Improving Bone Health in Drug Users: A Comparative Study of Rehabilitation Exercise Interventions

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Abstract: To investigate the impact of differentiated rehabilitation training on skeletal health among individuals recovering from drug addiction, this study conducted a randomized controlled intervention involving 40 male participants in a compulsory detoxification center. Participants were divided into four groups: control (NC), rehabilitation exercises (RE), running exercises (RP), and resistance-based training using equipment (EE), and underwent a six-month intervention. Ultrasound densitometry was employed to evaluate the bone mineral density of the calcaneus before and after the intervention, complemented by a lifestyle and substance-use questionnaire. Initial assessments showed 62.5% of participants had T-scores in the osteopenic range. Post-intervention data revealed significant BMD increases in all intervention groups compared to controls ($p < 0.05$), with the EE group showing the highest gains. These findings suggest that structured physical training, especially resistance-based exercises, can effectively improve bone health in drug rehabilitation populations and may serve as a preventive strategy against osteoporosis.

Keywords: Drug Addicts; Osteoporosis; Rehabilitation Training; Bone Mineral Density; Exercise Intervention

1. Introduction

Illicit drug use continues to pose a significant global public health challenge. According to the 2023 World Drug Report by the United Nations Office on Drugs and Crime (UNODC), approximately 296 million individuals worldwide used drugs in 2021—a 23% increase over the past decade [1]. The consequences of drug abuse are substantial, spanning individual health deterioration, social instability, and economic costs. In China, patterns of drug use have evolved from traditional opiates to synthetic substances such as methamphetamine, ecstasy, and novel psychoactive substances (NPS) like "stamps" and "Natasha," complicating the management of rehabilitation and increasing pressure on public health systems [2].

Individuals undergoing drug rehabilitation frequently exhibit impaired physical health. Accumulating evidence links prolonged drug use to skeletal complications, such as decreased bone mineral density (BMD), osteopenia, and osteoporosis [3]. Chronic exposure to substances such as cocaine and opioids has been associated with metabolic dysregulation and nutritional deficiencies, which in turn affect bone health [4].

Physical rehabilitation training has gained growing attention as a non-pharmacological adjunctive therapy in addiction treatment [5]. Nazmin and Mooney emphasized that exercise may activate reward pathways and reduce stress, supporting recovery in individuals with substance use disorders [6]. In particular, weight-bearing and resistance exercises are recognized for their potential to stimulate osteogenesis and suppress bone resorption. A systematic review by Zhang et al. confirmed the effectiveness of exercise in improving BMD and preventing osteoporosis [7].

However, the application of such interventions in drug rehabilitation settings remains underexplored. While meta-analyses have demonstrated that exercise can enhance abstinence rates and alleviate anxiety symptoms among individuals with substance use disorders [8], there is a paucity of comparative studies assessing the differential effects of specific exercise modalities—such as rehabilitation exercises, aerobic running, and resistance training—on skeletal outcomes [9].

Substance abuse may impair bone density through multiple mechanisms, including drug-induced metabolic imbalances, malnutrition, hormonal disruption, and physical inactivity. For instance, Opata et al. discussed how glucocorticoid use enhances bone resorption and suppresses formation, while stimulant-induced disordered eating patterns further compromise skeletal integrity [10]. Bowden highlighted that antiepileptic drug use in vulnerable populations could inhibit calcium absorption and alter hormonal homeostasis [11].

Adolescence is a critical period for peak bone mass accumulation. Research by Cashman et al. indicated that up to 40% of adult bone mass is acquired during this developmental stage. Early onset of drug use may therefore significantly impair peak bone accrual. Longitudinal studies on adolescent smokers have shown reduced bone accumulation rates, underscoring the long-term implications for osteoporosis risk.

Despite the prevalence of musculoskeletal complications among drug users—such as fractures, dental loss, and chronic musculoskeletal pain—rehabilitation programs often neglect targeted interventions for bone health. Existing rehabilitation protocols predominantly focus on psychological and pharmacological dimensions, while musculoskeletal restoration remains underemphasized [12].

Recent reviews have emphasized that although exercise interventions can yield comparable outcomes to pharmacological treatments in some health domains [13], limited research differentiates among specific exercise modalities in the context of drug rehabilitation. Therefore, there is a critical need for empirical studies comparing the effectiveness of distinct physical training regimens in this population.

