Exercise habits during high school days and calcaneal bone density in college students

Yoshio Kobayashi¹, Teruo Hosoi¹, Toshiko Takeuchi¹, Takayuki Nakao¹ and Yasuo Arai²

The Laboratory for Health and Human Performance, School of Arts & Sciences, Chukyo University¹, and The Department of Child Education, Nagoya Women's University²

ABSTRACT

Exercise has important effects on skeletal mineralization. Changes in bone stiffness as measured by ultrasound densitometry were investigated in 514 university students (236 males and 278 females). The subjects were divided into the following three groups; 1) those who participated in sport-club activity during both junior and senior high school days (6A), 2) those who participated in sport-club activity during either junior or senior high days (3A), and those who experienced no regular physical activities during high school days (NA). In males, bone stiffness was 11.4 and 16.5% higher (P<0.001) in the 6A than in the 3A and NA, respectively. The corresponding value for females was 13 and 16.8% (P<0.001), respectively. A significant difference (P<0.05) was also found between the 3A and NA in both male and female subjects. The same tendency was found in the muscle strengths of knee extensors. However, a significant correlation between the bone stiffness and the muscle strength was found in only females but not in males. Higher values were seen in soccer, track & field, and Judo athletes while lower values were in Kendo and swimming athletes. These data indicate that athletes involved in sports producing significant impact loading on the skeleton had greater bone stiffness, than athletes in sports producing loads to bone primarily through
muscular contraction. The present study clearly demonstrated that habitual physical activity during growth and adolescence is important in maximizing adults peak bone mass which is an important means of minimizing the future risk for significant osteoporosis.

Osteoporosis is a major community health problem affecting up to half of the elderly female population not only in this country but also in most Western countries\(^{(34)}\). While the postmenopausal state is considered to be a major factor, decreased physical activity has been reported to be significantly related to the development of osteoporosis\(^{(25)}\). Numerous reports\(^{(3, 27, 29)}\) indicate that physical activity is positively related to bone mineral density (BMD) and may, therefore, be an important factor in the prevention or treatment of osteoporosis.

Maximizing adult peak bone mass has been proposed as a means of minimizing the future risk for significant osteoporosis and / or osteoporotic fracture\(^{(32)}\). Studies of bone growth and development have therefore been initiated to monitor changes in BMD, bone mineral content, and longitudinal bone growth in immature subjects to determine what factor, if any, are important for optimal skeletal maturation\(^{(1, 5, 9)}\). One factor of particular interest has been the influence of childhood physical activity on skeletal maturation. If physical activity is an important determinant of bone mass, habitual physical activity performed during their school days and before adult peak bone mass is reached, is very important.

The use of ultrasound for assessing skeletal fragility has received significant attention in recent year, because the measurement has several potential advantages, including relatively low cost, no need for ionizing radiation, compact size, and ease of use. Consequently the ultrasonic measurement of bone has been suggested as an alternative method of assessing bone\(^{(10, 15)}\).

The primary purpose of this investigation was to evaluate the effects of habitual exercise during high school ages on bone stiffness which has a significant positive correlation to bone mineral content,
on the os calcis in both male and female college students. Isokinetic muscular strength was also evaluated as an indicator of habitual activity.

**MATERIAL AND METHODS**

*Source population*

The subjects recruited for this study were healthy students from Chukyo University and Nagoya Women's University. A total of 514 students (236 males and 278 females) volunteered in this study. Those subjects were classified into the following three groups based on their physical activity experiences:

- **Group I:** The subjects participated in sports club(s) throughout their 6-year high school days (6A);
- **Group II:** The subjects participated in sports club(s) either in junior high or in senior high days (3A); and
- **Group III:** The subjects had no experience of regular sport activities throughout their 6-year high school days (NA).

Regarding the 3A group, very limited subjects participated in sport club(s) in senior high school days, but most of the subjects belonged to the club(s) only in junior high school days.

*Bone mineral density measurements*

The Achilles ultrasound densitometer (Lunar Corporation, Madison, WI) was used for the determination of BMD. The system consists of two 2.54 cm diameter, unfocused transducers, mounted coaxially approximately 8.5 cm apart. Acoustic coupling is accomplished by submerging the transducer pair and the heel into a water bath maintained at 35°C, with surfactant to make the foot wet. One transducer acts as the transmitter and the other as the receiver. The subject's heel is positioned on the foot support plate. The heel is then positioned between the transducers, with the ultrasound beam propagating laterally through the center of the os calcis.
Broadband ultrasound attenuation (BUA) and Speed of Sound (SOS) were measured. A third parameter, termed Stiffness, was calculated by computer (20). This index, a combination of BUA and SOS expressed in percentage of young adults (% T-score), was established by Lunar and should not be confused with the biomechanical term defined by specialists of biomechanics.

