The American Journal of Chinese Medicine, Vol. 35, No. 3, 369–381

Institute for Advanced Research in Asian Science and Medicine

Comparison of the Effects of Tai Chi and Resistance Training on Bone Metabolism in the Elderly: A Feasibility Study

Chwan-Li Shen,* James S. Williams,‡ Ming-Chien Chyu,*,‡ Robert L. Paige,§ Allen L. Stephens,* Katherine B. Chauncey,† Fiona R. Prabhu,† Lee T. Ferris‡ and James K. Yeh¶

*Department of Pathology, †Department of Family Medicine
Texas Tech University Health Sciences Center, Lubbock, TX, USA
‡Department of Health, Exercise, and Sport Sciences
§Department of Mathematics and Statistics
Texas Tech University, Lubbock, TX, USA
¶Laboratory of Bone Metabolism
Winthrop-University Hospital, Mineola, NY, USA

Abstract: This feasibility study compared the effects of Tai Chi (TC) and resistance training (RT) on bone metabolism in the elderly. Twenty eight sedentary, elder adults, were randomized into either TC (n = 14, 78.8 +/−1.3 years) or RT (n = 14, 79.4 +/−2.2 years) to participate in 40 min of exercise per session, 3 sessions/week for 24 weeks. The outcome measures assessed were the concentrations of serum bone-specific alkaline phosphatase (BAP), pyridinoline (PYD), parathyroid hormone (PTH) and calcium, and urinary calcium. The TC group had a higher compliance rate than the RT group. After 6 weeks, (i) both TC and RT resulted in higher level of serum BAP relative to the baseline and the TC group exhibited a greater increase in serum BAP than the RT group; (ii) there was an increase of serum PYD in the RT group only, not in the TC group; and (iii) the BAP/PYD ratio was higher than baseline only in the TC group, and the increase of the ratio in the TC group was greater than that in the RT group. After 12 weeks, the increase in serum PTH in the TC group was higher than the RT group. After 24 weeks, there was a reduction of the urinary calcium level in the TC group relative to the baseline. In conclusion, these findings support that TC is beneficial for increasing bone formation in elderly, and long-term application is needed to substantiate the effect of TC as an alternative exercise in promotion of bone health.

Keywords: Mind-Body Exercise; Bone Biomarkers; Older Participants; Bone Disease.

Correspondence to: Dr. Leslie Chwan-Li Shen, Department of Pathology, Texas Tech University Health Sciences Center, BB 198, 3601 Fourth Street, Lubbock, Texas 79430, USA. Tel: (+01) 806-743-2815, Fax: (+01) 806-743-2766, E-mail: Leslie.Shen@ttuhsc.edu

Introduction

Studies (Adachi, 1996; Miller *et al.*, 2003; National Institutes of Health, 2000) have shown strong correlations between changes in bone mineral density and bone biomarkers. Osteogenic response can be monitored by changes of bone formation biomarkers (such as serum bone-specific alkaline phosphatase (BAP) and osteocalcein) and bone resorption biomarkers (such as serum and urinary pyridinoline (PYD), type I collagen cross-linked N- and C-telopeptides), which can provide a basis for explaining alterations in bone mineral density and can be used as early predictors (Adachi, 1996; Miller *et al.*, 2003). Osteogenic response can be modulated by the availability of calcium (Ca) and phosphate (Pi), and by calciotrophic hormones including parathyroid hormone (PTH) and 1,25-$(OH)_2$ vitamin D_3 (1,25-vit D_3) (Bouassida *et al.*, 2003; Thorsen *et al.*, 1997).

Exercise has been shown to benefit bone health (Bouassida *et al.*, 2003; Chan *et al.*, 2004; Dalsky *et al.*, 1998; Maddalozzo and Snow, 2000; Martin and McCulloch, 1987; Pruitt *et al.*, 1995; Rubin and Lanyon, 1984; Thorsen *et al.*, 1997; Vincent and Braith, 2002). Among different types of exercise, resistance training (RT), a weight-bearing exercise, has been shown to be effective in stimulating an osteogenic response (Martin and McCulloch, 1987; Rubin and Lanyon, 1984; Pruitt *et al.*, 1995; Vincent and Braith, 2002). Moreover, Thorsen *et al.* (1997) reported that moderate endurance exercise can influence plasma concentrations of PTH and 1,25-vit D_3 that are related to calcium metabolism and biomarkers of bone metabolism (Bouassida *et al.*, 2003; Thorsen *et al.*, 1997).

Recently, Tai Chi (TC) exercise has gained much attention in the rehabilitation and geriatric community (Chan *et al.*, 2004; Chen *et al.*, 2001; Qin *et al.*, 2002; Qin *et al.*, 2005; Wang *et al.*, 2004; Wolfson *et al.*, 1996; Wu, 2002). TC exercise features gentle, smooth, coordinated and flowing movements of different body parts accompanied by deep breathing and mental concentration to achieve improved fitness, health, and relaxation, as well as mind-body harmony and a balanced personal sense of well-being. Tai Chi is considered an exercise modality that may promote musculoskeletal health (Wang *et al.*, 2004; Wolfson *et al.*, 1996). However, systematic studies of TC's effect on bone health are limited (Qin *et al.*, 2002, Chan *et al.*, 2004) and there is no study to evaluate the effect of TC on bone metabolism in any population.