The objective of this study is to bridge this gap through the evaluation of three well-structured physical rehabilitation interventions—rehabilitation exercise, aerobic running, and resistance equipment training—on the BMD of male residents in a compulsory drug rehabilitation center in Zhejiang Province, China. By integrating questionnaire data with calcaneal BMD measurements across a six-month intervention period, this research seeks to inform the development of targeted physical rehabilitation strategies that can mitigate osteoporosis risk and enhance long-term physical health in individuals recovering from substance use disorders.

2. Methods

2.1 Participants

The study was conducted at a compulsory drug rehabilitation center in Zhejiang Province, China. A total of 40 male drug rehabilitation inmates, aged 38.46 ± 10.13 years, were recruited for the study. Participants were selected based on the following inclusion criteria: (a) male drug addicts, (b) at least one year remaining in their rehabilitation program, (c) no severe comorbidities, and (d) a history of drug use as defined by the World Health Organization's criteria for substance dependence. Participants with significant psychiatric disorders or contraindications to physical activity were excluded. Written informed consent was obtained from all participants prior to their involvement in the study.

2.2 Study Design

A randomized controlled trial (RCT) design was utilized in this study, which included 40 participants. The 40 participants were randomly assigned to one of four intervention groups: (1) normal correction control group (NC), (2) rehabilitation exercise group (RE), (3) running exercise group (RP), and (4) resistance equipment group (EE). The groups consisted of 10 participants each. The study spanned a six-month period, during which each intervention group received their respective rehabilitation training.

2.3 Intervention Protocol

2.3.1 Rehabilitation Exercise group (RE)

The RE group participated in a structured rehabilitation exercise program designed to improve general physical fitness and increase bone density. The program consisted of moderate-intensity exercises, including stretching, balance training, and low-impact aerobic exercises. The training was progressive, with the intensity and duration gradually increasing over the first month. Initially, sessions were 10 minutes long and gradually increased to 40 minutes per session by the third week. The group performed rehabilitation exercises three times a week for a total of six months. The target heart rate during aerobic exercises was maintained at 60-80% of the participants' maximum heart rate according to the FITT (Frequency, Intensity, Time, Type) principle.

2.3.2 Running Exercise group (RP)

The RP group engaged in a running program aimed at improving cardiovascular fitness and stimulating bone growth through weight-bearing activity. Similar to the RE group, the running sessions began with an adaptation period in the first week, with the duration starting at 10 minutes and gradually increasing to 40 minutes per session by the third week. The program also followed the FITT principles, with participants running at moderate intensity three times a week for six months. The target heart rate was maintained between 60-80% of the participants' maximum heart rate.

2.3.3 Resistance Equipment group (EE)

The EE group performed a resistance training program focusing on increasing bone density through mechanical loading. The program began with an adaptation phase in the first week, during which participants' one-repetition maximum (1RM) was measured for each resistance exercise. Training was based on 10RM (10 repetitions maximum) during the first phase and then adjusted to 8RM as the participants' strength improved. Each resistance training session consisted of three sets of each exercise, with 10-12 repetitions per set. The group participated in resistance training three times per week for six months, following the FITT principles.

2.3.4 Normal Correction Control group (NC)

The NC group continued their standard rehabilitation activities without any additional physical rehabilitation training. This group acted as a control for comparing the effects of the physical rehabilitation interventions on BMD.

2.4 Outcome Measures

2.4.1 Bone Mineral Density (BMD)

BMD was measured using ultrasound densitometry of the left calcaneus, a non-invasive and reliable method for assessing bone health. All participants underwent baseline and post-intervention BMD assessments. The BMD of each participant was recorded as T-scores, which were used to categorize bone density status. A T-score of ⩾ -1.0 indicates normal bone density, while a T-score between -1.0 and -2.5 signifies osteopenia, and a T-score < -2.5 is diagnostic of osteoporosis.

2.4.2 Questionnaire survey

A pre-intervention questionnaire was administered to all participants to collect data on their baseline physical activity habits, drug use history, dietary patterns, smoking, alcohol consumption, and use of nutritional supplements. The survey aimed to identify potential confounders and factors that might influence bone health.

2.5 Statistical Analysis

Data analysis was performed using SPSS software (Version 22.0) and JMP (Version 11). Participant characteristics and baseline measurements were summarized using descriptive statistics. Paired t-tests were applied to compare within-group pre- and post-intervention BMD values, while one-way analysis of variance (ANOVA) was used to compare BMD changes across the four groups. Statistical significance was set at $p < 0.05$. All data are presented as means ± standard deviations (SD).

