Effect of Bone Tissue on Vibration-Induced Electrical Activity of Muscles

Vibrasyonun İndüklediği Kas Elektriksel Aktivitesi Üzerine Kemik Dokusunun Etkisi

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Geliş Tarihi/*Received:* 16.03.2010
Kabul Tarihi/*Accepted:* 26.07.2010

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ABSTRACT Objective: The effect of muscle activity on bone tissue is well documented. However, there is not enough data on effect of bone tissue on muscle activity. The aim of this study was to determine whether bone exposed to cyclic mechanical loading affects muscle electrical activity in healthy adult volunteers. **Material and Methods:** Fifty-six volunteers were included in this study. Muscle electrical activity was measured on flexor carpi radialis (FCR) muscle at rest and maximal voluntary contraction (MVC) as EMGrms by surface EMG. Rest-EMGrms, MVC-EMGrms and H-reflex of the right FCR were measured before and during vibration. The right distal radius bone mineral content (BMC) and density were measured by DXA. **Results:** Rest-EMGrms significantly increased during vibration in all cases. Regression analysis revealed that ultradistal (UD) radius BMC was an independent predictor for the change in the rest-EMGrms during vibration. This analysis also indicated that UD radius BMC explained only 54.0% of the variance in the rest-EMGrms during vibration. MVC-EMGrms significantly increased during vibration. Regression analysis revealed that UD radius BMC was an independent predictor for the change in the MVC-EMGrms during vibration. This analysis also indicated that UD radius BMC explained only 28.3% of the variance in the MVC-EMGrms during vibration. H-reflex was significantly suppressed or depressed during vibration in all cases. **Conclusion:** The current study suggests that bone exposed to cyclic mechanical loading can affect muscle electrical activity, based on its BMC.

Key Words: Bone and bones; muscle, skeletal; vibration

ÖZET Amaç: Kas aktivitesinin kemik dokusu üzerine etkisi iyi bilinmektedir. Fakat, kemik dokusunun kas aktivitesi üzerine etkisi hakkında yeterli bilgi yoktur. Bu çalışmanın amacı sağlıklı erişkin gönüllülerde, siklik mekanik yüklenmeye maruz kalan kemiğin, kas elektriksel aktivitesi üzerine etkisi olup olmadığını incelemek idi. **Gereç ve Yöntemler:** Çalışmaya 56 gönüllü dahil edildi. Sağ fleksör karpi radialis (FKR) kasından istirahatte ve maksimal istemli kasılma (MIK) sırasında, yüzeyel EMG ile kas elektriksel aktivitesi EMGrms olarak ölçüldü. Sağ FKR kasında vibrasyondan önce ve vibrasyon sırasında istirahat-EMGrms, MIK-EMGrms ve H-refleksi kaydedildi. Sağ distal radius kemik mineral içeriği (KMI) ve yoğunluğu DXA ile ölçüldü. **Bulgular:** İstirahat-EMGrms vibrasyon sırasında tüm olgularda anlamlı olarak arttı. Regresyon analizi vibrasyon sırasında istirahat-EMGrms'de meydana gelen değişim için ultradistal (UD) radius KMI'nin bağımsız bir belirteç olduğunu gösterdi. Bu analiz aynı zamanda, UD radius KMI'nin, istirahat-EMGrms'de vibrasyon sırasında meydana gelen değişimin % 54'ünü açıkladığını göstermektedir. MIK-EMGrms vibrasyon sırasında anlamlı olarak arttı. Regresyon analizi, vibrasyon sırasında MIK-EMGrms'de meydana gelen değişim için ultradistal (UD) radius KMI'nin bağımsız bir belirteç olduğunu ortaya çıkardı. Bu analiz aynı zamanda, UD radius KMI'nin MIK-EMGrms'de vibrasyon sırasında meydana gelen değişimin %28.3'ünü açıkladığını göstermektedir. H-refleksi vibrasyon sırasında tüm olgularda suprese veya deprese oldu. **Sonuç:** Bu çalışma, siklik mekanik yüklenmeye maruz kalan kemiğin, KMI'ne bağlı olarak, kas elektriksel aktivitesini etkileyebileceğini öne sürmektedir.

