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# What are injury risk factors for elite wushu athletes?

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**Abstract**
Introduction. **Sports activity not only improves bone mineral density (BMD), bone mass (BM), and cardiopulmonary function, but also increases an incidence of sports injuries. As a result, BMD and BM can affect sports injuries, which in turn can have an impact on overall health and well-being.** Aim of Study. **This study aims to investigate the impact of BMD and BM on cardiopulmonary functions and sports injuries among elite wushu athletes, who are expected to represent Korea in the future. The study is aimed at understanding a relationship between these factors to help to prevent and manage injuries among elite athletes.** Material and Methods. **This study involved 60 wushu athletes who participated in training and competitions from January to December 2023. The athletes' BMD and BM were measured using DEXINO (StemLab, Kor). Additionally, their cardiopulmonary functions, $\dot{V}O_2$max, ventilation, and a ventilation threshold were evaluated with a POWERbreathe Plus (UK) device. An incidence of sports injuries was calculated as a 95% Poisson confidence interval (95% CI) per 1,000 hours of training participation.** Results. **BMD and BM correlated with cardiopulmonary functions such as $\dot{V}O_2$max (r = 0.502, r = 0.495, respectively) and ventilation (r = 0.426, r = 0.404, respectively). Furthermore, both BMD and BM were found to be correlated with sports injuries (r = –0.329, r = –0.409, respectively). Increasing BMD and BM leads to an increase in $\dot{V}O_2$max (p < 0.001) and ventilation (p = 0.001). On the other hand, decreasing BMD and BM increases the incidence of injuries per 1,000 hours of training.** Conclusions. **BMD and BM are related to cardiopulmonary functions and affect the injury incidence. Therefore, systematic management of BMD and BM is necessary to prevent injuries and improve performance of athletes.**

**KEYWORDS: bone mineral density, sports injuries, bone mass, wushu, cardiopulmonary functions.**

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## Introduction

Wushu is a traditional sport that originated in China. Although it is not yet an official Olympic sport, it was showcased as a demonstration event at the 2008 Beijing Olympics [1]. Today, wushu is practiced all over the world [24]. In general, sports activities are known to improve bone mineral density (BMD) and bone mass (BM), which in turn reduces a risk of fracture [26]. Furthermore, sports activities improve cardiopulmonary functions, as well as an ability to exchange oxygen in the cardiopulmonary system [14]. This leads to an increase in ventilation, maximum oxygen uptake, and ventilation thresholds [14]. BMD and BM are used to measure a fracture risk rate and allow for early diagnosis, while cardiopulmonary functions are used to indicate exercise performance [14, 26]. Regarding wushu, it has divided into two main categories: Taolu, which evaluates accuracy, agility, speed, and strength through standardized bare hands, long weapons, and short weapons; and Sanshou, which uses full contact punches, kicks, and throwing techniques with opponents

[1]. Therefore, sports injuries are a natural consequence for wushu athletes. These injuries are the biggest threat to athletes, as they can negatively affect performance and even lead to early retirement [21]. According to a study by Kim et al. [12], competing wushu athletes reported very high injury rates, along with taekwondo and judo. Taken together, practicing wushu can increase BMD, BM, and improve cardiopulmonary functions, but it may also be associated with an increased risk of sports-related injuries.

However, most sports medicine studies focused on evaluating and enhancing bone density and cardiopulmonary functions [10, 17], as well as conducting epidemiological investigations of sports injuries and rehabilitation exercises [6, 9]. In contrast, there are few studies on whether BMD, BM, and cardiopulmonary functions have an impact on an occurrence of sports injuries.

Therefore, it is unclear whether spending a lot of time on training and competing is ultimately beneficial or detrimental for elite wushu athletes. Accordingly, there is a need to conduct a study to identify and analyze factors that affect athletes' sports injuries and performance.

This study aimed to investigate how BMD and BM affect cardiopulmonary functions and sports injuries in elite wushu athletes who are expected to represent Korea in international competitions. These findings can help to enhance athletic performance of wushu athletes and reduce a risk of potential sports-related injuries.

