Evaluation of Osteoporosis Using Ultrasound

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ABSTRACT

We have developed an equipment using ultrasound transducers to help in the diagnosis of osteoporosis. The equipment consists of an X-Y axes displacement system controlled by a microcomputer and uses two ultrasound transducers in opposite sides to inspect the calcaneus region of the patient. We have used two pairs of transducers with 500 kHz and 1 MHz central frequencies. Each pair of transducers was fixed in the X-Y displacement system submerged in a small water tank with a support for the foot of the patient. The transmitter was excited with pulses of 400 - 600 kHz or 800 – 1200 kHz and the ultrasound waves propagating through the bone in the calcaneus region are received by the opposite transducer, amplified and acquired in a digital oscilloscope. The data are transferred to the microcomputer and the ultrasound attenuation and the ultrasound transmission velocity are determined. The system was tested in patients, selected from a group that had already been diagnosed using a DEXA equipment. The results showed that there is a decrease in the ultrasound transmission velocity and the ultrasound attenuation in osteoporotic patients when compared to healthy patients of the same sex and age group. The conclusion is that ultrasound attenuation and the transmission velocity in the calcaneus region may be used as parameters in the evaluation of osteoporosis using our new system.

Keywords: osteoporosis evaluation, calcaneus, ultrasound waves, ultrasound transducer, ultrasound attenuation, ultrasound transmission velocity.

1. INTRODUCTION

Many techniques based on radiation have been extensively used in the medical field, such as the X-ray tomography, computerized axial tomograph (TAC), magnetic resonance imaging (MRI), computed ultrasonic tomograph (CUT) and others[1,2]. The use of ultrasound has been growing continually due to its low cost, the possibility of getting images in real time, to provide information of the elastic properties of the tissue, its non-invasive characteristic and because it is a non-ionizing radiation. It has been largely used in the medical diagnosis in obstetrics and gynecology, ophthalmology, neurology, cardiology and also in therapeutic procedures[3]. Recently, it has been investigated as a method to help in the diagnosis of osteoporosis[4,5,6,7].

Osteoporosis has been known as one of the most important problems to be solved and became an important area of interest for researchers and governmental health care agencies[8,9,10]. One of the problems to control and to treat the disease is to identify the patient under risk of osteoporosis or osteopenia before the appearance of bone fractures. These fractures may occur due to a reduction in bone density and they result, usually, of small traumas

The current methods for diagnosis of osteoporosis involve densitometry using ionizing radiation[11] such as: 1) Dual Energy X-ray Absorptiometry (DEXA), used to measure bone density in the lumbar area of the dorsal spine in the femur, hip and several other parts of the body; 2) Single Photon Absorptiometry (SPA), used to measure bone density in outlying areas of the body as for instance forearm, calcaneus region and distal radius; 3) Computed Tomograph used to measure bone density in the lumbar area of the dorsal spine and 4) Ultrasound that is one of the most recent techniques, used to measure ultrasound transmission velocity and broadband attenuation in order to correlate these parameters with the vertebral bone density[6].

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The use of ultrasound as a method for diagnosis of the osteoporosis has generated great interest due to its relative low cost and mainly because of its non-ionizing characteristic. The method is used to inspect outlying areas such as calcaneus, forearm and proximal phalanxes to access information on the structure and bone mass trying to detect or to foresee the osteoporosis.

Our objective in this work was to develop an equipment using ultrasound transducers of low cost, safe and easy to manipulate helping in the diagnosis of osteoporosis in order to permit the use of the correct therapy as a mean to prevent surgical interventions and to keep the bone mass above the limit that indicates the presence of the disease.

2. MATERIAL AND METHODS

In this work, it was developed a system that allows X-Y axes displacement in the calcaneus region to measure the attenuation and the ultrasound transmission velocity. The developed system will be described in the following sections.

2.1. Developed Equipment

In order to collect the data to obtain the two desired parameters (attenuation and transmission velocity of the ultrasonic waves) the developed system uses two basic methods to accomplish those measurements: 1) the pulse-echo and 2) the transmission-reception.

