CORRELATIONS BETWEEN MUSCLE CONTRACTION AND BONE ELECTRICAL ACTIVITY

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Abstract. The increased incidence of osteoporosis is followed, as a direct consequence, by an increase of expenses for the treatment of patients suffering due to this disease. The aim of this study is to identify the most effective types of muscle contractions in the treatment of osteoporosis in order to develop kinetic programs adapted to individuals prone to osteoporosis or to those who already have this condition. The electrical activity has been recorded from the bone surface during muscle contractions. The results of this study showed that from the electrical point of view, on its surface, the bone behaves differently, depending on the type of muscle contraction.

Key words: osteoporosis, electrical potential, triceps brachialis muscle.

INTRODUCTION

Osteoporosis is the most common bone disease, characterized by the decrease of bone mass, the change of bone architecture, which determines the decrease in its resistance and the increase of fracture risk [4].

Mechanical stimulation of bones (loading, muscle contraction) is an important factor in achieving and maintaining the bone mass, while restricting skeletal loading (prolonged rest, weightlessness in case of cosmic flights, etc.) leads to decreased bone mass density and occurrence of osteoporosis [11].

The increased incidence of osteoporosis as an illness, but mostly the occurrence of its complications consisting mainly of fractures, have determined a continuous increase of expenses for the treatment of patients suffering from this condition. This raises the need to prevent the installation of osteoporosis by primary prophylaxis, but also its complications by secondary prophylaxis methods.

Received: September 2014;
in final form October 2014.

Muscle contraction determines a mechanical deformation of the bone that is followed by the occurrence of electrical phenomena which sensitize the osteocyte syncytial (bone's receptor organ), which triggers the bone mass formation process. The electrical activity of the bone occurring as a result of muscle contraction is dependent both on its solid and its liquid component. The solid component is represented by the collagen fibers through which the proteoglycans move and change the state of equilibrium in which the positive and the negative charges are on the surface of fibers, resulting in the occurrence of a piezoelectric phenomenon, while at the level of the liquid component of the bone, a ion movement is produced, determining the occurrence of electrical phenomena which are based on the electrokinetic phenomenon [12].

All types of mechanical actions exerted on the bone determine a potential difference at this level. In order to produce a potential difference, it takes an uneven compression on the bone, since an even one leads to the creation of equivalent electric fields around the osteons, not being followed by the occurrence of a potential difference [8].

The aim of our study is to establish a correlation between the muscle activity and electrical phenomena on the bone surface which may be useful for the identification of the most effective types of muscle contractions in the treatment of osteoporosis in order to be included in programs of physical therapy adapted to individuals prone to osteoporosis or those who already have this condition.

MATERIALS AND METHODS

We have performed 23 records for a group of people aged between 19 and 52 whose physical features are shown in Table 1.

Table 1

Physical state of the people who participated in the experiments for recording the electrical activity generated by different types of muscle contractions. NW – normal weight; OW – overweight

Age	No. of subjects	Sex	Weight status
19–30 years	11	9(M); 2(F)	NW
40–52 years	12	2(M); 10(F)	8(NW); 4(OW)

For signal recording, a 24-bit biosignal amplifier was used, called g.USBamp (g.tec Medical Engineering GmbH, Austria). The electrical information due to the triceps brachii muscle contraction was measured in two different places: at the skin level and at the bone surface.

Gathering the electrical information from the muscle at the skin level, it was performed with surface electrodes placed at the triceps brachii muscle, and for collecting the electrical activity in the insertion area of the triceps brachii muscle on the olecranon [5], needle electrodes were used. Needle electrodes have three concentric layers. The inner and outer layers are those by means of which the electrical potential is measured, while the middle layer is insulating, allowing the inner layer to collect the electrical activity only from the tip of the needle [2, 6].

Fig. 1. Application of surface electrodes and needle electrodes.

Needles with a length of 37 mm and a diameter of 0.45 mm were used. Surface electrodes have the shape of metal disks – generally of silver – that are applied on the surface of the skin on top of the muscle to be tested by means of a low impedance gel (Fig. 1). It was verified that the skin is clean and free of lesions. These electrodes have the advantage to allow an easy and quick, non-traumatic application, but also the great disadvantage that, due to the fact that the harvesting is not made directly from the muscle, the obtained result might interfere with potentials from other layers, such as neighboring muscles.