## Material and Methods

*Participants*

The study was conducted on elite wushu athletes who participated in high-level competitions and trained in training centers from January to December 2023. A total of 60 athletes took part in the study, and all of them were at least 18 years old (Table 1). The study was conducted in compliance with the Declaration of Helsinki. The elite wushu athletes trained for an average of 4 hours a day, 4.5 days a week, and participated in the training for 43 weeks.

**Table 1.** General characteristics of the subjects

| | Mean | SD |
|---|---|---|
| Age (years) | 24.87 | 4.12 |
| Height (cm) | 174.73 | 6.97 |
| Weight (kg) | 64.83 | 11.74 |
| BMI | 21.74 | 1.27 |

*Data collection and analysis*

On the first Wednesday afternoons of each month, the wushu athletes were subjected to comprehensive measurements of their BMD, BM, and cardiopulmonary functions. These measurements were conducted on their day of rest, after the athletes had rested comfortably for at least 30 minutes to ensure maximum stability. All athletes were instructed to drink at least 200 mL of water before the measurements. The measurements were taken monthly, and a mean value was recorded as data.

*Measure*

BMD measurement: In the study, BMD and BM of the athletes were measured using a device called DEXINO (StemLab, Kor), which is based on dual energy radiation absorption. To ensure accurate measurements, the athletes were instructed to wear comfortable clothing, remove metal objects that could interfere with X-rays, and lie down on a scanning table. A measurement posture was standardized by keeping both feet together and placing both hands comfortably on both sides of a body, with palms facing upwards. A measurement process took approximately 5 minutes and was conducted twice to collect an average value as data. Reliability of BMD and BM was tested using a test-retest method, and values showed high reliability with coefficients of 0.939 and 0.947, respectively.

Cardiopulmonary capacity measurement: The athletes' cardiopulmonary functions were measured using a POWERbreathe Plus (UK) device. To ensure accuracy, the athletes measured only oral cavity pressure by covering their noses and keeping their lips as close as possible to measuring instruments to avoid air leakage. Moreover, the athletes were instructed to sit directly on a chair without flexion or extension of their necks and trunks. They were also trained to avoid excessive shoulders movements during the measurements to prevent compensation movements. The athletes exhaled as much as possible upon hearing a "start" signal and then inhaled as deeply as possible to measure their maximum oxygen uptake ($\dot{V}O_2$max), ventilation (VE), and ventilation thresholds (VT). The measurements were taken twice, and an average value was recorded as data. Reliability of $\dot{V}O_2$max, VE, and VT was tested using the test-retest method, and values showed high reliability with coefficients of 0.903, 898, and 0.889, respectively.

Sports injury: Sports injuries are defined as damage to tissues or other physical functions caused by a rapidor repetitive transfer of kinetic energy caused by participation in sports activities, based on the International Olympic Committee (IOC) agreement [2].

In the current study, sports injuries were recorded using a daily injury report form issued by the IOC [2]. If the athletes developed injuries during the study, a sports doctor evaluated and recorded them on-site. All wushu athletes underwent training in the training centers for 9 months, equivalent to 39 weeks per year. During this period, the athletes received an average of 4 hours of training per day and 4.5 days of training per week. To calculate the total training time, the number of hours per day was multiplied by the number of days per week and then by the number of weeks per year. As a result, the total training time per athlete was approximately 702 hours. However, the training time for each athlete have been recalculated by excluding time when they could not participate due to injuries.

*Statistical analyses*

The athletes' general characteristics, bone density, and cardiopulmonary functions were analyzed using descriptive statistics. An incidence rate of sports injuries was calculated by determining the Poisson 95% confidence intervals (95% CI) per 1,000 hours of training. The Pearson's correlation was used to determine an association between bone density, cardiopulmonary functions, and occurrence of sports injuries. Furthermore, a simple linear regression was conducted to examine how bone density impacts cardiopulmonary functions and sports injuries. All statistical analyses were performed with SPSS ver. 27.0 (IBM Corp., Armonk, NY, USA), and a statistical significance level was set at $\alpha = 0.05$.