3. Results

3.1. Baseline Characteristics

At baseline, the 40 participants were randomly assigned to the four intervention groups: Normal Correction Control (NC), Rehabilitation Exercise (RE), Running Exercise (RP), and Resistance Equipment (EE). The participants' age ranged from 20 to 58 years, with an average age of 38.46 ± 10.13 years. All groups were comparable at baseline in terms of demographic characteristics and pre-intervention bone mineral density (BMD). The distribution of T-scores at baseline is summarized in **Table 1**, indicating that 62.5% of participants had BMD levels consistent with osteopenia, with T-scores between -1.0 and -2.5 SD.

Table 1. Baseline Distribution of T-scores in All Participants

T-Score Range	Frequency (n)	Percentage (%)
T > 0	8	20

0 ≥ T > -1	7	17.50
-1 ≥ T > -2.5	25	62.50
Total	40	100

3.2 Effect of Rehabilitation Interventions on BMD

3.2.1 Changes in T-scores by group

The mean pre- and post-intervention T-scores for each group are shown in **Table 2**. The NC group exhibited no significant change in bone mineral density (BMD) following the six-month intervention ($p > 0.05$), suggesting that standard rehabilitation practices had no substantial impact on BMD. In contrast, all intervention groups showed statistically significant improvements in BMD after the rehabilitation training, with the greatest improvement observed in the EE group.

Specifically, the RE group demonstrated a T-score increase from -0.99 ± 0.96 at baseline to -0.94 ± 0.92 post-intervention, with a mean change (ΔT) of 0.05 ± 0.11 ($p < 0.05$). Similarly, the RP group experienced a T-score improvement from -1.04 ± 0.82 to -0.98 ± 0.90, with a mean change (ΔT) of 0.06 ± 0.12, which was also statistically significant ($p < 0.05$). The EE group had the largest increase, with the T-score rising from -1.01 ± 0.92 to -0.92 ± 0.84, a mean change (ΔT) of 0.08 ± 0.21, which was statistically significant as well ($p < 0.05$).

Table 2. Pre- and Post-Intervention T-scores for Each Group

Group	Pre-Intervention T-score (Mean ± SD)	Post-Intervention T-score (Mean ± SD)	ΔT (Mean ± SD)	*p*-value
NC (Control)	-1.04 ± 1.03	-1.06 ± 1.02	0.02 ± 0.08	> 0.05
RE (Rehabilitation Exercise)	-0.99 ± 0.96	-0.94 ± 0.92	0.05 ± 0.11	< 0.05
RP (Running Exercise)	-1.04 ± 0.82	-0.98 ± 0.90	0.06 ± 0.12	< 0.05
EE (Resistance Equipment)	-1.01 ± 0.92	-0.92 ± 0.84	0.08 ± 0.21	< 0.05

3.2.2 Comparison of changes in BMD across groups

A one-way analysis of variance (ANOVA) was conducted to compare the mean changes in BMD (ΔT) across the four groups. The results revealed significant differences between the intervention groups and the NC group ($p < 0.05$). Specifically, the EE group demonstrated a significantly greater increase in BMD compared to both the RE and RP groups ($p < 0.05$). However, no significant difference was found between the RE and RP groups in terms of BMD change ($p > 0.05$), suggesting that the effects of rehabilitation exercises and running exercises on bone density were similar.

3.2.3 Effect of drug use on BMD

The relationship between drug use history and bone mineral density (BMD) was further examined. **Table 3** presents the correlation between weekly drug consumption and baseline BMD. Participants who consumed more than 2g of drugs per week (Group 3) had significantly lower BMD, with a mean T-score of -1.48 ± 0.76, compared to those who consumed less than 2g per week (Groups 1 and 2). Specifically, those who consumed less than 1g of drugs per week (Group 1, n = 23) exhibited the highest T-scores, averaging -0.95 ± 0.91, while those in the 1g ≤ M < 2g range (Group 2, n = 11) had a mean T-score of -1.01 ± 0.90. The differences between the high consumption group (M ≥ 2g) and the other two groups (M < 2g) were statistically significant ($p < 0.05$), suggesting that higher drug consumption is associated with a marked reduction in bone density.

