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Osteoporosis Diagnosis: A Review

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Abstract: ***Osteoporosis is a medical condition in which the bone becomes brittle & fragile from loss of tissue, as a result of hormonal changes or calcium deficiency or vitamin D. Osteoporotic fractures include increased pain, physical impairment, decreased quality of life, increased risk for new fractures & increased mortality. It's a silent disease as there are often no symptoms and a person may not know they have it until they experience a fracture after a minor incident, such as a fall, or even a cough or sneeze. For women, the risk of hip fracture is higher than the risk of breast, ovarian and uterine cancer combined. For men, the risk is higher than the risk for prostate cancer.***

The review gives us an information about the state of art facilities to diagnose osteoporosis such as MRI, X-Ray, CT and DEXA (Dual Energy X-ray Absorptiometry). These diagnostic tools are expensive and are not affordable nor portable. Hence they cannot be used for mass screening purposes. The review shows the availability of portable devices such as Ultrasound but the drawback being not accurate when compared to the gold standard DEXA. The review also shows various concepts such as frequency analysis of stress wave for early detection of osteoporosis. It specifies the methodology used such as stress wave technique. This gives a better understanding of the dynamic behavior of bone under impact force, the natural frequency of stress wave signal is a clear indication of mechanical stiffness of the bone under investigation, and to get better understanding of the dynamic behavior of bone under impact force. Hence we conclude that impulse response method can be used for the development of a hand held device to estimate Osteoporosis.

Keywords: Osteoporosis, Dual Energy X-ray Absorptiometry - DEXA, X-ray, Quantitative Ultrasound, Quantitative Compound tomography, Quantitative Magnetic resonance, Impulse method, stress wave, infrared scattering sensor.

I. INTRODUCTION

Osteoporosis is characterized as low bone mass disease & deterioration in microarchitecture of bone tissue leading to an increased risk of fracture. It occurs when the bone mass decreases more quietly then the body can replace it, leading to a net loss of bone strength. As a result the skeleton becomes fragile, so that even a minor injury or fall lead to a broken bone, (referred to as a fragility fracture). Osteoporosis has no signs or symptoms until a fracture occurs - this is why it is often called a 'silent disease' [1].

It is estimated that worldwide an osteoporotic fracture occurs every three seconds. At 50 years of age, one in three women and one in five men will suffer from a fracture in their remaining lifetime [16]. For women, the risk of hip fracture is higher than the risk of breast, ovarian and uterine cancer combined altogether. For men, the risk is higher than the risk for prostate cancer [3]. Approximately, 50 % of the people with one osteoporotic fracture will have another, with the risk of new the fractures rising exponentially with each fracture [11]. The number of patients suffering from Osteoporosis are 8.680 % men of 50 - 60 years & 20.616 % women of 40 - 60 years out of 1,31,10,50,517 total population of India. Concentrating on age group of 40-60 years of women & 50 - 60 years of men. ~ 10 % of Indian population is older than 50 years at present, however these figures are likely to go up to 34 % by 2050 [8]. Hence T score of patients will also grow accordingly till 2050, as in 2013, estimates suggested that ~ 50 million people in India had T score of < - 1 [9]. The Diagnostic that tools available for detection of osteoporosis are Dual Energy X ray absorptiometry - DEXA, Calcaneal Quantitative Ultrasound, Quantitative compound tomography, Quantitative magnetic resonance, Conventional X-ray, Infrared Scattering sensors, stress wave generation. DEXA costs around 22 Lacs -32 Lacs, Ultrasound around 3.95 Lacs - 4.95 Lacs.

Methodology used for detection of osteoporosis are:

1) DXA scan used to measure spine and hip bone density
2) DXA (peripheral DXA) measures bone mass at the forearm, finger and heel
3) SXA (single-energy X-ray absorptiometry) measures the heel or wrist
4) DPA (dual photon absorptiometry) measures the spine, hip or total body
5) SPA (single photon absorptiometry) measures the wrist
6) QCT (Quantitative Computed Tomography) measures the spine or hip
7) PQCT (peripheral QCT) measures the forearm
8) QUS (Quantitative Ultrasound) uses sound waves to measure the heel or finger

A. Dual Energy X-ray Absorptiometry (DEXA)

DEXA is the Gold Standard Method for diagnosing osteoporosis and estimating fracture risk. DXA is non-invasive also has low radiation exposure, and provides an accurate and precise measurement of BMD at the femoral neck, spinal vertebrae, wrist, and total body (Brown & Josse, 2002). During DXA measurement, imaging device is positioned above patient is placed on the padded table & below X-ray generator is present. The DXA machine sends an invisible beam of low-dose x-rays with high energy & low energy peaks is given to patient bones to be examined. High energy is absorbed primarily by soft tissue and low energy by bone. DXA machines feature special software that compute and display BMD measurements on a computer monitor. DXA measures bone mineral content (g) which represents total mass of an area [5].

