The Effects of Radius Bone Density on the Resting Myoelectrical Activity of Contralateral Wrist Flexors in Subjects Exposed to Unilateral Forearm Vibration

Unilateral Ön Kol Vibrasyonu Uygulanan Olgularda Radius Kemik Yoğunluğunun Kontralateral El Bilek Fleksör İstirahat Kas Elektriksel Aktivitesi Üzerine Etkisi

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ABSTRACT Objective: To investigate whether bone mineral density or bone mineral content of the ultradistal radius has any effect on the resting muscle activity of contralateral wrist flexor muscles during unilateral forearm vibration. **Material and Methods:** Ninety healthy adult volunteers (33 women, 57 men) were included in this study. The mean age of participants was 34.2 (20-52) years. The right forearm was exposed to vibration for 1 minute. The frequency of vibration was 46 Hz. The resting myoelectrical activities of the right and left wrist flexor muscles were simultaneously measured by surface electromyography before, during and after vibration. The right ultradistal radius bone mineral density and bone mineral content were measured by dual-energy X-ray absorbtiometry. **Results:** The resting myoelectrical activity of the left wrist flexor muscles significantly increased during vibration (from 2.0±0.8 microvolts to 4.5±2.2 microvolts, p=0.0001). It decreased to 1.8±0.9 microvolts after vibration (p=0.0001). Multiple linear regression analysis revealed that the right ultradistal radius bone mineral density was an independent predictor of the resting myoelectrical activity of the left wrist flexor muscles measured during vibration. However, age, gender, body mass index, the right ultradistal radius bone mineral content and, the right and left wrist flexor muscles' resting myoelectrical activity measured before vibration were not predictors (R2=0.772, F=301.8, p = 0.0001). **Conclusion:** It is suggested that the ultradistal radius bone may affect the resting myoelectrical activities in the contralateral wrist flexor muscles, based on its bone mineral density during unilateral forearm vibration.

Key Words: Vibration; muscle, skeletal; bone density

ÖZET Amaç: Unilateral ön kol vibrasyonu sırasında ultradistal radius kemik mineral yoğunluğu veya kemik mineral içeriğinin, kontralateral el bileği fleksör istirahat kas elektriksel aktivitesi üzerine etkisi olup olmadığını araştırmak idi. **Gereç ve Yöntemler:** Bu çalışmaya 90 sağlıklı genç erişkin (33 kadın, 57 erkek) alındı. Katılımcıların yaş ortalaması 34.2 (20-52) yıl idi. Sağ ön kola 1 dakika vibrasyon uygulandı. Vibrasyon frekansı 46 Hz idi. Vibrasyon öncesinde, sırasında ve sonrasında sağ ve sol el bilek fleksör istirahat kas elektriksel aktivitesi yüzeyel elektromiyografi ile eş zamanlı olarak ölçüldü. Sağ ultradistal radius kemik mineral yoğunluğu ve kemik mineral içeriği dual-enerji X-ışını absorpsiyometri ile ölçüldü. **Bulgular:** Vibrasyon sırasında sol el bilek fleksör istirahat kas elektriksel aktivitesi (2,0±0,8 mikro volttan 4,5±2,2 mikro volta) anlamlı olarak arttı (p=0,0001). Çoklu doğrusal regresyon analizi sağ ultradistal radius kemik mineral yoğunluğunun, vibrasyon sırasında ölçülen sol el bileği fleksör istirahat kas elektriksel aktivitesi için bağımsız bir prediktör olduğunu ortaya koydu. Bunu karşın, yaş, cinsiyet, vücut kitle indeksi, sağ ultradistal radius kemik mineral içeriği, vibrasyon öncesi ölçülen sağ ve sol el bilek fleksör istirahat kas elektriksel aktivitesinin prediktör değildi (R2=0,772, F=301,8, p=0,0001). **Sonuç:** Unilateral ön kol vibrasyonu sırasında, ultradistal radius, kemik mineral yoğunluğuna bağlı olarak, kontralateral el bilek fleksör istirahat kas elektriksel aktivitesini etkilemektedir.