Anahtar Kelimeler: Kemik ve kemikler; kas, iskelet; titreşim

Turkiye Klinikleri J Med Sci 2010;30(4):1346-56

A functional cooperation exists between bones and skeletal muscles. Bones work together with muscles as a simple mechanical lever system to produce body movement. One of the important functions of bones is to exert resistance against gravity in order to carry the body. In order to carry out their mechanical functions, bones need to have considerable resistance to deformation under load.[1] It is well-known that muscle activity (i.e., exercises) improves the resistance of bone to mechanical loading, and that it is also important for treating and preventing osteoporosis. Resistance and impact training have been shown to induce bone formation and/or prevent bone resorption.[2-4] Skeletal muscles have positive effects on bone structure and function. Can bones have an effect on muscle activity? There is only one study about the effect of bones on muscles. In this study, it was shown that bones may affect muscle strength gain in healthy young adult males.[5]

Vibration has a strong osteogenic effect.[6,7] Vibration-induced bone formation is neuronally regulated.[8] Vibration can also effectively enhance muscle strength and power.[9-13] Previous studies have shown that vibration increases muscle electromyograhic (EMG) activity.[14-22] But, it has not been reported whether bone has an effect on the increase in muscle EMG activity caused by vibration or not. The aim of this study was to determine whether radius bone exposed to cyclic mechanical loading affects muscle electrical activity of m. flexor carpi radialis in healthy adult volunteers.

MATERIAL AND METHODS

The current study was a prospective, double-blind, unicenter clinical trial.

ETHICS

The study was performed in accordance with the principles of Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board. This study was also registered Clinical Trials Protocol Registration System. Protocol ID is VGEAH FTR-2, ClinicalTrials.gov ID is NCT00961870. All participants were volunteers and provided written informed consents.

PARTICIPANTS

Eighty-three subjects who voluntarily accepted to participate in the study were assessed for eligibility. The following inclusion criteria were considered for the study: 20-55 years of age and right hand-dominance. Eighty-two subjects met these criteria. Hand dominance was determined by the preferred hand for writing.

Exclusion criteria were chronic metabolic/endocrine bone disease (including osteoporosis), myopathy, tendinopathy, neurologic disorders (hypoesthesia/anesthesia, epilepsy, paralysis), dermatologic disease, peripheral vascular disease, joint disease, non-cooperative subject, professional/regular sports activity (tennis, volleyball, etc.), engagement in heavy lifting work, history of right forearm/hand trauma, fracture or metalic implants.

Twenty-six subjects were excluded from the study. Eight subjects had postmenopausal or secondary osteoporosis, one subject had osteomalacia; and one subject was a wrestler. Ten subjects were excluded because the measurements could not be completed due to the pain in their right wrist during vibration. Another six subjects were excluded because they did not perform the forearm dual-energy X-ray absorptiometry (DXA) scan. Consequently, this study was conducted on 56 subjects (17 females, 39 males) who complied with the inclusion and exclusion criteria and had all necessary measurements available. This study report followed the guidelines of the CONSORT statements (Figure 1).

The mean age of subjects was 34.0 (20-55) years. Seventeen of the subjects were female and 39 were male. The mean age was 34.7 ± 7.5 years in females and 33.7 ± 9.9 years in males (p=0.723). The mean body mass index was 25.8 ± 2.9 kg/m^2 in females and 26.4 ± 3.4 kg/m^2 in males (p=0.542).

EXPERIMENTAL TESTS AND MEASUREMENTS

A- Forearm Vibration

The forearm vibration device consisted of a joystick unit, a weight (vibration load)-pulley system and a control panel. The subject was seated in an armchair. The right forearm was placed on the vi-

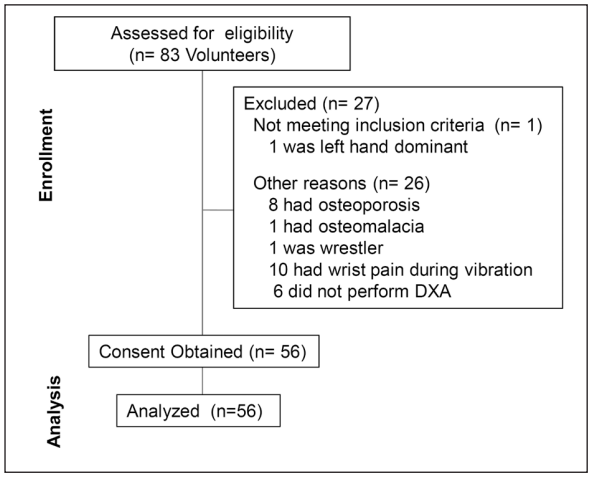

FIGURE 1: Flow chart of participants considered for inclusion.

bration device with the shoulder in 30 degrees abduction, the elbow in 90 degrees flexion and the forearm and wrist in a neutral position. The axis of rotation of joystick unit was aligned with that of the right wrist joint (Figure 2, 3). The same position was maintained in all experiments.