A study by Vincent and Braith (2002) has shown that short-term low-intensity RT exercise increased the bone formation to resorption ratio, and TC is considered a low-intensity exercise (Chen *et al.*, 2001; Wolfson *et al.*, 1996). Although the effects of RT and TC on cardiovascular risk factors (Thomas *et al.*, 2005) and risk of falls (Nowalk *et al.*, 2001) have been compared in elderly subjects, their relative effects on bone metabolism in the elderly, to our knowledge, have not been investigated. Therefore, the objective of this study was to compare the effects of 24-week RT and TC interventions on bone metabolism in the elderly. Furthermore, such an exercise-induced increase in the bone formation to resorption ratio resulted in modulation of calcitrophic hormones and calcium concentrations in serum and urine in human subjects (Bouassida *et al.*, 2003; Thorsen *et al.*, 1997). Hence, we hypothesized that short-term TC training would result in an increase of bone formation-to-resorption ratio and TC training would result in comparable effects as RT on osteogenic response in the elderly. In addition, calcitrophic hormones (PTH and 1,25-vit D_3) and calcium concentrations in serum and urine of subjects were also investigated in this study.

Methods

Study Design

This was a prospective, single-blind, randomized, and controlled 24-week intervention trial with 4 measurement periods (baseline, 6, 12, and 24 weeks). The RT group was the exercise control group. The assessors were blinded to the participants' treatment assignments.

Participants

Subjects were recruited from a local senior living campus in Lubbock, Texas. All subjects signed informed consent before participating in the study. The following inclusion criteria were applied to select participants: (i) male or female 65 years of age or older, (ii) ambulatory, and (iii) consent of primary family doctor. Exclusion criteria included (i) any uncontrolled chronic or terminal illness, (ii) history of any chronic liver disease, metabolic bone disease, renal disease, (iii) use of medication such as bisphosphonates, calcitonin, and selective estrogen receptor modular that may influence bone or calcium metabolism, (iv) regular exercise for more than 2 hours per week, and (v) currently smoking. Among the 39 candidates who signed the informed consent, 11 were excluded due to rheumatoid arthritis (n = 2), dementia (n = 2), regular exercise for more than 2 hours per week (n = 1), uncontrolled hypertension (n = 1), inability to stand without a cane (n = 1), and schedule conflict (n = 4). The remaining 28 subjects (22 female and 6 male) were admitted to the study, and were randomly assigned to either the RT or TC group with stratification based on age and gender. All participating subjects were asked to maintain their regular diet, medication, normal daily activities and lifestyle throughout the study. This study was approved by the local Institutional Review Board.

Exercise Intervention

Participants in both RT and TC groups attended three 40-min exercise sessions per week for 24 weeks. Each session consisted of 5 min of warm-up exercise, 30 min of exercise (RT or TC), and 5 min of cool-down exercise. An intervention duration of 24 weeks with 40-min exercise session at the frequency of 3 times per week was reported to be appropriate to evaluate bone turnover response to low-intensity exercise in elderly men and women (Vincent and Braith, 2002). The current low-intensity RT exercise protocol (Ferris *et al.*, 2005) was similar to that of Vincent and Braith (2002) for the elderly, consisting of one set of 10–12 repetitions for bench press, leg press, leg curl, leg extension, and seated row on a resistance exercise machine (Precor S3.21 Strength Multi Station), as well as shoulder press and arm curl exercises using dumbbells. Subjects rested for about one minute between exercises. The exercise intensity was set at 50% of the one repetition maximum, defined as the maximum weight a subject could handle using proper technique, as determined at the beginning of the study. The shoulder press and arm curl were performed using dumbbells. The training sessions were monitored by a certified fitness trainer.

Subjects in the TC group were taught by an experienced TC instructor and practiced the 24-form simplified Yang-style TC (Liang and Wu, 1996), the most popular form of TC among dozens currently being practiced worldwide (Wang *et al.*, 2004). In addition to the 5 min of warm-up and 5 min of cool-down exercise, the routine 24-form simplified Yang-style TC was repeated 5 times during the 30 min training period based on the standard speed of about 6 min per routine (Liang and Wu, 1996). The instructor explained and demonstrated how the exercise should be performed, and subjects followed.

Outcome Measures

Serum BAP activity and PYD concentration were measured with Metra™ BAP and PYD immunoassay kits, respectively (Quidel Corporation, CA). The intra- and inter-assay coefficients of variation (CV) for BAP were 5.2% and 5.0%, and for PYD were 8.0% and 10.4%, respectively. The concentration of serum PTH was measured with Intact PTH-IRMA assay (Nichols Institute Diagnostics, CA). The intra- and inter-assay CV for PTH were 1.8% and 6.1%, respectively. The concentration of 1,25-vit D_3 in serum was measured with 1,25-dihydroxyvitamin D ^{125}I RIA kit (DiaSorin Inc. MN), and the intra- and inter-assay CV were 7.7% and 11.1%, respectively. Serum and urinary Ca, Pi, and creatinine were measured by O-cresolphthalein complex using automated equipment (Dimension-RXL, Dade, Delaware).

