



Research Article

A Potent Calcium Dietary Consumption Improves Bone Mineral Density in Asian Older Adults

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Abstract

Osteoporosis is a long-term bone disease that causes a gradual loss of bone density and increases the risk of bone fractures. The Asia Pacific region shows a higher prevalence of osteoporosis and associated fractures. Increasing calcium uptake is a well-known method to improve bone health. We took a potent calcium carbonate (Sigma Anti-bonding Molecule Calcium Carbonate, SAC). This clinical investigation evaluates the impact of a potent calcium carbonate supplement on Bone Mineral Density (BMD) in an Asian cohort. A total of 82 participants were enrolled/stratified into three groups based on T-score: normal (n=18), osteopenia (n=31), and osteoporosis (n=33). T-scores, BMD, and speed of sound (SOS) were measured at baseline and following ~eight months of SAC intervention. All measurements were conducted at the distal radius, a clinically relevant site for assessing peripheral bone density.

After intervention, T-scores improved significantly (from -2.0 to -0.85, $p < 0.0001$) along with increased BMD (from 0.95 to 1.10 g/cm², $p < 0.0001$) across all ages and genders. SAC treatment also significantly increased SOS values from 3,946 to 4,079 ($p < 0.0001$). 65% of osteopenia participants (20/31) improved to normal after treatment, while 64% of osteoporosis participants (21/33) moved to osteopenia. Remarkably, 12% of baseline osteoporosis participants (4/33) transitioned into the normal bone density range. We found that a dietary supplement of potent calcium, SAC, leads to significant improvements in bone health in Asian individuals, a population with higher susceptibility to osteoporosis. These results suggest that SAC may be a useful option to attenuate osteoporosis.

Keywords: Osteoporosis; Osteopenia; Bone mineral density; Sigma Anti-bonding Molecule Calcium Carbonate (SAC)

Introduction

Osteoporosis is a chronic skeletal disorder defined by reduced bone mass and microarchitectural deterioration, which increases bone fragility and fracture risk [1]. Fractures due to osteoporosis are a major source of morbidity and mortality in older adults, imposing a substantial socioeconomic burden worldwide [2]. As the most common metabolic bone disease, osteoporosis is progressive and associated with pain, disability, and loss of independence [3,4]. Large population-based studies have shown excess mortality in individuals with osteoporosis compared with the general population, even when treated, partly due to fracture-related complications [5].

The prevalence of osteoporosis is rising with global population aging. It affects ~10% of the general population and up to 30% of post-menopausal women [6]. In Asia and other high-income regions, including Japan, South Korea, Taiwan, Singapore, and Australia, the burden of osteoporotic fractures is particularly significant [7]. Racial and ethnic differences are evident; for example, Asian adults often have lower bone mineral density (BMD) than White counterparts, largely due to differences in skeletal size and body composition [8,9].

Pharmacological therapies, particularly bisphosphonates, are widely prescribed for patients at high fracture risk. Meta-analyses confirm that bisphosphonates reduce overall fracture incidence (odds ratio 0.62, $p < 0.001$). Among several medication options, bisphosphonates are frequently prescribed as first-line therapy for patients with high fracture risk [10,11]. However, these agents do not fully halt disease progression, and residual fracture risk remains high. Adjunctive calcium and vitamin D supplementation are often

recommended, although the optimal regimen remains uncertain [12]. Consequently, more effective and targeted treatment options for osteoporosis are urgently needed. Additionally, research results showed that even if osteoporosis is treated, the mortality rate and fractures still increase [5,13].

Calcium carbonate is a common supplement derived from natural sources such as oyster shell. Sigma Anti-Bonding Molecule Calcium Carbonate (SAC) is a modified form with weakened sigma anti-bonding, yielding higher bioavailability than conventional calcium carbonate [14]. In animal studies, SAC improved bone density by modulating osteocalcin, collagen, and mineral deposition without adverse effects [15]. Despite promising preclinical evidence, its efficacy in humans has not been evaluated. This study aimed to assess the effect of SAC supplementation on bone mineral density in an Asian population.