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

The angular motion of the joystick unit was provided by an electric motor, with a range of 6 degrees. Vibrations in the 30-100 Hz frequency range were reported to provide more increase in muscle electromyographic (EMG) activity.[10,19,23] The frequency of vibration was 46 Hz in the study.

The vibration load was attached with a rope and pulley system to the joystick to provide mechanical loading to the distal forearm. The vibration load was equal to 1/3 of the ideal body weight of the subject. *Ideal body weight* was calculated as *(Ideal body mass index)* x *(body height)*^{2} . The mean vibration load was 20.2 (18-23) kg in females and 23.8 (18-28) kg in males.

B- Electrophysiologic Tests

The muscle electrical activities and H-reflex were evaluated in the right flexor carpi radialis (FCR) muscle.

I- Measurements of Muscle Electrical Activity

Measurements of muscle activity were performed by an EMG bio-feedback device (Neurotrac ETS, Verity Medical, U.K.). The amplitude of the surface EMG was derived from the root mean squared form of the raw signal. The EMG-root mean square (EMGrms) representing the mean power of the signal was expressed as microvolt (μV).

One minute of muscle electrical activity was recorded in the FCR muscle at rest. The mean activity was defined as the rest-muscle electrical activity (rest-EMGrms) (Figure 4a, 4b).

To measure muscle electrical activity at maximal voluntary contraction, the subject performed a series of brief (5 seconds) MVCs separated by rest intervals of 5 seconds (Figure 4c, 4d). The mean of the muscle electrical activity recorded during 5 MVCs was defined as the maximal voluntary con-

FIGURE 2: Experimental design. **a.** Control panel, **b.** LCD Monitor, **c.** EMG device, **d.** Vibration device; **d1.** Joystick unit, **d2.** Vibration load.

FIGURE 3: Localization of surface EMG electrodes for EMGrms records.

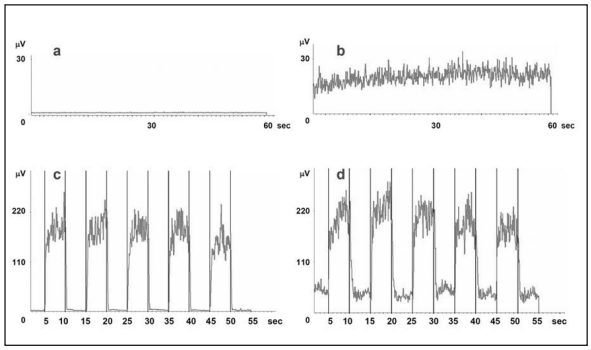

FIGURE 4: Surface EMG records: **a.** Rest-EMGrms before vibration, **b.** Rest-EMGrms during vibration, **c.** Maximal voluntary contraction-muscle electrical activity before vibration, **d.** Maximal voluntary contraction-muscle electrical activity during vibration.

traction-muscle electrical activity (MVC-EMGrms). Data were accepted if the coefficient of variation for MVC-EMGrms values did not exceed 15%.

Vibrations generated peculiar, non-negligible motion artifact on skin electrodes, resulting in an overestimation of muscular activity.[19,24,25] Appropriate filtering was used to obtain artifact-free signals in this study. Vibration frequency was 46 Hz, while band pass filter was 100 Hz and 370 Hz. In order to prevent a relative motion between skin and electrode, certain precautions were taken, including (1) the shaving and cleaning of the skin where the electrodes were to be placed; (2) self-adhesive skin electrodes; (3) using the same electrode for no more than two subjects.

The recording electrodes were placed on the skin covering the belly of the right FCR muscle. The distance between the two electrodes was 2 cm. Ground electrodes were placed lateral to these electrodes. Electrode (Dura-Stick® II Chattanooga group) size was 5x5 cm (Figure 3).

EMG range: 0.2 to 2000 μV RMS (continuous), sensitivity: 0.l μV RMS, Band pass filter: 3dB Bandwidth, 100 Hz ± 5% to 370 Hz ± 10%. Accuracy: 4% of μV reading ±0.3 μV at 200 Hz.