Subjects were asked to refrain from caffeine and strenuous physical activity for 24 hours before blood and urine samples collection. All samples were collected at baseline (0 week), 6, 12, and 24 weeks of intervention. Overnight fasting blood samples were collected and serum was separated from blood, and the second morning void urine samples were collected. All samples were aliquoted and stored at −80°C before analysis.

Block Food Frequency Questionnaire

Information of average daily calcium and vitamin D intake of each subject was collected using the Nutrition Checklist developed by the Nutrition Screening Initiative Project of the American Dietetic Association and the American Academy of Family Physicians (Block *et al.*, 1994), and confirmed that all subjects had adequate Ca and vitamin D intake from their diets and/or dietary supplements before and throughout the intervention (see Table 1).

Table 1. Descriptive Variables and Outcome Measures at Baseline

Variables	Resistance Training (n = 14)	Tai Chi (n = 14)	p-value
Age, years, mean ± SD	79.4 ± 2.2	78.8 ± 1.3	0.84
Gender, n (%)			1.00
Male	4 (29%)	3 (21%)	
Female	10 (71%)	11 (79%)	
Weight, kg, mean ± SD	70.2 ± 6.61	69.26 ± 3.57	0.90
Height, cm, mean ± SD	167.22 ± 3.22	163.83 ± 7.20	0.43
Body mass index (kg/m^2)	24.55 ± 1.42	25.69 ± 0.85	0.51
Calcium intake (mg/day)	1450.0 ± 168.0	1425.0 ± 225.0	0.93
Vitamin D intake (IU/day)	352.6 ± 64.2	441.3 ± 98.5	0.45
"How is your general health condition?"			0.38
Good	9 (64%)	11 (79%)	
Satisfactory	5 (36%)	2 (14%)	
Not good	0 (0%)	1 (7%)	
"What is your routine exercise pattern?"			1.00
Never	12 (86%)	12 (86%)	
< 30 min per week	2 (14%)	2 (14%)	
"Do you have a family history of osteoporosis?"			0.12
Yes	3 (21%)	8 (57%)	
No	11 (79%)	6 (43%)	
"Have you ever had a bone fracture?"			0.45
Yes	6 (43%)	9 (64%)	
No	8 (57%)	5 (36%)	
Serum BAP (U/L) ± SEM	25.04 ± 1.99	24.44 ± 2.57	0.86
Serum PYD (nmol/L) ± SEM	2.39 ± 0.39	2.31 ± 0.22	0.87
PTH (pg/ml) ± SEM	58.39 ± 9.79	42.65 ± 4.68	0.17
1,25-vit D_3 (pg/ml) ± SEM	32.78 ± 3.25	29.57 ± 2.56	0.44
Serum Ca (mg/dL) ± SEM	9.00 ± 0.12	8.78 ± 0.09	0.14
Serum Pi (mg/dL) ± SEM	3.83 ± 0.11	3.86 ± 0.11	0.81
Urine Ca (mg/g crt) ± SEM	157.1 ± 37.9	172.3 ± 33.3	0.77
Urine Pi (mg/g crt) ± SEM	636.8 ± 41.4	705.7 ± 90.8	0.49

Note: There were no significant differences between the two groups in any measure.
SD: Standard deviation; SEM: standard error of mean.

Statistical Analysis

Statistical analysis was conducted using SAS version 8.0 (SAS Inc., Cary, NC). Descriptive data were reported as mean ± standard deviation or mean ± standard error of mean for baseline characteristics. A Mann-Whitney Rank Sum test was conducted to compare continuous variables between groups at baseline, while Fisher's exact test was conducted to compare categorical variables between groups at baseline. Each outcome measure was presented as percentage change relative to the baseline ± standard error of the mean. Time, group, and interaction effects for each outcome variable were examined using a 2 (treatment) × 3 (times) mixed, repeated measures analysis of variance (ANOVA) model to determine differences within and between groups over time. Results were considered significant if $p < 0.05$.

Results

Baseline Characteristics

Baseline characteristics by exercise groups are shown in Table 1. There were no significant differences in any baseline status or outcome measures between two groups. There was also no significant difference in dietary Ca and vitamin D intake throughout the 24-week study period within each exercise group or between the two groups.

Attrition and Compliance

Among the 14 subjects in the TC group, 2 dropped out of the study due to family reasons (n = 2). Among the 14 subjects in the RT group, 2 dropped out due to a heart attack at home (n = 1) and loss of interest (n = 1). There was no significant difference in attrition rate between the groups. The TC group had a higher compliance rate (97%, ranging from 89% to 100%) than the RT group (84%, ranging from 65% to 100%). The baseline characteristics of the 4 dropout subjects did not significantly differ from the 24 subjects who completed the trial.

Changes in Bone Biomarkers

Figure 1 shows the concentration changes of bone biomarkers BAP and PYD in both exercise groups. After 6 weeks of intervention, the serum BAP level was significantly higher than baseline in both groups, while the TC group exhibited a significantly greater increase than the RT group (Fig. 1A). The serum BAP at week 12 was significantly lower than week 6 in both groups, and the same was observed at week 24. At week 6, there was a significant increase relative to baseline in serum PYD concentration in the RT group (Fig. 1B), while such increase was insignificant in the TC group ($p = 0.054$). The serum PYD at week 12 was significantly lower than week 6 in both groups. At week 6, the BAP/PYD ratio was significantly higher than the baseline in the TC group (Fig. 1C) ($p = 0.024$), and the increase of the ratio in the TC group was significantly greater than that in the RT group ($p = 0.019$). In the RT group, the ratio was significantly lower than the baseline at week 24 ($p = 0.019$).

