The Study of Bone Metabolism Markers in Male College Artistic Gymnasts

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Objective: This study clarified bone turnover at different training intensities based on the annual schedule of a male college artistic gymnastics club.

Methods: For 21 male college artistic gymnasts, bone metabolism markers (bone alkaline phosphatase (BAP), intact procollagen type 1 N-terminal propeptide (P1NP), bone-specific tartrate-resistant acid phosphatase 5b (TRACP-5b), type I collagen crosslinked N-telopeptide in serum (s-NTX), type I collagen crosslinked N-telopeptide in urine (u-NTX)) were measured during three periods: pre-season, with gradually increasing training intensity at the beginning of a competition; competition, when gymnasts compete and train at the highest strength; and training, with lower intensity training after competition. Gymnasts train by practicing their techniques.

Results: Procollagen type 1 N-terminal propeptide, a bone formation marker, showed significantly higher concentration during the competition period (129.4 ± 50.7 μg/l) than during the training period (116.8 ± 47.2 μg/l) (p < 0.01). Also, bone-specific tartrate-resistant acid phosphatase 5b, a bone resorption marker, showed significantly higher concentration during the pre-season (677.2 ± 218.8 mU/dl) and training periods (743.2 ± 231.9 mU/dl) than during the competition period (577.0 ± 203.0 mU/dl) (p < 0.01). Moreover, concentrations were higher during the training period (743.2 ± 231.9 mU/dl) than during the pre-season period (677.2 ± 218.8 mU/dl) (p < 0.05). Results of BAP and s-NTX respectively resembled those of P1NP and TRACP-5b. No significant change was observed in u-NTX.

Conclusion: Bone metabolism marker results suggest that bone formation is dominant when training intensity is higher and strong mechanical stress is placed on bones. Bone resorption is dominant when training intensity is lower and less mechanical stress is placed on bones.

Key words: male college artistic gymnasts, prospective study, bone turnover, TRACP-5b, P1NP

Introduction

Marked technical development has occurred in gymnastics. Performances today must include many increasingly difficult techniques, which are expected to impose ever-increasing physical burdens on artistic gymnasts1) 2). Moreover, bone stress injuries, including stress fractures, persist as an important risk for athletes and coaches. Not a few athletes must suspend training, cancel a competition, or give up a career because of bone stress injuries. The risk of stress fracture is reportedly higher in female athletes with low bone mineral density, an indicator of low bone strength, and who have amenorrhea3). Some athletes can achieve good performance without experiencing stress fracture, irrespective of low bone mineral density. Therefore, it is difficult to predict the onset of stress fracture by bone mineral density alone. It has been reported recently that 70% of bone

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strength is dependent on bone mineral density. The other 30% depends on bone quality (bone metabolism, collagen cross-link) [4]. Moreover, many indicators of change exist in bone mineral density, but the obtained results do not reflect the timely bone conditions at the time of measurement [5, 6]. To prevent stress bone injuries, it is therefore necessary to ascertain bone conditions at a given time to the greatest degree possible.

Bone metabolism markers that have been widely used in preceding studies include bone alkaline phosphatase (BAP) and N-telopeptide cross-link of type I collagen (NTX). However, these indicators present the difficulty that they are affected by exercise, diet, and renal function. Moreover, they show intra-day and inter-day variation [6, 7].

A new bone resorption marker "bone specific tartrate resistant acid phosphatase 5b (TRACP-5b)" shows very little intra-day and inter-day variation and little effect sustained by renal or hepatic function disorder or by diet [6, 10]. Nevertheless, most reports of studies investigating TRACP-5b have examined patients with osteoporosis or postmenopausal women. Few reports describe studies that have examined athletes in Japan or overseas.

The usefulness of intact procollagen type I N-terminal propeptide (P1NP) as a bone formation marker has also been reported recently [11-17]. Actually, P1NP is an elongated monomer or trimer protein with molecular weight of 35,000 that is present in blood. After procollagen type I is synthesized in osteoblasts and is excreted extracellularly, it is incorporated into collagen fiber as type I collagen. During that time, the cleaved C-terminal propeptide (P1CP) and N-terminal propeptide (P1NP) are released into the blood [16, 19]. Most of these propeptides derive from bone tissue. Therefore, their usefulness as bone formation markers has been confirmed [18, 19]. Particularly, P1NP is regarded as a useful bone formation marker [11-17] that indicates bone formation at a stage earlier than bone alkaline phosphatase (BAP), which has been used widely in preceding studies because P1NP is produced during the formation of type I collagen [18, 19]. Nevertheless, no report in the literature has described studies of P1NP in athletes.