II- Measurements of H-Reflex

Peak-to-peak amplitudes of the H-reflex and M-wave were determined. The amplitude of H-reflex increased linearly with increasing stimulus intensity. After the maximum H-reflex amplitude (Hmax) was obtained, the amplitude of H-reflex decreased with increasing stimulus intensity.

The maximum M-wave amplitude (Mmax) was determined by increasing stimulus intensity to the point at which no further increase in amplitude of motor response was obtained and H-reflex was also suppressed (abolished).

The stability of the Mmax amplitude in each test position was regarded as proof of an unchanged relation between nerve, muscle and electrodes.

The H-reflex was evoked with bipolar stimulating surface electrodes (cathode proximal, interelectrode distance 2 cm). Electrodes were connected to a constant-current stimulation unit (Keypoint Portable® Alpine Biomed). Rectangular electric pulses of 0.5 msec duration at a frequency of 1 Hz were used. The right median nerve was stimulated just above the elbow. For determining proper electrode positioning, a stimulator electrode was placed over the predicted path of the nervus medianus and then carefully moved until the best M wave was obtained.

The recording electrodes were placed on the skin covering the belly of the right FCR muscle; the reference electrode was placed 2 cm distally (Figure 5). Signals were amplified from disposable, pregelled, self-adhering Ag-AgCl electrodes (15x20 mm, Medtronic®) Sensitivity: 5mV, Filters: Low pass 20 Hz, High pass 10 kHz. Sweep speed: 10 ms/D.

A round (15 mm) pre-gelled, Ag-AgCl self-adhesive ground electrode (Kendall®) was placed between the stimulating and recording electrodes (Figure 5).

C- Measurements of Bone Mineral Density and Content

After the experiment, the right distal radius [ultradistal (UD) radius, mid radius and total radius] bone mineral densities (BMD) and bone mineral contents (BMC) were measured by DXA (GE-LUNAR DPX PRO Lunar Corporation, Madison, WI, USA) in all participants. The coefficient of variation for all distal radius BMD measurements was below 1.41%.

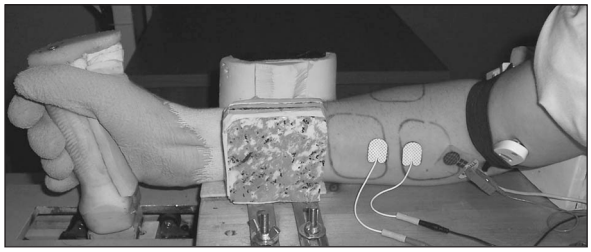

FIGURE 5: Localization of surface EMG electrodes for H-reflex records.

D- Procedure

Subjects visited the laboratory on one occasion for testing. Then, forearm DXA scan was performed. Experiment protocol was schematized in Figure 6.

An LCD monitor displaying motor unit activity with surface EMG of FCR muscle was used to provide visual feedback when the subjects were asked to completely relax the muscles of their forearm during both training (Figure 2). After the training (familiarization) period, rest-EMGrms were measured before and during vibration.

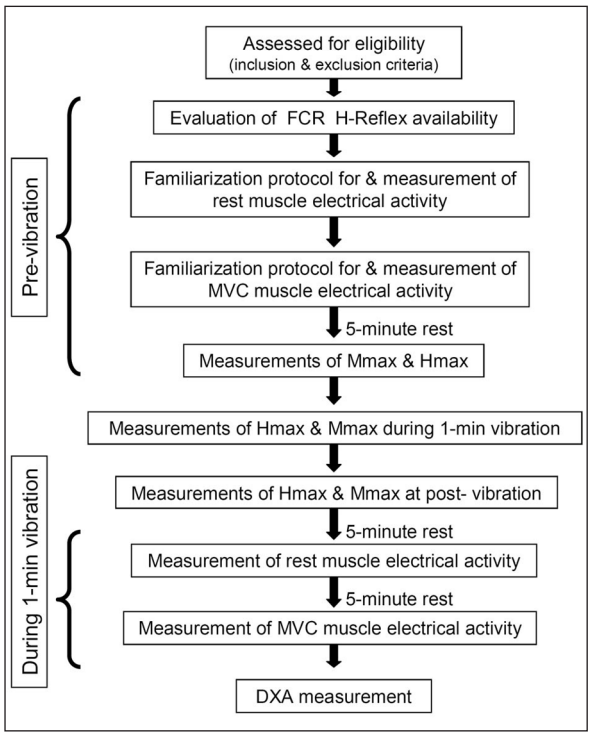

FIGURE 6: Experimental protocol and flow chart.
MVC: maximal voluntary contraction, Mmax: maximum M-wave amplitude, Hmax: maximum H-reflex amplitude, DXA: Dual-energy X-ray absorptiometry.