Changes in Calcitrophic Hormones

The concentration changes of serum calcitrophic hormones are shown in Fig. 2. There was a significant increase in serum PTH from week 6 to week 12 in the TC group (Fig. 2A). At week 12, the TC group exhibited a significantly greater increase in serum PTH concentration than the RT group. On the other hand, no statistically significant change in serum 1,25-vit D_3 concentration was observed in either group during the entire study period (Fig. 2B).

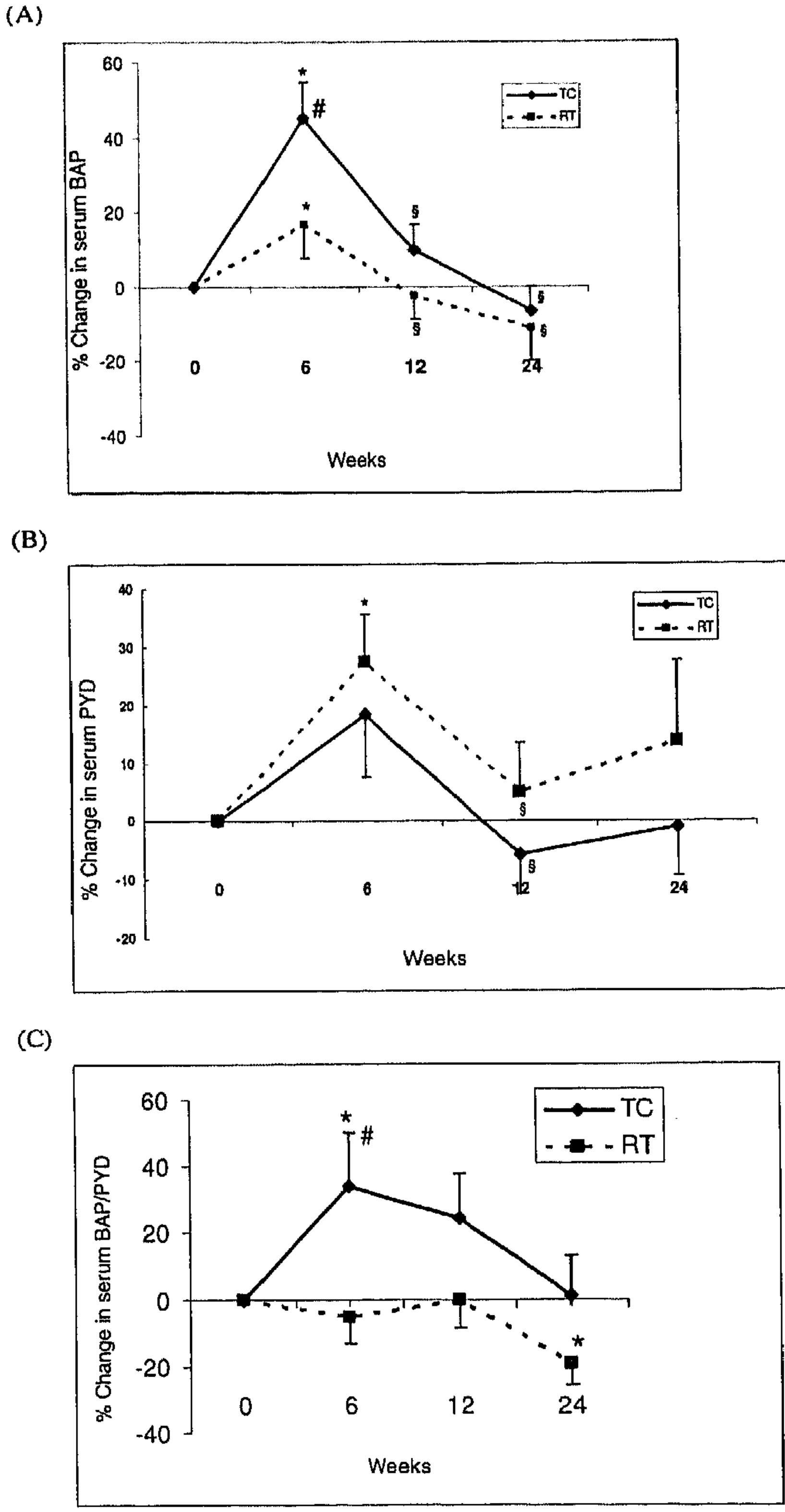

Figure 1. Mean ± standard error of the percentage change relative to baseline for measures of serum BAP (A), serum PYD (B), and serum BAP/PYD ratio (C). BAP = Bone alkaline phosphatase; PYD = pyridinoline; TC = Tai Chi group; RT = resistance training group. *Significantly different from baseline of the same group ($p < 0.05$). #Significantly different between TC and RT groups at a particular time ($p < 0.05$). §Significantly different from week 6 of the same group ($p < 0.05$).

