45 participants without T2DM (HbA1c level, 4.0–6.0%). All participants in this study signed a written informed consent.

Questionnaire data were gathered by either self-report or face-to-face interview. The blood samples were collected by clinical nurses after participants' questionnaires were taken. There were no requirements of fasting before drawing blood.

2.2 | Ethics considerations

Ethics approval was obtained from the human research ethics committee of our college and its affiliated hospital.

2.3 | Measurements

2.3.1 | Demographic characteristics

Demographic features of participants were collected by a demographic questionnaire including age, gender, weight, height, education level, monthly income, calcium intake, and smoking and alcohol consumption.

2.3.2 | The Chinese version of Medical Outcomes Study Social Support Survey(MOS-SSS-C)

The Chinese version of Medical Outcomes Study Social Support Survey (MOS-SSS-C) was translated and assessed by Yu, Lee, and Woo (2004) from the original English version of MOS-SSS (Sherboume & Stewart, 1991). The scale was mainly used to measure multidimensional function aspects of social support of chronically ill patients. The MOS-SSS-C contains 19 items that cover four dimensions of social support: tangible support, affectionate support, positive social interaction, and emotional information support. It is a five-point Likert-type scale for each item, with "0"

standing for "none of the time" and "5" for "all the time." The higher scores indicate the more social support received. Cronbach's α and test–retest reliability of the original English version were 0.97 and 0.78, and that of the MOS-SSS-C were 0.98 and 0.84, respectively. Criterion-related construct validities were assessed by correlations with the MOS-SSS-C ($r = 0.82$) and the Hospital Anxiety and Depression Scale ($r = -0.58$).

2.3.3 | The Chinese version of Health-Promoting Lifestyle Profile II (HPLP-II)

The Chinese version of Health-Promoting Lifestyle Profile II (HPLP-II) was tested to be a reliable and valid instrument in Chinese populations (Cao, Guo, Ping, & Zheng, 2016). The original version of HPLP was developed and further refreshed by Walker et al. (1995). The adapted Chinese scale has 40 items, including six dimensions of interpersonal relationship, health responsibility, physical activity, stress management, spiritual growth, and nutrition. Higher scores suggest better health-promoting lifestyles. Cronbach's α coefficient of six dimensions ranged from 0.64 to 0.78, the split-half reliability coefficient was between 0.64 and 0.78, and the test–retest reliability was 0.68.

2.3.4 | Biological detections

Two milliliters of venous blood were collected in anticoagulant tubes for HbA1c assays, and 3–5 mL in drying tubes for PINP and β-CTX detections. HbA1c, a measure of weighted average blood glucose level over the preceding 2–3 months, was assessed using Roche/Hitachi Cobas c701. A computer-controlled automatic analyzer (Roche Cobas e601) for chemiluminescence workstation was employed to determine β-CTX and PINP levels.

2.4 | Data analysis

Data were analyzed using SPSS. Descriptive statistics were performed to describe demographic characteristics. Shapiro–Wilk test was used to test the normal distribution, while K related samples test was used to analyze the skewed distribution. Associations between continuous variables were described by Spearman's correlation coefficients. The skewed data of BTM (PINP and β-CTX) levels were appropriately transformed to normal distribution using Blom's formula. The multiple regression was used to determine relationships of personal characteristics, social support, health-promoting lifestyles, HbA1c, and BTMs. Univariable model was used to evaluate the effect of gender difference on associations of HbA1c with BTMs when the P value was more than .001 in the test of Box's Test of Equality of Covariance Matrices, and above .05 in the test of Levene's Test of Equality of Error Variances. Covariates were incorporated in the final model according to the method suggested by Meeker, Yang, Ye, Calafat, and Hauser (2011) and the covariates that were considered as potential confounders in a model were all included in final models to maintain consistency. Weight was the covariate in our current study. A difference at the $P < .05$ level was considered statistically significant.