The recording and data processing were performed using MATLAB & SIMULINK® software package, following the sequences:

1. Filtering the data recorded with a high-pass filter (frequencies below 15 Hz being removed).

2. Calculation of absolute values of data and filtering with a moving-average filter with a window of 100 samples.

3. Dividing the data into segments of 0.5 seconds.

4. Manual rejection of segments containing artifacts.

5. From the entire record, 3 seconds were selected for each contraction.

RESULTS

In order to see the effect of the muscle contractions on the bones, we have measured the electrical activity of triceps brachialis during its contraction in different external effort conditions. All the six experiments that follow were realised with the subject in pron position with the arm laid lateral in horizontal plane. Only the forearm may move according to experimental purpose.

The experimental data for each type of effort conditions we investigated are presented in graph in Figs. 2–7. In each figure the records symbolize:

a) The recording of the potential harvested from the olecranon through the inner layer of the needle electrode (Ch1-inside);

b) the recording of the potential harvested from the olecranon through the outer layer of the needle electrode (Ch2-inside);

c) the recording of the electrical activity of the triceps brachii harvested through the surface electrode (Ch3-EMG outside);

d) the recording of the potential difference between the inner and outer layer of the needle electrode (Ch1-Ch2 is the difference of records a and b).

e) the filtered absolute values of the potential difference (record d) registered by the needle electrode at the surface of the bone.

MEASUREMENT OF ELECTRICAL POTENTIAL OF MUSCLE DURING THE FOREARM ROTATION WITHOUT GRAVITATIONAL ATTRACTION

In this case, the movement produced by the triceps brachii muscle contraction had to get over only the forearm rotation in horizontal plane to eliminate gravitational attraction. We have named as contraction without gravitational attraction (CWGA). The forearm rotation appears in all the movement produced by the triceps branchii muscle. So, it may be considered as a reference state for the other experiments which follow.

MEASUREMENT OF ELECTRICAL POTENTIAL OF MUSCLE DURING THE CONTRACTION AGAINST GRAVITATIONAL FIELD (CAGF)

For this experiment, the movement of forearm was produced against gravitational field; the triceps brachii muscle had to get over both the weight (the gravitational force) of the forearm and its rotation around the elbow. Also, this experiment may be the reference for the muscle contraction acting against external forces.