Anahtar Kelimeler: Titreşim; kas, iskelet; kemik yoğunluğu

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Vibration has been reported to have a positive effect on muscle strength and power.[1-3] Previous studies have shown that vibration also increases the electromyographic (EMG) activity of the muscles.[4-6] Attempts to explain vibration-induced increases in the EMG activity were based on the tonic vibration reflex. Tonic vibration reflex activates the muscle spindles, thereby enhancing the excitatory drive reflex of the alpha motoneurons.[7] On the contrary, it was shown that the vibration treatment did not enhance the muscle spindle sensitivity and led to presynaptic inhibition of muscle spindle group Ia afferents.[8-11] As an alternative to tonic vibration reflex, recently described bone myoregulation reflex has been suggested to explain the increased muscle strength and electrical activity induced by vibration. Through the bone myoregulation reflex, bone is sensitive to mechanical stimuli and can send mechanical input signals to central nervous system, resulting in neuronal stimulation of muscle activity.[12,13]

The vibration can increase the strength of the contralateral and ipsilateral muscles.[14] It has been reported that strength training of one limb increases the voluntary strength not only in the trained limb, but also in the contralateral untrained limb. This phenomenon is known as "cross-education". It can occur with training accomplished by voluntary effort or electrical stimulation of muscles or by mental practice of unilateral contractions.[15,16]

Wang and Salem were the first to show that the cross-education phenomenon could occur with vibration.[14] They showed increases in the handgrip strength of both the trained and contralateral untrained arms in premenopausal healthy women who had been trained with cyclic mechanical loading on unilateral distal radius for six months.[14]

The bone has been reported to have a potential effect on the ipsilateral muscle activity.[12,13] However, whether the bone has any effect on the contralateral homologous muscle activity is not known. This study investigated whether the bone mineral density (BMD) or bone mineral content (BMC) of the distal radius had any effect on the resting muscle activity of the contralateral wrist flexor muscles during unilateral forearm vibration in healthy adults.

MATERIAL AND METHODS

1. PARTICIPANTS

One hundred and thirty-two research participants who voluntarily accepted to participate in the study were assessed for eligibility. All met the following inclusion criteria: 20-55 years of age and right-hand-dominance. According to the criteria presented in Table 1, 33 of these individuals were excluded from the study. Consequently, this study was completed with 90 participants (33 women, 57 men).

The mean age of the participants was 34.2 (20-52) years. The mean age was 33.4 ± 9.1 years in women and 34.7 ± 8.1 years in men (p=0.482). The mean body mass index (BMI) was 27.8 ± 5.2 kg/m^2 in women and 27.4 ± 3.5 kg/m^2 in men (p=0.655).

Ethical approval was obtained from the local Institutional Review Board. The study was performed in accordance with the principles of Declaration of Helsinki. All participants were volunteers and provided written informed consent.

2. EXPERIMENTAL DESIGN

The current study was a double-blind, self-controlled, clinical trial.

TABLE 1: Exclusion criteria (The numbers of cases excluded were expressed in parenthesis).

Chronic metabolic/endocrine bone disease (including osteoporosis) (7)
Myopathy (0)
Tendinopathy (1)
Neurologic disorders (hypoesthesia/anesthesia, epilepsy, paralysis) (6)
Dermatologic disease (0)
Peripheral vascular disease (0)
Joint disease (0)
Non-cooperative participants (3)
Professional/regular sports activity (tennis, volleyball, etc.),
Engagement in heavy lifting work (0)
History of right forearm/hand trauma, fracture or metallic implants (2)
Participants could not complete the intervention due to the pain in their right wrist during vibration (6)
Participants did not perform the forearm dual-energy X-ray absorbtiometry scan (8)

