

1 Title page

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3 Effective Brief, Low-impact, High-intensity Osteogenic Loading in Postmenopausal
4 Osteoporosis

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14 Short running head:

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16 Osteostrong® use in Osteoporosis

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18 **Abstract**

19 Background: Osteoporosis is characterized by reduced bone mineral density

20 (BMD) and disrupted microarchitecture estimated by trabecular bone score (TBS),

21 resulting in increased bone fracture risk. "Osteostromg[®]" is a bone-strengthening

22 system implementing 4 devices and incorporating brief (10-minute), weekly, low-

1 impact, and high-intensity osteogenic loading exercises. We evaluated the efficacy
2 of the Osteostrong® intervention in postmenopausal osteoporotic women.

3 Methods and Subjects:

4 147 postmenopausal osteoporotic women were separated into two groups: Group
5 A comprised 74 women receiving Osteostrong® intervention (mean age 58.8 years,
6 56.6-61 years 95% CI), and was subdivided into G1 receiving no antiresorptive
7 medication, and G2 on such medication. Group B comprised 73 women that
8 received no Osteostrong® intervention (mean age 61.8 years, 59.4-64.1 95% CI)
9 and was subdivided into G3 on no antiresorptive therapy, and G4 on such
10 treatment. All participants underwent a physical examination and had an
11 assessment for secondary osteoporosis. Dual-energy X-ray absorptiometry (DXA)
12 examinations (Horizon W [S/N 300472M]) were performed at the time of trial
13 inclusion and 12 months later.

14 Results: Statistically significant increases were observed in the following
15 parameters: i) BMD of the lumbar spine (L1-L4) in G1($p=0.0039$), G2($p<0.001$),
16 and G4($p=0.0059$): ii) TBS in G2($p=0.0078$): iii) BMD of the right femoral neck in
17 G1($p=0.0382$) and G4($p=0.032$): iv) BMD of the left femoral neck G2($p=0.0089$)
18 and in G4($p=0.0498$) and total femur in G2($p=0.0162$).

19 Conclusions: Osteostrong® improved BMD of the lumbar spine in women with
20 osteoporosis both off and on antiresorptive treatment. Furthermore, Osteostrong®
21 enhanced the effect of antiresorptive therapy on BMD and TBS of the spine, hip
22 and femoral neck.

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3 **Introduction**

4 At the dawn of the 21st century, health and wellness-directed measures in Western
5 civilization seem to have successfully addressed many problems of everyday life.

6 Nevertheless, an increased fracture risk state, known as osteoporosis, which is
7 characterized by decreased bone mineral density (BMD) and disrupted
8 microarchitecture due to various factors, remains a global health burden. The
9 endpoint of osteoporosis is the low-energy fracture, and pain, immobilization, and
10 disability, in general, remain some of the main reasons for drug development and
11 research on alternative methods to delay or postpone their incidence. Expected
12 fragility fractures per year rise to 4.5 million in the European Union and 1.5 million
13 in the USA, at a 12- to 18-billion-dollar expense for the healthcare systems with a
14 previous report projecting even higher costs in the years to come (1, 2). Almost $\frac{3}{4}$
15 of these fractures affect postmenopausal women. This makes the prevention of
16 osteoporotic fractures a global priority for healthcare systems.

17 Apart from dual-energy x-ray absorptiometry (DXA), which is currently considered
18 the gold standard for evaluating BMD, measurement of the trabecular bone score
19 (TBS) that consists of a grey-level textural measurement, which is typically
20 obtained from conventional lumbar spine DXA- BMD images, serves as a validated
21 index of bone microarchitecture that is correlated with the mechanical properties
22 of bone (3). TBS has been added to the already established methods of fracture
23 risk assessment tool (FRAX) and BMD for predicting fracture risk (3).

