Short note

ELECTRICAL PHENOMENA IN BONE#

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Abstract. The electrical activity in bone is influenced by a number of physical factors that affect the process of bone formation by attracting electrical phenomena in bone. The methods used in this study consisted in performing an electronic search of the PubMed to identify the studies that contain information about the electrical activity in bone. Electrical potentials are dependent on the properties of the solid and fluid phases of bone. Mechanical deformation of bone can be followed by piezoelectric and electrokinetic phenomena.

Key words: piezoelectric effect, streaming potential, electrical activity.

INTRODUCTION

There are numerous studies about the electrical activity of the bone and about how electricity affects osteogenesis. Since the early eighteenth century, scientists attempted to use electricity in order to strengthen a fractured tibia by electric shock treatment, for 6 weeks [2].

Current studies have expanded, following not only the effect of electricity, but also of electromagnetic stimulation on the bone and cartilage. Studies made by Fukada and Yasuda highlight the piezoelectric effect in bone [4].

It is already known that crystals are substances that demonstrate a periodicity, a rhythm, a repetition of patterns. Therefore, any event that occurs in the crystal radiates, resonates and shows electricity and magnetism. Bone is a crystal formed, in turn, of several crystals that exhibit piezoelectric properties due to collagen fibers, but where we also find other electrical phenomena arising from the contribution of the liquid component of bone.

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MATERIALS AND METHODS

An electronic search of the PubMed was performed in order to identify the studies that contain information about electrical activity in bone. A total of 25 articles were evaluated. These must respect the following inclusion criteria: (1) to be based on clinical or *in vitro* studies whose aim was to study the electrical activity in bone; (2) to highlight bone reaction during mechanical loading; or (3) to highlight the bone reaction when it is subject to the action of an electric current, including when they used the techniques based on electrical phenomena in order to heal the fractures. Articles were excluded if they were: (1) not published in English or French; (2) focused on bone metabolism without involving electrical phenomena. From these articles only a few of main results were extracted, but also the authors' main conclusions.

RESULTS AND DISCUSSION

The articles were grouped into the following categories:

A. Articles that try to explain the morpho-functional substrate of electrical phenomena in bone.

B. Articles that study the bone changes due to the use of piezoelectric materials with the external application or implantation.

C. Articles containing studies that aim the bone reaction during mechanical loads.

D. Articles that study bone changes by applying the physical stimuli on bone.

ARTICLES THAT TRY TO EXPLAIN THE MORPHO-FUNCTIONAL SUBSTRATE OF ELECTRICAL PHENOMENA IN BONE

The evaluated studies report that:

1. Electrical potentials are dependent on the properties of the solid and fluid phases of bone.

2. Regarding the liquid component:

- Changes in properties of the fluid phase can modify the electrical potentials like streaming and zeta potentials [6, 24].
- "The measurements of bovine bone and tendon show that the values of the piezoelectric strain constant d14 decrease with hydration" [15].
- Also, they demonstrated the importance of the electric double layer at the fluid-bone matrix interface in triggering the electromechanical effects in bone. Experimental results indicate that the zeta potentials of bone are dependent on the concentration of ions in the fluid, being able to reverse its polarity at high concentrations of NaCl and KCl [17].

3. Regarding the solid component, it was demonstrated its role in triggering the piezoelectric effect, specify that bone piezoelectricity originates from collagen fibers and not from minerals (hydroxyapatite crystals), because they are centro-symmetric and do not produce such phenomena. The piezoelectricity property of collagen that acts as a crystal was demonstrated both macroscopically and microscopically [23].

“The magnitude of the piezoelectric constant depends on the angle between the applied pressure and the axis of the bone” [4].

4. Comparing the involvement of the liquid phase and solid phase in the appearance of electrical phenomena followed by bone formation, the studies evaluated show:

- Using a SiNuPrOs model that allows exchange of information between the different structural scales of cortical bone, the study reports that the collagen, thanks to its piezoelectric properties, more than the fluid, has an important role in the transmission of information in the bone, information necessary for inducing an osteon reconstruction that is best adapted to local mechanical stress [21].
- I found a study whose authors believe that the role of piezoelectric effect in transmitting information to the receptor organ of bone is minor and propose other hypotheses such as streaming potential, which could explain the role of fluid in osteocyte's mechano-sensory function [1].
- In another study the author proposes that the current information about piezoelectric and streaming potential phenomena which turn up in the bone should be reevaluated in terms of the importance to cell signaling [12].