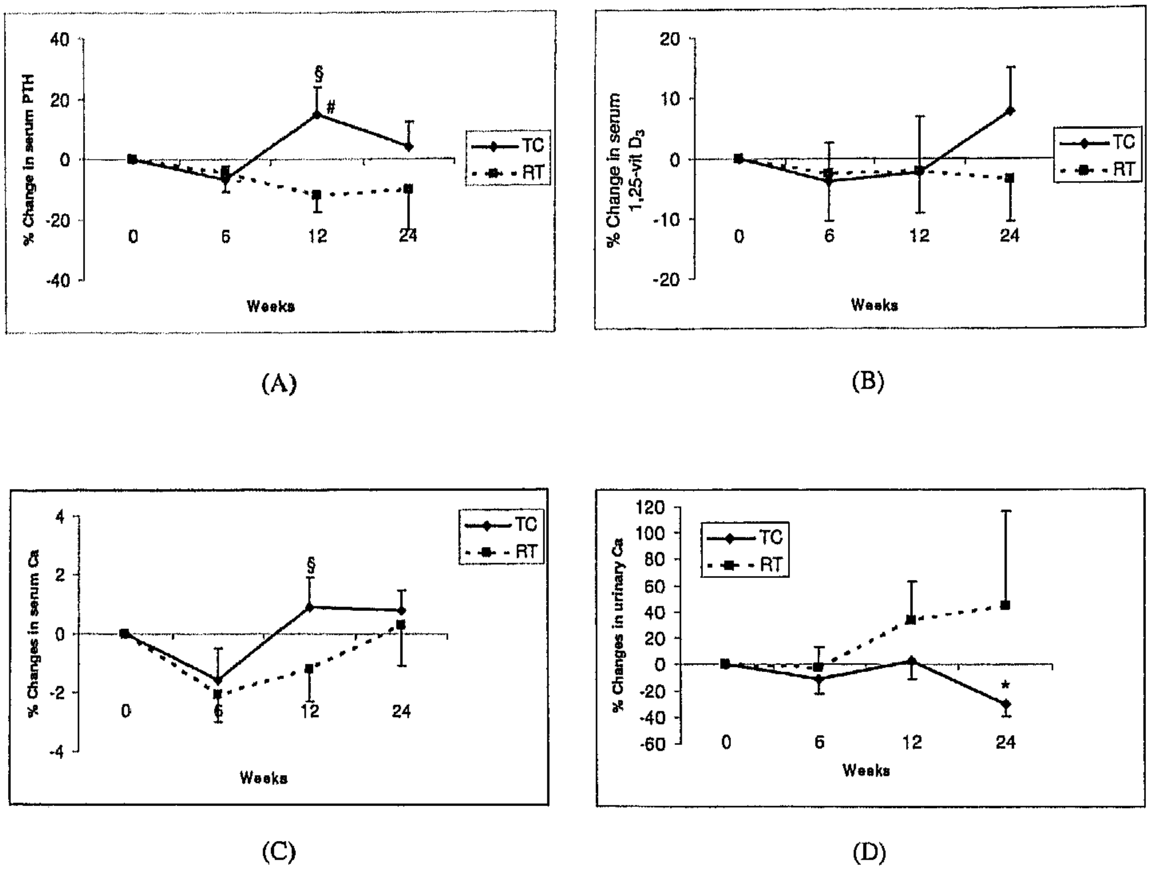

Figure 2. Mean ± standard error of the percentage change relative to baseline for measures of serum PTH (A), serum 1,25-vit D_3 (B), serum Ca (C), and urinary Ca (D). PTH = Parathyroid hormone; 1,25-vit D_3 = 1,25-$(OH)_2$ vitamin D_3; TC = Tai Chi group; RT = resistance training group. *Significantly different from baseline of the same group ($p < 0.05$). #Significantly different between TC and RT groups at a particular time (ps < 0.05). §Significantly different from week 6 of the same group ($p < 0.05$).

Changes in Serum and Urinary Ca and Pi

The serum Ca concentration at week 12 was significantly higher than week 6 in the TC group (Fig. 2C). Compared to the baseline, the urinary Ca concentration at week 24 in the TC group was significantly lower (Fig. 2D). No change in serum or urinary Pi concentration was observed during the entire study period in both groups (data not shown).

Other than the above changes, no interaction (time × exercise effect) was observed for any outcome measure at any time point.

Discussion

This feasibility study is the first longitudinal study to compare the effects of two fundamentally comparable types of exercise, in terms of intensity and weight-bearing, on osteogenic response in the elderly. The results of this study suggest that it is easier for the elderly to adhere to a TC exercise program than RT as the subjects in the TC group had a higher average compliance rate than those in the RT group ($p = 0.003$). This finding is similar to previous studies (Wang *et al.*, 2004; Wu, 2002) which suggested that TC is a feasible alternative exercise for seniors.