*Isokinetic strength*

To clarify the effects of habitual physical activity on their fitness levels, isokinetic strength of the quadriceps muscle was assessed for the same leg as used for the bone density measurement with a CYBEX 330 Extremity System (Division of Lumex, Inc, NY) in 217 students (114 males and 103 females). Maximal voluntary contractions at 120, 180, and 240° s⁻¹ were measured for knee extension. Straps were used to immobilize the upper body and a knee brace for maximum stabilization clamped over the distal third of the quadriceps. The subjects grasped handles on the sides of seat and the command “ready-set-go” was used for each contraction. Subjects were instructed to perform each movement as fast and as hard as possible upon hearing “go”. At each test speed, four submaximal repetitions were performed for familiarization, followed by a 15-s rest concluding with three recorded maximum extension-flexion repetitions. Sixty-second rest was allowed between each measurement. Gravity effect torque was corrected for all subjects as indicated by the manufacturer. Measurements of peak torque (highest value during three repetitions) and total work (repetition which produced the greatest work) were used to evaluate isokinetic strength.

*Statistical analysis*

Statistical analyses of data were performed using analysis of variance (ANOVA) with repeated measures. When significant differences occurred among the means, a Scheffe post-hoc analysis was utilized to determine which groups were different.
RESULTS

Characteristics of the study groups are shown in Table 1. The average age of male participants was 19.1, 18.9, and 18.9 years old for the 6A, 3A, and NA groups, respectively. The corresponding values of female subjects were 19.6, 19.6, and 19.7 years old, respectively. In the male subjects, there was no significant difference in age, height, mass, and BMI while female subjects demonstrated that the 6A group was significantly greater than the NA group in height (P<0.05); and was greater than the 3A and NA groups in mass (P<0.01) and BMI (P<0.05).

Table 1. Physical characteristics of three groups in male and female

<table>
<thead>
<tr>
<th>Group</th>
<th>6A</th>
<th>3A</th>
<th>NA</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>(N=110)</td>
<td>(N=64)</td>
<td>(N=62)</td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>19.1 (1.1)</td>
<td>18.9 (1.1)</td>
<td>18.9 (1.1)</td>
<td>NS</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>60.2 (6.5)</td>
<td>60.3 (8.3)</td>
<td>62.0 (6.1)</td>
<td>NS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.3 (5.1)</td>
<td>169.9 (5.9)</td>
<td>169.2 (6.8)</td>
<td>NS</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>20.5 (1.9)</td>
<td>20.9 (2.6)</td>
<td>21.4 (2.5)</td>
<td>NS</td>
</tr>
<tr>
<td>Female</td>
<td>(N=112)</td>
<td>(N=72)</td>
<td>(N=94)</td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>19.6 (1.1)</td>
<td>19.6 (1.3)</td>
<td>19.7 (1.0)</td>
<td>NS</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>53.0 (5.3)</td>
<td>50.4 (7.4)</td>
<td>50.7 (5.7)</td>
<td>6A : 3A, NA**</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>159.3 (5.3)</td>
<td>158.9 (4.7)</td>
<td>157.4 (4.4)</td>
<td>6A : NA*</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>21.0 (2.0)</td>
<td>20.2 (1.5)</td>
<td>20.4 (2.1)</td>
<td>6A : 3A, NA*</td>
</tr>
</tbody>
</table>

Data are presented as means (SD)

BMI = body mass index

6A, 3A, and NA denote athletes during high school days, athletes during either junior or senior high school days, and non-athletes during high school days, respectively.