Subjects were also trained for maximal voluntary contraction of FCR. Following a 1-minute period of rest, MVC-EMGrms was measured before and during vibration. During the tests, participants were guided and encouraged to perform maximal muscle performance by standardized auditory feedback in every repetition.

After measuring muscle electrical activity, the position of the EMG bio-feedback electrodes were marked on the skin with a semi-permanent marker and then removed from the skin. The other electrodes were then placed for H-reflex testing. Subjects were required to try to remain relaxed throughout the H-reflex testing. Before vibration, Mmax and Hmax were respectively measured at rest. While Hmax was elicited, vibration application was started without changing the location of the electrodes or the position of the subjects. H-reflex response was tried to elicit again during vibration application. After H reflex study, Mmax was measured during vibration.

Immediately after vibration, Hmax and Mmax were respectively measured once again. Subjects were then allowed a rest period of 5-minutes. EMG bio-feedback electrodes were again placed over the skin region which was marked by a semi-permanent marker previously. First, rest-EMGrms during vibration was measured. Subjects were allowed to rest for 5 minutes again. During vibration, MVC-EMGrms was measured. Each vibration was applied for about 1 minute.

As vibration was applied, certain precautions were taken in addition to the training protocol to prevent voluntary muscle contractions during the rest period, since they could affect muscle electrical activity. To prevent a subject's hand from slipping over the joystick during vibrocompression, and thus causing muscle contraction due to his/her attempt to re-grab the joystick, subjects wore a rubber glove, and the distal radius was supported from both the medial and lateral sides (Figures 3 and 5).

Any complaint (such as pain, paresthesia) of the right upper extremity during vibration was qu-

estioned. Test room temperature was maintained at 25.0 ± 1.0 ^{0}C during the study.

BLINDING

In this study, the effects of bone on changes of muscle electrical activity during vibration were examined. Since the right distal radius BMD/BMC measurements were done after electrophysiology, neither the subjects nor the researchers who measured the muscle electrical activity (MAS & IK) knew the distal radius BMD/BMC values. BMD/BMC measurements were done by AO, and she did not have any information about the results of electrophysiological measurement. Thus, this was a double-blind study since both the researchers and the subjects were blind in terms of the effects of bone on changes of muscle electrical activity occurring during vibration tests.

STATISTICAL ANALYSIS

The normal distribution of data was confirmed with the Kolmogorov-Smirnov test. Continuous variables were summarized as arithmetic means and standard deviations (SD).

The EMGrms measured at vibration was normalized:

Normalized rest EMGrms = [(rest EMGrms at vibration) - (rest EMGrms before vibration)] x100 / (rest EMGrms before vibration)

Normalized MVC EMGrms = [(MVC EMGrms at vibration) - (MVC EMGrms before vibration)] x100 / (MVC EMGrms before vibration)

To compare H-reflexes between subjects and conditions, Hmax was normalized to the Mmax (Hmax/Mmax).

The unpaired samples t-test was used to analyze the statistical difference in the BMD, BMC, rest-EMGrms, MVC-EMGrms between males and females. Measured values of the muscle electrical activity before and during vibration were compared with the paired samples t-test in males and females. Measured values of the Hmax and Mmax before, during and after vibration were compared with general linear model repeated measures. The Bonferroni test was applied for pair wise comparisons. Using a Bonferroni correction $[1-(1-a)^{1/n}]$ with a=0.05 and n=3, results with a p value ≤ 0.017 were considered significant, where n was the number of experiments for H-reflex.

A multiple linear regression analysis was performed to detect independent predictors for the occurrence of the change in the rest-EMGrms during vibration and to find confounding effects between potentially independent predictors. 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 stepwise method was used to construct multiple linear regression models. This regression analysis was also applied for MVC-EMGrms. A p value of less than 0.05 was considered statistically significant.

PASW Statistic 18 data management software package was used.

Power Analysis

For the given effect size (population mean difference of rest-EMGrms of 35.8, SD 27.2), sample size (56 pairs), and alpha (0.05, 2-tailed), power is 0.989.

RESULTS

The right distal radius BMD and BMC values were shown in Table 1.