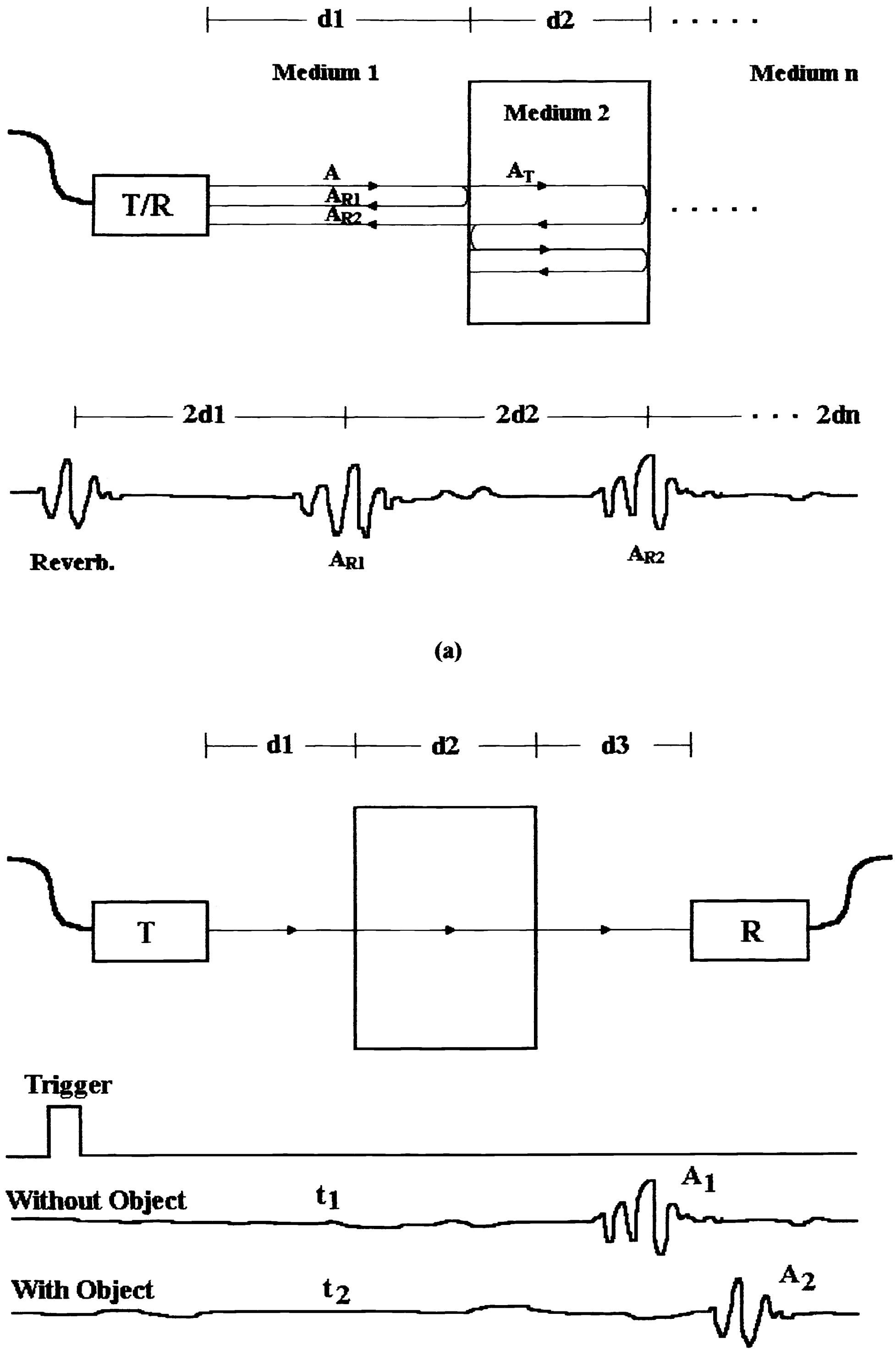
In the pulse-echo method (Figure 1a), the same transducer acts as the transmitter and the receiver of ultrasonic waves. In those case, an electric pulse is applied to the transducer that generates an ultrasonic wave (A in the Figure 1a). The ultrasonic wave propagates through the medium 1 and as soon as it finds the interface between the media 1 and 2, part of it is reflected (AR1) and the other part propagates through the medium 2 (AT). By the same way, the wave that propagates through the medium 2, when finding another interface, will have part of it reflected and part of it transmitted. The waves reflected that are captured by the transducer (AR1 and AR2), accomplish information about the distance or sound propagation velocity through the relationship ($S = Vt$), where S is the traveled space (in the pulse-echo method, the ultrasonic wave propagates in an equivalent distance of two times the distance between the transducer and the object), V is the velocity of the sound in the medium and t, the elapsed time between the application of the pulse and the reception of the echo.

In the transmission-reception method (Figure 1b), independent transducers are used to transmit and to receive the ultrasonic waves. In this case, an electric pulse is applied to the transmitter, generating an ultrasonic wave that propagates through the medium and will be captured by the receiving transducer. Using this method it may be possible to obtain information about the propagation time and attenuation of the ultrasonic waves as a function of the presence or not of the objects (mediums with different acoustic characteristics) in the path of propagation wave.