*P<0.05  **P<0.01  NS = no significant

Table 2 presents calcaneal ultrasonic measurements in the three groups. All ultrasound parameters were significantly lower in the 3A and NA groups than in the 6A groups (BUA, SOS, and Stiffness: P<0.001). A statistical difference was also found between the 3A and NA groups (P<0.05). In the male subjects, stiffness was 11.4 and 16.5%
Table 2. SOS, BUA, and stiffness values on the os calcis in male and female for three groups

<table>
<thead>
<tr>
<th>Group</th>
<th>6A (N=110)</th>
<th>3A (N=64)</th>
<th>NA (N=62)</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOS (m/sec)</td>
<td>1586 (31)</td>
<td>1561 (28)</td>
<td>1548 (25)</td>
<td>6A : 3A, NA*** 3A : NA*</td>
</tr>
<tr>
<td>BUA (dB/MHz)</td>
<td>126 (10)</td>
<td>122 (9)</td>
<td>119 (8)</td>
<td>6A : NA***, 6A : 3A** 3A : NA*</td>
</tr>
<tr>
<td>STIFFNESS</td>
<td>108.2 (14.3)</td>
<td>97.2 (11.5)</td>
<td>93.8 (11.6)</td>
<td>6A : 3A, NA*** 3A : NA*</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOS (m/sec)</td>
<td>1575 (34)</td>
<td>1559 (27)</td>
<td>1548 (27)</td>
<td>6A : NA***, 6A : 3A** 3A : NA**</td>
</tr>
<tr>
<td>BUA (dB/MHz)</td>
<td>121 (11)</td>
<td>115 (8)</td>
<td>113 (7)</td>
<td>6A : 3A, NA*** 3A : NA**</td>
</tr>
<tr>
<td>STIFFNESS</td>
<td>101.9 (14.5)</td>
<td>93.2 (11.2)</td>
<td>89.1 (11.3)</td>
<td>6A : 3A, NA*** 21.0 (2.0) 20.2 (1.5) 20.4 (2.1) 3A : NA*</td>
</tr>
</tbody>
</table>

Data are presented as means (SD). SOS = sound of speed; BUA = broadband ultrasound attenuation. 6A, 3A, and NA denote athletes during high school ages, athletes during either junior or senior high school days, and non-athletes during high school days. *P < 0.05, **P < 0.01, ***P < 0.001

higher in the 6A group than in the 3A and NA groups, respectively. The corresponding value for the female subjects was 13 and 16.8%, respectively.

The effects of body mass, height, and BMI on ultrasound values were compared. In both sexes, no significant correlations were found between body sizes and any bone measurements.

Isokinetic muscle strengths of quadriceps are presented in Figs. 1 and 2. Each of the correlation coefficients for the peak torque to total work relationship was greater than $r=0.90$ ($P<0.01$). In the male subjects, the 6A group was significantly greater ($P<0.05-0.01$) in peak torque than both the 3A and NA groups at all test speeds except for the speed of $240\text{\,s}^{-1}$. No significant difference was found between the 3A and NA groups. In the female subjects, on the other
Fig. 1. Knee extension peak torque. Values are means ± SD. *A, *B, and *C indicate a significant difference between the 6A and 3A or NA with $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

Fig. 2. Knee extension total work. Values are means ± SD. *A, *B, and *C indicate a significant difference between the 6A and 3A or NA with $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.
Fig. 3-A. Relationship between bone stiffness on the os caalcis and level of peak torque of the knee extensors tested at test speed of 120°s⁻¹.

(Male)

hand, the values of peak torque in the 6A group were significantly greater (P<0.001) at all test speeds than in both the 3A and NA groups. Again no difference was found between the 3A and NA groups. Comparisons among the groups in both males and females for total work (Fig. 2) indicated that significant greater values (P<0.05–0.001) at all angular velocities tested were found in the 6A group than in the other two groups. As with the peak torque results, there was no significant difference between the 3A and NA groups.

The relationship between bone stiffness and quadriceps strength as tested by the peak torque at 120°s⁻¹, is shown in Figures 3-A (male) and 3-B (female). No significant correlation coefficient (r=0.14) was seen in the male groups while bone stiffness was significantly
Fig. 3-B. Relationship between bone stiffness on the os calcis and level of peak torque of the knee extensors tested at test speed of 120°s⁻¹. (Female) positively correlated with quadriceps muscle strength in the female groups (r=0.40, P<0.01). The regression equation was: bone stiffness = 74.39 + 0.26 (peak torque) at a test speed of 120°s⁻¹.

In Fig. 4, bone stiffness on the os calcis in the 6A are shown for various sport activities. Among the male subjects, the top three sports with the highest values were demonstrated by track and field, soccer, and tennis; and track and field, Judo, and basketball among the female subjects. The lowest values for male and female subjects were seen in Kendo and swimming, respectively.
Fig. 4. Bone stiffness on the os calcis of various athletes as a percent of nonathlete controls (shown as 100%).