Materials and Methods

Study Design and Participants

This retrospective study was conducted at a medical clinic in Vancouver, Canada. Participants were recruited through newspapers, social media, and word-of-mouth advertisements. Participants received 7.6 mg SAC daily, administered as 5 ml of solution diluted in 500 ml of water per 70 kg body weight, taken twice daily on an empty stomach or between meals. Individuals were excluded if they had: 1) received osteoporosis treatment within the past year; 2) significant hepatic impairment (cirrhosis, active hepatitis); 3) impaired renal function or history of kidney/urinary stones; 4) inability to perform light exercise or maintain regular meals; 5) secondary osteoporosis requiring other treatments. After providing written informed consent, all participants underwent baseline bone density assessment using ultrasound and were prescribed SAC. The protocol was approved by the Institutional

Review Board (Protocol no. MCC23681).

Bone Density Measurement

Bone density was assessed with a portable ultrasound device (BeamMed™ MiniOmni™). Daily calibration was performed using a standard block. Measurements were taken from the distal radius with the participant seated and forearm resting on the device [16].

Data Processing and Transformation

Ultrasound-derived speed of sound (SOS) values were converted to BMD and T-scores using Asian population reference standards from the World Health Organization (WHO) and regional epidemiological studies. Data conversion was validated to ensure consistency and minimize errors. The standard deviation (SD) of BMD in individuals compared to young adults is referred to as the T score. Based on this score, individuals were classified as normal (T-score > -1.0), osteopenia (-2.5 < T-score < -1.0), or osteoporotic (T-score ≤ -2.5) [4]. A T-score of 0 was defined as a BMD value of 1.2 g/cm².

Sample Size Calculation

The sample size was calculated using G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Germany) to ensure adequate statistical power (0.80) at an alpha level of 0.05. For the chi-square test, an effect size of 0.6 (medium to large, based on prior literature) and 2 degrees of freedom were assumed, totalling 82 participants.

Statistical analysis

The efficacy of SAC was evaluated based on changes in bone mineral density (BMD), T-score, and speed of sound (SOS) of the distal radius after approximately 8 months of treatment.

Baseline Characteristics

Baseline characteristics of the study participants were compared across three clinical groups (normal, osteopenia, and osteoporosis). Numerical variables were analyzed using one-way analysis of variance (ANOVA) for comparisons across the three groups. Categorical variables were analyzed using the chi-square test or Fisher’s exact test when expected cell counts were less than 5.

Within-Group Changes: Changes in BMD, T-score, and SOS from baseline to post-treatment within the same group were analyzed using a paired t-test.

Between-Group Comparisons: Between-group differences in BMD changes after treatment were analyzed using analysis of covariance (ANCOVA), with baseline BMD as a covariate. For T-score and SOS, similar ANCOVA models were applied, with baseline T-score and SOS as respective covariates. To address multiple comparisons across BMD, T-score, and SOS, a Bonferroni correction was applied, adjusting the significance level to $p < 0.0167$ (0.05/3).

All statistical analyses were performed using IBM SPSS Statistics version 26 (IBM Corp., Armonk, NY, USA).

Results

Baseline characteristics

A total of 82 participants participated in this study. Table 1 presents the baseline characteristics of the participants, which showed no significant differences in the measured parameters except average age. The average age was approximately 54 for normal, 62 for osteopenia, and 64 for the osteoporosis group ($p<0.0001$).

Variables		Normal (n=18)	Osteopenia (n=31)	Osteoporosis (n=33)	p value
Age ± SD		54.0 ±9.7	62.3 ± 9.7	63.6 ± 7.1	<0.0001
Gender	Male	8	8	5	0.07
	Female	10	23	28	
Weight ± SD (kg)		60.5 ± 11.8	58.5 ± 8.4	58.2 ± 5.6	0.65
Height ± SD (cm)		163.0 ± 6.0	161.3 ±6.8	157.9 ± 4.9	0.10
BMI ± SD		22.6 ± 3.2	22.4 ± 2.3	23.0 ± 1.9	0.86
Intervention ± SD (days)		279 ± 223	215 ± 249	273 ± 272	0.59

Table 1: Characteristics of participants.