This study was conducted to clarify bone turnover in periods of different training intensity based on the annual schedule of a male college artistic gymnastics club. It was expected to yield valuable data to support suggestions for coaching gymnastics.

Methods

1. Participants

This study examined 21 male college artistic gymnasts of Juntendo University. Their club, which shows a very high level of achievement, includes a Japan national team member of the 2012 London Olympics and one of the 2014 World Gymnastics Championships. The subject population also includes event winners of the All-Japan Artistic Gymnastics Championships and many high-ranking athletes in all-Japan championship-level competitions. They can be regarded as a top-level athlete population in Japan. This study was conducted with the approval of the Ethics Committee of Juntendo University. All participants were informed of the objective, contents, and precautions of the study, after which they gave their written consent to participation.

2. Parameters and methods

Measured parameters in this study were body composition, bone strength, and bone metabolism markers in urine (type I collagen crosslinked N-telopeptide in urine (u-NTX)) and blood samples (BAP, P1NP, TRACP-5b and type I collagen crosslinked N-telopeptide in serum (s-NTX)) as described below. Participants observed dietary restrictions for 12 hr before blood collection.

3. Experimental design

Measurements were taken in three periods: the pre-season period, when training intensity is gradually increased at the beginning of a competition period (April); the competition period, when gymnasts participate in competitions and the training program intensity and training strength are the highest (July); and the training period, when the competition period is over, training intensity is lower, and training is done to improve their techniques (January) (Figure-1).

1) Bone strength evaluation

Using a quantitative ultrasonic analyzer (AOS-100; Aloka Co. Ltd., Tokyo), the Osteo-sono assessment index (OSI) of the right calcaneus was
measured as an indicator of bone strength. OSI was measured by fixing with an oscillator with subsequent transmission and reception of a low-frequency pulse wave at a center frequency of 0.5 MHz, with calculation \( \text{SOS}^2 \times \text{TI} \) from the speed of sound \( \text{SOS} \) after passing the calcaneus and the transmit index \( \text{TI} \). The value to set the indicator (Z score) using the mean OSI of the same age designated as 100 and the standard deviation 1SD were calculated simultaneously.

2) Bone metabolism markers

Bone metabolism markers were measured in blood and urine. Blood was collected during 7:30 A.M. to 9 A.M. Urine was collected from the second urination of the morning. The measured bone formation markers were bone alkaline phosphatase (BAP) and intact procollagen type I N-terminal propeptide (P1NP). Actually, BAP was measured using CLESA (Access ostase; Beckman Coulter Inc., Tokyo, Japan). P1NP was measured using RIA (Procollagen Intact P I NP; Fujirebio Inc. Tokyo, Japan) in units of micrograms per liter. Bone-specific tartrate-resistant acid phosphatase 5b (TRACP–5b), type I collagen crosslinked N-telopeptide in serum (s–NTX), and type I collagen crosslinked N-telopeptide in urine (u–NTX) were measured as bone resorption markers. TRACP–5b was measured using EIA (Osteorinse; DS Pharma Biomedical Co. Ltd. Osaka, Japan) in units of milli-units per deciliter. In addition, s–NTX was measured using ELISA (OSTEOMARK NTx Serum; Alere Medical Co. Chiba, Japan) in units of nanomoles of BCE per liter. u–NTX was measured using ELISA (Osteomark; Alere Medical Co., Chiba, Japan). For u–NTX, the creatinine equivalent was used for analysis to exclude the kidney effects. The unit used was nanomoles of bone collagen equivalents (BCE) per millimoles of creatinine (CRE). Measurement of the bone metabolism markers was conducted by the Health Sciences Research Institute, Inc.

3) Body composition

Height was measured using a height meter (YG-200; Yagami Inc.). Participants were measured with the back, buttocks, and heels touching the meter, keeping the eye-ear plane horizontal.

