Electro-Acoustic Device for Hip Dysplasia Assessment

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A device for making diagnosis of dysplasia at the development fracture in newborns, assessment of osteoporosis and injuries of the skeletal system is presented. Its functioning is based on generation of acoustic resonance by sound transmitted through the bone under study. The device operates with a transmitter and an acoustic receiver coupled to the surface, just above the bone area under study. The measurements at the femoral bone in newborns indicate that the dominant frequency is around 160 Hz, which is consistent with other studies. Data comparisons with ultrasound technique suggest that this device could be an alternative for both dysplasia's studies of the hipbone and estimations of bone density.

Keywords: hip dysplasia, acoustic resonance, osteoporosis, densitometry, nondestructive technique

Different nondestructive techniques (NDT) in medicine have been applied for several years, these cover a wide range of techniques targeting different areas of study; such as visual inspection [1-4], penetrating solutions, chemical tests [5-8], nuclear radiation, sound, ultrasound, thermal, microwave, as well as the techniques based on electromagnetic effects as well [9-16]. Also these NDT are applied in detection and distribution of aluminum of bones, biomechanical studies to bone health assessment and dysplasia of the hip [17-19].

It is known that bone tissue is constantly changing, and in turn, it acts as a shield to protect delicate internal organs. One of the big problems in the elderly is the osteoporosis that generally causes hip problems. The bone specialists confirm the fracture by radiography. However, X–rays may not see linear fractures in the first instance. Thus when pain persists, the patient may undergo an MRI or a bone gammagraphy.

An alternative could be the electro-acoustic implementation of the portable device that is presented in this work. This one is able to make the diagnosis of hip-dislocation in newborns and other irregularities in vivo of the skeletal system in old people, and for making diagnosis of hip dislocation in newborns and other irregularities in the skeletal system in vivo is presented; furthermore, its characterization and some preliminary in vivo results are also included. This device emits a sound at a certain frequency on one end of the femoral bone and captures the signal on the pubis of hipbone. Thus, the acoustic signal travels through the femur and hip up to the pubis; so, power changes and/or frequency changes in the measurements are used to diagnose the possibility of hipbone dysplasia and/or osteoporosis.

The article is organized as follows. In section two we present a brief state of the art associated with sound propagation. In section three describes the method proposed in this paper. In section four we present the results obtained and finally, in section five presents the conclusions and future work.

Experimental part

Methods and materials

Sound is a mechanical wave that propagates through matter such as a gas, liquid or solid; and its properties change when traveling from one medium to other. A bone is a solid medium in which sound travels to a certain speed depending on two conditions: the Young's modulus and the density.

To model the acoustic behavior of the femoral bone, it is considered as a rod with both ends fixed, (fig. 1) shows a rod of length *L* and one element of a x b dimensions. The

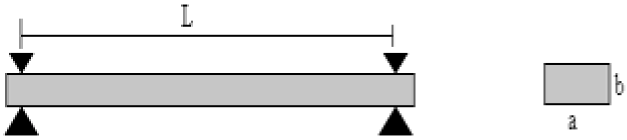

Fig. 1 Rod attached at the ends by a soft node pair

differential equation that models the motion of the rod is given by eq. (1)

$$\frac{\partial^4 \psi}{\partial x^4} + \frac{\rho_{ab}}{YI}\frac{\partial^2 \psi}{\partial t^2} = 0, \qquad (1)$$

where ψ is the transverse displacement of a point x at time t, ρ_{ab} is the density of the element, Y is the Young's modulus of the material and $I = ab^3 / 12$ is the inertia moment of the rod. The solution of eq. (1) allows the calculation of the frequencies of vibration, given as

$$f_n = \frac{r_n^2}{2\pi}\sqrt{\frac{YI}{\rho_{ab}L^4}} = C_n\sqrt{\frac{YI}{\rho_{ab}L^4}}, \qquad (2)$$

where f_n is the frequency of the normal mode of vibration and C_n are the numbers that correspond to it.

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Using eq. (2) is possible to assess the natural frequency of oscillation of the bone and to determine the bone density. The approach is valid because the femoral bone is attached to tendons in which the Young's modulus is around 6000 and 240 kg / cm^3, respectively, while the Young's modulus of the fresh bone is 210000. Therefore, due to the great difference between these values, the bone can be considered as subject to a pair of elastic supports at the ends, which reduces some resonance artifacts that can be caused by the bone connected to rigid ends.

It is assumed that the acoustic resonance of a very porous solid material occurs at low frequency, while the resonance frequency of a less porous solid of the same material will be higher. Then, we can establish that the oscillation frequency of a healthy bone is higher than the frequency of a bone with osteoporosis. If the height of the subject under study or the length of his femur or radius are known it is possible to estimate the bone density of the bone in question. The height of the subject is an important factor because studies show that there is direct relationship between the height of human beings and some of the bones mentioned above [19].