Changes of T-score, SOS, and BMD by clinical group, gender, and age group

T-scores, SOS, and BMDs were measured at baseline and ~8 months of SAC. As expected, the mean differences from baseline were statistically significant among clinical groups ($p<0.0001$, Figure 1). After treatment, SAC treatment significantly increased T score (-2.01 vs. -0.85, $p<0.0001$, Table 2), SOS (3,946 vs. 4,079, $p<0.0001$, Table 2), and BMD (0.95 vs. 1.10 g/cm², $p<0.0001$, Table 3) regardless of gender and age groups. These improvements were more pronounced among participants with osteoporosis and in male subjects ($p<0.0001$) (Figure 1D). The efficacy of SAC was more evident in the men's group overall (Figure 1D, Table 2).

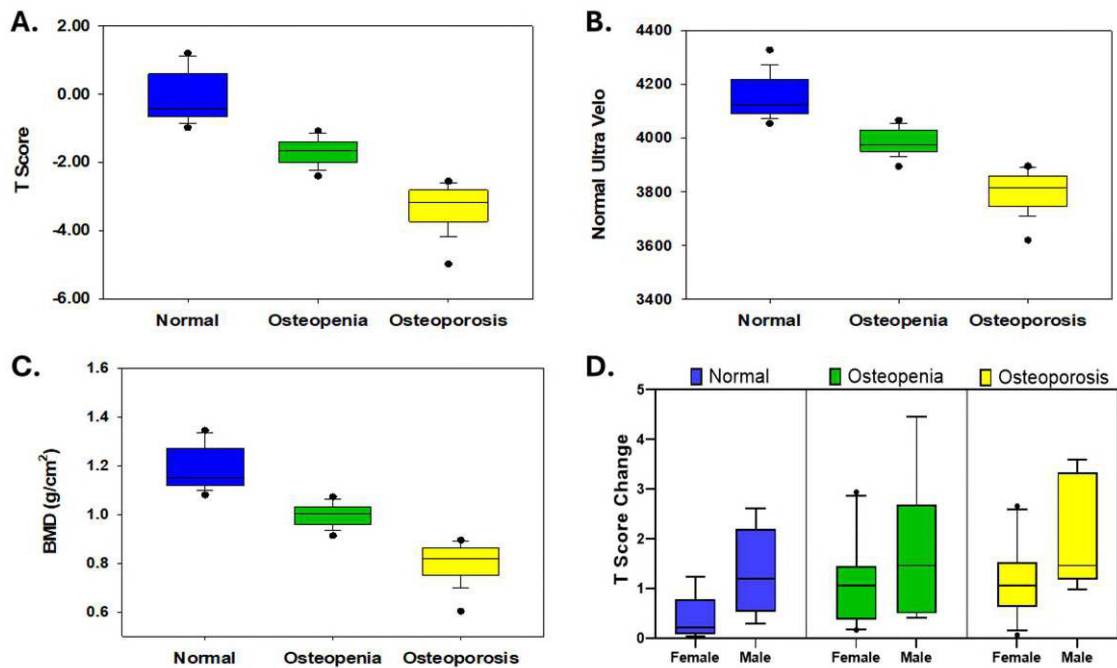


Figure 1: Baselines of T-Score, SOS, BMD, T Score Changes with 10th, 25th, median, 75th, 90th values in clinical groups. A: Median of T-scores are -0.11 (normal) vs -1.68 (osteopenia) vs. -3.34 (osteoporosis, $p<0.0001$). B: Median of SOS Scores are 4,153 vs 3,983 vs 3,798 ($p<0.0001$), and C: Median of BMD are 1.19 vs 1.00 vs 0.80 ($p<0.0001$). D. T score change after SAC treatment. Male and osteoporosis groups showed higher efficacy than female and other clinical groups ($p<0.0001$).

	Gender	values	number	p value
Age ± SD	Female	58.0 ± 10.2	61	0.858
	Male	58.5 ± 11.0	21	
SOS ± SD (%)	Female	2.91 ± 0.02	61	0.004
	Male	4.75 ± 0.03	21	
T-Score ± SD (%)	Female	51.8 ±45.3	61	0.001
	Male	262.0 ± 494.2	21	
BMD ± SD (%)	Female	13.6±10.2	61	0.035
	Male	20.0±15.9	21	
Menopause				
Age ± SD	Yes	61.3 ± 6.23	48	<0.0001
	No	43.5 ± 8.89	13	

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SOS ± SD (%)	Yes	3.16 ± 2.04	48	0.075
	No	2.00 ± 2.04	13	
T-Score ± SD (%)	Yes	48.6 ± 40.7	48	0.288
	No	63.8 ± 59.7	13	
BMD ± SD (%)	Yes	15.1 ± 10.2	48	0.028
	No	8.11 ± 8.34	13	

Table 2: Changes of T-score, SOS, and BMD by gender or menopausal status.