The combination of the two methods in the system, make it possible to obtain information about the distance among objects, ultrasound velocity in the medium and attenuation of the ultrasonic waves. The block diagram of the developed system to collect data in the calcaneus region is shown in Figure 2.

The system is formed basically by a X-Y axes displacement unit, where the ultrasonic transducers are coupled, that uses step motors for positioning and is controlled by the microcomputer through an Input/Output data board. We have mounted two pairs of transducers (transmitter and receiver) using PZT ceramic discs of 21.4 mm diameter, 4 mm thickness (central frequency 500 kHz) and 25.4 mm diameter, 2 mm thickness (central frequency 1 MHz). Each pair of transducers of the same frequency were fixed in the X-Y displacement system submerged in a small water tank with a support for the foot of the patient. The transmitter was excited with two or four cycles of square pulses (48 Vpp) of 400 - 600 kHz or 800 – 1200 kHz, depending of its central frequency. The ultrasonic waves, generated by the transmitter, propagates through the bone in the calcaneus region and are received by the opposite transducer, amplified and acquired in a digital oscilloscope. The data are transferred to the microcomputer through a GPIB IEEE-488 pattern and the ultrasound attenuation and the ultrasound transmission velocity are determined.

Figure 3 shows some transducers developed in the laboratory and Figure 4a and 4b shows the X-Y axes displacement unit and the positioning of the transducers in relation to the patient's foot inside of the tank with water to accomplish the measurements.



(b)

Figure 1 – Methods to accomplish attenuation and velocity measurements: **(a)** Pulse-Echo; **(b)** Transmission-Reception

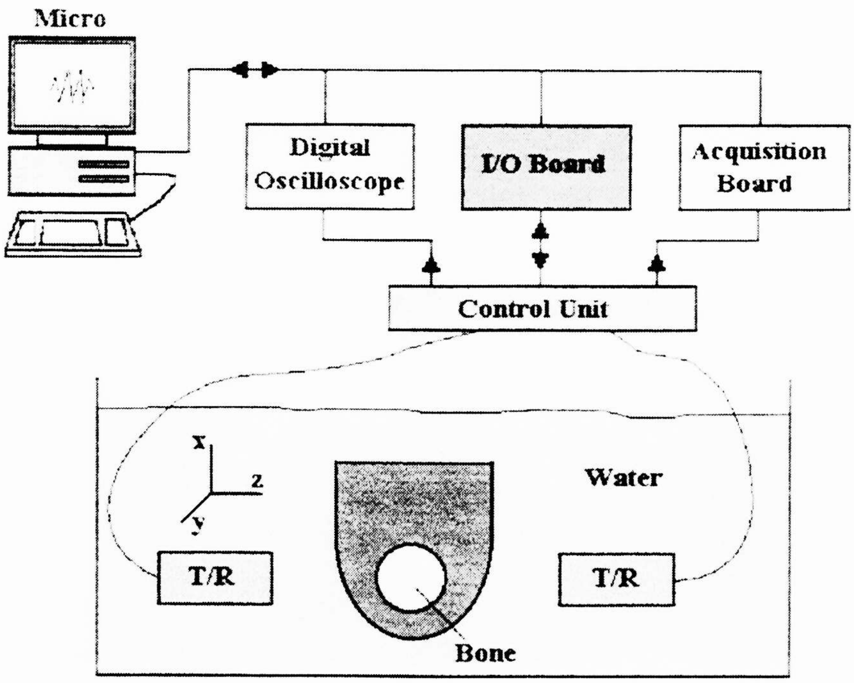


Figure 2 – Developed system to collect data in the calcaneus region.