ARTICLES THAT STUDY THE BONE CHANGES DUE TO THE USE OF PIEZOELECTRIC MATERIALS WITH EXTERNAL APPLICATION OR IMPLANTATION

Evaluated studies revealed that the use of materials with piezoelectric properties lead to stimulation of bone formation:

- A study that used a custom-made piezoelectric loader in order to apply a 0.5 N loads to achieve a load through a lateral-medial direction on the left knee of mice, demonstrated the anabolic effect of loading, followed by increasing bone formation in femoral shaft on the knee femoral, compared to the controlateral knee (that was used as non-loading control) The enhancement was most significant with 10 and 15 Hz loading frequency, compared with 5 and 20 Hz loading frequency [25]. Another study using polyvinylidene fluoride actuators reported similar data [18].
- The implantation of the polymer poly-L-lactic acid induced the growth of bone, which, according to the authors, was caused by piezoelectric polarization [3, 8].
- The author of a study that investigated many biological substances: polysaccharides, proteins and deoxyribonucleates concluded that the origin of piezoelectricity lies in the internal rotation of dipoles [3].

ARTICLES CONTAINING STUDIES THAT AIM THE BONE BEHAVIOR DURING MECHANICAL LOADS

The data in these studies highlight the following:

- Mechanical deformation of bone can be followed by a piezoelectric and an electrokinetic response [24].
- The collagen fibers are surrounded by a matrix consisting in the hyaluronate and proteoglycans. It seems that the muscular contraction produces the large charged proteoglycans stream past the collagen wires, followed by an electrical phenomenon [16].
- Bone loading achieved on laboratory animals or on people during practicing a kinetic programs was followed by increasing bone formation. Also, the studies suggest that once bone has adapted to a loading state, the remodeling rates reduce gradually while maintaining bone volume fraction and stiffness [9]. Also, the studies reveal that muscle-derived stem cells are able to differentiate into cartilage and bone and can directly participate in fracture healing. "The role of muscle-derived stem cells is particularly important in fractures associated with more severe injury to the periosteum" [19].
- Not any kind of mechanical loading of bone is accompanied by bone formation: depending on how compressive forces acted, there were highlighted areas where bone formation occurs and areas where bone resorption occurs [13]. Measurements at the cortical bone have shown that the recorded potential changed their polarity according to the osteons state, which are different in the place where the bone was compressed, from the place in which the bone has been put into tension [11]. On the other side, they observed that, if a uniform compression is achieved, the radial electric field around the osteons is equivalent and no electrical potential generated by stress (SGP) was produced, while in the case of non-uniform compression, the electric field was different and they could determine SGP [7].
- Studies on the behavior of the bone to the mechanical stress which generates the action potential, using microelectrodes, have shown that the potential generated in the bone has an intensity of 1–2 orders of magnitude greater than that measured at the macro level by determining average value of the electric fields [20].

ARTICLES THAT STUDY BONE CHANGES BY APPLYING THE PHYSICAL STIMULI ON THE BONE

The evaluated studies report that:

- The electrical activity of bones is influenced by a number of physical agents such as low level laser therapy, ultrasound and electrical and electromagnetic fields, exercises, agents that promote osteogenesis [10, 22].
- A synthesis taking into account both clinical and *in vitro* studies confirmed the beneficial role of electrical stimulation on bone repair, but the authors' conclusion was that the parameters used require improvements [5].

• Investigating the electrical properties of collagen fibrils and apatite minerals, the authors of a study found that bone, when polarized electrically by applying an external voltage, depolarizes by two mechanisms: one of them attributed to collagen fibrils because decalcified bone exhibits depolarization peak at 100 °C, and the other attributed to apatite minerals because calcined bone exhibits depolarization peak at 500 °C [14].

CONCLUSIONS

The electrical potentials are dependent on the properties of the solid and fluid phases of the bone: the mechanisms underlying electrical activity are not perfectly superposable in the dry bone and hydrated bone, where, besides the piezoelectric mechanism which arises both in dry bone as well as in the hydrated bone, in the hydrated bone was highlighted another mechanism represented by streaming potential. On the other hand, mechanical deformation of bone can be followed by a piezoelectric and an electrokinetic one. The piezoelectric mechanism triggered in bone is supported by a number of studies that have shown that this is due to collagen fibers, collagen that has piezoelectric properties, both at macroscopic and microscopic level.

The bone loading is, generally, followed by increasing bone formation, but not any kind of mechanical loading is accompanied by bone formation; so, depending on how compressive forces acted, we can obtain formation or resorption of bone. A similar situation was also found in the application of electrical current when both the formation and bone resorption can be obtained, depending on the polarity of the current used.

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