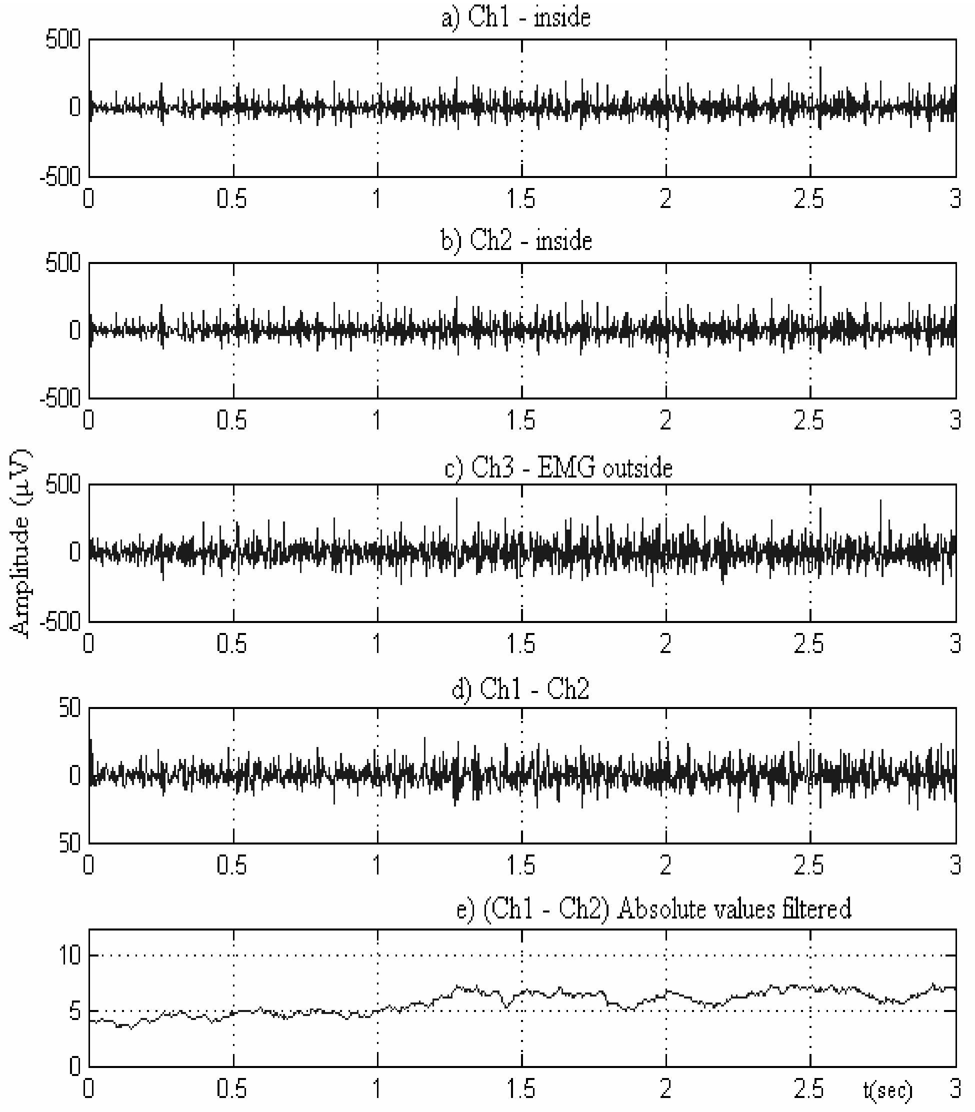

Fig. 2. The amplitude of the electrical potential of the triceps brachialis muscle during the forearm rotation around the elbow in horizontal plane. This is a muscle contraction without gravitational attraction (CWGA).