Weight and body fat percentages were measured (InBody430; Biospace Co. Ltd.). Subjects mounted the meter. Then they input their age, height, and sex to the meter. After taking a measurement position, they were measured.
4) Statistical analysis

All values are shown as mean±standard deviation. Statistical analysis software (IBM SPSS ver. 22.0; IBM Corp. Armonk, NY) was used. One-way repeated measures ANOVA was performed, followed by a multiple comparison test (Tukey method) for comparison of the three periods: pre-season, competition, and training. Unless stated otherwise, significance was inferred for \( p < 0.05 \).

Results

1. Physical characteristics

Physical characteristics of the 21 participants are presented below: (i) pre-season period (age 19.5±1.1 years, height 164.2±4.8 cm, weight 59.2±4.9 kg, body fat percentage 8.7±2.1%, BMI 21.9±1.3 kg/m\(^2\)); (ii) competition period (age 19.7±1.1 years, height 164.3±4.8 cm, weight 58.5±4.9 kg, body fat percentage 8.1±2.0%, BMI 21.7±1.3 kg/m\(^2\)); and (iii) training period (age 20.2±1.1 years, height 164.5±4.9 cm, weight 59.4±4.9 kg, body fat percentage 9.6±2.7%, BMI 21.9±1.3 kg/m\(^2\)).

2. Bone strength

Table 1 presents the mean and the standard deviation of the Osteo-sono assessment index (OSI), OSI (Z score) (Z score of osteo-sono assessment: percentage to mean strength of the same age), and the transmit index (TI). For strength, no significant difference was found between the pre-season period, the competition period, and the training period. However, the mean OSI (Z score) of all participants was assessed as greater than 120% during all periods, showing that the subject population had higher strength than the same age population.

3. Bone metabolism markers

Table 2 presents the bone metabolism markers. In addition, BAP, a marker of bone formation, was significantly higher during the competition period than during the pre-season period or training period (\( p < 0.01 \)). No significant difference was found between the pre-season period and the competition period. P1NP was significantly higher during the competition period than during the training period (\( p < 0.05 \))(Figure-2). No significant difference was found between the pre-season period and the competition period, or between the pre-season period and the training period.

Serum NTX (s-NTX), a marker of bone resorption, was significantly higher during the pre-season period.

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Table 1  Comparison of bone strength at the calcaneus measured by quantitative ultrasonic analyzer among each period

<table>
<thead>
<tr>
<th></th>
<th>Pre-season period</th>
<th>Competition period</th>
<th>Training period</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSI ( \times 10^{-6} )</td>
<td>3.7±0.5</td>
<td>3.7±0.6</td>
<td>3.7±0.5</td>
<td>NS</td>
</tr>
<tr>
<td>Z Score %</td>
<td>120.1±18.1</td>
<td>121.0±19.3</td>
<td>121.2±16.8</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, non-significance

Table 2  Comparison of the bone metabolism markers among each period

<table>
<thead>
<tr>
<th></th>
<th>Pre-season period</th>
<th>Competition period</th>
<th>Training period</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAP ( \mu g/l )</td>
<td>25.0±10.3</td>
<td>23.5±8.2</td>
<td>19.5±16.9</td>
<td>PP, CP&gt;TP**</td>
</tr>
<tr>
<td>PINP ( \mu g/l )</td>
<td>129.0±50.5</td>
<td>129.4±50.7</td>
<td>116.7±47.1</td>
<td>CP&gt;TP</td>
</tr>
<tr>
<td>s-NTX amolBCE/l</td>
<td>27.2±7.1</td>
<td>24.6±5.2</td>
<td>28.1±6.0</td>
<td>PP&gt;CP*, TP&gt;CP**</td>
</tr>
<tr>
<td>u-NTX amolBCE/mmol-CRE</td>
<td>89.9±47.5</td>
<td>90.0±59.3</td>
<td>75.7±39.9</td>
<td>NS</td>
</tr>
<tr>
<td>TRACP-5b mU/dl</td>
<td>677.1±218.7</td>
<td>577.0±202.9</td>
<td>743.2±231.9</td>
<td>PP, TP&gt;CP**, TP&gt;PP*</td>
</tr>
<tr>
<td>BAP/TRACP-5b</td>
<td>3.7±1.1</td>
<td>4.3±1.6</td>
<td>2.8±1.7</td>
<td>(CP&gt;PP*, PP&gt;TP*, CP&gt;TP**</td>
</tr>
<tr>
<td>BAP/s-NTX</td>
<td>92.3±26.7</td>
<td>95.0±25.4</td>
<td>69.1±18.2</td>
<td>PP, CP&gt;TP**</td>
</tr>
<tr>
<td>BAP/u-NTX</td>
<td>30.9±9.7</td>
<td>31.1±11.8</td>
<td>27.9±7.9</td>
<td>NS</td>
</tr>
<tr>
<td>PINP/TRACP-5b</td>
<td>19.3±5.2</td>
<td>23.2±7.0v</td>
<td>16.4±6.9</td>
<td>CP&gt;PP, PP&gt;TP**, PP&gt;TP*</td>
</tr>
<tr>
<td>PINP/s-NTX</td>
<td>475.6±127.6</td>
<td>517±125.5</td>
<td>413±132.7</td>
<td>PP&gt;TP*, CP&gt;TP**</td>
</tr>
<tr>
<td>PINP/u-NTX</td>
<td>159.9±46.0</td>
<td>167.9±55.9</td>
<td>163±46.6</td>
<td>NS</td>
</tr>
</tbody>
</table>