3 | RESULTS

3.1 | Demographic characteristics

The mean age was 63.68 ± 10.78 (range, 41–85) years and the mean body mass index (BMI) was 25.19 ± 3.30 (16.53–34.38) kg/m^2. The mean levels of PINP and β-CTX were 41.64 ± 15.71 and 0.21 ± 0.09 ng/mL, respectively. Despite differences in glucose levels, there were no significant discrepancies in age, gender, weight, height, BMI, smoking and alcohol consumption, and education levels among groups. Most (91%) were married and lived with a spouse or children. Female participants in this study had no smoking and drinking habits, while male participants with smoking and drinking behaviors were asked to narrate the dose. In diabetes groups (groups A and B), the time of evolution of T2DM was 7.47 ± 5.65 years, most patients (74.6%) received oral medication treatments, and 11.5% patients received insulin therapy. Moreover, scores of social support and its subscales were all negatively associated with HbA1c levels. Scores of social support in diabetes groups were significantly lower than that in group C ($P < .001$). Similarly, scores of four subscales in diabetes groups were all declined ($P = .001$, $P < .001$, $P < .001$, and $P = .001$, respectively), especially the score of positive social interaction, which was decreased by 25.9% in group A compared with that in group C ($P < .001$).

According to K related samples tests, there was a significant difference in scores of HPLP among three groups ($P = .001$). Moreover, statistical differences were observed in scores of five subscales including interpersonal relations, nutrition, health responsibility, stress management, and spiritual growth ($P < .001$, $P = .001$, $P = .001$, $P < .001$, and $P < .001$, respectively). Specifically, compared with control group C, scores of interpersonal relations and spiritual growth in diabetes group A were decreased to 83.56% ($P < .001$) and 77.97% ($P < .001$), respectively; whereas scores of health responsibility in diabetes group B were increased to 116.51% ($P < .001$). Nevertheless, no significant difference was observed in scores of exercise subscale among the three groups ($P = .116$).

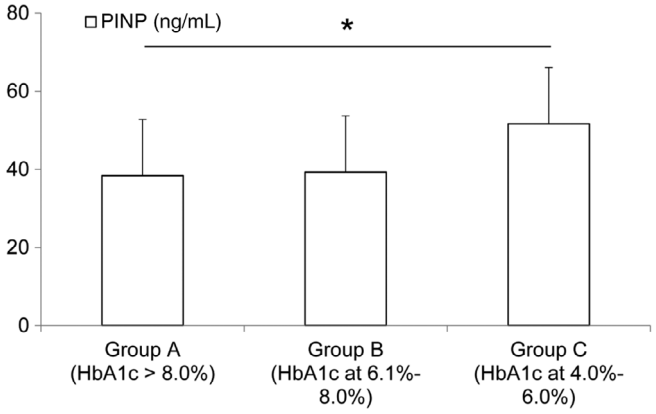

FIGURE 2 Levels of PINP of the study population. $N = 175$. HbA1c, glycemic hemoglobin; PINP, serum procollagen type I amino-terminal propeptide. Error bars represent the standard deviation.
*$P < .05$, compared with control group C

3.2 | Relationships between HbA1c and BTMs

The HbA1c level was apparently higher in diabetes groups (groups A and B) and compared with group C, a 1.8-fold increase in HbA1c levels in group A was observed ($P < .001$). In contrast, levels of BTMs were significantly lower in diabetes groups. PINP and β-CTX levels in group A were decreased to 77.4% ($P = .002$; Figure 2) and 82.6% ($p = .043$; Figure 3) of the control group C, respectively. The correlations between HbA1c and BTMs were further analyzed by multivariable linear models. As expected, an inverse correlation between HbA1c and PINP was observed ($P = .001$). Moreover, HbA1c levels were also negatively associated with β-CTX levels after adjustment for weight (β = −.425, 95%CI: −0.789, −0.062; Table 1). Meanwhile, the multiple linear regression was also used to assess the relationship between bone formation (PINP) and bone resorption (β-CTX), with results indicating that β-CTX explained 30.4% of the variance of PINP (β = .552, $P < .001$; Table 2).

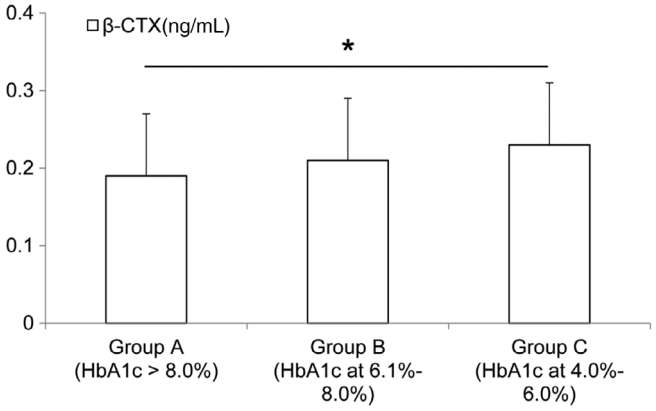

FIGURE 3 Levels of β-CTX of the study population. N = 175. β-CTX, serum β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen. Error bars represent the standard deviation.
*$P < .05$, compared with control group C