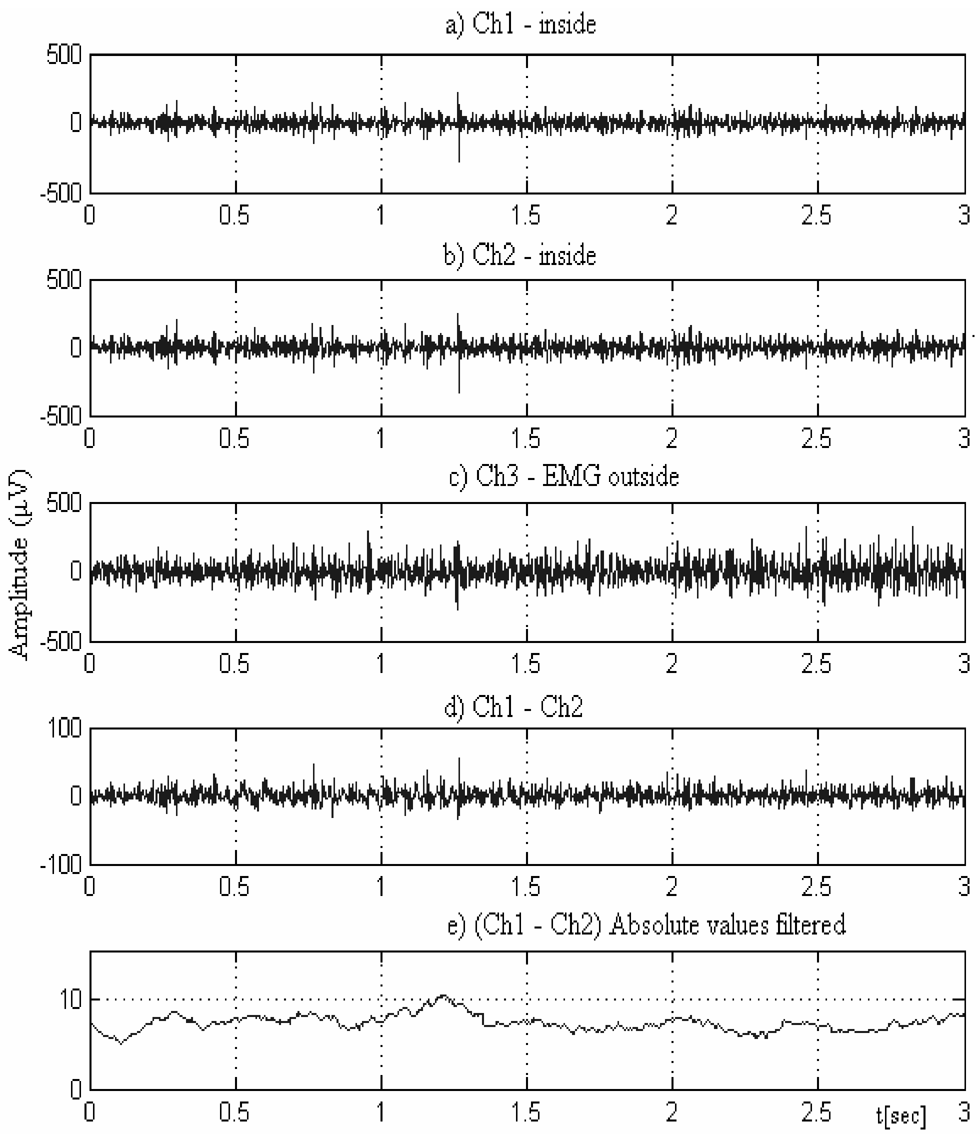

Fig. 3. The amplitude of the electrical potential of triceps brachialis during the muscle contraction against gravitational field (CAGF). The muscle acts to move the forearm against gravitational attraction and for its rotation around the elbow.

MEASUREMENT OF ELECTRICAL POTENTIAL OF MUSCLE DURING THE CONTRACTION WITH WEIGHT (CW)

The subject performed the elbow extension movement with a 3 kg weight in the hand, a movement that was done against gravity. The triceps brachii muscle had to get over both the rotation around the elbow and weight of the forearm, too.

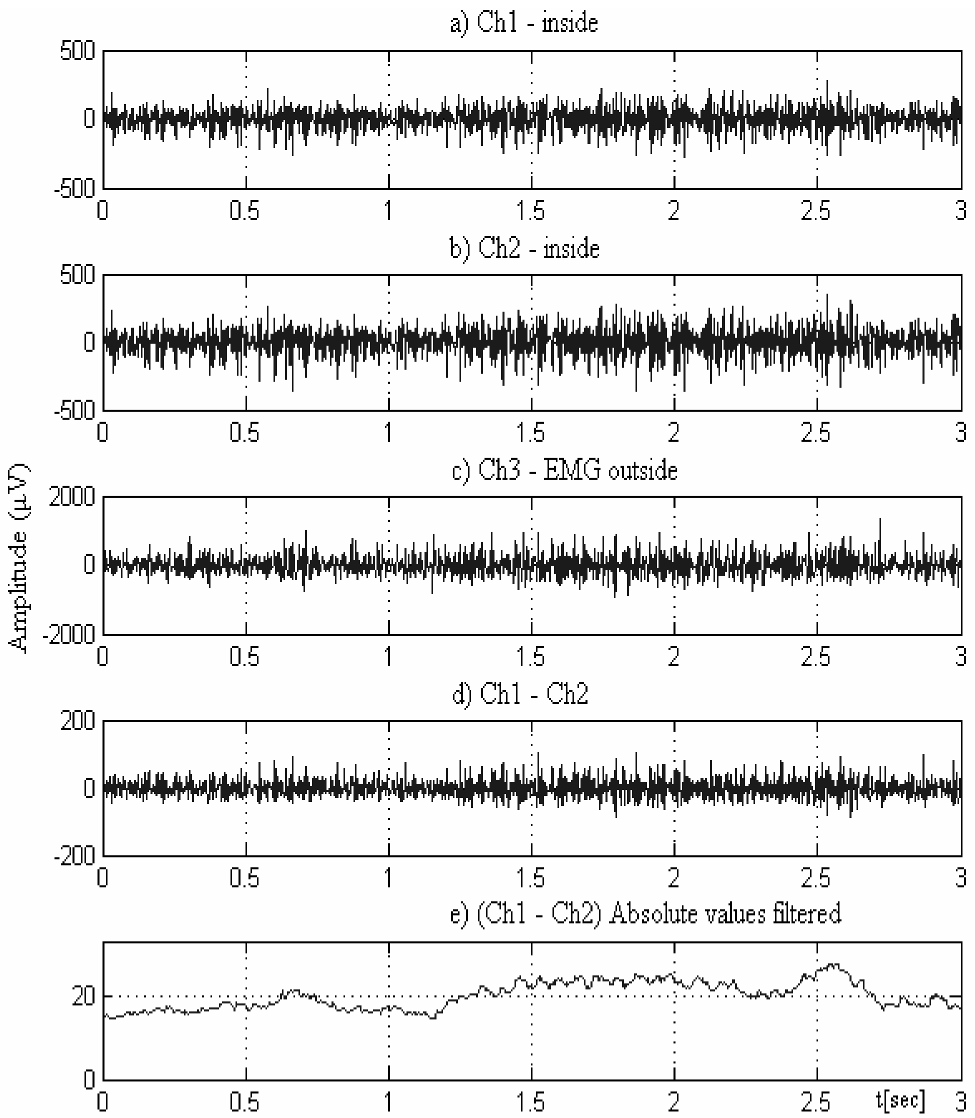

Fig. 4. The amplitude of the electrical potential of triceps brachialis muscle during its contraction with weight.

