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Osteoporosis Detection by Impulse Response Technique

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Abstract: Osteoporosis in women is increasingly being recognized as an important health issue. The dynamic characteristics of bone which provides quantitative information concerning the mechanical properties of the bone along with measurement of Bone Mineral Density (BMD) can help in the early detection and better diagnosis of osteoporosis. In this paper quantitative assessment of osteoporosis is carried out by impulse response test on the tibial bone. The stress waves are generated in the tibial bone by the impact of impulse force hammer are monitored by accelerometers, and are analyzed in the frequency domain. The natural frequency of stress wave signal is significantly decreased in osteopenia and osteoporosis subjects indicating decrease in mechanical strength of the bone and bone mineral mass.

Index terms: Osteoporosis, Natural frequency, Tibial bone, Impulse response

I. INTRODUCTION

Osteoporosis is a condition wherein the density of the bone gradually reduces to a point below normal. The integrity of the bone and the bone tissue deteriorates, resulting in the bone being fragile, and thus more susceptible to fracturing. The condition usually displays no obvious symptoms until the weakened bone fractures. These fractures lead to deformity, loss of mobility and independence. Osteoporotic fractures were defined as fractures that occur with a minor trauma equivalent to that generated by a fall from a standing height or lower. However, fractures of the fingers, face, skull, and toes were not regarded as osteoporotic fractures. Osteoporotic fractures were further classified into non vertebral fractures, clinical vertebral fractures, and multi-fractures[1]. With increasing population of elderly women, the assessment and treatment of osteoporosis has become an important problem in clinical gynecology. The decrease in biomechanical strength of bone with age is much more pronounced than the loss of bone mass due to perforations during the remodeling process. In women, Bone mineral loss occurs with aging, menopause, and disuse. Since the bone is a viscoelastic material [3], it's response to high strain loading cannot be assumed to be the same as predicted by a static analysis. This means that it needs to be subjected to dynamic tests in order to predict its dynamic characteristics under both the normal and the diseased state. This is done in order to simulate realistic loading conditions, and in the case of this project, since the bone being considered is the tibia, the loading conditions being referred to here is the normal use of this bone in day to day life such as walking etc.

The choice of the tibia as a measurement site is validated by the fact that it contains approximately 25-30% trabecular bone and 70- 75% cortical bone by volume, and is subjected to extreme loading conditions during daily activities [4]. The trabecular bone is highly active in remodeling process and shows changes within bone tissue earlier than cortical bone. Observable changes are also seen in cortical bone during bone metabolism [5].

Stress waves generated by impulse force provide quantitative information concerning the mechanical properties of the bone in question. Development of a successful technique of this type would have many clinical applications such as in diagnosis of osteoporosis and the evaluation of fracture healing.

III. SCOPE OF WORK:

In this paper, a portable and simple device is implementation using impulse response technique to determine osteoporosis is presented. It is a non-invasive technique that considers the natural frequency of the *tibia.* The natural frequency is found to be positively correlated to the standard osteoporosis index (stiffness index). The output is the natural frequency of the bone in consideration. Standard value ranges of frequency that indicated normal bone, osteopenia or osteoporosis are found. Depending upon the output of the device the patient can be diagnosed with normal bone, osteopenia or osteoporosis.

III. DESIGN & IMPLEMENTATION

Accelerometer is placed on the tibia of the patient to be tested. The accelerometer used, ADXL335 is 3 axis accelerometers. The X - axis of the accelerometer, corresponding to the longitudinal axis of the bone is the only axis being taken into consideration. When impacted by a hammer, the vibrations thus caused are sensed by the accelerometer, which return a value to the 89C51 microcontroller in the form of an analog voltage signal that is dependent on the value of the resonant frequency of the bone.

The resonant frequency of the bone is directly dependent on the bone mineral density, which is defined as the amount of mineral content per square centimeter of the bone. Bone density is used in clinical medicine as an indirect indicator of osteoporosis and fracture risk.