1 Despite the plethora of drugs used to delay and/or treat osteoporosis, very few
2 non-pharmaceutical methods have been tested and even fewer have succeeded.
3 Until recently, the treatment of osteoporosis in the setting of bone fractures,
4 especially those of the lumbar spine level, consisted of pharmacotherapy, surgery,
5 and the avoidance of everyday exercise, with controversial results. The literature
6 describes non-pharmaceutical methods to reduce fracture risk due to osteoporosis
7 as traditional, complementary, and integrative medicine (4). Patients often use
8 these methods without informing their physicians, making it even more difficult to
9 evaluate the possible protective effects of these practices against osteoporosis (4).
10 Among these proposed methods, supplementation of calcium and vitamin D along
11 with exercise remains the most often recommended modality for osteoporosis
12 prevention according to worldwide clinical practice guidelines, although specific
13 parameters of exercise are not defined (4-6).

14 There is substantial patient interest in non-pharmacologic approaches to treating
15 or preventing osteoporosis and Osteostrom[®] is one such intervention, whose
16 efficiency, however, has not been evaluated in clinical trial yet. Interestingly,
17 suggestions for exercise to strengthen the musculoskeletal system and to increase
18 balance have been provided in recent treatment guidelines for osteoporosis and
19 fracture prevention, without specific instructions for the duration, extension, type of
20 exercise, and other important parameters (7, 8).

21 Osteogenic loading is based on Wolff's law suggesting that a healthy animal's bone
22 will adjust to the forces applied to it (9). The internal structure of trabeculae
23 experiences adaptive alterations, which are subsequently followed by secondary
24 adjustments to the external cortical part of the bone. This process could result in

1 the thickening of the bone. Conversely, when the load on a bone is reduced, the
2 bone experiences a decrease in density and strength due to the absence of the
3 necessary stimulus required for continuous remodeling (10-12). Osteostrong[®], a
4 brief, low-impact, and high-intensity osteogenic loading training modality with
5 once-weekly, 10-minute sessions, using patented devices, known as “Spectrum”,
6 is described below. Although several people have used the Osteostrong[®]
7 intervention with reportedly beneficial effects on bone density, the method has
8 been less studied for its efficacy in improving bone density and quality in subjects
9 with osteopenia or osteoporosis.

10 **Methods and Study Population**

11 **Osteostrong[®] Method**

12 Osteostrong[®] consists of a series of brief, 10-min total, weekly exercises of
13 osteogenic loading tailored specifically for every person to ameliorate
14 osteoporosis. This exercise is facilitated using four different apparatuses and is
15 characterized by low impact but high intensity, making it more attractive for patients
16 to adhere to and to avoid possible risks of lumbar or other injury, especially for the
17 elderly and individuals with more severe osteoporosis. This equipment applies a
18 certain dosage of force specific to the participants’ multiples of bodyweight (MOB),
19 allowing for an increased likelihood of osteogenesis. Spectrum devices emulate
20 these forces in a safe and controlled environment. Designed to enable users to
21 assume optimal leverage positions, each device allows high-force application in
22 static postures, aiming to achieve bone-strengthening impact without actual high-
23 impact activity, taking advantage of the individual’s physiological strength limit
24 preventing injury. The four Spectrum devices are based on Growth Trigger (GT),

1 indicating each device's objective to facilitate bone adaptation (Upper GT, Lower
2 GT, Postural GT, and Core GT), each focusing on distinct regions of the
3 musculoskeletal system. The Upper GT targets the kinetic chain from hands to
4 clavicle; the Lower GT from feet to hip; the Postural GT from feet to neck; finally,
5 the Core GT focuses on the rib cage. Moreover, the Osteostrom[®] intervention
6 program includes falls prevention and balance training, with a focus on posture,
7 stability, mobility, and coordination.