MEASUREMENT OF ELECTRICAL POTENTIAL OF MUSCLE DURING THE ECCENTRIC CONTRACTION (EC)

The movement was performed as follows: while the doctor, making the grip in the distal 1/3 forearm, exerts pressure at this level, the patient tried to resist this movement, thus obtaining a contraction that generates a distance between the insertion ends of the muscle, which explains the name “eccentric” of this type of contraction.

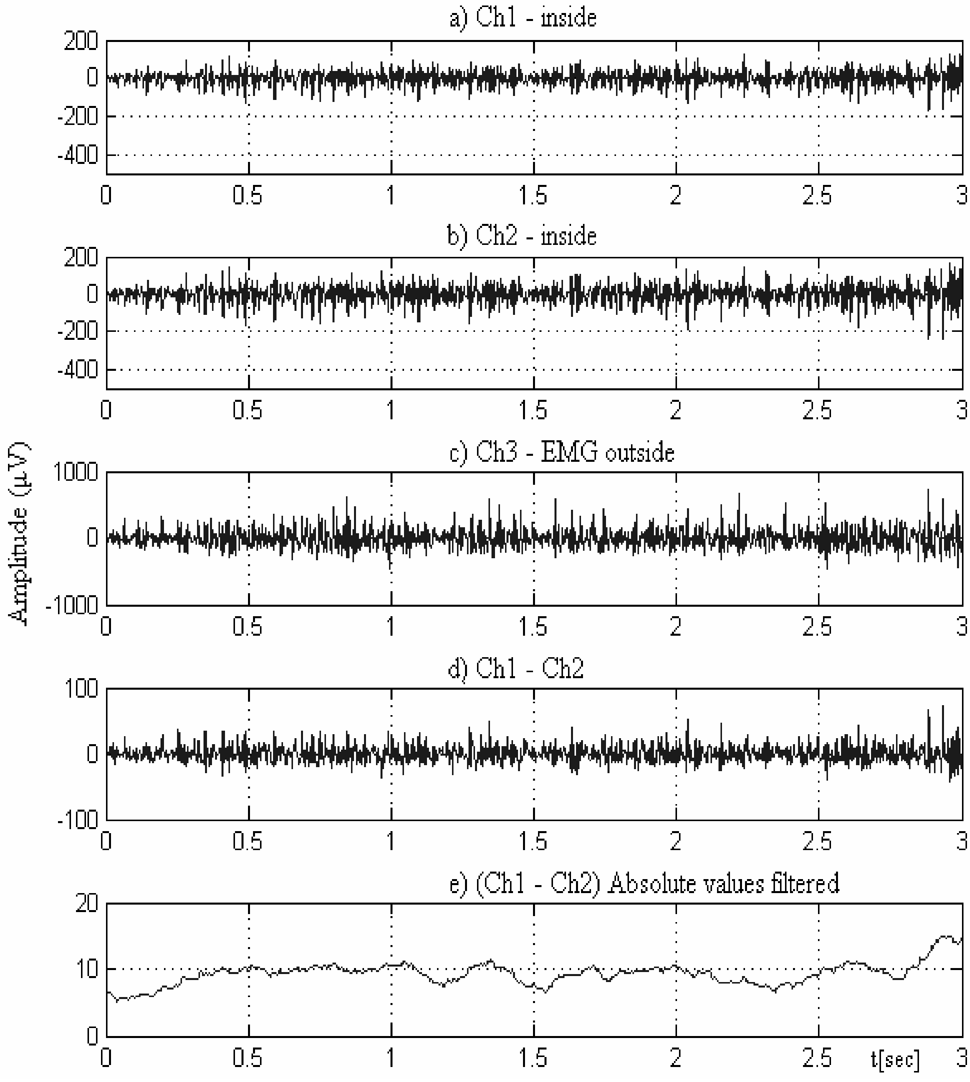

Fig. 5. The amplitude of the electrical potential of the triceps brachialis muscle during the eccentric contraction.

MEASUREMENT OF ELECTRICAL POTENTIAL OF MUSCLE DURING THE ISOMETRIC CONTRACTION IN THE ELONGATED AREA (ICEA)

The grip was made in the distal 1/3 forearm, opposing high resistance when the subject tried to make an extension. Since the opposed resistance is very high, the subject fails to move the forearm, which is why this type of contraction is called isometric contraction.