The similar changes in osteogenic response (bone biomarkers) in both exercise groups indicated that TC exercise induces a response similar to that of RT. After 6 weeks of intervention, both exercise groups demonstrated higher bone formation rates (indicated by an increase of BAP concentration data, Fig. 1A) as compared to baseline. This finding is similar to that of Menkes *et al.* (1993) who reported that significant increases in both BAP and osteocalcin occurred as a result of RT. The increase in concentrations of bone formation marker BAP may be due to elevated skeletal modeling associated with dynamic loading of exercise. This loading may create streaming potentials within bone and stimulate new bone formation in cross-sectional area (Rubin *et al.*, 1992; Woo *et al.*, 1981). From the bone resorption point of view, the serum PYD concentration in the RT group increased by 27% after 6 weeks and returned to the baseline value after 12 weeks. Returning of the BAP and PYD values to baseline may be related to the reduced activation frequency of new remodeling sites as a result of bone adaptation to exercise after a long intervention period, as observed in previous animal studies (Chambers *et al.*, 1993; Hillam and Skerry, 1995). The findings of the present study agreed with those of Vincent and Braith (2002) who reported that low-intensity RT similar to that employed in the present study had no influence on BAP or PYD after 6 months of intervention.

Measurement of individual markers of osteogenic response is useful in evaluating whether a specific intervention has influenced the rate of bone turnover, and in monitoring the efficacy of a treatment on bone. However, when viewed in isolation, these markers may not indicate whether the increased turnover translates into bone anabolism or catabolism during bone remodeling. On the other hand, the ratio of bone formation to bone resorption (BAP/PYD ratio in this study) has been considered an indicator of the state of bone turnover (Adachi, 1996; Miller *et al.*, 2003). An increase in the BAP/PYD ratio may indicate a state of bone turnover in favor of bone formation, while a decreased ratio may indicate a state in favor of bone resorption (Adachi, 1996; Miller *et al.*, 2003). The findings of the present study indicated a greater increase in BAP/PYD ratio from baseline to week 6 in the TC than the RT group, and a decreased ratio in the RT group but no net change in the TC group after 24 weeks. Bone biomarkers provide useful information concerning bone turnover, particularly in short-term interventions where the time may be too short for BMD to manifest any significant change. However, the relationship between the early change of BAP/PYD ratio and BMD during TC intervention should be investigated in future studies with a larger sample size.

Evidence supports a positive relationship between weight-bearing exercise and bone metabolism in the elderly (Vincent and Braith, 2002; Brahm *et al.*, 1997). One major difference between RT and TC is that RT involves extrinsic weights that may provide greater weight bearing compared with TC which does not involve any additional load other than the body weight. However, the current RT exercise, including chest press, leg press, leg curl, seated row, leg extension, shoulder press, and arm curl, featured sitting and lying positions where partial or total body weight rested on the bench. On the other hand, TC exercise involved shifting body weight so slowly that almost the entire body weight is supported alternately by one of the two legs, creating a significant weight-bearing condition (Kirsteins *et al.*, 1991). This may in part explain the different effects of TC on bone biomarkers when compared to RT, as demonstrated by the present findings. Therefore, the overall challenge to the bone provided by TC may have resulted in a similar osteogenic response as RT in the elderly.

Parathyroid hormone may play a key role in the changes of the bone markers. Elevated PTH produces an increase of bone remodeling and this fact may decrease bone quality. In the present study, the group of Tai Chi had high levels of serum Ca and PTH from week 6 to week 12, followed by a decrease in urinary Ca excretion after 24 weeks; whereas, there was no difference in the concentrations of serum Ca and PTH, and urinary Ca in the present RT group throughout the study period. These results of Tai Chi exercise agreed with previous studies that exercise raised serum concentrations of Ca (Bouassida *et al.*, 2003; Hillam and Skerry, 1995) and PTH (Thorsen *et al.*, 1997; Brahm *et al.*, 1997; Kirsteins *et al.*, 1991), with lowered urinary concentration of Ca (Grimston *et al.*, 1993). The reason why the Tai Chi group resulted in a higher serum PTH than those in the RT group is not clear. We are not able to predict if such transient increases in serum PTH would affect bone quality. Therefore, future studies will be needed to confirm and elaborate our findings from the Tai Chi group.

There is an increasing body of evidence suggesting the importance of oxidative stress in bone metabolism and bone loss (Nohl, 1993; Basu *et al.*, 2001; Isomura *et al.*, 2004; Bai *et al.*, 2004). Lowering the level of oxidative stress is an important strategy to deal with osteoporosis-related bone metabolism or bone loss. According to a recent review, exercise can have positive or negative effects on oxidative stress depending on training load, training specificity and the basal level of training (Finaud *et al.*, 2006). Specifically, it was reported by Goto *et al.* (2003) that high-intensity exercise increases oxidative stress including plasma concentrations of 8-OHdG and serum concentrations of malondialdehyde-modified low-density lipoprotein in humans, whereas moderate exercise tends to decrease both indices of oxidative stress. Tai Chi has been characterized as an exercise of moderate intensity (Lan *et al.*, 2001; 2004). Tai Chi couples muscular activity with an internally directed focus, producing a temporary self-contemplative mental state. Such internal focus is in contrast to conventional body-centered aerobic and muscular fitness exercise in which there is little or no mind component (Chu, 2004).

We recognize there are limitations in the present study. The sample size is relatively small and the changes of bone markers are transient. A longer follow-up study that incorporates measurements of bone mineral density would be advisable to further elucidate the clinical significance.