8 **Study Population**

9 A total of 147 postmenopausal women with osteoporosis of the lumbar spine and/or
10 femoral neck or total hip, who were followed at and recruited from the Unit on
11 Clinical and Translational Research in Endocrinology, National and Kapodistrian
12 University of Athens, Greece, were enrolled. All participants were Caucasian adults
13 of Greek origin. A consent form was obtained from all the participants. Inclusion
14 criteria were female gender, menopause that presented either early or at the
15 expected age, osteoporosis measured by DXA in either lumbar spine and/or hip.
16 Exclusion criteria were secondary osteoporosis and recent bone fracture. Patients
17 were assigned to the various treatment groups according to their status and
18 preference, after they had been informed about the Osteostrom[®] intervention.
19 Patients were divided into two groups. Group A included 74 women treated with
20 Osteostrom[®] (mean age: 58.8y, 95%CI 56.6-61); Group A was subdivided into G1,
21 which included women who had no parallel antiresorptive treatment, and G2, which
22 included women who were treated in parallel with either oral bisphosphonates or
23 denosumab. Group B included 73 women who had no Osteostrom[®] intervention
24 (mean age 61.8y, 95%CI 59.4-64.1). Group B was subdivided into G3, which

1 included women who did not receive antiresorptive treatment, and G4, which
2 included women who were treated with such medication. Data regarding BMI and
3 age are shown in Table 1. None of the patients from either groups G1 or G3 had
4 previous antiresorptive treatment. Regarding groups G2 & G4, for detailed
5 information, see the supplementary Table S1 (13). In groups G2 and G4,
6 Denosumab, alendronate and risendronate were the antiresorptive drugs used. All
7 patients received 1200 mg calcium and Vitamin D supplementation as required.

8 All participants underwent a complete physical examination and an assessment
9 for exclusion of secondary osteoporosis. Details from medical history, such as
10 uptake of glucocorticoids or previous fragility bone fracture were retrieved, and
11 laboratory tests to exclude primary hyperparathyroidism, connective tissue
12 disorders, hypercortisolism, Vitamin D insufficiency or other conditions, such as
13 sarcoidosis or blood malignancy, were conducted. DXA examination [Horizon W
14 (S/N 130472M)] twice, at the time of inclusion in the trial and 12 months later, was
15 performed. Bone markers [C-terminal telopeptide of type I collagen (CTX-I) and N-
16 terminal propeptide of type I procollagen (PINP)] were examined after the
17 intervention in groups G1 and G2. Statistical analysis was performed using the
18 freeware R (4.2.2) and examined during the study period for significant mean
19 differences in the recorded response variables.

20 **Results**

21 The main adverse event that was feared by the participants and closely monitored
22 by the Osteostrom® facility personnel was a new bone fracture at any site and/or
23 a muscle or tendon trauma during the procedure. None of these events occurred
24 to any participant. In total, 13 patients experienced joint pain, and 3 patients

1 dropped out from the study because of it. BMD measurements at baseline and 12
2 months later are shown in Table 2. Paired Student t-test of all the parameters
3 before and after the Osteostrom® intervention showed the following: a statistically
4 significant increase in T-score (L1-L4) and BMD of the lumbar spine (L1-L4) in
5 groups G1 (n=50, % of positive differences (End-Start) = 72 %, Mean difference
6 0.245, p<0.001) and (n=48, % of positive differences (End-Start): 56.2%,
7 p<0.0039) respectively, G2 (n=21, % of positive differences (End-Start) = 85.7%,
8 p<0.001) and (n=21, % of positive differences (End-Start) = 76.2%, p<0.001)
9 respectively, and G4 (n=25, % of positive differences (End-Start) = 72%, p=0.0024)
10 and (n=26, % of positive differences (End-Start) = 65.4%, p=0.0059), respectively.
11 A statistically significant increase in T-score (TBS), as well as TBS, was found in
12 the G2 group (n=18, % of positive differences (End-Start) = 66.7%, p=0.0025) and
13 (n=20, % of positive differences (End-Start) = 60%, p=0.0078), respectively. A
14 statistically significant increase in T-score and BMD of the right femoral neck BMD
15 was shown in G1 group (n=44, % of positive differences (End-Start) = 47.7%,
16 p=0.0496) and (n=44, % of positive differences (End-Start) = 47.7%, p=0.0382),
17 respectively. A statistically significant increase in T-score and BMD of the Left
18 femoral neck was shown in G2 group (n=22, % of positive differences (End-Start)
19 = 54.5%, p=0.0152) and (n=22, % of positive differences (End-Start) = 63.6%,
20 p=0.0089) respectively. A statistically significant increase in T-score and BMD of
21 the Left femur total was shown in G2 group (n=22, % of positive differences (End-
22 Start) = 54.5, p=0.0162) and (n=21, % of positive differences (End-Start) = 66.7%,
23 p=0.0304), respectively, and G4 but only regarding BMD (n=27, % of positive
24 differences (End-Start) = 70.4%, p=0.0498). All data are shown in Figure 1 and
25 Table 2. Regression analysis regarding age and BMI was assessed, but no