Hardware description

A software application was implemented in Matlab® platform in order to perform the study. A stimulation signal was generated and the measured data from the stimulation were recorded and plotted in real time. A standard system was designed in order to replace the computer and have a portable device; this is based on a PIC16F877 micro-controller, with the same routine previously used. An actuator is used in the system to promote the stimulation of the bone; this actuator comprises a coil and a magnet, which has a vibrating effect (diapason). The sound registered travels through the femur up to the pubis in the hipbone of the subject under study or the bone in evaluation and a microphone records it. The signal is amplified by an electronic amplification stage and transported to the analog inputs of the PIC16F877 microcontroller for processing. The signal is detected by an electronic stethoscope which is connected to the amplification stage and finally it is analyzed by an algorithm stored in the program memory of the processor (fig. 2).

Software description

A computational algorithm stored in the memory of the microprocessor was developed to generate a signal with different frequencies; an amplification stage was added to a stethoscope as the emitting signal on the femoral bone for dislocations of the hipbone diagnosis. At one end of the pubis, on the hipbone, the stethoscope was placed in order to sense the transmitted signal. The signal is taken to the electronic system for evaluation and issues the results of the subject under study.

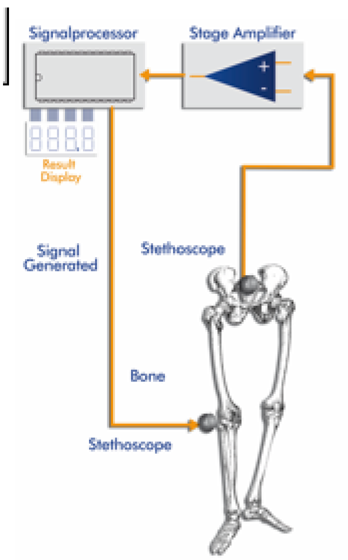
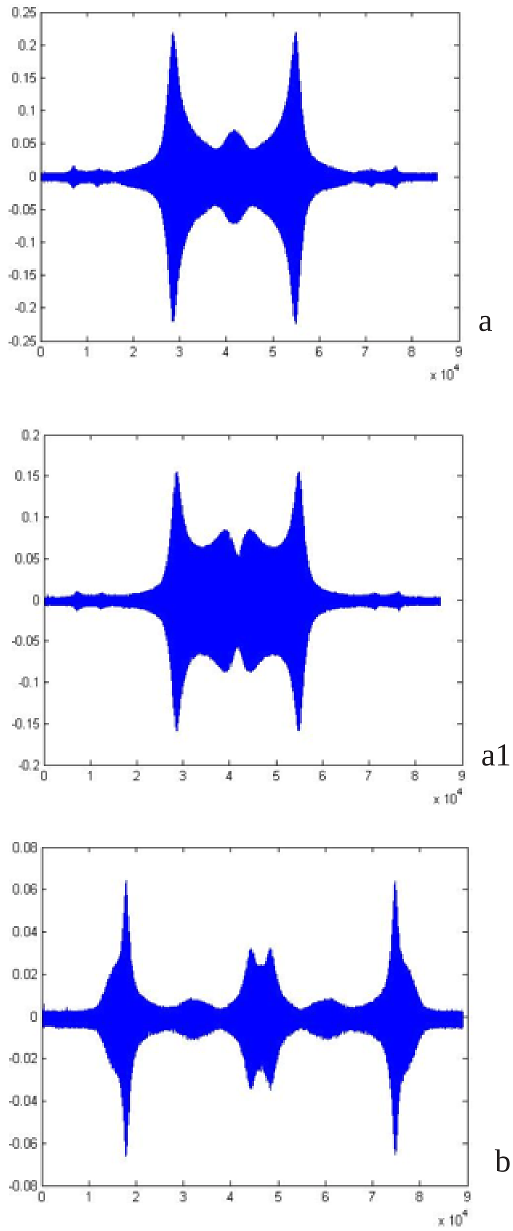


Fig. 2 Scheme used for the measurements of acoustic resonance in the human bone

The operation of the device is based on the detection of irregularities of the skeletal system to measure changes in the power of an audio signal that travels through the femur until its end at the hip pubis. In order to know the signal behaviour through a sample, an experiment with its theoretical complement was performed. For the experiment, wooden cylinder's of Scots pine (Pinus sylvestris) r = 1.1cm radius, density of r = 0.54 kg / m^3 humidity of 12 %, modulus of Young of 9x109 N/m^2 in the direction of the fibers, each with length of 25, 35 and 45 cm; respectively, were studied. For the data acquisition the pieces were subjected to a sweep ascending and descending frequency in a range from 200 to 2000 Hz. The frequency variation was made linearly and signals were captured by one sensor positioned on top central part and a second sensor on the side opposite to the location of the actuator on top of the end piece.