This study mainly investigated the effects of right ultradistal radius BMD/BMC on the resting myoelectrical activity of the left wrist flexor muscles (WFM) during vibration. The resting myoelectrical activities of the WFM before, during and after vibration and the right distal radius BMD were measured in all participants. Since the BMD/BMC measurements were done only after the electrophysiological tests, neither the researcher who measured the resting myoelectrical activity nor the participants knew the BMD/BMC values. BMD/BMC measurements were done by another researcher who did not have any information about the results of the electrophysiological measurement. Thus, this was a double-blind study since both the researchers and the participants were blind in terms of the effects of bone on the myoelectrical activity occurring during the vibration.

FIGURE 1: Experimental design:
a. The liquid crystal display monitor,
b. The control panel,
c. The electromyography device,
d. The joystick unit,
e. The vibration load

3. EXPERIMENTAL PROCEDURE

3.1 Forearm Vibration

The forearm vibration device consisted of a joystick unit, a weight-pulley system and a control panel. The subject was seated in a chair. The right forearm was placed on the vibration device with the shoulder in 30 degrees abduction, the elbow in 90 degrees flexion and the forearm and wrist in the neutral position. The axis of rotation of joystick unit was aligned with that of the right wrist joint. The same position was maintained in all experiments (Figure 1).

The joystick unit was capable of performing both an angular and a sliding motion simultaneously. The angular motion obtained the vibration effect and the sliding motion obtained the compression effect.

The angular motion of the joystick unit was provided by an electric motor. The range of angular motion was 6 degrees. The maximum frequency of vibration of the joystick unit was 46 Hz . Vibrations in the 30-100 Hz frequency range were reported to provide more increase in myoelectrical activity.[5,17,18] The frequency of vibration used in the study was 46 Hz.

The weight was attached to the joystick with a rope and pulley system to provide mechanical loading to the forearm (compression effect). This weight was defined as vibration load. Maximum tolerated vibration load was applied. Based on our previous experimental experience, maximum tolerated vibration loads were determined with the following formulas. The vibration load was equal to 1/3 of the ideal body weight (IBW) in the women. It was equal to 3 kg + 1/3 of the IBW in the men. IBW was calculated as. The ideal BMI was determined using the BMI tables adjusted according to the height and gender. The mean vibration load was 19.8 (18-24) kg in women and 25.6 (17-28) kg in men.

Participants were asked not to voluntarily contract the muscles under study while the measurements of the resting myoelectrical activity were taken. A familiarization protocol was performed to prevent voluntary contraction during the electrophysiological tests. EMG bio-feedback was used for the familiarization. An LCD screen showing simultaneously both the right and left WFM electrical activities provided the visual feedback (Figure 1). The participants were instructed to completely relax their forearm muscles and to monitor their myoelectrical activities from the screen.

When vibration was applied during the electrophysiological tests, in addition to the familiarization protocol, precautions were taken to prevent voluntary muscle contractions. The subject's hand may slip over the joystick during vibration and WFM contraction may occur due to his/her attempt to maintain his/her hand position. To prevent the subject's hand from slipping over the joystick, participants wore a rubber glove, and the right forearm was supported from both the medial and lateral sides (Figure 1).

Any complaint involving the right upper extremity during vibration was attended to. The mean test room temperature was 24.7±1.5 °C during the study.

3.2 EMG Analysis

One minute of myoelectrical activity was recorded from the WFM at rest. The mean myoelectrical activity was calculated as the root mean squared (RMS) using the EMG device software, and defined as the "resting myoelectrical activity". The resting myoelectrical activities of the right and left WFM were simultaneously measured by surface EMG, before, during and after vibration (Figure 2). The vibration was applied for 1 minute. Postvibrational resting myoelectrical activity was measured within 30 seconds after vibration.

The self-adhesive skin electrodes were placed on the skin covering the belly of the right and left WFM. The electrode pair was placed away from each other approximately 2 cm. The electrode size was 5×5cm.