Table 3. Relationship between Weekly Drug Consumption and Baseline BMD

Weekly Drug Consumption (g)	N (Number of Participants)	T-score (Mean ± SD)	*p*-value
(1) M < 1	23	-0.95 ± 0.91	-
(2) 1 ≤ M < 2	11	-1.01 ± 0.90	> 0.05 (1)vs(2)
(3) M ≥ 2	6	-1.48 ± 0.76	< 0.05 (1)vs(3)

Additionally, the duration of drug use was found to influence baseline BMD, as shown in Table 4. Participants with a drug history of 10 years or more (Group 3) had the lowest mean T-score of -1.44 ± 0.60, which was significantly lower than those with a history of less than 5 years (Group 1, n = 13, T-score = -0.92 ± 0.84) and those with 5 to 10 years of drug use (Group 2, n = 15, T-score = -1.25 ± 0.97). The differences between these groups were statistically significant ($p < 0.05$), indicating that a longer duration of drug use is associated with more severe bone density loss.

These findings underscore the cumulative negative effects of both the quantity and duration of drug use on skeletal health. Higher drug consumption and prolonged use significantly correlate with lower bone mineral density, increasing the risk of bone-related complications in drug-dependent individuals.

Table 4. Relationship between Duration of Drug Use and Baseline BMD

Duration of Drug Use (Years)	N (Number of Participants)	T-score (Mean ± SD)	p-value
(1) Y < 5	13	-0.92 ± 0.84	-
(2) 5 ≤ Y < 10	15	-1.25 ± 0.97	< 0.05 (1)vs(2)
(3) Y ≥ 10	12	-1.44 ± 0.60	< 0.05 (1)vs(3)

3.3 Subgroup Analysis Based on Physical Activity History

A subgroup analysis was conducted to evaluate the impact of pre-existing physical activity habits on the effectiveness of rehabilitation training. Table 5 summarizes the results for participants with and without a history of regular physical activity. Participants who reported regular exercise prior to the intervention (n = 23) demonstrated significantly higher T-scores at baseline, with a mean pre-intervention T-score of -0.85 ± 0.93, compared to those who had no regular exercise habits (n = 17), whose baseline T-score was significantly lower at -1.21 ± 0.86.

Table 5. Comparison of BMD Changes Based on Physical Activity History

Group	Regular Physical Activity	No Regular Physical Activity
N (Number of Participants)	23	17
Pre-Intervention T-score (Mean ± SD)	-0.85 ± 0.93	-1.21 ± 0.86
Post-Intervention T-score (Mean ± SD)	-0.75 ± 0.88	-1.12 ± 0.90
ΔT (Mean ± SD)	0.10 ± 0.15	0.09 ± 0.14
p-value	< 0.05	

Moreover, participants with regular physical activity prior to the intervention showed greater improvements in bone mineral density (BMD) after the rehabilitation program, with a mean ΔT of 0.10 ± 0.15, which was statistically significant ($p < 0.05$). In contrast, those without regular exercise habits exhibited a smaller change in BMD, with a mean ΔT of 0.09 ± 0.14, indicating less pronounced improvement. This difference in BMD changes between the two groups was also statistically significant ($p < 0.05$), suggesting that prior engagement in physical activity may enhance the effectiveness of rehabilitation training in improving bone density.

4. Discussion

This study provides valuable insights into the complex relationship between drug use, physical activity, and bone mineral density (BMD) in individuals undergoing rehabilitation. The findings highlight the detrimental effects of both the quantity and duration of drug use on skeletal health, emphasizing the need for comprehensive rehabilitation programs that address bone health. Additionally, the study underscores the importance of physical activity history as a predictor of rehabilitation success, which has significant implications for the design of future drug rehabilitation protocols.

4.1 Impact of Drug Use on Bone Health

Our results demonstrate that higher drug consumption and longer drug use history are significantly associated with lower bone mineral density. Participants who consumed more than 2g of drugs per week and those with a drug history of more than 10 years exhibited the most severe decreases in BMD. These findings are consistent with previous studies that have identified drug abuse, particularly the long-term use of substances such as opioids and stimulants, as a major risk factor for osteoporosis and bone-related complications [14].