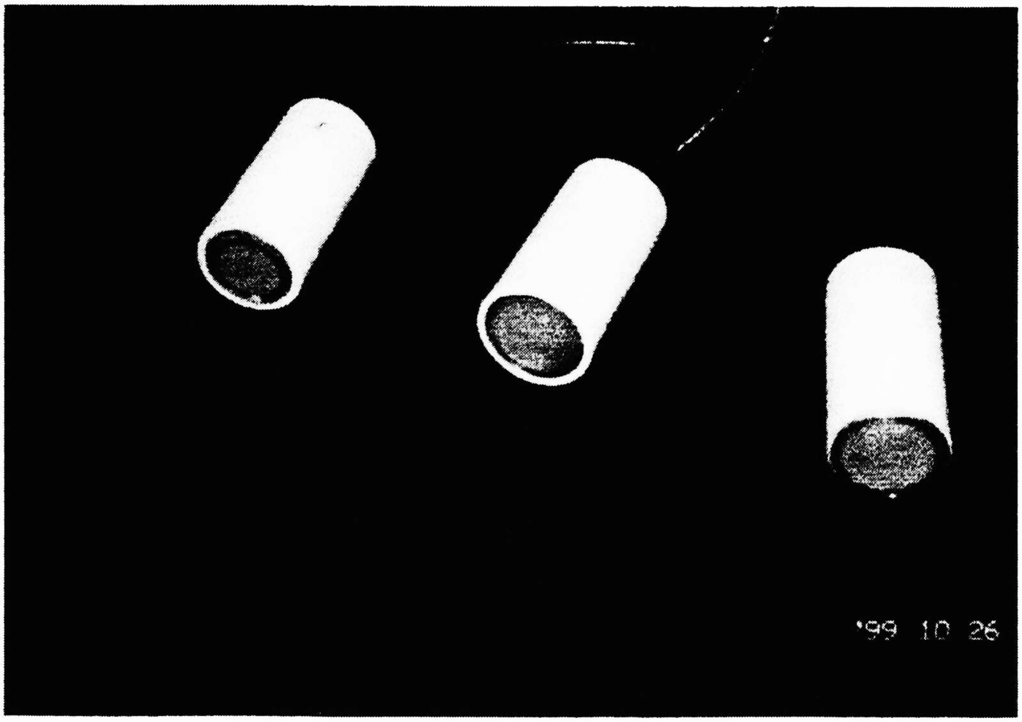
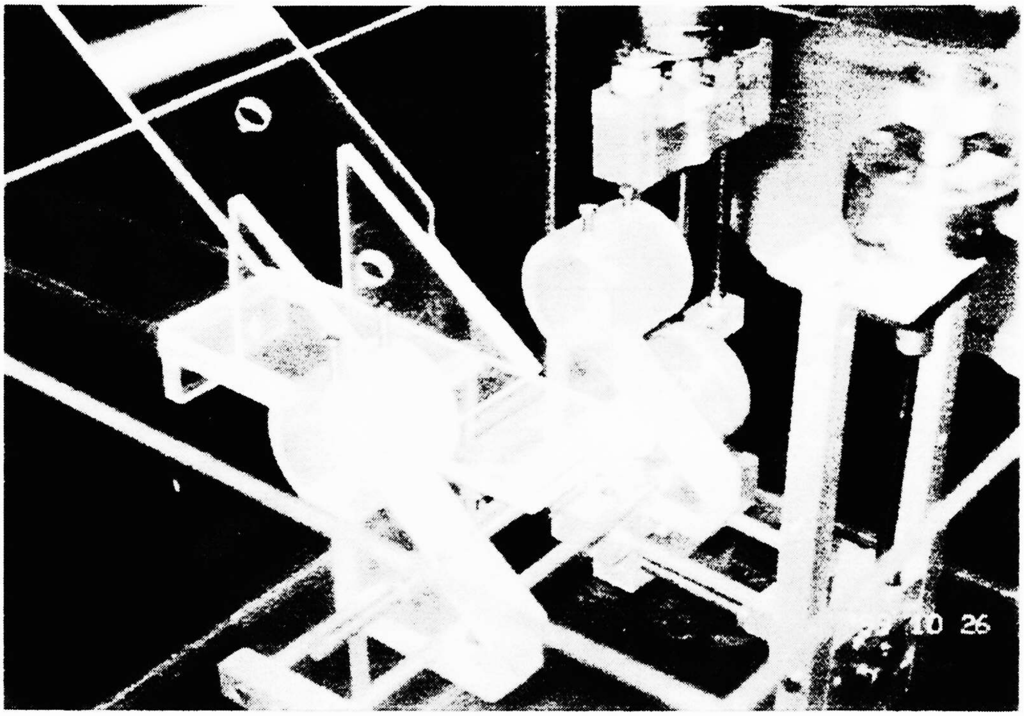
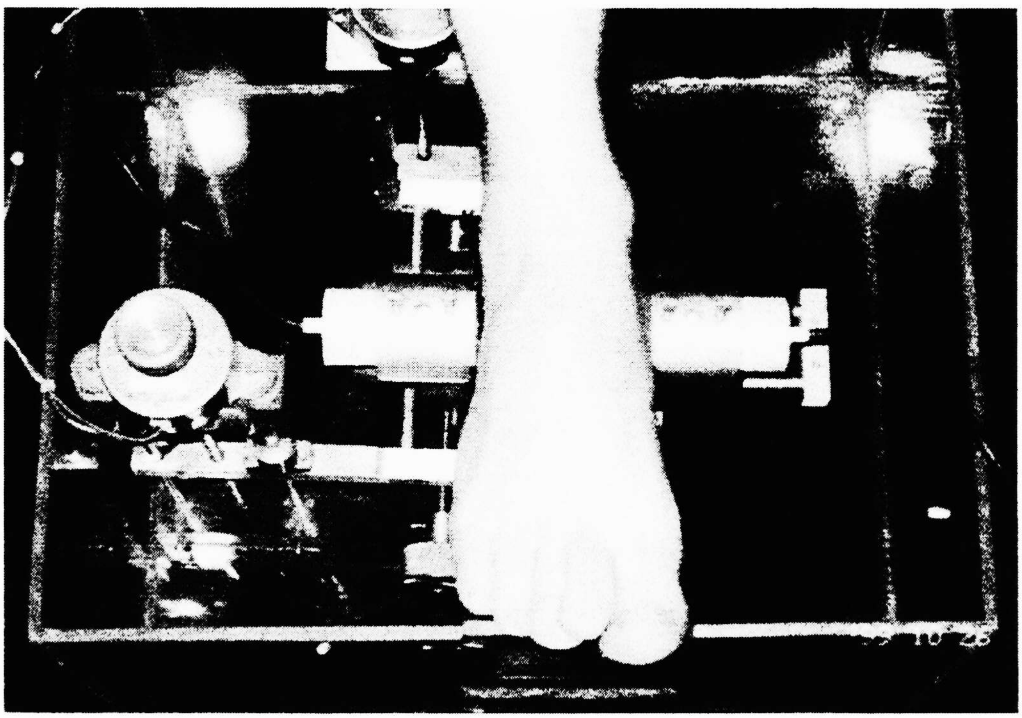