The resting myoelectrical activity was expressed as microvolt (µV). It was measured using a surface EMG device (NeuroTrac ETS, Verity Medical, UK. EMG range: 0.2 to 2000 µV RMS, sensitivity: 0.1 µV RMS, Notch filter: 50Hz, Common mode rejection ratio: 130 dBs).

Vibrations generated peculiar, non-negligible motion artifacts on skin electrodes, resulting in an overestimation of muscular activity. An appropriate filtering has been suggested to obtain artifact-free signals from muscle.[5,19,20] There was a possibility of motion artifacts occurring in the right WFM during vibration. Therefore, the selected band pass filter was 100-370 Hz. Certain precautions were taken in order to prevent a relative motion between skin and electrodes such as (1) shaving and cleaning of the skin where the electrodes were to be placed; (2) using self-adhesive skin electrodes; (3) using the same electrode for no more than two participants.

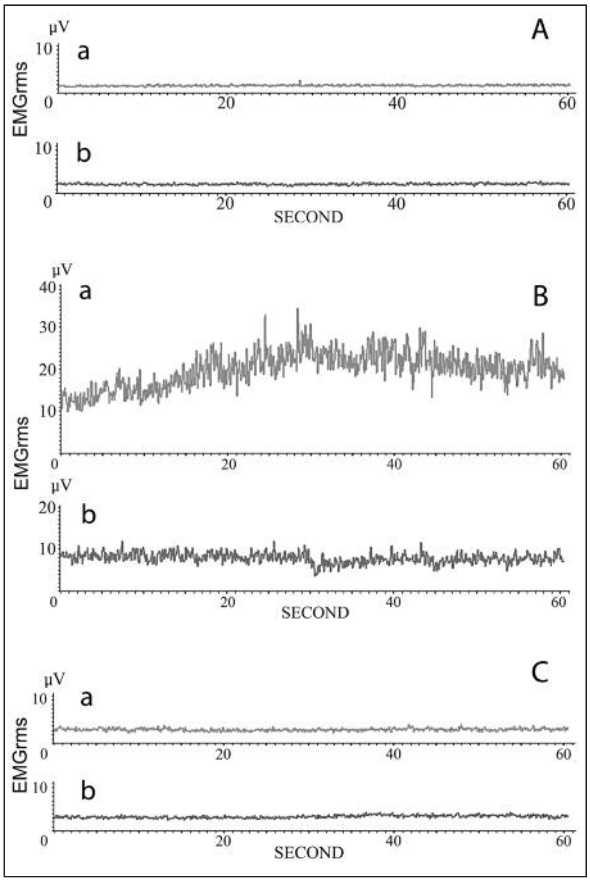

FIGURE 2: Resting myoelectrical activity (EMGrms) of the right (a) and left (b) wrist flexor muscles before (A), during (B) and after (C) vibration.

The left forearm was not exposed to vibration. Therefore, the selected band pass filter was 18-370 Hz.

3.3 Measurements of Bone Mineral Density and Content

The ultradistal radius BMD and BMC were measured by dual-energy X-ray absorptiometry (GE-LUNAR DPX PRO Lunar Corp., Madison, WI, USA). The coefficient of variation for the BMD measurements was below 1.41%.

4. STATISTICAL ANALYSES

The Kolmogorov-Smirnov test was used to confirm that data were normally distributed. Continuous variables were summarized as arithmetic mean and standard deviation (SD). The unpaired samples t-test was used to analyze the statistical difference in the age, BMI, BMD, and BMC between men and women.

The resting myoelectrical activity data were analyzed using a 2 × 2 [Time (before, during and after vibration) × Gender] ANOVA appropriate for multiple dependent variables with repeated measures. The Bonferroni test was applied for pair-wise comparisons.