## Results

The wushu athletes had an average BMD of 1.24 ± 0.08 (g/cm) and BM of 2.49 ± 0.16 (kg) (Table 2). In addition, $\dot{V}O_2$max was 59.07 ± 6.41 (ml/min/kg), VE was 111.83 ± 12.42 (l/min), and VT was 2.11 ± 0.54 (l) (Table 2). Lastly, 179 sports injuries occurred, with an incidence of 2.98 ± 1.36 (95% CI 2.56-3.45) sports injuries per athlete. In addition, the incidence of sports injuries per 1,000 hours of training was 3.85 ± 1.76 (95% CI 3.31-4.46) (Table 2).

**Table 2.** Bone mineral density, bone mass, cardiopulmonary functions, and sports injuries in the elite Wushu athletes

| | Mean | SD |
|---|---|---|
| Bone mineral density | 1.24 | 0.08 |
| Bone mass | 2.49 | 0.16 |
| $\dot{V}O_2$max | 59.07 | 6.41 |
| Ventilation | 111.83 | 12.42 |
| Ventilation threshold | 2.11 | 1.36 |
| Sports injuries per 1,000 hours of training | 3.85 | 1.76 |

*Relationship between BMD, BM, cardiopulmonary functions, and sports injuries*

BMD and BM correlated with cardiopulmonary functions such as $\dot{V}O_2$max (r = 0.502, r = 0.495, respectively) and VE (r = 0.426, r = 0.404, respectively). Furthermore, both BMD and BM were found to be correlated with sports injuries (r = –0.329, r = –0.409, respectively). However, there was no correlation between cardiopulmonary functions and sports injuries (Table 3).

*Effects of BMD and BM on cardiopulmonary functions and sports injuries*

For each 0.006 and 0.003 increase in BMD, $\dot{V}O_2$max ($p < 0.001$) and VE ($p = 0.001$) increased by 1. Additionally, for every 0.015 decrease in BMD, the incidence of injuries per 1,000 hours of training

**Table 3.** Relationship between bone mineral density, bone mass, cardiopulmonary functions and sports injuries

| | Bone mineral density | Bone mass | $\dot{V}O_2$max | Ventilation | Ventilation threshold | Sports injuries per 1,000 hours of training |
|---|---|---|---|---|---|---|
| Bone mineral density | 1 | | | | | |
| Bone mass | 0.839** | 1 | | | | |
| $\dot{V}O_2$max | 0.502** | 0.495** | 1 | | | |
| Ventilation | 0.426** | 0.404** | 0.326* | 1 | | |
| Ventilation threshold | 0.168 | 0.162 | 0.193 | 0.461** | 1 | |
| Sports injuries per 1,000 hours of training | –0.329* | –0.409** | –0.199 | –0.113 | 0.018 | 1 |

* <0.05; ** <0.01

increased by 1 ($p = 0.010$) (Table 4). For each 0.013 and 0.005 increase in BM, $\dot{V}O_2max$ ($p < 0.001$) and VE ($p = 0.001$) increased by 1. Additionally, for every 0.038 decrease in BM, the incidence of injuries per 1,000 hours of training increased by 1 ($p = 0.001$) (Table 5).

**Table 4.** Simple linear regression between bone mineral density and cardiorespiratory functional capacity, sports injuries

| □ | B | Beta | t | p |
|---|---|---|---|---|
| $\dot{V}O_2max$ | 0.006 | 0.502 | 4.422 | <0.001 |
| Ventilation | 0.003 | 0.426 | 3.581 | 0.001 |
| Sports injuries per 1,000 hours of training | –0.015 | –0.329 | –2.654 | 0.010 |

Dependent variable: bone mineral density.

**Table 5.** Simple linear regression between bone mass and cardiorespiratory functional capacity, sports injuries

| □ | B | Beta | t | p |
|---|---|---|---|---|
| $\dot{V}O_2max$ | 0.013 | 0.495 | 4.338 | <0.001 |
| Ventilation | 0.005 | 0.404 | 3.364 | 0.001 |
| Sports injuries per 1,000 hours of training | –0.038 | –0.409 | –3.409 | 0.001 |

Dependent variable: bone mass.