Figure 3 – Transducers developed in the laboratory.



(a)



(b)

Figure 4 – **(a)** X-Y axes displacement unit inside the small water tank; **(b)** Positioning of the transducers in relation to the patient's foot.

3. TESTS AND RESULTS

The system was tested in twelve volunteers female patients, aging from 60 to 70 years, selected from a group that had already been diagnosed by the Bone Mineral Density (BMD) using a DEXA (Dual Energy X-ray Absorptiometry) equipment. The Ultrasound Transmission Velocity (UTV) and the ultrasound attenuation (Broadband Ultrasound Attenuation – BUA) were measured.

The patients were selected in order to obtain three groups of four subjects according to the bone mineral density value[8]: 1)Normal, with a value for bone mineral density within 1 standard deviation (SD) of the young adult reference mean (t-score ≥ -1); 2)Osteoporosis, with a value for bone mineral density 2.5 SD or more below the young adult mean (t-score ≤ -2,5) and 3)Severe (established) osteoporosis, with a value for bone mineral density 2.5 SD or more bellow the young adult mean in the presence of one or more fragility fractures.

The BMD mean values for the three groups and the four measurement matrix (8x8 X-Y points) mean values of BUA and UTV, corresponding to the four patients in each of the three groups, are presented in the Table 1 below.

Table 1- UTV, BUA and BMD values for Normal, Osteoporotic and Severe (established) osteoporotic groups.

Group	**Number of Patients**	**UTV (m/s)** **mean ± sd**	**BUA (dB/MHz)** **mean ± sd**	**BMD (g/cm^2)** **mean ± sd**
Normal	4	1613 ± 42.3	92.3 ± 9.9.	0.826 ± 0.010
Osteoporotic	4	1570 ± 38.1	83.2 ± 7.7	0.687 ± 0.029
Severe Osteoporotic	4	1531 ± 45.0	54.7 ± 8.8	0.379 ± 0.008

The results showed that there is a decrease in the ultrasound transmission velocity and the ultrasound attenuation in osteoporotic patients when compared to healthy patients of the same sex and age group.

4. CONCLUSION AND FUTURE WORK

The previously experimental results showed that the developed system was suitable to collect data in the calcaneus region and that the measured parameters (Broadband Ultrasound Attenuation and Ultrasound Transmission Velocity) may be used in the evaluation of osteoporosis.

The number of patients used in the preliminary test of the equipment was not so adequate because it may considered not statistically significant, but the results have shown its usefulness and make it possible to extend the experiments in a future work. We intend to test the equipment with a more significant number of patients and also to test a new method using signal processing of the acquired ultrasound waves to try to determine non-linearity caused by the wave propagation in bone.

5. ACKNOWLEDGMENTS

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