1 statistically significant results were observed, Table S2 (13). For G2 and G4
2 patients receiving Denosumab, a regression analysis regarding TBS changes was
3 performed, but although a trend for increased TBS was observed, it was not
4 statistically significant (Table S3, Figure S1)(13) . For G3 patients who received
5 neither Osteostromg[®] intervention nor antiresorptive treatment a slight deterioration
6 was seen in all parameters but none of them was statistically significant. No
7 statistically significant correlations were found in either P1NP or CTX-1 levels and
8 BMD changes, in any of the groups.

9 **Discussion**

10 This is the first study that clearly demonstrates benefit from Osteostromg[®]
11 intervention in postmenopausal women. A significant improvement in BMD and T-
12 score in the lumbar spine in subjects who had an Osteostromg[®] intervention
13 regardless of antiresorptive medication was found. Additionally, the TBS of the
14 spine was significantly improved in the group that received the combination of
15 Osteostromg[®] intervention and anti-osteoporotic medication. Moreover, BMD and
16 T-score of the femoral neck and hip in both left and right side improved significantly
17 in subjects who had an Osteostromg[®] intervention and furthermore in those who
18 also had anti-osteoporotic treatment. As expected, patients without any
19 pharmaceutical or training intervention showed a slight, non-significant decline in
20 all mentioned bone parameters.

21 Osteoporosis reflects the risk of bone fracture, often resulting in pain, surgery, and
22 complications owing to prolonged hospitalization and workforce loss. Osteoporosis
23 is a global socioeconomic burden that affects millions of people and is associated
24 with a low quality of life. Despite the administration of numerous treatment

1 modalities over the years, no nonpharmacological approach has demonstrated
2 satisfactory results.

3 Literature has extensively discussed various exercise modalities and their effects
4 on bone mass and, eventually, osteoporosis. The notion of a “mechanostat” on
5 bone was introduced by Wolff and then described in detail by Frost (9-12). The
6 idea of a bone sensor that responds positively to external forces through muscle
7 training, resulting in improved thickness and microarchitecture has been
8 compelling but never shown in a clinical trial. This is the first time that the
9 administration of training in a calculated and individually tailored manner has
10 shown a positive effect on the density of the bone marrow of the spine. The lack of
11 contraindications to this treatment modality, as it does not interfere with any other
12 medication, makes it more attractive irrespectively of age, socioeconomic status,
13 and comorbidities, resulting in strong adherence to an exercise plan.

14 Earlier studies have shown a positive effect of low-load, high-repetition resistance
15 exercise on the lumbar spine BMD of otherwise healthy postmenopausal women
16 compared to controls who did not exercise (14). Although the beneficial effect of
17 progressive resistance training on the lumbar spine was not indicated in any of the
18 literature reviews (15), perhaps because of the large variation in the studies
19 included, the approach of low-intensity, high-repetitive exercise tends to be
20 abandoned as more recent evidence emerges. Alternative methods of training,
21 such as Tai Chi Chuan, have also shown beneficial effects on lumbar spine BMD
22 (16), but availability is certainly an issue. In men with osteopenia, High-intensity
23 resistance, and impact training (HiRIT) has shown a beneficial effect on bone
24 geometry and strength in the femoral neck compared to isometric training based

1 on machines (17). Similarly, stable values for lumbar spine BMD after 12 months
2 of high-intensity exercise were shown in men with osteosarcopenia according to
3 the Franconian Osteopenia and Sarcopenia Trial (FrOST) (18).