Results and discussions

Figure 3 shows the sensed signal recorded through the frequency sweep described above and the table 1 show the comparison of the frequencies found theoretical and experimentally.



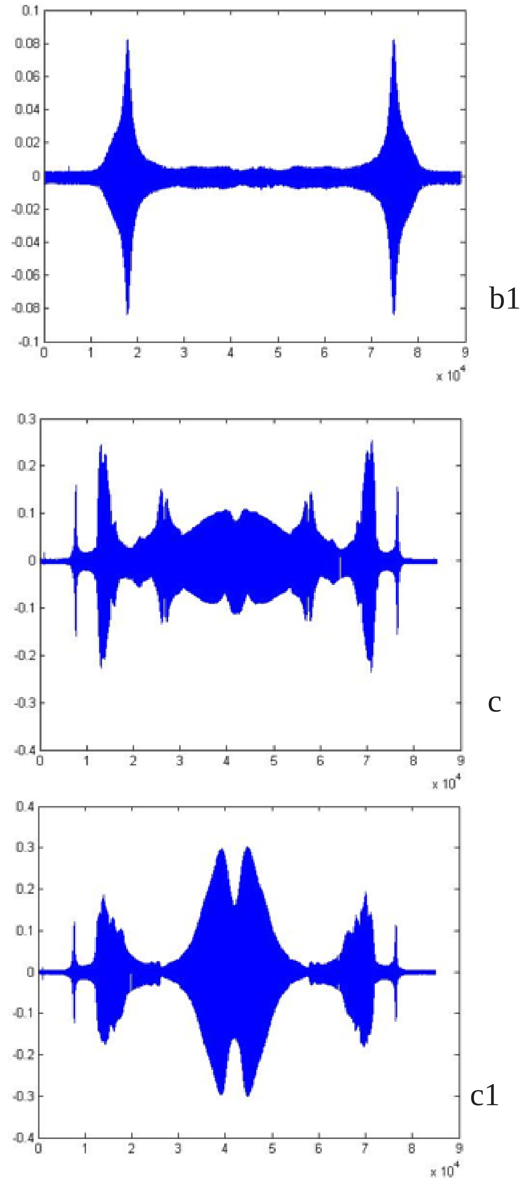


Fig. 3 Registered signal from frequency sweep upward and downward order-in ranges of 200-2000 Hz with linear variation. The left column shows the behavior of the signal for the sensor in the middle of the bar, plots a) 25 cm, b) 35 cm, and c) 45 cm; as long as, in the right column is shown the behavior of the signal for the sensor to the opposite end of the actuator in the piece a1) 25 cm, b1) 35 cm, and c1) 45 cm

A frequency spectrum was obtained from the fast Fourier transform (FFT), on each of the maximum peaks that are related to the calculated resonance frequency. In a range of 200 points around the center point, a value of 4.064×10^4 Hz was obtained for a piece of 25 cm, a frequency of 4.636×10^4 Hz for the piece of 35 cm and 6737 Hz for the piece of 45 cm of length. A diverse range of harmonics relative to the stimulation frequency was obtained, (fig. 4) shows the frequency spectra.

The device developed can be used at a fixed rate to be applied to sound transmission tests in the diagnosis of congenital hip dislocation in newborns. It is important to mention that a percent of affected children are diagnosed by the medical doctor, but a large percent is done by the family, usually after second half of life of the infant.

When is required an assessment of dislocation, it is recommended to put the actuator near a joint to avoid interference with other bones. The actuator emits a sound that is transmitted mostly through the bone, place the microphone on the iliac crest located on the same side of the femur in question, extend the foot of the subject in analysis, and observe in the instrument display the value brand for powerful sound. The whole operation must be repeated on the other side of the individual and compares the values, if the powers are very similar means that there is no dysplastic lesion in hip, if variations having greater than 10 percent means that there is a break and must be addressed promptly.

As a second analysis, the same operation is performed by flexing the leg of the individual being tested toward his chest at an angle of 90 degrees, and performs power comparisons, having to match the powers, which for most display cases is that there is no damage of dysplasia.