A multiple linear regression analysis was performed to detect independent predictors of the resting myoelectrical activity measured during vibration and to find confounding effects between potentially independent predictors. A stepwise method was used to construct multiple linear regression models. A variable was entered into the model if the probability of its score statistic was less than the Entry value (0.05) and was removed if the probability was greater than the Removal value (0.1).

A p value of less than 0.05 was considered statistically significant. The software package used for data management was PASW Statistic 18.

RESULTS

The right ultradistal radius BMD and BMC were significantly higher in men compared to women (Table 2).

TABLE 2: The right ultradistal radius bone mineral density (BMD) and bone mineral content (BMC) in men and women (mean±SD).

Bone densitometry measurements	Men (n=57)	Women (n=33)	p
BMD (g/cm^2)	0.591 ± 0.071	0.513 ± 0.056	0.0001
BMC (g)	2.351 ± 0.487	1.752 ± 0.263	0.0001

The Time effect was found to be significant, while the Time-by-Gender interaction was not significant for the resting myoelectrical activity of the right WFM and, for the resting myoelectrical activity of the left WFM (p= 0.0001 and p= 0.076 ; p= 0.0001 and p= 0.527, respectively). PostHoc analysis revealed that the resting myoelectrical activity of the right and left WFM significantly increased during vibration (Table 3).

Multiple linear regression analysis revealed that the right ultradistal radius BMD was an independent predictor of the resting myoelectrical activity of the right WFM measured during vibration. However, age, gender, BMI, the right ultradistal radius BMC and the right WFM resting myoelectrical activity measured before vibration were not (R=0.900, F=380.4, p= 0.0001) (Table 4).

Multiple linear regression analysis revealed that the right ultradistal radius BMD was an independent predictor of the resting myoelectrical activity of the left WFM measured during vibration. However, age, gender, BMI, the right ultradistal ra-

TABLE 3: The resting myoelectrical activity of the right and left wrist flexor muscles before, during and after vibration (mean ± SD)

Muscles	Resting myoelectrical activity	Men (n=57)	Women (n=33)	Total (n=90)
	Pre-vibration (µV)	2.0 ± 0.8	2.4 ± 0.7	2.1 ± 0.7
The right wrist flexors	During-vibration (µV)	33.2 ± 15.8	33.6 ± 14.9	33.4 ± 15.4 [a]
	Post-vibration (µV)	2.1 ± 1.0	2.1 ± 1.0	2.1 ± 1.0 b,[c]
	Pre-vibration (µV)	1.9 ± 0.8	2.3 ± 0.6	2.0 ± 0.8
The left wrist flexors	During-vibration (µV)	4.1 ± 2.1	5.1 ± 2.4	4.5 ± 2.2 [a]
	Post-vibration (µV)	1.6 ± 0.9	2.0 ± 0.8	1.8 ± 0.9 [b,d]

µV: microvolts, [a] p=0.0001 for comparison previbration and during vibration, [b] p=0.0001 for comparison during vibration and postvibration, [c] p=1.0 for comparison previbration and postvibration, [d] p=0.009 for comparison previbration and postvibration.

dius BMC and, the right and left WFM resting myoelectrical activity measured before vibration were not (R^2= 0.772, F=301.8, p= 0.0001) (Table 4).

DISCUSSION

Cross-education phenomenon occurs after a multi- or single-session training.[16,21] In the present study one session vibration was applied. The major finding of this study was an increase in the resting myoelectrical activity of the contralateral homologous muscle associated with the ipsilateral ultradistal radius BMD during unilateral forearm vibration.