In conclusion, our feasibility study indicated that subjects in the Tai Chi group had a higher compliance rate than those in the resistance training group. Tai Chi may be an alternative exercise providing greater benefits than resistance training with respect to bone metabolism in the elderly as demonstrated with a lower urinary Ca concentration at the end of study. Further studies using a larger sample size and long-term Tai Chi intervention in which the changes in bone mineral density could be assessed as a clinical outcome are needed to confirm the present findings.

Acknowledgments

This study was supported by Helen Jones Foundation and Carillon Education and Research Center, Lubbock, Texas. We thank all members of the Board, administration, and participating subjects at Carillon Senior Living Campus for their contributions to this study. We also thank Kendra O'Keefe and Kimberly Hale for helping with the RT intervention. We thank Beatrice Perez and Julio Viramontes for helping with blood collection.

References

Adachi, J.D. The correlation of bone mineral density and biochemical markers to fracture risk. *Calcif. Tissue Int.* 59(Suppl I): S16–S19, 1996.

Bai, X.C., D. Lu, J. Bai, H. Zheng, Z. Ke, X. Li and S. Luo. Oxidative stress inhibits osteoblastic differentiation of bone cells by ERK and NF-κB. *Biochem. Biophys. Res. Commun.* 314(1): 197–207, 2004.

Basu, S., K. Michaelsson, H. Olofsson, S. Johansson and H. Melhus. Association between oxidative stress and bone mineral density. *Biochem. Biophys. Res. Commun.* 288: 275–279, 2001.

Brahm, H., K. Piehl-Aulin, B. Saltin and S. Ljunghall. Net fluxes over working thigh of hormones, growth factors and biomarkers of bone metabolism during short lasting dynamic exercise. *Calcif. Tissue Int.* 60(2): 175–180, 1997.

Block, G., L.M. Coyle, A.M. Hartman and S.M. Scoppa. Revision of dietary analysis software for the Health Habits and History Questionnaire. *Am. J. Epidemiol.* 139(12): 1190–1196, 1994.

Bouassida, A., D. Zalleg, M.A. Ajina, N. Gharbi, M. Duclos, J.P. Richalet and Z. Tabka. Parathyroid hormone concentrations during and after two periods of high intensity exercise with and without an intervention recovery period. *Eur. J. Appl. Physiol.* 88: 339–344, 2003.

Chan, K., L. Qin, M. Lau, J. Woo, S. Au, W. Choy, K. Lee and S. Lee. A randomized, prospective study of the effects of Tai Chi Chuan exercise on bone mineral density in postmenopausal women. *Arch. Phys. Med. Rehabil.* 85: 717–722, 2004.

Chambers, T.J., M. Evans, T.N. Gardner, S.A. Turner and J.W. Chow. Induction of bone formation in rat trail vertebrae by mechanical loading. *Bone Mineral.* 20: 167–178, 1993.

Chen, K.M., M. Snyder and K. Krichbaum. Facilitators and barriers to elders' practice of t'ai chi. A mind-body, low-intensity exercise. *J. Holist. Nurs.* 19(3): 238–255, 2001.

Chu, D.A. Tai Chi, Qi Gong and Reiki. *Phys. Med. Rehabil. Clin. N. Am.* 15(4): 773–781, vi. Review, 2004.

Dalsky, G.P., K.S. Stocke, A.A. Ehsani, E. Slatopolsky, W.C. Lee and S.J. Birge Jr. Weight-bearing exercise training and lumbar bone mineral content in postmenopausal women. *Ann. Intern. Med.* 108: 824–828, 1998.

Ferris, L.T., J.S. Williams, C.-L. Shen, K.A. O'Keffe and K.B. Hale. Resistance training improves sleep quality in older adults — a pilot study. *J. Sports Sci. Med.* 4: 354–360, 2005.

Finaud, J., G. Lac and E. Filaire. Oxidative stress-relationship with exercise and training. *Sports Med.* 36(4): 327–358, 2006.

Goto, C., Y. Higashi, M. Kimura, K. Noma, K. Hara, K. Nakagawa, M. Kawamura, K. Chayama, M. Yoshizumi and I. Nara. Effect of different intensities of exercise on endothelium-dependent vasodilation in humans: role of endothelium-dependent nitric oxide and oxidative stress. *Circulation* 108(5): 530–535, 2003.

Grimston, S.K., K.E. Tanguay, C.M. Gundberg and D.A. Hanley. The calciotrophic hormone response to changes in serum calcium during exercise in female long distance runner. *J. Clin. Endocrinol. Metab.* 78: 867–872, 1993.

Hillam, R.A. and T.M. Skerry. Inhibition of bone resorption and stimulation of formation by mechanical loading of the modeling rat ulna *in vivo*. *J. Bone Miner. Res.* 10: 683–689, 1995.

Isomura, H., K. Fujie., K. Shibata, N. Inoue, T. Iizuka, G. Takebe, K. Takahashi, J. Nishihira, H. Izumi and W. Sakamoto. Bone metabolism and oxidative stress in postmenopausal rats with iron overload. *Toxicology* 197(2): 92–99, 2004.

Kirsteins, A.E., F. Dietz and S.M. Hwang. Evaluating the safety and potential use of a weight-bearing exercise, Tai-Chi Chuan, for rheumatoid arthritis patients. *Am. J. Phys. Med. Rehabil.* 70(3): 136–141, 1991.