4 Previous studies have shown that osteogenic loading positively affects spinal
5 osteoporosis. HiRIT has been assessed previously in postmenopausal women
6 with encouraging results (17-23). Additionally, the high-intensity exercise
7 implemented not only did not cause extra-vertebral fractures but also improved
8 thoracic kyphosis in this group of patients (17, 20, 22). Moreover, HiRIT was
9 associated with greater improvement in BMD of the lumbar spine of osteoporotic
10 postmenopausal women compared with medium-intensity resistance and impact
11 training (MiRIT), thus diminishing the fear of new fractures in this sensitive
12 population, despite the small number of clinical trials evaluating HiRIT (23-26).

13 According to the Preferred Reporting Items for Systematic Reviews and Meta-
14 Analyses (PRISMA) statement (27), literature reviews based on (a) controlled
15 trials, (b) isolated DRT with at least one exercise and one control group, (c)
16 intervention durations ≥ 6 months, (d) BMD assessments at the lumbar spine or
17 proximal femur, and (e) cohorts of postmenopausal women, revealed that once-
18 weekly exercise benefitted postmenopausal women with osteoporosis in
19 comparison to more frequent exercise concerning lumbar spine BMD, and was the
20 sole parameter that could be suggested regarding the modus of exercise (25, 26,
21 28-30). Similar positive results for lumbar spine BMD after high-intensity exercise
22 were reported in another review further supporting this argument (31). Moreover,
23 positive effects of high-intensity exercise on lumbar spine BMD in postmenopausal
24 women with osteopenia or osteoporosis were also shown in the ACTLIFE-RCT trial

1 (32). Nevertheless, it is difficult to address all parameters needed for optimal
2 outcomes through exercise. Even when classified according to the type of exercise
3 (weight-bearing, dynamic resistance, and mixed interventions), no clear
4 differences were observed, as all were beneficial for the lumbar spine BMD of
5 postmenopausal women (29). A recent review and meta-analysis isolated 14 of
6 780 studies concerning the mode (resistance only vs. combined resistance and
7 weight-bearing exercises), frequency, volume, load, and program length (33). It
8 was shown that increases in BMD were favored by combined resistance and
9 weight-bearing exercises, lower volumes, and higher loads, although lumbar spine
10 BMD did not benefit from current resistance exercise programs, leaving room for
11 improvement in this domain (33). To address the difficult aspects of the optimal
12 resistance training modality, a new trial is currently underway (34).

13 The beneficial effect of progressive resistance training with specifically tailored,
14 multicomponent exercise programs, along with other health adjustments for
15 balance and nutrition, have been recommended for the management of patients
16 with osteoporosis. Implementation of these encouraging results fueled the recent
17 UK guidelines. Resistance and impact training is recommended for patients with
18 osteoporosis; however, it is clearly stated that the benefit of physical activity often
19 outweighs the risk of harm (28). Nevertheless, a more careful approach regarding
20 the intensity of exercise was adopted because of the lack of evidence of the
21 beneficial effect of high- vs. moderate-intensity training.

22 Exercise recommendation for osteoporosis is often a sensitive matter, especially
23 in the lumbar spine, as the incorrect application of force by the individual may result
24 in new fractures, causing more pain and disability. Osteostrom[®], which consists of

1 a series of brief, 10-min, weekly exercises of osteogenic loading tailored
2 specifically for every person to ameliorate osteoporosis, showed opposite results.
3 It was well-tolerated by patients of different ages and socioeconomic levels who
4 followed this program for an entire year. Additionally, despite the intensity of the
5 exercise, no adverse events such as new fractures, muscle trauma, or other
6 injuries were reported, thus enhancing patient commitment to the exercise
7 program. This exercise is facilitated using four different apparatuses and is
8 characterized by low impact but high intensity, making it more attractive for patients
9 to adhere to and avoid possible risks of lumbar injury, especially for the elderly and
10 individuals with more severe osteoporosis. A previous pilot study on just one
11 subject, who was an astronaut, of weekly 15-min exercise for 6 months showed an
12 increase in body strength but no other osteoporosis parameters, perhaps due to
13 the short period of assessment (35, 36).