** \( p < 0.01 \), * \( p < 0.05 \), NS: non-significance
period than during the competition period ($p<0.05$). It was significantly higher during the training period than during the competition period ($p<0.01$). No significant difference was found between periods for urine NTX (u-NTX). Results show that TRACP-5b was significantly higher during the pre-season period and the training period than during the competition period ($p<0.01$). It was significantly higher during the training period than during the pre-season period ($p<0.05$) (Figure-3).

Moreover, regarding the relation between bone formation markers and bone resorption markers, no significant difference was found in any item (BAP/u-NTX and P1NP/u-NTX) related to urine NTX (u-NTX), although comparison of the bone formation marker BAP and the bone resorption marker TRACP-5b (BAP/TRACP-5b) revealed that the latter was significantly higher during the competition period than during the training period ($p<0.05$) (Figure-4). Comparison of the bone formation marker P1NP and the bone resorption marker TRACP-5b (P1NP/TRACP-5b) were significantly higher during the competition period than during the pre-season period or the training period ($p<0.01$). They were significantly higher during the pre-season period than during the training period ($p<0.05$) (Figure-4). Comparison of the bone formation marker P1NP and the bone resorption marker s-NTX (P1NP/s-NTX) revealed that they were significantly higher during the pre-season period than during the training period ($p<0.05$), and were significantly higher during the competition period than during the training period ($p<0.01$).

**Discussion**

For this study, we performed strength measurements, urine NTX analysis by urine collection, and bone metabolism analysis with blood samples (bone resorption markers TRACP-5b and s-NTX, and bone formation markers P1NP and BAP) of male college artistic gymnasts during the annual training schedule divided into major periods.

Results show that concentrations of bone formation marker P1NP were significantly higher during the competition period ($129.4\pm50.7 \, \mu g/l$) than during the training period ($116.8\pm47.2 \, \mu g/l$). It was also significantly higher during the competition period than during the pre-season period ($p<0.05$), and was higher during the pre-season period than during the training period ($p<0.05$). Bone formation marker BAP and bone resorption marker s-NTX (BAP/s-NTX) were both significantly higher during the pre-season period. Moreover, the bone formation marker P1NP and the bone resorption marker TRACP-5b (P1NP/TRACP-5b) were significantly higher during the competition period than during the pre-season period or the training period ($p<0.01$). They were significantly higher during the pre-season period than during the training period ($p<0.05$) (Figure-4). Comparison of the bone formation marker P1NP and the bone resorption marker TRACP-5b (P1NP/TRACP-5b) revealed that they were significantly higher during the pre-season period than during the training period ($p<0.05$), and were significantly higher during the competition period than during the training period ($p<0.01$).
was also shown in the previous study of Hirota et al. BAP and P1NP showed the similar tendency, which study found no significant difference in urine NTX bone metabolism markers in urine as samples blood samples show less intra-day variation than intra-day variation in serum NTX (s-NTX) although one report describes the existence of intra-day variation in serum NTX (s-NTX) similarly to urine NTX (u-NTX)²³. In fact, our study found no significant difference in urine NTX (u-NTX). As a result of controlling exercise and food intake of the day before blood sampling and carefully managing the timing of blood sampling, there was no major difference in the results of TRACP-5b and s-NTX. It was suggested that these markers shows similar results in strictly controlled conditions; however, it is not always possible to strictly control the conditions in practical situations. Therefore, a new bone resorption marker, TRACP-5b, was used as a main indicator of bone resorption for comparison and discussion.