	Gender	T-score			
		Baseline ± SD	After ± SD	N	p value
All		-2.0±1.38	-0.85±1.51	82	<0.0001
Normal	All	-0.11±0.69	0.70±1.09	18	<0.0001
Normal	Female	-0.22±0.76	0.21±0.63	10	0.01
Normal	Male	0.03±0.62	1.33±1.26	8	0.004
Osteopenia	All	-1.68±0.37	-0.46±1.11	31	<0.0001
Osteopenia	Female	-1.69±0.40	-0.63±0.89	23	<0.0001
Osteopenia	Male	-1.64±0.37	0.04 ± 1.56	8	0.013
Osteoporosis	All	-3.34±0.66	-2.06±0.98	33	<0.0001
Osteoporosis	Female	-3.37±0.69	-2.23±0.91	28	<0.0001
Osteoporosis	Male	-3.20±0.48	-1.10±0.78	5	0.015
SOS					
All		3946±153	4079±164	82	<0.0001
Normal	All	4153±79	4246±113	18	<0.0001
Normal	Female	4163±87	4212±71	10	0.012
Normal	Male	4140±71	4289±144	8	0.004
Osteopenia	All	3983±48	4123±122	31	<0.0001
Osteopenia	Female	3995±44	4116±100	23	<0.0001
Osteopenia	Male	3949±42	4141±180	8	0.13
Osteoporosis	All	3798±76	3946±105	33	<0.0001
Osteoporosis	Female	3804±79	3934±104	28	<0.0001
Osteoporosis	Male	3769±56	4011±89	5	0.015
BMD					
All		0.95 ± 1.65	1.10 ± 0.18	82	<0.0001
Normal	All	1.19±0.08	1.28±0.13	18	<0.0001
Normal	Female	1.17±0.09	1.22±0.08	10	0.01
Normal	Male	1.20±0.07	1.36±0.15	8	0.004
Osteopenia	All	1.00±0.05	1.14±0.13	31	<0.0001
Osteopenia	Female	1.00±0.05	1.12±0.11	23	<0.0001
Osteopenia	Male	1.00±0.04	1.20±0.19	8	0.013

Osteoporosis	All	0.80±0.08	0.95±0.12	33	<0.0001
Osteoporosis	Female	0.80±0.08	0.93±0.11	28	<0.0001
Osteoporosis	Male	0.82±0.06	1.07±0.09	5	0.015

Table 3: T-score, SOS, BMD changes by gender and clinical groups.

The status of menopause is critical to bone health. As expected, participants with menopause showed significantly lower values of SOS (3,888 vs. 4,110, $p<0.0001$), T-score (-2.64 vs. -0.69, $p<0.0001$), and BMD (0.88 vs. 1.12, $p<0.0001$). The percentage increase in BMD after treatment was significantly higher in the menopausal group compared to the non-menopausal female group (15.1% vs. 8.1%, $p=0.028$). This association was not observed in changes of SOS ($p=0.075$) and T-score ($p=0.288$, Table 2).

Aging is a well-established risk factor for osteoporosis and plays a critical role in bone health deterioration. Significant inverse relations between age and bone health were observed on T-score (Pearson correlation with age, -0.41, $p<0.0001$), SOS (Pearson correlation with age, -0.43, $p<0.0001$), and BMD (Pearson correlation with age, -0.41, $p<0.0001$) (Figure 2). Efficacy of SAC was observed in all age groups. Therefore, there is no significant difference in efficacy among age groups (SOS change $p=0.114$, T-Score change $p=0.324$, BMD change $p=0.124$) (Figure 3).