The analog voltage is converted into a digital value by the ADC. The ADC has resolution of 8 bits which means that

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the analog value can be quantized into 256 different levels. These digital values can be considered to be the impulse responses. The impulse referred to in the term impulse response is generally a short duration time domain signal, and the impulse response of the system is defined as the output signal that results when an impulse is applied to the system input, the system here being the bone, and the impulse is provided by the hammer at regular intervals. This impulse response is then converted to a frequency response using a Discrete Fourier Transform. The natural frequency is estimated.

The natural frequency is plotted against the Stiffness Index to determine BMD, which is a sufficient parameter to diagnose osteoporosis.

The block diagram of proposed device is shown in figure1.The setup shown comprises an impulse force hammer. This hammer provides the impulse to the system that is the tibial bone. This impulse response is analyzed to characterize the bone and to find its natural frequency.

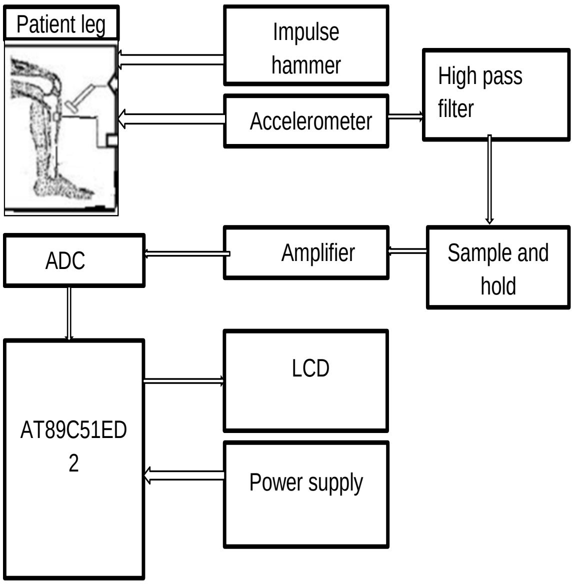

Figure 1: Block diagram of showing natural frequency determination of tibia

The accelerometer gives output as an analog voltage which varies in according to vibrations caused in tibial bone. The accelerometer that is interfaced with ATMEL microcontroller is connected in line with the bone for assessment. Output of the accelerometer is passed through high pass filter to remove the DC content in the output and then given to sample hold circuit of ADC. The ADC 0804 interfaced with 89C51 converts the analog voltage to digital samples.

The digital samples are analyzed inn frequency domain. Then the natural frequency of the bone is determined. The device is supported with user interface to display the result of diagnosis.

IV. RESULTS AND DISCUSSION

The natural frequency of the device is correlated to with stiffness index obtained by standard methods such as QUS (Quantitative Ultrasound technique) & DXA(Dual Energy X-Ray Absorptiometry). The standard devices use stiffness index of the bone as a parameter to determine BMD. The natural frequency (output of device) is with correlated to the stiffness index (output of QUS) with coefficient of correlation (r=0.646) as seen in figure 2.

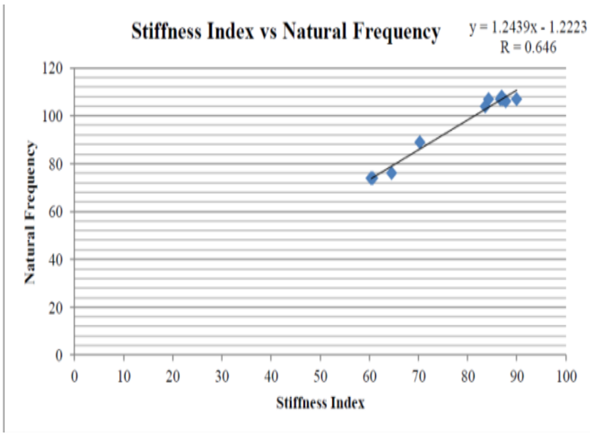

Figure 2. Natural Frequency Vs Stiffness Index

The patients under test were classified as normal, osteopenia and osteoporosis depending on natural frequency readings. The results show that the bone mineral loss and decrease in mechanical stiffness of bone with increase in age is very well reflected by decrease in natural frequency. This is also shown graphically. The Stiffness Index is a function of BUA (Broadband Ultrasound Attenuation) and SOS (Speed of Sound). The Stiffness Index(SI) is given as[1],