Moreover, the marker showed higher values than the standard for ordinary adult men of the same age, indicating enhanced bone turnover compared to that of ordinary people. No clear change was observed in strength throughout the year, but it has been reported from earlier studies that the bone mineral density of female artistic gymnasts is higher than that of athletes in other sports (cross-country, swimming racing, and athletics) and of women who do not exercise.²⁰ ²¹ Moreover, it is estimated based on the results presented above that the strength of male artistic gymnasts is higher than that of athletes in other sports.

As described earlier, BAP, which has been used widely in earlier studies, is an excellent bone formation marker.¹⁷ However, PINP was also measured in this study because of its usefulness. It has attracted attention recently because it is particularly sensitive. Moreover, its intra-day and inter-day variations are smaller,¹⁷ our results of Bap and PINP showed the similar tendency, which was also shown in the previous study of Hirota et al.²² Therefore, PINP was used as a main indicator of bone formation for comparison and discussion.

Problems related to the characteristics of the existing bone resorption marker NTX have been pointed out in earlier studies by Miki et al. showing that the bone resorption marker NTX, which has been used most frequently, exhibits notable intra-day and inter-day physiological variations attributable to the effects of diet and hormones, etc., and that care should be taken in the interpretation of observations over time.⁹ In addition, Mochizuki et al. described that bone metabolism markers in blood samples show less intra-day variation than bone metabolism markers in urine as samples,⁹ although one report describes the existence of intra-day variation in serum NTX (s-NTX) similarly to urine NTX (u-NTX)²³. In fact, our study found no significant difference in urine NTX (u-NTX). As a result of controlling exercise and food intake of the day before blood sampling and carefully managing the timing of blood sampling, there was no major difference in the results of TRACP-5b and s-NTX. It was suggested that these markers shows similar results in strictly controlled conditions; however, it is not always possible to strictly control the conditions in practical situations. Therefore, a new bone resorption marker, TRACP-5b, was used as a main indicator of bone resorption for comparison and discussion.

Results show that bone strength was evaluated as higher than 120% in the Z score of the Osteo-sono assessment index compared to ordinary adult men, indicating that these study participants have high bone strength. Higher bone turnover than the standard of ordinary adult men was high in all periods, indicating high bone resorption and bone formation, indicating a high-turnover type bone turnover (coupling). Bone formation was enhanced and bone resorption was suppressed (bone formation-dominant coupling) during the competition period, when the training program and training intensity are highest and when strong mechanical stress is applied to bones (Figure-4). However, bone formation was suppressed and bone resorption was enhanced during the training period, when each technique is emphasized individually for training to learn new techniques and to improve others. Therefore, training intensity is lower and mechanical stress is applied to bones less frequently (bone resorption-dominant coupling).

An earlier report described that participants who perform exercise in which strong mechanical stress is applied, such as jumping actions, had higher bone mineral density.²¹ It has also been reported that bone formation was enhanced, although bone resorption was not changed, by regular exercise in which strong mechanical stress, such as jumping actions, was applied²⁵. Results demonstrated that bone mineral density is low in participants, such as long distance runners, who did exercises in which only a small load was applied repeatedly.²⁰ ²⁷ Additionally, accumulation of microdamage caused by repeated loads on bones reportedly enhances bone resorption.²⁸ From these points, one can infer that strong mechanical stress greater than a predetermined level is necessary to enhance bone formation, although bone resorption might be
enhanced when small external force is applied repeatedly by the gradual accumulation of micro-damage because mechanical stress that is sufficiently strong to enhance bone formation is not applied. This fact is reflected in the results of this study. Strong mechanical stress to bones caused by high training intensity enhanced bone formation, but bone resorption was enhanced by the repeated application of mild mechanical stress during training at lower training intensity, even in participants who were high-level gymnasts. Moreover, because bone remodeling occurs rapidly in high turnover type coupling, the possibility cannot be denied that bone strength decreases faster than in ordinary people because bone resorption-dominant coupling continues.