Lan, C., S.Y. Chen, J.S. Lai and M.K. Wong. Heart rate responses and oxygen consumption during Tai Chi Chuan practice. *Am. J. Chin. Med.* 29(3-4): 403–410, 2001.

Lan, C., S.Y. Chen and J.S. Lai. Relative exercise intensity of Tai Chi Chuan is similar in different ages and gender. *Am. J. Chin. Med.* 32(1): 151–160, 2004.

Liang, S.Y. and W.C. Wu. *Tai Chi Chuan: 24 and 48 Postures with Martial Applications*. YMAA Publication Center, Roslindale, MA, 1996.

Maddalozzo, G.F. and C.M. Snow. High intensity resistance training: effects on bone in older men and women. *Calcif. Tissue Int.* 66(6): 399–404, 2000.

Martin, A.D. and R.G. McCulloch. Bone dynamics: stress, strain and fracture. *J. Sports Sci.* 2: 155–163, 1987.

Menkes, A., S. Mazel, R.A. Redmond, K. Koffler, C.R. Libanati, C.M. Gundberg, T.M. Zizic, J.M. Hagberg, R.E. Pratley and B.F. Hurley. Strength training increases regional bone mineral density and bone remodeling in middle-aged and older men. *J. Appl. Physiol.* 74(5): 2478–2484, 1993.

Miller, L.J. 3rd, C.S. Crowson, W.M. O'Fallon, H.W. Wahner and B.L. Riggs. Relative contributions of bone density, bone turnover, and clinical risk factors to long-tern fracture prediction. *J. Bone Miner. Res.* 18(2): 312–318, 2003.

National Institutes of Health. *Osteoporosis Prevention, Diagnosis, and Therapy*. NIH Consensus Statement Online 27–29 March 2000, Vol. 17, pp. 1–36.

Nohl, H. Involvement of free radicals in ageing: a consequence or cause of senescence. *Br. Med. Bull* 49(3): 653–667, 1993.

Nowalk, M.P., J.M. Prendergast, C.M. Bayles, F.J. D'Amico and G.C. Colvin. A randomized trial of exercise programs among older individuals living in two long-term care facilities: the FallsFREE program. *J. Am. Geriatr. Soc.* 49(7): 859–865, 2001.

Pruitt, L.A., D.R. Taaffe and R. Marcus. Effects of a one-year high-intensity versus low-intensity resistance training program on bone mineral density in older women. *J. Bone Miner. Res.* 10: 1788–1795, 1995.

Qin, L., S. Au, W. Choy, P. Leung, M. Neff, K. Lee, M. Lau, J. Woo and K. Chan. Regular Tai Chi Chuan exercise may retard bone loss in postmenopausal women: a case-control study. *Arch. Phys. Med. Rehabil.* 83(10): 1355–1359, 2002.

Qin, L., W. Choy, K. Leung, P.C. Leung, S. Au, W. Hung, M. Dambacher and K. Chan. Beneficial effects of regular Tai Chi exercise on musculoskeletal system. *J. Bone Miner. Metab.* 23(2): 186–190, 2005.

Rubin, C.T. and L.E. Lanyon. Regulation of bone formation by applied dynamic loads. *J. Bone Joint Surg. Am.* 3: 397–402, 1984.

Rubin, C.T., S.D. Brain and K.J. McLeod. Suppression of the osteogenic response in the aging skeleton. *Calcif. Tissue Int.* 50: 306–313, 1992.

Thomas, G.N., A.W. Hong, B. Tomlinson, E. Lau, C.W. Lam, J.E. Sanderson and J. Woo. Effects of Tai Chi and resistance training on cardiovascular risk factors in elderly Chinese subjects: a 12-month longitudinal, randomized, controlled intervention study. *Clin. Endocrinol. (Oxf.)* 63(6): 663–669, 2005.

Thorsen, K., A. Kristoffersson, J. Hultdin and R. Lorentzon. Effect of moderate endurance exercise on calcium, parathyroid hormone, and markers of bone metabolism in young women. *Calcif. Tissue Int.* 60: 16–20, 1997.

Vincent, K.R. and R.W. Braith. Resistance exercise and bone turnover in elderly men and women. *Med. Sci. Sports Exerc.* 34(1): 17–23, 2002.

Wang, C., J.P. Collet and J. Lau. The effect of Tai Chi on health outcomes in patients with chronic conditions. *Arch. Intern. Med.* 164: 493–501, 2004.

Wolfson, L., R. Whipple, C. Derby, J. Judge, M. King, P. Amerman, J. Schmidt and D. Smyers. Balance and strength training in older adults: intervention gains and Tai Chi maintenance. *J. Am. Geriatr. Soc.* 44(5): 498–506, 1996.

Wu, G. Evaluation of the effectiveness of Tai Chi for improving balance and preventing falls in the older population — a review. *J. Am. Geriatr. Soc.* 50: 746–754, 2002.

Woo, S.L., S.C. Kuei, D. Ameil, M.A. Gomez, W.C. Hayes, F.C. White and W.H. Akeson. The effect of prolonged physical training on the properties of long bone: a study of Wolff's law. *J. Bone Joint Surg.* 63A: 780–786, 1981.