$$SI = [(0.67 \times BUA) + (0.28 \times SOS) - 420]$$

As per our analysis, the natural frequency for normal is identified to be above 100 Hz, osteopenia is identified to be between 77 Hz to 97 Hz, and osteoporosis is identified to be below 77 Hz. These are displayed as digital values on the LCD.

Table 1: Readings taken from a Quantitative Ultrasound Technique machine and the corresponding values of natural frequencies

Age(Years)	Natural Frequency(Hz)	BUA(dB/Mhz)	SOS(m/s)	Stiffness Index
36	107	110.92	1555.83	89.9488
38	108	118.88	1525.99	86.9268
38	107	107.54	1552.23	86.6762
40	104	119.38	1512.87	83.5882
41	106	115.84	1536.21	87.7516
42	74	98.57	1479.67	60.3495
45	107	110.88	1545.86	87.1304
46	89	103.74	1502.92	70.3234
47	76	97.77	1496.52	64.5315
48	107	108.23	1541.93	84.2545
48	74	95.29	1488.81	60.7111

The BUA and SOS are used by the QUS machine to derive the Stiffness Index from the relation as shown above.

The figure 4 indicates the ranges of the frequency. The Table 2 shows the ranges of Stiffness indices that help diagnose osteoporosis and osteopenia.

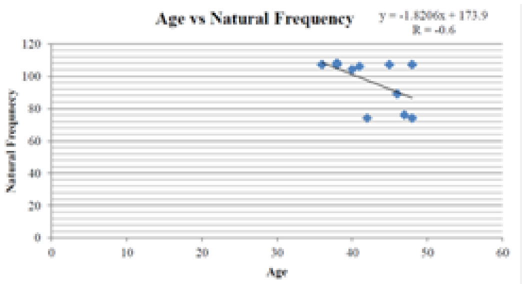

Figure 3. Graph of Age vs. Natural Frequency

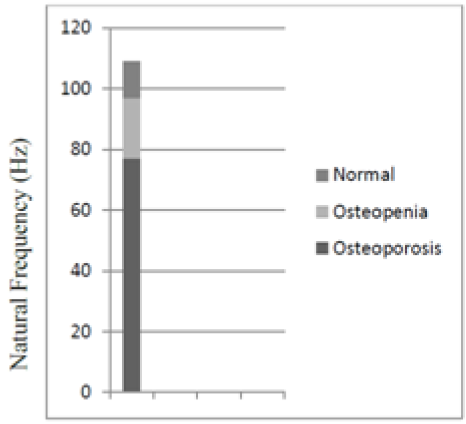

Figure 4: Graphical representation of frequency ranges for different ailments

Table 2: Stiffness Index for different conditions of tibia

Ailment	Stiffness Index
Osteoporosis	59.89 – 69.82
Osteopenia	69.82 – 82.38
Normal Bone	82.38 – 108.96

V. CONCLUSION

The current methods used to diagnose osteoporosis which includes DXA and QUS were found be expensive and complicated. They also require expert staff to handle the equipment. The device designed to monitor the stress wave propagation in tibial bone was effectively used in the assessment of osteoporosis. The dynamic behavior of the tibial bone, when under impact gives an indication of the mechanical stiffness of the bone under scrutiny. The feature analyzed is the natural frequency which is found to be correlated to the stiffness index. The device designed is portable, easy to operate, inexpensive and offers an easy first line method to diagnose osteoporosis. The coefficient of correlation was found to be 0.646 between Stiffness Index and natural frequency of the tibia.

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