## Discussion

The current study examined how BMD and BM affect the cardiopulmonary functions and sports injuries in the elite wushu athletes. This information can aid in development of injury prevention programs and enhance athletic performance.

BMD is a crucial factor in improving athletes' performance as it is closely related to injuries and can be used to evaluate early injury diagnosis [15]. Additionally, cardiopulmonary functions are linked to muscle strength and endurance [19], and enhancing an oxygen exchange ability of cardiopulmonary functions increases metabolic and oxidative abilities, thus reducing fatigue [13]. This is an essential factor in evaluating athletes' exercise performance. Lastly, sports injuries are the greatest enemies that adversely affect athletes' performance and their overall health [18]. Therefore, managing BMD, cardiopulmonary capabilities, and sports injuries should be a top priority for athletes.

In this study, it was found that BMD and BM of the elite wushu athletes had the correlated relationship with their cardiopulmonary functions $\dot{V}O_2max$ and VE. This correlation could occur because BMD and BM are closely linked to muscles. Sports activities not only strengthen muscles, but also affect BMD and BM [7]. This is because muscle activity is a significant part of a skeletal system's mechanical load, making muscles closely related to BMD and BM [3]. As a result of muscle strengthening and an increase in BMD and BM, a number and density of capillaries also increase [5]. This facilitates oxygen transfer to mitochondria, thereby increasing efficiency of oxidase and oxygen utilization [5]. Thus, an increase in bone density and muscle strengthening result in an increase in $\dot{V}O_2max$ and VE [16].

In addition, the present study found that sports injuries in the elite wushu athletes were correlated with their BMD and BM. Approximately 70% of bone strength is affected by bone density [4], and a decrease in BMD is commonly associated with a decrease in BM [11]. The current study also found the strong correlation between BMD and BM. When BMD and BM decrease, there is an imbalance in bone mineral absorption and formation, which can increase likelihood of injuries due to changes in a bone tissue microstructure and adverse effects on bones [8]. Moreover, the decrease in BMD also leads to a decrease in muscle strength and muscle mass, resulting in back pain, such as disc injuries [20]. A study by Wren et al. [25] found that BMD at a site where ligament and tendon injuries occurred was lower than at a normal site, and this was lower even years after the injury occurred [23]. Therefore, low BMD and BM can increase an incidence of ligament and tendon injuries, as well as muscle and bone injuries. However, these factors have not been clarified yet. Therefore, additional studies are required to fully understand a relationship between tendon and ligament damage and bone density, as well as effects of reduced bone density after injuries. Meanwhile, Tenforde et al. [22] are concerned that athletes with low BMD are at an increased risk of bone stress injuries and long-term bone health issues, such as osteopenia and osteoporosis, if their bone health is compromised. Therefore, the authors recommended careful assessments of adequate energy availability, calcium, vitamin D, and other nutrients to optimize skeletal health.

## Conclusions

BMD and BM correlated with cardiopulmonary functions such as $\dot{V}O_2max$ and VE. Furthermore, BMD and BM were found to be correlated with sports injuries. For every increase in BMD and BM, $\dot{V}O_2max$ and VE increased. Furthermore, the incidence of injuries per 1,000 hours of training increased for every decrease in BMD and BM. Therefore, systematic management is necessary for BMD and BM to prevent injuries and enhance athletes' performance.

The present study has several advantages. The study on the elite wushu athletes was conducted for one year, monitoring their cardiopulmonary functions, bone density, and sports injuries. The authors ensured accurate data collection by consistently documenting all injuries by sports physicians. Although the study has limitations, such as inability to provide information on training load and unknown unreported injuries and mechanisms. Lastly, it is important to note that the results of this study may not apply to other sports, such as underwater sports, since it was conducted only on wushu athletes.

**Conflicts of Interest**

The authors have no competing interests to declare.

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