14 Similar results were reported from another group, as HiRIT showed a beneficial
15 effect in total hip, femoral neck volumetric and geometric section modules in
16 comparison to a low intensity Pilates based exercise (LiPBE). This effect was
17 further augmented in patients that received antiresorptive treatment in addition to
18 HiRIT (24).

19 The beneficial results of exercise in diminishing fracture risk, the main endpoint of
20 all anti-osteoporotic interventions, was observed in a retrospective, observational
21 study of men (37). This study demonstrated that vigorous but not moderate
22 exercise resulted in a decreased hazard ratio for fracture risk in life-long athletes,
23 and this effect was progressively more evident with passing years. These results

1 encourage the future application of Osteostrom® principles in other groups of
2 individuals vulnerable for osteopenia or osteoporosis.

3 Our study had some limitations. Not all patients who were asked to take part in the
4 study accepted to participate with various explanations (difficult to adhere to the
5 weekly appointments due to long distance, work schedule, lack of time, other
6 responsibilities, fear of trauma). Also, inadvertently, some serum parameters, such
7 as CTX and NTX concentrations, were not obtained. Furthermore, some patients
8 failed to follow-through and remain in the study during the entire year of treatment.

9 On the other hand, the study had certain advantages. The patients were recruited
10 from both the public and private medical sector, thus reflecting a socioeconomically
11 balanced group. Measurements of BMD and TBS were performed in the same
12 DXA machine in all patients, decreasing the variability and increasing the validity
13 of the results. Furthermore, the patients were referred from the entire Athens
14 metropolitan area to the same principal investigators, who screened and evaluated
15 all the participants in the study, using a similar approach.

16 In conclusion, the study demonstrated that the Osteostrom® intervention is a safe,
17 brief method with a significant positive impact on the BMD and TBS of the lumbar
18 spine, hip and femoral neck, in women with postmenopausal osteoporosis. The
19 study suggests that Osteogenic loading has an additive/synergistic effect with anti-
20 osteoporotic medication, augmenting the latter's efficacy and resulting in improved
21 bone strength and quality, and, hopefully, a reduced risk of bone fractures.

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5 **Data Availability Statement**

6 The authors confirm that the data supporting the findings of this study are available
7 within the article and supplementary materials (13) and can be available upon
8 request.

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7

8 **Table 1: BMI and age in the different subgroups.**

9

	G1		G2		G3		G4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
age	57.71	7.86	61.05	12.07	58.78	9.83	64.38	9.36
BMI	24.08	4.71	22.84	2.22	25.42	4.28	25.07	4.02

10

11 **Table 2: Statistics in parameters measured at baseline and 12 months later.**