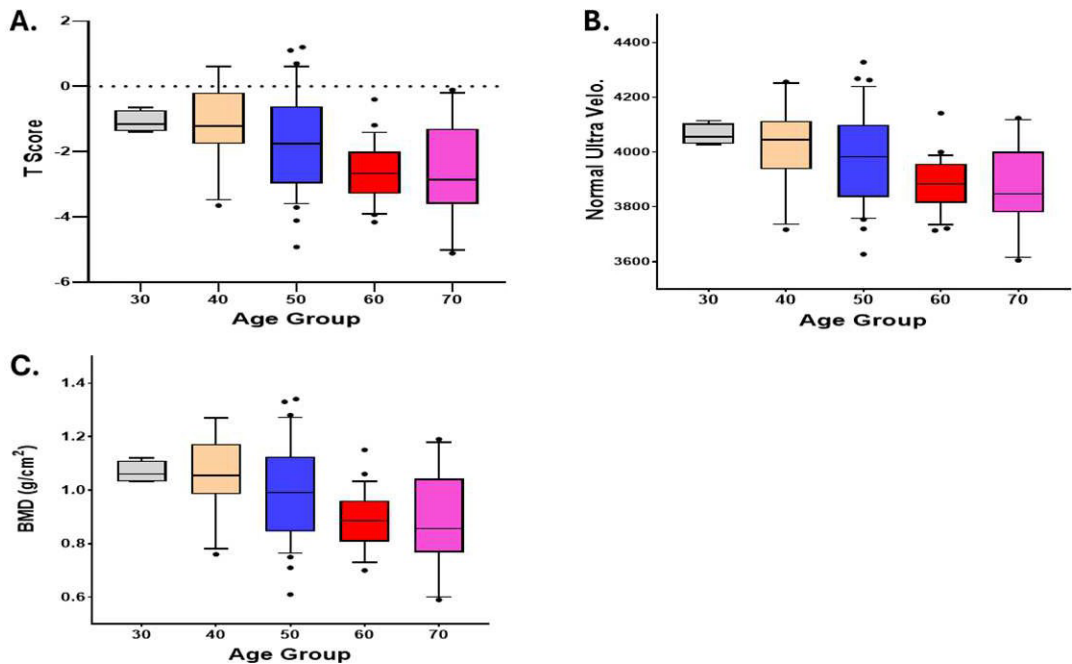


Figure 2: Inverse relationship between age and bone health. A: T-score ($p<0.0001$), B: SOS ($p<0.0001$), C: BMD ($p<0.0001$)