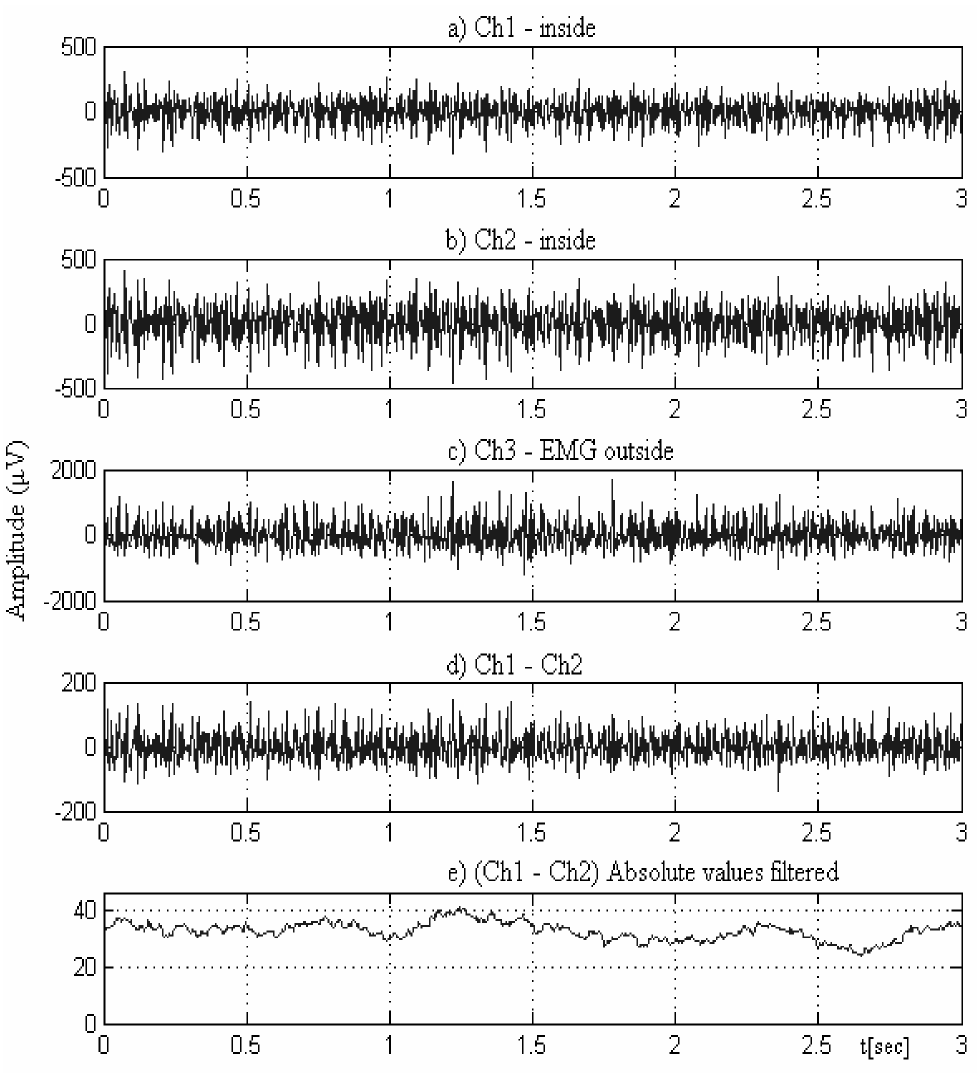

Fig. 6. The amplitude of the electrical potential during the isometric contraction in the elongated area of the triceps brachialis muscle.

MEASUREMENT OF ELECTRICAL POTENTIAL OF MUSCLE DURING THE ISOMETRIC CONTRACTION IN THE SHORTENED AREA (ICSA)

The grip was made in the distal 1/3 forearm, opposing high resistance when the subject tried to make an extension from the shortening position of the triceps, i.e. from the position with the extended elbow.