DEXA uses an X-ray beam composed of 2 different photos energies (constant & pulsed). T Score Normal (greater than and equal to -1.0), Osteopenia (<-1.0 but >-2.5), Osteoporosis (greater than and equal to -2.5) Severe osteoporosis (greater than and equal to -2.5 with a fragility fracture) [14].

The DEXA scanners consists of a low-dose x-ray tube having two energies for separating mineral and soft-tissue components, also has an high-resolution multidetector array. The devices have one of two different systems, a fan beam device that emits alternating high (140 kVp) and low (70–100 kVp) x-rays and the sweeps across a scan area or a constant x-ray beam with a rare-earth filter and the energy-specific absorption, which separates photons of higher (70 keV) and lower (40 keV) energy [4].

B. pDXA

pDXA is Peripheral Dual Energy X-ray Absorptiometry used to measure bone mineral density (BMD) at the forearm, finger phalanges and calcaneus. Radiographic absorptiometry (RA) and quantitative ultrasound (QUS) are other technologies for assessing the skeletal health at peripheral skeletal sites. Some advantages of pDXA compared to central DXA are that instruments are smaller and more portable, requiring minimal space to operate, and they are less expensive. Also, since the measurement sites are a significant distance from radiation sensitive organs, the radiation doses are extremely small and even lower than the doses associated with central DXA of the hip and spine. Nevertheless, pDXA may be subject to the radiation protection regulation in many countries [12].

C. Quantitative Computed Tomography (QCT)

In quantitative computed tomography (QCT), the X-ray source and the detector rotate in a synchronized fashion around a subject as X-rays are passed through the body. Mathematical algorithms obtained are then used to reconstruct the attenuation data into 3D images. The use of a bone mineral (or hydroxyapatite) phantom allows calibration of the imaging data, providing a measurement of bone density that is unlike DXA which is independent of bone size and can be obtained separately in the trabecular and cortical bone compartments. Hence this method shows that osteoporosis can be diagnosed with the CT attenuation using values derived from the CT scans of abdomen ordered for reasons other than the measurement of bone mineral density (BMD). Using CT attenuation, significant proportion of older patients who sustain a fracture of the cervical spine have osteoporosis [13].

D. Quantitative Ultrasound (QUS)

Ultrasound techniques that are used to assess material properties, are well known from industrial material testing. The first experiments to determine material properties of bone using ultrasound transmission velocity (UTV) were performed in the 1960s. The ultrasound transmission velocity or speed of sound was calculated as the quotient of the transit time of the ultrasound wave through bone and the diameter of this bone that's given in meters per second [2].

Quantitative ultrasound is Low cost compound to DEXA & QCT, less investigation time is required, US is a mechanical wave characterized by the frequency exceeding the threshold of audibility of the human ear (> 20KHz). It's based on reflection of US waves, it involves the transmission of US pulses through the investigated bone tissue & detection of transmitted pulses once they have been passed through the medium. The bone that is to be investigated is placed between 2 probes, broad caster & receiver. US pulse is transmitted to cortex & after propagation along cortical bone layer parallel to its long axis is received by another ultrasound transducer at a known distance.

Compared to DXA, QUS is radiation-free, fast, portable, less time-consuming, and can be performed at a considerably lower unit cost. In addition, a recent meta-analysis showed QUS can predict hip fracture in elderly men and women independent of the risk estimates from DXA (Moayyeri, et al., 2012). While QUS has the potential to increase DXA screening efficiency and cost-effectiveness by reducing the number of individuals referred for DXA who are otherwise healthy, or identifying the individuals at high risk of fracture who should receive treatment, but its clinical use is less well defined. Currently, there are no universal guidelines for diagnostic cut-offs, and the accuracy of QUS in identifying osteoporosis remains unclear [9].