The rest-EMGrms increased during vibration (Table 2). The mean increase in rest-EMGrms was 35.8 ± 27.2 μV in all subjects.

Multiple linear regression analysis revealed that UD radius BMC was an independent predictor

TABLE 1: The right distal radius bone mineral density (BMD) and bone mineral content (BMC) [mean(SD)].

	Region of interest	Male (n=39)	Female (n=17)	p value
BMD (g/cm^2)	UD-radius	0.587 (0.076)	0.531 (0.057)	0.009
	Mid-radius	0.924 (0.085)	0.841 (0.071)	0.001
	Total-radius	0.768 (0.072)	0.704 (0.055)	0.002
BMC (g)	UD-radius	2.20 (0.30)	1.72 (0.19)	0.0001
	Mid-radius	2.68 (0.31)	2.10 (0.21)	0.0001
	Total-radius	12.25 (1.75)	9.09 (0.78)	0.0001

UD: ultradistal

TABLE 2: Rest muscle electrical activity (Rest-EMGrms) (μV) before and during vibration [mean(SD)]

Rest-EMGrms	Male (n=39)	Female (n=17)	p value
Before vibration	2.9 (1.5)	3.1 (0.9)	0.507
During vibration	36.9 (28.9)	43.1 (23.5)	0.442
p value	0.0001	0.0001	

for the change in the rest-EMGrms with vibration [increase in rest-EMGrms= 7.082 (UD radius BMC)]. However, age, gender, mid radius BMC, total radius BMC and distal radius BMDs were not (R= 0.741, Adjusted R square= 0.540 F= 65.6 p=0.0001) (Table 3). This analysis also indicated that UD radius BMC explained only 54.0% of the variance in the rest-EMGrms of FCR with vibration.

During MVC, 12.2% (16.4 ± 14.2 μV) decrease in muscle electrical activity was detected in 9 subjects (3 female, 6 male) with vibration while 26.4% (37.8 ± 38.6 μV) increase in muscle electrical activity was detected in 47 subjects (14 females, 33 males) with vibration. Despite the two opposed effects, the statistical analysis of the whole population indicated that the mean effect was an increase of MVC-EMGrms during vibration (Table 4). The mean increase in rest-EMGrms was 20.2 ± 29.5 μV in all subjects.

Multiple linear regression analysis revealed that UD radius BMC was an independent predictor for the change in MVC- EMGrms with vibration [increase in MVC-EMGrms= 7.082 (UD radius BMC)]. However, age, gender, mid radius BMC, total radius BMC and distal radius BMDs were not. (R= 0.544, Adjusted R square= 0.283 F= 22.7 p=0.0001) (Table 3). This analysis also indicated that UD radius BMC explained only 28.3% of the variance in the MVC- EMGrms of FCR with vibration.

Before the experiments, FCR H-reflex was evoked and recorded in only 33 of the subjects. In 24 subjects out of 33 whose H-reflex was elicited, it was found that H-reflex was suppressed (abolished) during vibration. Then, it was recovered within 30 seconds after vibration.

In 9 subjects out of 33 whose H-reflex was elicited, it was found that H-reflex was depressed (reduced) during vibration. Hmax amplitude measured during vibration was lower than Hmax measured both before vibration (p=0.003) and after vibration (p=0.005). Also, the Hmax/Mmax measured during vibration was lower than the Hmax/Mmax measured both before vibration (p=0.007) and after vibration (p=0.003) (Table 5).

It was found that Mmax did not change during or after vibration in all 33 subjects.

Mild paresthesia in the right hand occured during vibration and resolved completely within 5-10 seconds after vibration in all cases.

DISCUSSION

The present study had two main sets of findings. First, vibration-induced increases in muscle electrical activity of FCR, was related to UD radius BMC. Secondly, the FCR H-reflex was suppressed or depressed during vibration.

Previous studies have shown that EMG activity at rest was increased by vibration.[17,23] In the present study, it was found that there was an increase in EMG activity at rest during vibration, and that UD radius BMC might have an effect on this increase.

TABLE 3: Results of multiple linear regression for increase in rest-EMGrms and MVC-EMGrms.