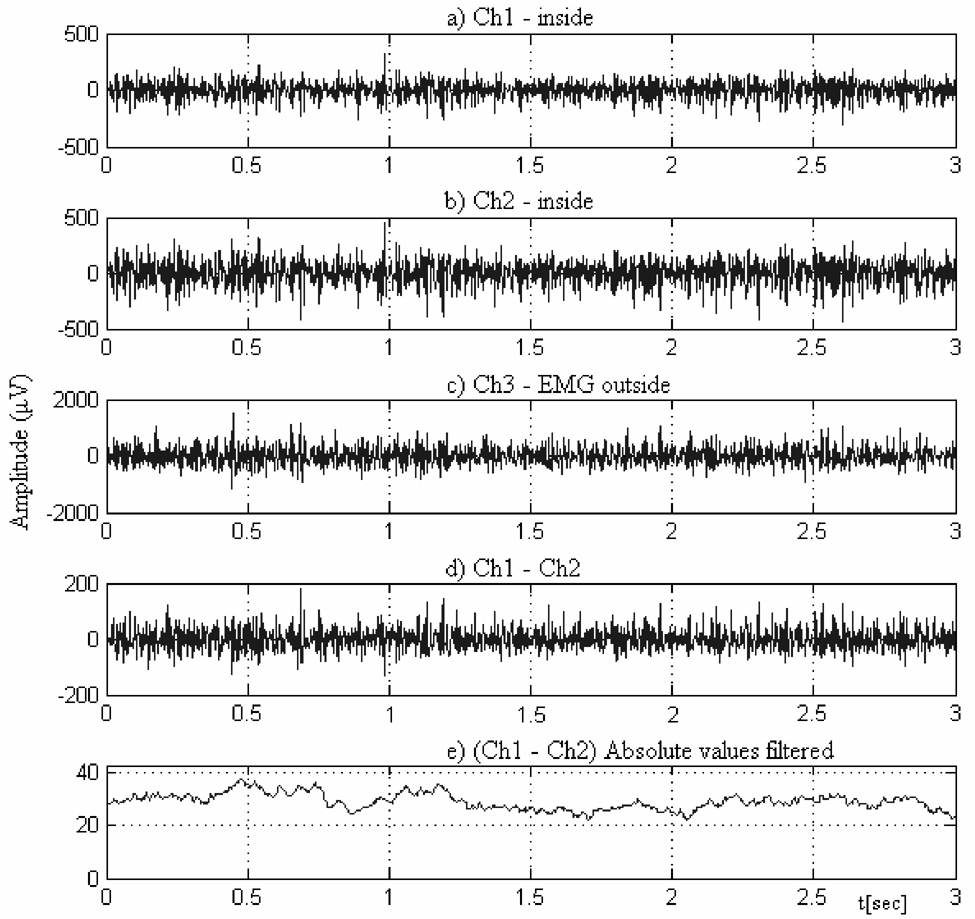

Fig. 7. The amplitude of the electrical potential during the isometric contraction in the shortened area of the triceps brachialis muscle.

In the experiments performed we followed:

1. The analysis of the electrical activity from the bone surface during muscle contraction;

2. The identification of the types of muscle contractions that lead to the largest potential differences on the bone surface.

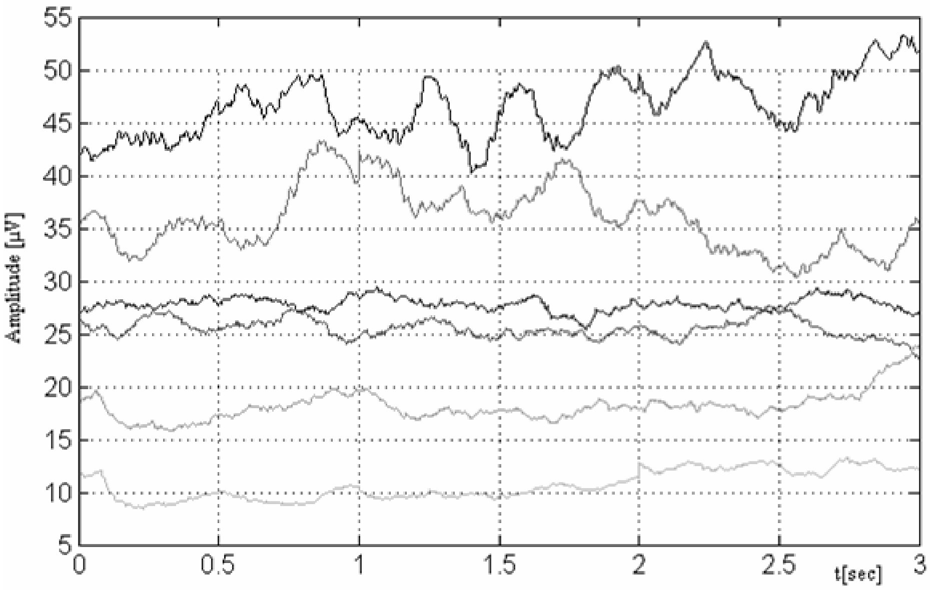

Fig. 8. Average values of the electric potential obtained for the 23 records in each from the six types of experiments.