The mechanisms underlying these effects are multifaceted. Chronic drug use can disrupt calcium metabolism, interfere with hormonal regulation, and decrease physical activity, all of which contribute to bone resorption and reduced bone formation. For example, stimulant use has been shown to impair calcium absorption and alter vitamin D metabolism, both of which are crucial for bone health. Additionally, opioids are known to cause secondary hypogonadism, further exacerbating bone loss [15]. Our study corroborates these findings, showing that drug use significantly reduces BMD, particularly in individuals with a history of prolonged or high-dose drug consumption. These results underscore the importance of early intervention and monitoring bone health in drug-dependent populations.

4.2 Duration and Intensity of Drug Use as Determinants of BMD

This study further supports the findings of prior research on the relationship between the duration of drug use and bone density. Participants with more than 10 years of drug use history had significantly lower BMD than those with shorter histories, reinforcing the idea that prolonged drug use has a cumulative negative impact on bone health [16]. Interestingly, while the intensity of drug consumption (i.e., the amount consumed per week) also correlated with lower BMD, the duration of drug use may have a more lasting effect, as bone mineral density deteriorates gradually over time.

The importance of duration as a key determinant of bone health is not fully understood, but it may relate to chronic alterations in bone remodeling, including decreased osteoblast activity and increased osteoclast activity due to prolonged substance use. This suggests that drug rehabilitation programs should not only focus on cessation but also on addressing long-term health consequences, such as osteoporosis, which may require prolonged intervention and monitoring.

4.3 The Role of Physical Activity in Enhancing Rehabilitation

One of the most significant findings of this study is the positive impact of prior physical activity history on BMD improvement during rehabilitation. Participants with regular exercise habits prior to the intervention exhibited significantly higher baseline BMD and greater improvements after rehabilitation, compared to those without such habits. These findings align with the extensive body of literature suggesting that physical exercise, particularly weight-bearing and resistance training, is essential for improving bone mineral density and preventing osteoporosis [17,18].

The beneficial effects of physical activity on bone health are well-established. Exercise increases bone density by stimulating osteogenesis through mechanical loading and enhancing the hormonal environment, which promotes bone formation. A study by Matos et al. [19] in postmenopausal women demonstrated that weight-bearing exercise could increase BMD by up to 1.17%, while resistance training has been shown to be particularly effective in increasing bone mass in both young and older adults. These findings suggest that incorporating regular physical activity into drug rehabilitation programs can significantly enhance rehabilitation outcomes by improving skeletal health, particularly in individuals with pre-existing low BMD.

Moreover, the positive effects of exercise on BMD observed in this study underscore the importance of exercise adherence during rehabilitation. Participants who engaged in regular physical activity prior to rehabilitation may have developed greater muscle strength and coordination, allowing them to better tolerate and benefit from the rehabilitation exercises. This highlights the need for rehabilitation programs to not only include exercise but also promote adherence to physical activity routines to maximize the benefits for bone health and overall well-being.

4.4 Integrating Exercise into Drug Rehabilitation Programs

This study strongly supports the integration of structured physical activity into drug rehabilitation programs. Given the significant improvements in bone health seen in participants with regular exercise habits, future rehabilitation protocols should prioritize physical activity as a core component. This could include tailored exercise regimens such as resistance training, aerobic exercises, and flexibility routines, all of which have been shown to improve bone density [20]. Furthermore, personalized exercise programs that account for the physical capabilities of individual participants, such as those with severe osteopenia or osteoporosis, may be necessary to ensure safety and efficacy.

Additionally, the role of physical activity extends beyond bone health. Exercise is known to improve cardiovascular function, reduce anxiety, and enhance mood, all of which are crucial for individuals recovering from drug addiction. As noted by Mooney et al, exercise can also activate brain reward pathways, reducing the risk of relapse by helping individuals regain a sense of well-being. Thus, the incorporation of physical activity into rehabilitation not only addresses the physical aspects of recovery but also contributes to psychological and emotional healing.

5. Conclusion

This study demonstrates that both the quantity and duration of drug use are significantly associated with reduced BMD, increasing the risk of osteopenia and osteoporosis. Conversely, regular physical activity prior to rehabilitation is linked to higher baseline BMD and greater post-intervention improvement, highlighting the value of integrating structured exercise into drug recovery programs.

These findings suggest that drug rehabilitation should adopt a comprehensive approach, combining psychological treatment with physical health interventions. Routine BMD monitoring and targeted exercise regimens should be incorporated to mitigate long-term skeletal complications and support holistic recovery. Future research is needed to clarify the mechanisms of exercise-induced bone improvements and to optimize rehabilitation strategies for drug-dependent populations.

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