TABLE 1 Adjusted regression coefficients for BTMs in relation to HbA1c[a]

	BTMs (β-coefficient, 95% CI)	
Blood sugar level	**PINP**	**β-CTX**
HbA1c		
Group A, above 8.0	−0.657 (−1.019; −0.296)	−0.425 (−0.789; −0.062)
Group B, between 6.1–8.0	−0.577 (−0.946; −0.208)	−0.241 (−0.612; 0.131)
Group C, normal level within 6.0	0	0
P for trend	.001*	.072

Note: $N = 175$.
Abbreviations: BTMs, bone turnover markers; β-CTX, β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen; CI, confidence interval; PINP, procollagen type I amino-terminal propeptide.
[a]Adjusted weight.
*$p < .05$.

3.3 | Influence of gender on the relationships between HbA1c and BTMs

Effects of demographic characteristics on BTMs were analyzed by multiple linear regressions and results demonstrated that gender was the significant predictor for PINP (β = .552, $P = .020$; Table 3) and weight for β-CTX (β = −.023, $P = .012$; Table 4). Moreover, gender difference not only significantly affected the relationship between HbA1c and the bone formation marker ($P = .003$; Table 3), but also played a suggestive effect on the relationship between HbA1c and the bone resorption marker ($P = .070$; Table 4). Additionally, the uni-variable model was used to test the gender difference in BTMs. After adjustment for weight, PINP ($P < .001$) and β-CTX ($P = .009$) levels were

TABLE 2 Relationships between bone formation of PINP and bone resorption of β-CTX

	PINP				
Variable	**B**	**SE B**	***P***	**95% CI**	R^2
β-CTX	0.552	0.063	<.001*	0.426; 0.677	0.304

Note: $N = 175$. $F(1, 173)$ 75.629, $P < .001$.
Abbreviations: β-CTX, β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen; CI, confidence interval; PINP, procollagen type I amino-terminal propeptide; SE, standard error.
*$P < .05$.

TABLE 3 Multiple linear regression of PINP

Variables	B	SE B	t	*P* value	95% CI
Age	0.004	0.007	0.480	.632	−0.011; 0.018
Gender	0.552	0.234	2.355	.020*	0.149; 1.068
Height	0.007	0.017	0.396	.692	−0.025; 0.040
Weight	−0.006	0.009	−0.651	.516	−0.023; 0.012
BMI	0.349	0.252	1.383	.169	−0.149; 0.848
Education	−0.081	0.104	−0.775	.439	−0.278; 0.132
Calcium intake	0.127	0.258	0.491	.624	−0.339; 0.678
Income	0.076	0.114	0.664	.508	−0.134; 0.313
Smoking	0.276	0.228	1.212	.227	−0.222; 0.669
Alcohol	−0.052	0.214	−0.244	.808	−0.442; 0.401
HbA1c·gender	−0.108	0.036	−2.979	.003*	−0.180; −0.037

Note: $N = 175$. $F(9, 165) = 2.614$, $P = .008$.
Abbreviations: CI, confidence interval; PINP, procollagen type I amino-terminal propeptide; SE, standard error.
*$P < .05$.

TABLE 4 Multiple linear regression of β-CTX

Variables	B	SE B	t	*P* value	95% CI
Age	0.006	0.007	0.865	.388	−0.008; 0.021
Gender	0.381	0.234	1.627	.106	−0.081; 0.843
Height	0.018	0.017	1.072	.285	−0.015; 0.051
Weight	−0.023	0.009	−2.548	.012*	−0.041; −0.005
BMI	0.003	0.254	0.011	.991	−0.499;0.504
Education	−0.128	0.104	−1.233	.219	−0.333; 0.077
Calcium intake	0.223	0.258	0.863	.389	−0.287; 0.732
Income	0.105	0.114	0.920	.359	−0.120; 0.329
Smoking	0.272	0.227	1.198	.233	−0.177; 0.722
Alcohol	−0.015	0.214	−0.071	.944	−0.438; 0.408
HbA1c·gender	−0.067	0.037	−1.823	.070	−0.140;0.006

Note: $N = 175$. $F(9, 165) = 2.667$, $P = .006$.
Abbreviations: BMI, body mass index; β-CTX, β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen; CI, confidence interval; SE, standard error.
*$P < .05$.

statistically different in genders. Males had lower levels of BTMs compared with females (Table 5).