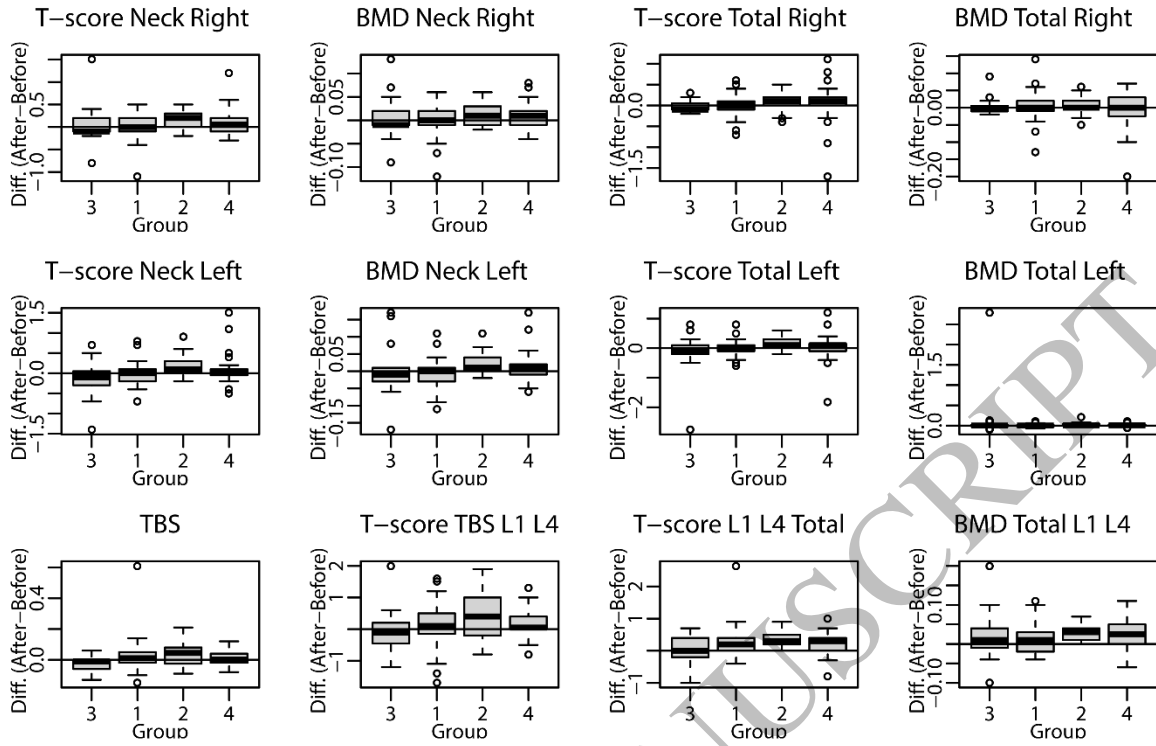
Parameters	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	G1		G2		G3		G4	
BMD L1-L4 (start)	0,812	0,08771	0,768	0,1032	0,87	0,1074	0,832	0,1556
BMD L1-L4 (end)	0,821	0,08737	0,8	0,104	0,856	0,1144	0,84	0,1209
BMD NECK LEFT (start)	0,64	0,07427	0,6	0,06343	0,655	0,08191	0,608	0,08176

BMD NECK LEFT (end)	0,636	0,07025	0,621	0,06817	0,682	0,1016	0,612	0,08575
BMD NECK RIGHT (start)	0,64	0,07152	0,6	0,06495	0,664	0,08356	17,779	101,4818
BMD NECK RIGHT (end)	0,645	0,06874	0,611	0,06537	0,683	0,09976	0,633	0,08424
BMD TOTAL LEFT (start)	0,752	0,0842	0,708	0,07276	0,685	0,515	0,744	0,08974
BMD TOTAL LEFT (end)	0,752	0,07694	0,739	0,05876	0,79	0,1096	0,745	0,1048
BMD TOTAL RIGHT (start)	0,757	0,0769	0,724	0,06329	0,77	0,09892	0,749	0,08316
BMD TOTAL RIGHT (start)	0,757	0,07789	0,736	0,07131	0,778	0,09414	0,74	0,09188
TBS (start)	1,235	0,09561	1,18	0,1228	1,277	0,08472	1,221	0,09591
TBS end	1,254	0,1298	1,218	0,09899	1,242	0,1246	1,212	0,07276
vitamin d(ng/ml) (end)	32,834	8,2531	33,218	6,3648	28,623	8,8252	33,242	7,7111
vitamin d (ng/ml) (start)	27,846	8,127	29,541	7,5346	27,53	9,5668	40,453	46,5642
BMI	24,08	4,7143	22,836	2,2203	25,418	4,2792	25,068	4,0199
PINP (ng/ml) (end)	48,32	19,41	23,71	13,06	69,1	36,2	21,40	19,94
CTX-1(ng/ml) (end)	0,57	0,26	0,55	0,49	0,77	0,24	0,32	0,02

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Figure 1
162x104 mm (DPI)