DISCUSSION

In general, there is a high correlation of ultrasound variable with BMD in vitro\(^{21,35}\) and in vivo\(^{30,37}\). Ultrasound seems capable of giving information not only on density but also on architecture and elasticity\(^{16,19}\). Speed of Sound (SOS) represents the velocity of ultrasound transmission through the bone, and is influenced not only by bone density but also by trabeculae quantity, spacing, and orientation. Many studies in which ultrasound bone densitometer was used to discriminate between normal and osteoporotic subjects, generally show that BUA is significantly lower in osteoporotic subjects than in normal age-adjusted subjects. The Achilles densitometer has been shown to provide good precision (\(<2\%\)) in adults\(^{7,83}\).

The purpose of this study was to determine the effect of habitual physical activity during high school days on the os calcis of college students. In both male and female, the highest values of all ultrasonic
parameters including stiffness, SOS and BUA were observed in the 6A group. Furthermore, we found that the magnitude of an increase in bone mass was clearly influenced by the time spent in sport activities during high school days (6A > 3A > NA in bone stiffness as shown in Table 2). In the present study the bone stiffness of the 6A group was greater by 16.5 and 14.4% in male and female, respectively than the NA group. However, there is considerable variation in the magnitude and significance of the differences observed between athletes and non-athletes depending on the age, sex, type of sports and training, and bone site under investigation. Some of the studies of young men have shown differences extending above 40%\(^{(18,36)}\).

The 6A groups in both male and female also demonstrated the highest values in muscle strengths of the knee extensors as compared to the 3A and NA groups (Figs. 1 and 2). The results may suggest that BMD is a function of muscle strength; and are consistent with the findings of previous studies\(^{(1,2,26,31)}\). Cross-sectional studies\(^{(4,11)}\) which had measured BMD of the lumbar spine, and other parts of the body including calcaneus in young female athletes, showed that BMDs were found to be approximately 9 to 26% higher in young female weightlifters than in endurance athletes and control individuals. Young weight-trained males similarly have greater femoral and spinal bone mineral densities than do runners and control individuals\(^{(2,15)}\). Thus, muscle activities through heavy loading to bone is associated with an elevated BMD, inferring a bone formation response to high strain magnitudes, that is, the direct action of muscle pulling on bone. This theory can be clearly supported by the finding that male swimmers, who were not engaged in any other type of training (i.e. weight training), were found to have greater lumbar spine and radial BMD than nonexercising males\(^{(24)}\). The higher bone densities would have to be attributed to the effects of muscle pull.

Although a significant positive correlation was found between bone stiffness and peak torque of the knee extensors (120° s\(^{-1}\) of test speed) in females, no such relation\((r = 0.14)\) was found in male subjects as shown in Figs. 3-A and-B. Furthermore, no significant differences were found between the 3A and NA groups in either peak torque nor
total work of the knee extensors of both male and female subjects (Figs. 1 and 2). These findings in the present study suggest another factor(s) influencing the elevated bone stiffness in the athlete groups. One of those factors which were effective on bone mineralization appear to be related to the mechanical stresses applied. Previous cross-sectional studies involving tennis players have demonstrated cortical hypertrophy and increased BMD in the playing arms\(^{12,14}\). Other studies have shown increased BMD in the os calcis of runners\(^{38}\), and the lumbar spine of weightlifters\(^{6}\). In the present study, we used the calcaneus as the measurement site. The force imposed on the calcaneus are highly correlated to the level of force of the ground reaction force (GRF\(_z\)). It is without doubt that the athletes in the 6A groups more frequently experienced the greater GRF\(_z\) through various sports activities during the high school days.

Fig. 4 shows comparisons of bone stiffness of athletes to that of the nonathlete control group. Athletes have higher values than their less active peers. Swimming, nonweight-bearing activity and male Kendo are the exception. The results support the concept that the dominant factor in daily physical activity relating to bone mineral density is the participation in site specific high load activities, i.e., for the calcaneus, high calcaneal loads. The difference between the athletic and sedentary groups varies depending on the type of activity. Weight-bearing activities (in the presence of gravitational forces) have generally been considered to have a positive influence on bone health. In particular, activities such as running and landing from a jump which generate external loads on the human body of between 3–5 times body weight\(^{8,23}\) and 7–10 times body weight\(^{17,22}\) at impact respectively, might be expected to stimulate the modeling process. The external GRF\(_z\)s imposed by landing from a jump, such as would be expected to occur during gymnastics, tumbling, and dance routines, have also been determined to reach similar values. Even though small numbers of subjects were tested, the mean value of the female swimmers in this study was lowest among the various sports. This may implicate that the transmission of the external GRF\(_z\) to bone of the skeleton would be expected to exceed the forces generated
through muscular contraction in a nonweight-bearing activity such as swimming. Hutchinson and colleagues\(^{(13)}\) defined walking, swimming, cycling as low-load activities while jogging, volleyball, basketball, raquetball as high-load in their study in which 26-51 year-old men participated as subjects. They reported that calcaneal bone mineral density was 12% higher in the high-load group than the low-load group. The highest level of bone stiffness in female Judo athletes in the present study seemed to be influenced by the dual effects of heavy mechanical forces through weight training on the skeleton and of the raised muscle strength.