Unfortunately, one participant sustained a stress fracture in the left tibia during the study period. This participant experienced a complete open fracture of the lower left leg even though he had pushed off in a normal reasonable position in a combination part of successive elements (successive salto) during floor exercises of the Tokyo Representative Selection Competition held in June 2014 for the National Sports Festival. The bone turnover of this participant showed bone resorption-dominant coupling with both bone formation and bone resorption similar to the value of the mean of all participants in the training period, although bone formation was enhanced and bone resorption was suppressed in other participants in the pre-season period compared to the training period (Table-3) (Figure-5). These results suggest that this participant had a stress fracture of the lower left leg in which one factor was the absence of a change to bone formation-dominant bone turnover (coupling) although the pre-season period had begun, leading to a complete open fracture of the lower left leg even though he had pushed off in a normal reasonable position.

Table-3 Comparison of bone metabolism markers between a subject with open fracture and subjects without fracture in pre-season period

<table>
<thead>
<tr>
<th></th>
<th>Subjects without fracture (n=21)</th>
<th>A subject with open fracture (n=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAP μg/l</td>
<td>25.0±10.3</td>
<td>20.5</td>
</tr>
<tr>
<td>P1NP μg/l</td>
<td>129.0±50.5</td>
<td>98.7</td>
</tr>
<tr>
<td>s-NTX nmolBCE/l</td>
<td>27.2±7.1</td>
<td>28.4</td>
</tr>
<tr>
<td>u-NTX nmolBCE/mmol・CRE</td>
<td>89.9±47.5</td>
<td>69.7</td>
</tr>
<tr>
<td>TRACP-5b mU/dl</td>
<td>677.1±218.7</td>
<td>808.0</td>
</tr>
<tr>
<td>BAP/s-NTX</td>
<td>92.3±26.7</td>
<td>72.2</td>
</tr>
<tr>
<td>BAP/u-NTX</td>
<td>30.9±9.7</td>
<td>29.4</td>
</tr>
<tr>
<td>BAP/TRACP-5b</td>
<td>3.7±1.1</td>
<td>2.5</td>
</tr>
<tr>
<td>P1NP/s-NTX</td>
<td>475.6±127.6</td>
<td>347.5</td>
</tr>
<tr>
<td>P1NP/u-NTX</td>
<td>159.9±46.0</td>
<td>141.6</td>
</tr>
<tr>
<td>P1NP/TRACP-5b</td>
<td>19.3±5.2</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Figure-5 Comparison of P1NP, TRACP-5b and P1NP/TRACP-5b value between a subject with open fracture and mean of subjects without fracture in pre-season period.
Therefore, based on practical results of an athlete who actually sustained a stress fracture and sustained a complete open fracture as described above, the need exists to survey bone turnover regularly as a duty of coaching gymnastics. Particularly, it is important to devote attention to changes in bone metabolism markers when the training period with lower training intensity changes to a pre-season period, when training intensity increases at the beginning of the competition period. Appropriate measures must be taken based on the results, such as reviewing the training amount and training program as well as investigation and consideration of the nutrient intake situation.

Particularly for TRACP-5b obtained as a result of this study, correlation with other bone metabolism markers and standard values has been demonstrated. Moreover, the difference from existing bone metabolism markers and the usefulness of this measurement method have been reported^{10, 29}. For P1NP, its usefulness has also been described in a report of an earlier study as the most sensitive marker in recent years^{30}. It also showed more accurate bone metabolism than the other markers examined in this study. Therefore, this report is the first to describe the relation of P1NP and TRACP-5b with periods divided by exercise intensity in male artistic gymnasts at a high performance level.

Based on observations obtained in this study, P1NP and TRACP-5b sensitively reflect bone turnover. They are likely to be useful as bone metabolism markers. They can be regarded as extremely useful indicators for the prevention of stress bone injuries and for conditioning in situations not only of gymnastics but also of other sports in the future, although it is necessary to consider sex differences, age, and subdivision of the performance level.

The results for male college artistic gymnasts presented above demonstrated that bone formation-dominant bone turnover occurred during when training intensity was high and strong mechanical stress is applied to bones. Training intensity bone resorption-dominant bone turnover occurred when the training intensity was lower and less mechanical stress was applied to bones.

Conflict of Interest

The authors declare that they have no conflict of interest related to this study or this report.

References