3.4 | Correlations of social support, health-promoting lifestyles, HbA1c, and BTMs

Correlation analyses were performed using Spearman correlation. HbA1c levels were inversely correlated with social support ($r = −0.344$, $P < .001$) as well as its four subscales including tangible support ($r = −0.218$, $P = .004$), affectionate support ($r = −0.415$, $P < .001$), positive social interaction ($r = −0.367$, $P < .001$), and emotional support ($r = −0.273$, $P < .001$). Likewise, there were negative correlations between HbA1c and health-promoting lifestyles ($r = −0.230$, $P = .002$) as well as its subscales including

TABLE 5 Gender difference in bone turnover markers after adjusting for weight[a]

	Bone turnover markers	
Gender	Transformed values of PINP mean[b] [SE]	Transformed values of β-CTX mean[b] [SE]
Male	−0.365 [0.113]	−0.235 [0.114]
Female	0.267 [0.096]	0.172 [0.097]
P for trend	<.001*	.009*

Note: $N = 175$.
Abbreviations:β-CTX, β-isomerised carboxy-terminal cross-linking telopeptide of type I collagen; PINP, procollagen type I amino-terminal propeptide.
[a]Adjusted weight.
[b]The values of PINP and β-CTX were transformed to the normal distribution.
*$P < .05$.

interpersonal relations ($r = -0.355$, $P < .001$), nutrition ($r = -0.248$, $P = .001$), stress management ($r = -0.328$, $P < .001$), and spiritual growth ($r = -0.424$, $P < .001$). However, health responsibility ($r = 0.114$, $P = .132$) and exercises ($r = -0.085$, $P = .261$) showed no significant correlations with HbA1c levels. Moreover, there were also no significant correlations between BTMs and social support and health-promoting lifestyles.

4 | DISCUSSION

In the present study, we explored associations between glycemic control (HbA1c) and BTMs (PINP and β-CTX) in 175 people with/without T2DM, and evaluated the influence of gender difference on those associations, and further analyzed correlations of social support, health-promoting lifestyles, HbA1c, and BTMs. The findings indicate that HbA1c levels are negatively correlated with serum BTMs, and both social support and health-promoting lifestyles play positive roles in better glycemic control but not bone remodeling.

It has been known that PINP and β-CTX play important roles in diagnosis and therapeutic evaluation of osteoporosis, as well as prevention of fracture (Gao et al., 2017; Vasikaran et al., 2011). PINP, as a well-accepted marker of bone formation, is produced by formation of type I collagen, a major component of bone matrix, by amino-terminal and carboxy-terminal splicing of type I procollagen in osteoblasts (Lee & Vasikaran, 2012). Meanwhile, β-CTX, as a marker of bone resorption, reflects the degradation of type I collagen by osteoclasts to produce amino-terminal and carboxy-terminal fragments. In the current study, the mean levels of PINP and β-CTX were 41.64 ± 15.71 and 0.21 ± 0.09 ng/mL, respectively. It is noticed that the current values of PINP and β-CTX are a little lower than the values reported by (Li et al., 2014), who performed a cross-sectional study in 3,800 healthy Chinese participants. Nevertheless, this difference is foreseeable and understandable, since PINP and β-CTX levels are usually reduced in a population with T2DM. Our findings are in agreement with many previous studies. The study by Shu et al. (2012) reported that PINP was significantly lowered in 25 premenopausal women with T2DM compared with that in the control. Another study by Stage et al. (2018) found an inverse correlation between HbA1c and β-CTX, but the correlation between HbA1c and PINP was not significant after a 24-month clinical trial in anti-diabetes treatments. We speculate that different sample sizes and intervention measures may partially account for this discrepancy.

Notably, our study detected the influence of gender difference on relationships between HbA1c and BTMs. To be specific, males had lower levels of bone formation and resorption than females, suggesting that males are more susceptible to osteoporosis. Similarly, Stage et al. (2018) observed that men with T2DM had a 15% reduction in β-CTX levels, although the gender difference in PINP levels was not statistically significant. The main reason may be that males are more likely to be exposed to osteoporosis-related adverse influential factors such as smoking and alcohol. Interestingly, we also observed that weight was negatively correlated to β-CTX but not PINP, indicating that relatively less body weight may contribute to the increment of bone resorption of people with T2DM, and this result is in agreement with a previous study (Stage et al., 2018).