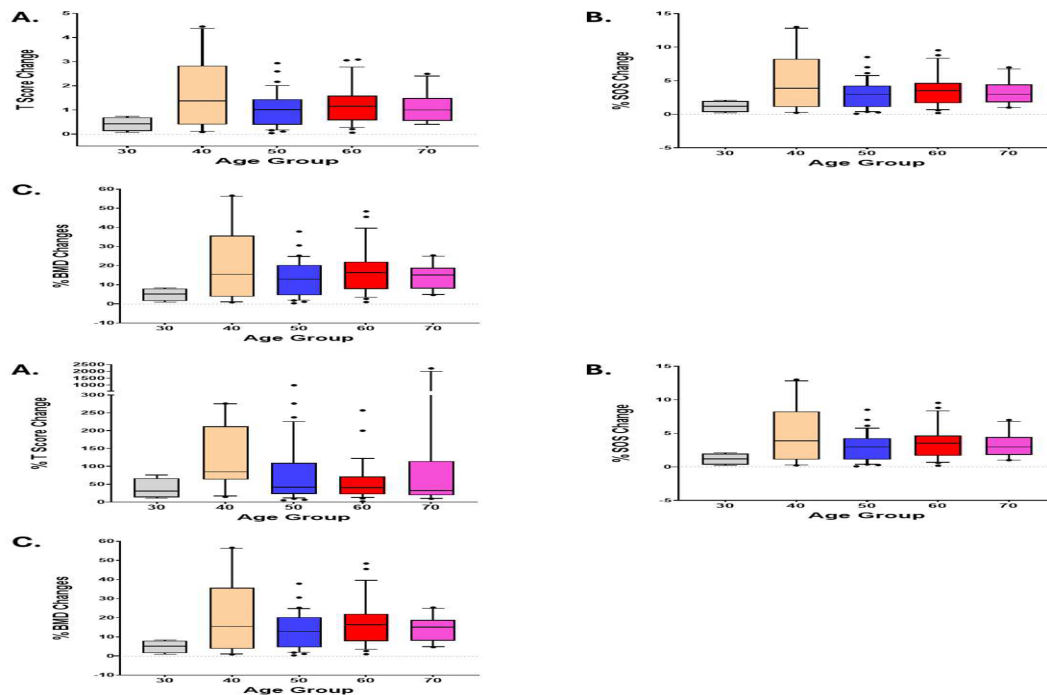


Figure 3: Efficacy of SAC by age groups. Efficacy of SAC was observed in all age groups. There is no significant difference in efficacy among age groups. A: T-score change $p=0.324$, B: SOS change $p=0.114$, and C: BMD change $p=0.124$.

Among 82 participants, 65% of the osteopenia participants (20/31) improved to the normal range after 8 months of treatment, while 64% of participants with osteoporosis (21/33) were reclassified into the osteopenia group. Moreover, 12% of osteoporosis participants (4/33) improved to the normal range (Figure 4).

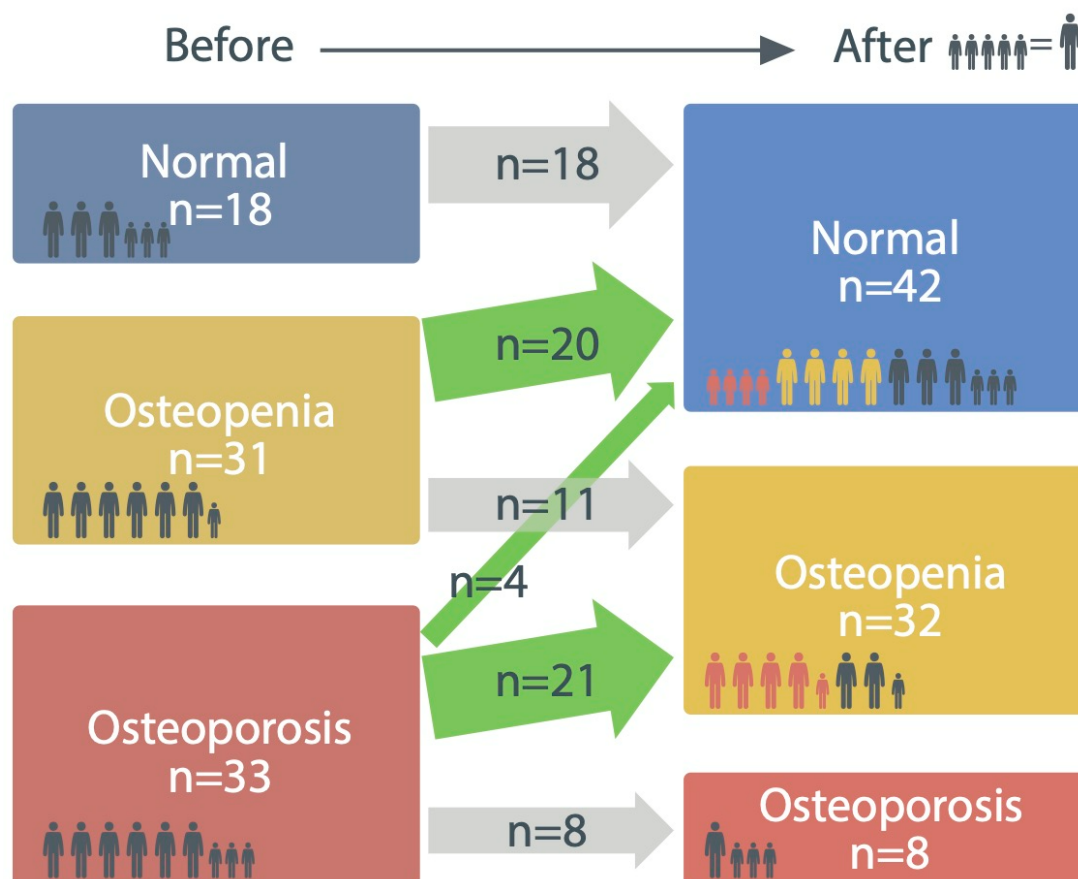


Figure 4: Distribution of clinical group before and after treatment based on T-score. 65% of participants with osteopenia (20/31) were improved to the normal group after treatment, while 64% of participants with osteoporosis (21/33) became the osteopenia group. Notably, 12% of osteoporosis participants (4/33) improved to the normal range.