Table 1

COMPARISON OF THE FREQUENCIES FOUND THEORETICAL AND EXPERIMENTALLY WHEN PERFORMING FREQUENCY SWEEP

Sample [cm]	25	35	45
Measured point to 2000 Hz frequency	4.064×10^4	4.636×10^4	4.104×10^4
Point obtained for the maximum peaks	2.75×10^4	1.786×10^4	1207×10^4 6737×10^4
Theoretical Results	1538.27	784.83	664.15 474.77
Experimental Results	1420.30	742.64	5.37
Difference %	7.67	721.91 486.63	8.00 2.44

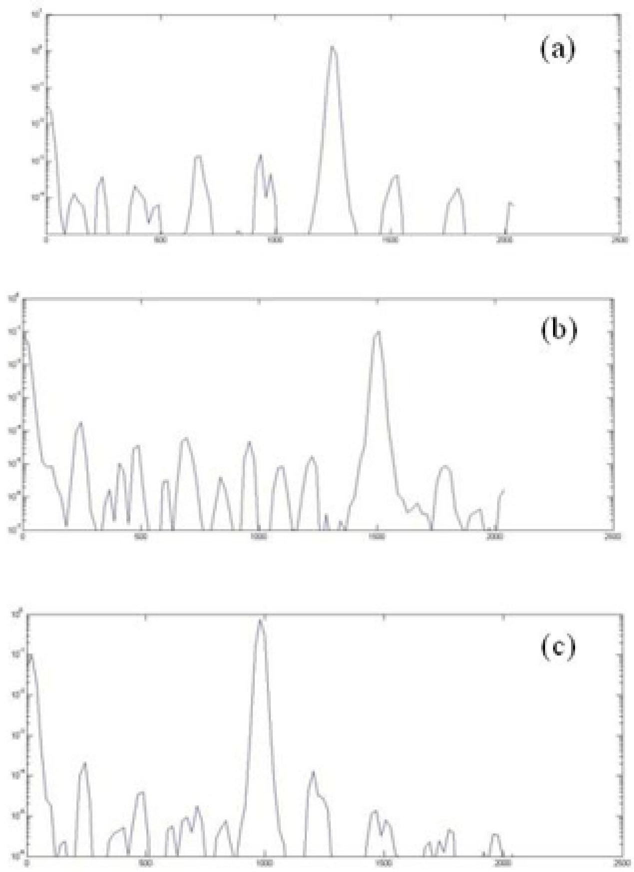


Fig. 4 Frequency spectra calculated from the FFT of the signal measured at the center of the piece,
a) piece of 25 cm, b) piece of 35 cm, c) piece of 45 cm.

Applying this principle, this device is used to determine the existence of fractures and low levels of calcium. Verifying if the transmission medium of sound is affected, the signal will be partially truncated at the point where the medium is interrupted. Bone is a material with a certain hardness and therefore a good sound transmitter, if at any point a transmitter is placed at a particular frequency, it is expected that a known distance a power level of sound has to be detected; with this approach it is possible to establish a relationship in the breakpoint of sound and where there may be a fracture or injury. The amplitude of the signal captured through the receiver indicates if suffering from a dysplasia of the hip, this is, a rate analysis form in/out signal determines if there is a dislocation of bone in the femur or in the hipbone.

According to the comparison of the results of the recorded audio signals and correlating with clinical results (X-ray CT). In the first experiment (fixed position), when comparing the recorded audio signal at the opposite end, if the signal is less means that the hip is affected, otherwise considered unaffected hip bone. Furthermore, for the flexural test were recorded two signals, the first in a fixed position (0 degrees) and in flexion (90 degrees). If at comparison of the two audio signals results with one of some greater amplitude, that means the hip bone has had involvement, otherwise the hip is considered healthy.

These encouraging results not replace standard clinical maneuvers, however, this technique can be considered as an alternative for the detection of disease in developing dysplastic hip.

Conclusions

The electro-acoustic device has shown a good system for detecting irregularities in the skeletal system, such as fractures, injuries and osteoporosis. Its operation is based on the acoustic driving on solid media and its particular resonance in the parts that make up the human skeletal system. This noninvasive device, not require ionizing radiation and patients do not experience any pain associated with the transfer of acoustic waves through the bone segments in evaluation. The device uses sound transmission through segments of the skeletal system, a transmitter and a receiver in contact with the surface contact was fixed, taking care that the device was aligned just above the bone evaluation, the signal is processed in real time and permits the evaluation instantly, also allows store the information obtained for further evaluations, the device allows rapid changes in the parameters for obtain information with a higher accuracy rate. The sound transmission tests do not distinguish between physiological immaturity, subluxation or dislocation of the hip.

This new modality of detection of irregularities in the skeletal system is an excellent alternative that avoids the risks from ionizing radiations. The use of the compared sound transmission device is a very good and objective choice for detecting abnormali- ties of the hip. It does not replace the usual clinical maneuvers, but it complements them and it has the distinction of not including the human factor. It is important to point out that the procedure does not present any risk to the patient because it is a noninvasive procedure and because he/she is not exposed to any ionizing radiation. The protocol was approved by the Research Committee from the Health Sciences and Engineering Division, Universidad de Guanajuato (Celaya—Salvatierra Campus) and by the Bioethics Committee of Celaya's General Hospital belonging to the Ministry of Health for the state of Guanajuato.

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