Maximizing adult peak bone mass has been proposed as a means of minimizing the future risk for significant osteoporotic fracture\(^{(32)}\). Bone mass reaches its maximum at 30 to 35 years of age. However, Snow-Hartrer and Marcus\(^{(32)}\) have suggested that peak bone density is reached much earlier than previously reported. Therefore, maximizing adult peak bone density during growth and adolescence is important in minimizing bone loss during menopause. After the early stage of the 30s, a gradual loss begins which is faster in the trabecular bone and is further accelerated in women during menopause\(^{(28)}\).

In summary, participating in regular sport programs during growth and adolescence appear to have a positive effect on enhancing bone mass. The mean values of bone stiffness index in both male and female non athletes during high school days did not reach the standard levels (100 according to the manufacture) which should be expected to be obtained by young adults (20s). Such a low level of adult peak bone mass through sedentary life style during the growth and adolescence is critical, especially when considering prevention of osteoporosis in post menopausal women. The results of the present study confirmed the correlations between muscle strength and BMD. However, weight-bearing sports requiring impact loads of greater than 3 times or more body weight are more effective than nonweight-bearing sports such as swimming.

Acknowledgements. This study was supported by research grants from
REFERENCES


Bone density in college students
(Kobayashi, Hosoi, Takeuchi, Nakao and Arai)


運動が骨形成に重要な役割を有することはこれまでの研究で明らかにされている。今日特に、高年令女子の骨の粗鬆化にもなる骨折は高齢化社会の先進国において深刻な問題となっている。骨粗鬆症予防の面で有効な方法の一つは成人期に達するまでにできるだけ大きな頂値骨量を獲得することである。そこで本研究では、大学生を対象に彼らの発育発達期におけるスポーツ参加と現在の骨密度との関連を検討した。男女1-2年次学生514名（男子：236、女子：278名）が本研究に参加し、中学、高校期とも活発な運動活動に参加した群（6A）、中学ないし高校のいずれかで運動に参加した群（3A）、および全く規則的に運動に参加しなかった群（NA）の三群に区分された。骨密度は超音波骨密度測定装置（アキレス）を用いて右足脛骨で計測され、BONE STIFFNESSという指数で評価した。さらに、等速性筋力測定装置（サイベックス330）を用いて右膝伸展筋群の筋力を測定し、骨密度との関連を検討した。男子学生では、6A群におけるSTIFFNESSは3AおよびNA群よりそれぞれ11.4、16.5%有意に高い値を示し、女子学生においても同様に6A群は3A群より13%（P<0.001）、NA群より16.8%（P<0.001）高い値を示した。また男女各3A群とNA群間に有意差を認めた。脚伸展筋群の筋力（角速度120°/s）においてもSTIFFNESSと同様の傾向が観察された。しかし、6A群でのSTIFFNESSと脚伸展筋群の筋力との間の正の有意な相関は女子群のみに見られ（r=0.40，p<0.001）、男子群には見られなかった。さらに6A群を彼らが参加したスポーツ種目別に区分して骨密度を比較すると、サッカー、陸上競技、柔道に高い値が示され、剣道と水泳に低い値が見られた。以上のように、本研究は成人期頂値骨量の最大化において発育発達期における活発な運動習慣が有意に働くことを示した。骨の強化のメカニズムとして、運動群の高い筋力値から、頻繁な筋収縮が骨形成に関与したことと、男子運動群の筋力と骨密度の低い相関から、スポーツ活動による骨への力学的衝撃負荷の繰り返しが考えられる。

小林義雄、細井輝男、竹内敏子、中尾隆行（中京大学教養部健康スポーツ科学研究室） 荒井康夫（名古屋女子大学児童教育学科、体育研究室）