Discussion

In this study, we observed that 8 months of daily SAC supplementation significantly improved BMD, T-score, and SOS in both men and women across all age groups and all clinical groups. To the best of our knowledge, this is the first study to investigate the effects of SAC in humans.

Calcium plays a crucial role in many physiological processes. In mammals, serum calcium is tightly maintained in a narrow range (1-1.3 mM) [17]. Normally, dietary calcium is absorbed via the lumen with the aid of Vitamin D, but it is immediately bound to albumin, becoming physiologically inactive.

The SAC is a calcium carbonate formulation characterized by weak sigma anti-bonding interaction with water molecules,

forming $\text{Ca}(\text{H}_2\text{O})_6$. Due to its loosely bound molecules, it enables absorption into the bloodstream without vitamin D, staying bioavailable ionized calcium. Such elevation of bioavailable calcium in the body resulted in an increase in extracellular calcium. In the bone environment, these extracellular Ca^{2+} signals interact with BMP and promote osteoblast differentiation, resulting in bone formation from the bone marrow-mesenchymal stem cells and increasing BMD, depicted in Figure 5 [18]. Furthermore, it is likely to reduce parathyroid hormone secretion, mitigating calcium loss and suppressing osteoporosis progression. As shown in the animal model [15]. We hypothesized that oral consumption of SAC increases serum bioactive calcium without or with minimal interruption of total calcium homeostasis and improves patients' osteoporosis status.