		Unstandardized Coefficients		Standardized Coefficients		
Dependent variable	Independent variable	B	Std Error	Beta	t	p value
Rest-EMGrms	UD radius BMC	7.082	0.874	0.741	8.103	0.0001
MVC-EMGrms	UD radius BMC	9.355	1.963	0.544	4.765	0.0001

MCV-EMGrms : Maximal voluntary contraction-muscle electrical activity
Rest-EMGrms: Rest-muscle electrical activity

TABLE 4: Maximal voluntary contraction-muscle electrical activity (MCV- EMGrms) (μV) before and during vibration [mean(SD)].

MCV- EMGrms	Male (n=39)	Female (n=17)	p value
Before vibration	164.7 (61.7)	140.3 (43.2)	0.146
During vibration	197.0 (75.4)	162.1 (49.5)	0.087
p value	0.0001	0.009	

Previous studies reported an increase in voluntary muscle contraction-EMGrms activity during vibration.[18,19,21,25] The results of the present study consistent with those reported in the literature. This study also suggested that BMC might have an effect on the MVC-EMGrms changes.

Statistical analysis indicated that UDradius BMC explained only 28.3% of the variance in the MVC-EMGrms with vibration. It seems that the contribution of UDradius BMC to MVC-EMGrms changes were more limited than its contribution to rest-EMGrms changes. This finding can be explained by muscle fatigue. The vibration load should be in an optimal range to elicit strength and power enhancement. Vibration superimposed MVC may elicit neuromuscular fatigue and a decline in EMG activity.[10,26,27] For some of our subjects, MVC-EMGrms did not increase, rather they decreased. In these cases, it might have been due to excessive vibration load that caused muscle fatigue. In this study, the vibration load was equal to 1/3 of the ideal body weight of the subjects. This load might have been excessive, so the load required to apply optimal mechanical load to the distal radius should be determined in future studies using different methods.

POTENTIAL NEUROLOGICAL MECHANISMS OF VIBRATION-INDUCED INCREASES IN EMG ACTIVITY

EMG activity increase induced by vibration is attributed to some neurologic mechanisms such as an enhancement of recruitment and synchronization of motor units.[16,19,23,28] Various receptors may activate these neurological mechanisms. The most studied receptor is muscle spindle. Attempts to explain vibration-induced increases in EMG activity are often based on the tonic vibration reflex (TVR). TVR activates the muscle spindles, thereby enhancing the excitatory drive reflex of the alpha motoneurons. [18,22,29-31] Bosco et al. have suggested that mechanism vibration, which causes the activation of the gamma fusimotor input that enhances muscle spindle sensitivity and the discharge of group Ia afferents, increases motoneuron activation.[15,32] Nevertheless, it was shown that the vibration treatment did not enhance muscle spindle sensitivity.[33,34]

H-reflex, like TVR, is elicited by group Ia afferents stimulating the alpha motor neuron. Several studies have shown that the vibration suppresses the H-reflex amplitude.[27,35-37] In the present study, FCR H reflex was found to be suppressed or depressed during vibration, as well. H-reflex suppression/depression caused by vibration is explained by presynaptic inhibition of muscle spindle group Ia afferents. [25,38-40]. Consequently, muscle spindle can not be responsible for the increased muscle electrical activity during vibration.

In addition to this study, many other studies have also shown that vibration-induced tonic contraction of muscles might coexist with the inhibition of H-reflex (vibration paradox). To resolve

TABLE 5: Changes in Hmax, Mmax, Hmax/Mmax of the right FCR muscle with vibration [mean(SD)].

	Subjects with H-reflex suppressed (n=24)			Subjects with H-reflex depressed (n=9)		
	Mmax (mV)	Hmax (mV)	Hmax/ Mmax	Mmax (mV)	Hmax (mV)	Hmax/ Mmax
Before vibration	14.6 (2.9)	3.3 (1.4)	0.23 (0.08)	16.9 (3.6)	3.7 (1.5)	0.22 (0.07)
During vibration	14.7 (3.0)	-	-	16.0 (4.5)	1.4 (0.6)	0.10 (0.05)
After vibration	14.5 (2.9)	3.1 (1.8)	0.21 (0.10)	15.2 (3.1)	4.0 (1.7)	0.26 (0.09)
p value	0.645	0.407	0.493	0.575	0.010	0.003

Hmax: maximum H-reflex amplitude
Mmax: maximum M-wave amplitude

vibration paradox, it is suggested that the TVR Ia reflex pathway is polysynaptic.[38] However, it has been shown that the TVR Ia reflex pathway is not polysynaptic, but possibly monosynaptic.[18,41] Consequently, changes in muscle electrical activity and the H-reflex response in opposite directions suggest that vibration-induced increases in EMG activity cannot be explained by TVR.