An average of electrical potentials was performed for the 23 records for each type of contraction, the result being presented in Fig. 8 and having the following meaning:

– The lower graph, that starts from 12 μV value, corresponds to potential differences recorded during the muscle contraction for the forearm rotation around the elbow in horizontal plane, that is contraction without gravitational attraction (CWGA). The average values are of approximately 8–13 μV;

– The graph that starts from 19 μV value corresponds to potential differences recorded during the contraction to move the forearm against gravitational field (CAGF), whose average values are of approximately 16–24 μV, most of them being around 17 μV;

– The graph that starts from 26 μV value corresponds to potential differences recorded during the contraction with weight (CW), whose average values are of approximately 23–27 μV, most of them around 25 μV;

– The graph that starts from 27 μV value corresponds to potential differences recorded during isomeric contraction in the shortened area of the muscle (ICSA), whose average values are of approximately 26–27 μV, most of them around 28 μV;

– The graph that starts from 36 μV value corresponds to potential differences recorded during eccentric contraction (EC), whose average values are of approximately 31–43 μV.

– The highest graph that starts from 42 μV value corresponds to potential differences recorded during isomeric contraction in the elongated area of the muscle (ICEA), whose average values are of approximately 41–53 μV.

DISCUSSION

The electrical signal recorded at the level of a muscle is the sum of the electrical signals produced in each activated motor unit. This signal depends on several factors, among which: the number and size of activated motor units, as well as the discharge frequency of alpha motor neurons in the anterior horns of the spinal cord. The types of activated motor units and the pulse discharge rate differ depending on the type of contraction performed: therefore, while generally the first activated motor units are the small ones, it seems that in the eccentric contraction the large motor units are initially activated, while the pulse discharge rate is higher in the concentric than in the eccentric or isometric contraction. The increase in the number of active motor units has as result the increase in contractile force [3]. Eccentric contraction has the greatest capacity to generate force, followed by isometric and concentric contraction [10]. However, the maximum eccentric contraction cannot be maintained at maximum for the entire amplitude of the angle of movement, so that sometimes the force obtained by the isometric contraction can be higher [9]. Also, during maximum eccentric contractions there has been shown a reduced activation of muscle [1] and different recruitment patterns [7].

By analyzing this graph, it can be seen that the lowest values of the potential difference on the surface of the bone were recorded during the contraction carried out for forearm rotation around elbow in horizontal plane, that is without gravitational attraction, followed by the contraction for forearm rotation around elbow in vertical plane, that is against gravitational field. Comparable values are obtained for the contraction by weight and isomeric contraction in the shortened area of the muscle, slightly higher for the latter. The values obtained during the isometric contraction in the elongated area of the muscle were the most important, followed by the eccentric contraction ones. Their values were between 8 and 55 μV.

From an electrical point of view, on its surface the bone behaves differently, depending on the type of muscle contraction. The highest values of the potential difference were recorded for the isometric contraction in the elongated area of the muscle, while the lowest values were recorded in case of zero gravity contractions.

It is planned, based on the results obtained in this study, to draw kinetic programs for patients with osteoporosis or which present risk factors for osteoporosis. It is intended, therefore, that these results underlying kinetic programs adapted to the clinical and functional features of each patient, should be followed by a clinical study applied to people with bone mass deficit.

The potential differences measured by needle electrode at the bone surface will be used for the calculation of the mechanical stress induced at the bone level by the muscle contraction (inverse piezoelectric effect). For this aim we have to determine the piezoelectric module for bone.

Another future target is to find a correlation between the electric activity at the skin level and the electric activity at the bone surface, using the mathematical transformations of electrical signal, in order to avoid the pain caused by the introduction of needle electrode in the muscle.

CONCLUSIONS

The results reported in this study prove the good correlation of the electric signals recorded at the bone surfaces and the type of muscles inducing the mechanical stress on the bone. This correlation is a promising working hypothesis for designing personalized therapeutic kinetic programs for patients with osteoporosis.

Acknowledgements. The authors of this paper thank Mr. Elton Claudiu Dincă for his contribution to the execution of this project, the company g.tec. Medical Engineering GmbH in Austria for supplying the equipment, and Mr. Associate Prof. Marian Poboroniuc, PhD, Faculty of Electrical Engineering, “Gheorghe Asachi” Technical University of Iaşi for his support.

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