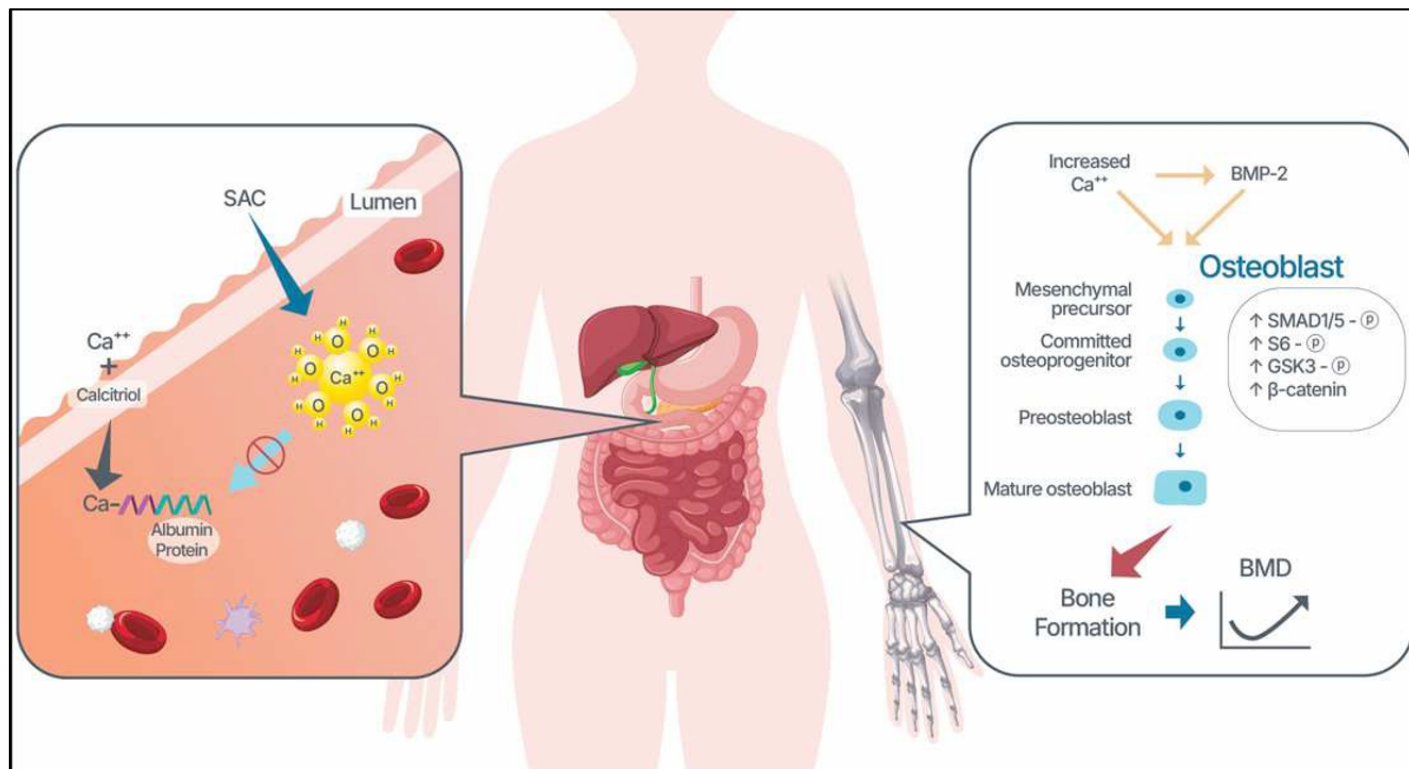


Figure 5: Proposed mechanism of how SAC improves BMD. Due to a weak intermolecular bonding of SAC with water molecules, forming $\text{Ca}(\text{H}_2\text{O})_6$, the SAC enables absorption into the bloodstream without vitamin D, staying bioavailable as ionized calcium. It elevates extracellular calcium in the bone microenvironment. This extracellular calcium and BMP-2 cooperatively promote the osteoblast differentiation/activity, increasing bone formation.

SAC differs from conventional calcium carbonate in its weak sigma anti-bonding, which enhances solubility and absorption, allowing bioactive calcium to remain in circulation without reliance on vitamin D [14]. Increased extracellular calcium may stimulate osteoblast differentiation via BMP signalling and suppress parathyroid hormone, thereby reducing bone resorption [15, 18].

Based on a 16% increase in BMD by SAC treatment, a significantly reduced fracture risk was anticipated in participants (Table 3) as previous studies demonstrated an inverse relationship between BMD change and fracture risk [19]. A meta-analysis study reported that a calcium supplement is effective in increasing BMD and reducing fractures of the bone [19, 20].

Menopause is one of the established risk factors for osteoporosis. It leads to low bone density and progresses into a decrease in

BMD [21]. In fact, osteoporosis affects 30% of post-menopausal women [6]. In our study, the percentage of BMD after treatment of the menopausal group showed higher improvement compared to the non-menopausal female group (15.15% vs. 8.11%, $p=0.028$). Estrogen deficiency due to menopause can, in part, explain osteoporosis. Low estrogen levels lead to the outflow of calcium from the bones. This process lowers parathyroid hormone level and calcium absorption, contributing further to calcium loss from the bone [22, 23].

Our findings should be interpreted cautiously. First, the small sample size and retrospective design limit generalizability. Second, ultrasound, though cost-effective and widely available, is less established than DXA for guiding osteoporosis management. Third, most participants were East Asian, so findings may not extrapolate to other populations.

Despite these limitations, SAC demonstrated consistent efficacy and safety, making it a promising candidate for osteoporosis prevention and treatment. Larger, prospective randomized controlled trials with DXA-based endpoints and fracture outcomes are warranted.

Asian populations are more susceptible to osteoporosis than individuals of other racial backgrounds. Based on BMD, 32 % of 65-79 years old, and 18% of 50-64 years old Asian females have osteoporosis [24]. In addition, low calcium intake, a small body frame, and low physical activity contribute to a higher risk.

A larger, well-designed study with higher statistical power and a longer follow-up period is needed to further validate our findings. We are aware of the limitations of this study. Although ultrasound measurement costs less and has been proposed as a potential alternative to DXA measurements of bone mineral density (BMD), there is still uncertainty in the incorporation of ultrasound in the clinical management of osteoporosis. However, ultrasound is more widely used in clinics. Significant progress has been made, and new studies are promising. The second limitation is a small sample size, which limits generalizability. Finally, most participants are of East Asian descent. Therefore, these findings may not be extrapolated to other populations. Despite these limitations, SAC demonstrated consistent efficacy and safety, making it a promising candidate for osteoporosis prevention and treatment. Larger, prospective randomized controlled trials with DXA-based endpoints and fracture outcomes are warranted.

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All authors are to declare non-financial interests in relation to the submitted work.

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