It might be argued that the suppression/depression of the H-reflex may result from the stimulation of other mechanoreceptors such as cutaneous receptors, Golgi tendon organs, and joint capsule receptors.

It is known that an acute reduction in tactile sensibility appears during and for a time after, exposure to vibration, and that this reduction depends to a large extent on a depression of the excitability of the tactile units.[42,43] Gillies et al. showed that the H-reflex was not suppressed by the selective vibration of cutaneous receptors, and that this suppression was still observed after the hind limb was skinned in cats.[36] Cody et al. and Martin et al. also showed that the vibration of cutaneous receptors did not cause any significant effect on the reflex response.[18,20]

Joint receptor afferents often respond in both directions (e.g. flexion and extension) and in more than one axis of rotation (e.g. abduction/adduction and extortion/intorsion). Accordingly, as a group, joint afferents have a very limited capacity to unambiguously encode forces applied through bone, so it is highly unlikely that these could serve as a substrate for osseoperception.[44] In the present study, cyclic mechanical loading was applied over the long axis of the radius. During vibration, a total of 6 degrees flexion-extension movement was applied to the right wrist. We believe that the effect of joint capsule mechanoreceptor activity on changes of EMGrms was insignificant during vibration.

Tendons contain specialized sensory endings, the encapsulated Golgi tendon organs. Muscle spindle also has secondary endings (group II afferents). It is improbable that secondary spindle endings and Golgi tendon organs play any part in H-reflex suppression.[35,36,39,44]

BONE MECHANORECEPTORS AND AFFERENTS

An increase in muscle electrical activity at rest indicates an increase in motor neuron pool activation.[25,37] In the present study, it was found that there was an increase in EMG activity at rest during vibration, and that the UD radius BMC might have had an effect on this increase. This finding supports the assumption that, the bone exposed to cyclic mechanical loading may neuronally regulate muscle activity.

Based on the bone myoregulation reflex, bone is sensitive to mechanical stimuli and can send mechanical input signals to central nervous system (CNS) and so neuronally regulate muscle activity.[5] It is well-known that osteocytes are the primary mechano-sensors in bone. Osteocytes embedded in bone matrix are interconnected by numerous dendritic processes to form a wide, mechanosensitive cellular network.[1,45,46] Sensory nerve fibers terminate in the vicinity of bone cells. Although there is no synaptic connection between bone cells and these fibers, bone cells may directly influence sensory nerve signaling via the direct, non-synaptic connections that exist between sensory fibers and bone cells.[5,47] It has been demonstrated that bone exposed to cyclic mechanical loading sends mechanical input signals to CNS.[8,47] Skeletal muscles are supplied by alpha motor neurons. The function and activity of these muscles are regulated by CNS.[1]

The present study suggests that bone (UD radius) has an effect on change in muscle electrical activity of FCR muscle during vibration, and this effect is related to its BMC. Why is BMC related with the change in muscle electrical activity? A possible explanation for this is that osteocytes are the primary mechano-sensors in bone matrix.

Osteocytes embedded in bone matrix form a regular cellular network. The number of osteocytes vary in narrow physiological limits in healthy humans.[1,48] Osteocyte density positively correlates with BMC.[49] Therefore, UD radius BMC may be an indicator for the total number of osteocytes in healthy adults. However, the total number of osteocytes in distal radius was not determined in this

study. Future studies are needed to clearly show whether osteocytes have an effect on muscle electrical activity during vibration.

STUDY LIMITATIONS

The FCR H-reflex could not be evoked and recorded in some volunteers prior to the experiments. The H-reflex percentage occurrence varied between 73% and 100% of the population.[37] In this study, the FCR H-reflex could be evoked in only 33 of the subjects. The FCR H-reflex was suppressed or depressed during vibration in all 33 subjects. There were no cases where the H-reflex amplitude was unchanged or increased during vibration. These results also compatible with those reported in the literature. Therefore, we believe that the lack of H-reflex response in some cases does not make the results questionable.

CONCLUSION

This is the first study evaluating the effect of bones on muscle electrical activity. According to the results of the current study conducted in healthy adult volunteers, it may be suggested that bones can regulate muscle activity, based on its BMC. This finding is consistent with bone myoregulation reflex and may also help to explain the increases in vibration-induced muscle EMG activity. Potential effects of the bones on muscle activity may help to better understand exercise physiology.

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