The cyclic mechanical loading to the bone stimulates the osteocytes.[22] Based on the bone myoregulation reflex, the osteocytes exposed to cyclic mechanical loading can send mechanical input signals to central nervous system and thus neuronally regulate muscle activity.[12,13]

In this trial, the BMD was accepted as an indicator of the osteocyte number. BMD indicates the bone mass per unit volume. In normal healthy humans, the osteocytes embedded in the bone matrix that form dendritic connections with each other exhibit a regular alignment.[23] The osteocyte number determines the bone mass. There is a highly correlated linear relationship between the extracellular matrix volume and osteocyte density in human cancellous bone.[24]

According to bone myoregulation reflex, the more the osteocytes are stimulated by the cyclic mechanical loading, the more the increase in the muscle strength and activity may occur.[12,13] The present study showed that the higher the ultradistal radius BMD is, the increase in the resting myoelectrical activity of WFM during vibration may be more.

In this trial, the right ultradistal radius BMD was lower in women compared to men. The mean vibration load applied to women was approximately 6 kg (22.6%) less than that applied to men. Since the increase in the resting myoelectrical activity of the WFM was proportional to the right ultradistal radius BMD, and the vibration load applied to women was lower, the increase in the resting electrical activity of the WFM during vibration is expected to be lower in women compared to men. However, in contrast to what was expected, the increase in the resting electrical activity during vibration was the same in men and women. How can this contradiction be explained?

Based on the bone myoregulation reflex, the osteocytes embedded in the bone matrix, which are stimulated by the deformation of this matrix during mechanical loading, have a regulatory effect on the muscle activity. Therefore, the stiffness or the elasticity of the bone matrix was reported to be also important in the occurrence of the reflex response as well as the total number and the density of osteocytes.[12,13]

The elasticity of the bone matrix is expressed by the Young's modulus. In humans, it is not possible to measure the bone elasticity by in vivo biomechanical tests. However, the in vivo Young's modulus of the bone can be calculated by high-resolution 3-T MRI. The Young's modulus of the ultradistal radius calculated by the high-resolution 3-T MRI technique was shown to be lower in women compared to men.[25] Thus, a higher rate of osteocytes can be stimulated during vibration in women compared to men, since the impact of compression and decompression on the bone caused by the cyclic mechanical loading may be more marked

TABLE 4: Result of multiple linear regression for resting myoelectrical activity measured during vibration.

Dependent variable	Independent variable	Unstandardized coefficients B	Unstandardized coefficients SE	t	p
Resting myoelectrical activity of the right wrist flexor muscles	Ultradistal radius BMD	58.221	2.985	19.506	0.0001
Resting myoelectrical activity of the left wrist flexor muscles	Ultradistal radius BMD	7.786	0.448	17.372	0.0001

SE: Standard Error.

in women. Therefore, the rate of osteocytes stimulated by cyclic mechanical loading (the number of osteocytes stimulated/the total number of osteocytes per unit volume) may be higher in women even if the ultradistal radius BMD is lower. This may explain why the resting myoelectrical activity of the WFM during vibration was increased in women to the same extent as in the men.

This study had certain limitations. The first was the fact that the total number of osteocytes per unit volume could not be calculated. Considering the literature, BMD was accepted as the indirect indicator of the total osteocyte number per unit volume. The second limitation was the fact that the Young's modulus of the cases was not calculated in the present study. The Young's modulus of the ultradistalradius is reported to be lower in women.[25] Although our results can be explained by the Young's modulus, the effect of the ultradistal radius Young's modulus on the increase in the muscle resting myoelectrical activity induced by vibration was not determined.

CONCLUSION

According to the results of the current study, it may be suggested that the ultradistal radius bone can affect the resting myoelectrical activity of the contralateral homologous muscle, as well as the myoelectrical activity of the ipsilateral wrist flexor muscles, based on its BMD during unilateral forearm vibration. The potential effect of the BMD on the resting myoelectrical activity suggests that high bone density is important for achieving a high muscle activity. In this respect, acquiring a higher peak bone density may be important. The growing years provide a valuable window of opportunity for building peak bone density. Many factors influence the accumulation of bone mineral during childhood and adolescence, including diet and physical activity among others.[26,27] Therefore, a potential effect of the bone on muscle activity may be important for exercise physiology and development of a healthy body.

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