It is known that social support mainly consists of tangible support, affectionate support, positive social interaction, and emotional support (Sherboume & Stewart, 1991). Accumulating evidence indicates that social support has a strong impact on individuals' health, and better social support will bring about desirable diabetes outcomes in comparison to controls (Badedi et al., 2016; Nicklett et al., 2013), especially decreasing the incidence of diabetes-related complications (Brinkhues et al., 2018). In our present study, we found that participants with higher HbA1c levels (>8%) had less social support than individuals in the other two groups. The state of low social support is called social vulnerability that is indeed higher among frail individuals (Melchiorre et al., 2013). We also observed that the four dimensions of social support were all closely correlated with better diabetes control. The improvement of diabetes control could be partially attributable to alleviating diabetes distress and sharing disease burdens with important relatives (Lee, Piette, Heisler, & Rosland, 2018), and partially attributable to enhanced treatment adherence (Gomes-Villas Boas, Foss, Freitas, & Pace, 2012). However, there were no significant relationships between social support and BTMs (PINP or β-CTX) in the current study. In the following step, we will perform intervention studies for social support to make certain if more social support could contribute to improvements in bone health.

Health-promoting lifestyles encourage individuals with T2DM to modify their unhealthy behaviors, thereby improving their health status. Health-promoting lifestyles mainly comprise interpersonal relations, nutrition, stress management, exercises, and spiritual growth (Walker et al., 1995). Lifestyle interventions of exercises and weight loss have been considered as the more effective way to control and improve diabetes compared to the diabetes support and education control in the Look AHEAD study (2012). Around 5,000 individuals with T2DM had the partial remission rate of 22% after 1-year lifestyle intervention. Partial remission of T2DM is defined as HbA1c of 5.7–6.5%. In the current study, we found that health-promoting lifestyles including better interpersonal relations, nutrition, stress management, and spiritual growth were correlated with downregulation in

HbA1c levels. Compared to individuals in groups B and C, subjects with HbA1c above 8.0% conducted worse health-promoting lifestyles. Nonetheless, we did not observe any correlations between health-promoting lifestyles and BTMs. We think that further interventions of health-promoting lifestyles in bigger study populations are needed to verify whether health-promoting lifestyles such as improved nutrition and exercise could improve bone formation and resorption. Alternatively, determinations of other biomarkers of bone formation and resorption such as osteocalcin and tartrate-resistant acid phosphatase would provide further insights into the correlation between health-promoting lifestyles and bone remodeling.

4.1 | Implications for clinical practice

Community nurses need to ensure holistic and contextual approaches in intervention developments and implementations for individuals with T2DM. Specifically, social support can be effectively acquired through peer support and health management skills. Health-promoting lifestyles must include culturally appropriate content, outcomes, and strategies, such as changing unhealthy nutrition habits, enriching physical activities and exercises to promote bone health (Ardawi, Rouzi, & Qari, 2012). The focus on patient-centered care demands caregivers to play significant roles in preventing diabetes complications, such as osteoporosis. Moreover, supplementary education for nurses or caregivers should include culture-specific health programs in enhancing resistance to diabetes-related osteoporosis.

4.2 | Limitations of the study

This study has certain limitations. First, the relatively small sample size and homogeneity of study participants would reduce the power and likelihood of distinguishing differences in outcomes. Second, the information that whether study participants used hypoglycemic agents such as thiazolidine drugs or ovarian hormones, was not collected in this study. Third, we did not measure whether the amount and variety of exercises had any relationships with BTMs. Lastly, we did not fully consider the variability of BTM assays, such as biological variability, seasonal variation.

5 | CONCLUSION

The present study observed a negative correlation between HbA1c levels and bone turnover in individuals with T2DM. Poor bone remodeling might be attributed to various factors, such as body weight loss and bad blood glucose control. Additionally, more social support and healthy lifestyles will function significantly in blood sugar control although they do not positively correlate with bone remodeling in this sampling.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

M. H. designed the study, analyzed data, and prepared the manuscript; J. C. collected samples and data; X. Z. and H. Y. collected samples and analyzed data; and C. L. designed the study, interpreted data, and critically revised the manuscript.

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