In the cross-sectional study conducted in HIV patients attending the Clinic of Infectious and Tropical Diseases of Brescia during 2014 and underwent lumbar/femoral dual-energy X-ray absorptiometry, vertebral fracture assessment and calcaneal quantitative ultrasound. The assessment of osteoporosis diagnostic accuracy was performed for calcaneal quantitative ultrasound and for vertebral fracture comparing them with dual-energy X-ray absorptiometry [10].

E. Conventional Radiography

The detection of osteopenia by conventional radiography is influenced by many physical variables, as well as the subjective opinions, the diagnosis of osteopenia derived from conventional radiographs is susceptible to a high degree of error Lachmann and Whelan stated that only under very favorable radiographic conditions it could decalcification of < 20 % be recognized. Those authors also assumed that in most of the bones calcium loss must be 20 – 40 %. Aside from the osteoporotic fractures, Doyle et a1 found none of the criteria that are generally regarded as signs of spinal osteopenia are reliable to assess longitudinal changes in bones density in the course of osteoporosis. The Semi quantitative grading techniques, such as vertebral or femoral indices have proven to be neither precise nor sensitive enough to diagnose osteopenia at an early stage, or to follow the course of osteoporosis [2].

F. Quantitative Magnetic Resonance (QMRI)

In MR imaging the compact bones does not give a signal due to its low water content when used in the standard sequences. However, the differences in magnetic susceptibility between bone marrow and trabecular bone result in a distortion in the lines of force, causing strong local inhomogeneities. Such magnetic field inhomogeneities results in a dephasing of the transverse magnetization in bone marrow tissue, with decrease in the marrow transverse relaxation time (T2) and consequently, a reduction of signal intensity in the gradient-echo images [2].

G. Infrared Scattering Sensors

The infrared method by the infrared scattering sensors approach is applied to study the bone characteristics. In this method the aim was to understand how the resulting infrared signal is been affected by the application of scattered light through a part of the body. This non-invasive approach is preferred and especially of interest because of its low cost and the elimination of any harmful side effects due to its fact that near infrared light is non-ionizing. Hence, Doctors and patients do not have to be concerned about the number of scans since the patients could undergo multiple number of scans as needed without too much risk, and being less expensive also [8].

H. Impulse Response Method

In the Impulse response method stress waves are generated in the tibial bone by the impact of the impulse force hammer that are monitored by accelerometers, and are analyzed in the frequency domain. The natural frequency of the stress wave signal is significantly decreased in osteopenia and osteoporosis subjects indicating decrease in mechanical strength of the bone and the mineral mass of bone [7].

Hence, the technique gives a better understanding of the dynamic behavior of the bone under impact force and the natural frequency of stress wave Signal will give us a clear indication of mechanical stiffness of the bone under investigation [6]. Tejeshwini E et al, shown the further work could be extended by making the impulse hammer completely automated in order to make the impact force periodic and also to prevent the disturbances which are caused due to human contact and other noises. [15] The feature analyzed in this method is of the natural frequency which is found to be correlated with the stiffness index. The device designed is portable, easy to operate, inexpensive [17].

S. Mythili and G. Athisha [18], observed that there exists a relationship between BMI and BMD among subjects. By using Statistical test it's proved the hypothesis. The technique also gives a better understanding of the dynamic behavior of bone under impact force, and also the natural frequency of stress wave Signal is a clear indication of the mechanical stiffness of the bone under investigation [19].

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Table 1: Comparison between diagnostic methods available for detecting osteoporosis.

	DEXA	US	QCT	Stress wave
Ionization Radiation	☑	☒	☑	☒
Cost	>20L	>3.5L	$65k	~5000
Precision	☑	☒	☑	☑
Portable	☒	☑	☒	Hand held
Accuracy	Very High	Not comparable	True Tendency value	Trying to make as accurate as DEXA
Artifacts	☑	☒	☑	☒
Reproducibility		☒		☑
Useful as Screening tool	☒	☑	☒	☑

II. CONCLUSION

It is evident osteoporosis will be rampant among Indian population. Early diagnosis and treatment prevents patients from osteoporosis related fractures and prevents co-morbidities arising out of it.

The review we found Stress wave method is most efficient one, though DEXA is the Gold Standard for analysis of Osteoporosis. Since, it is not portable and not economically feasible much easier, and cost efficient, portable methods like stress wave analysis can be adopted to design a hand held osteoporosis estimating device in future that can be used for prolongation of disease by patients easily.

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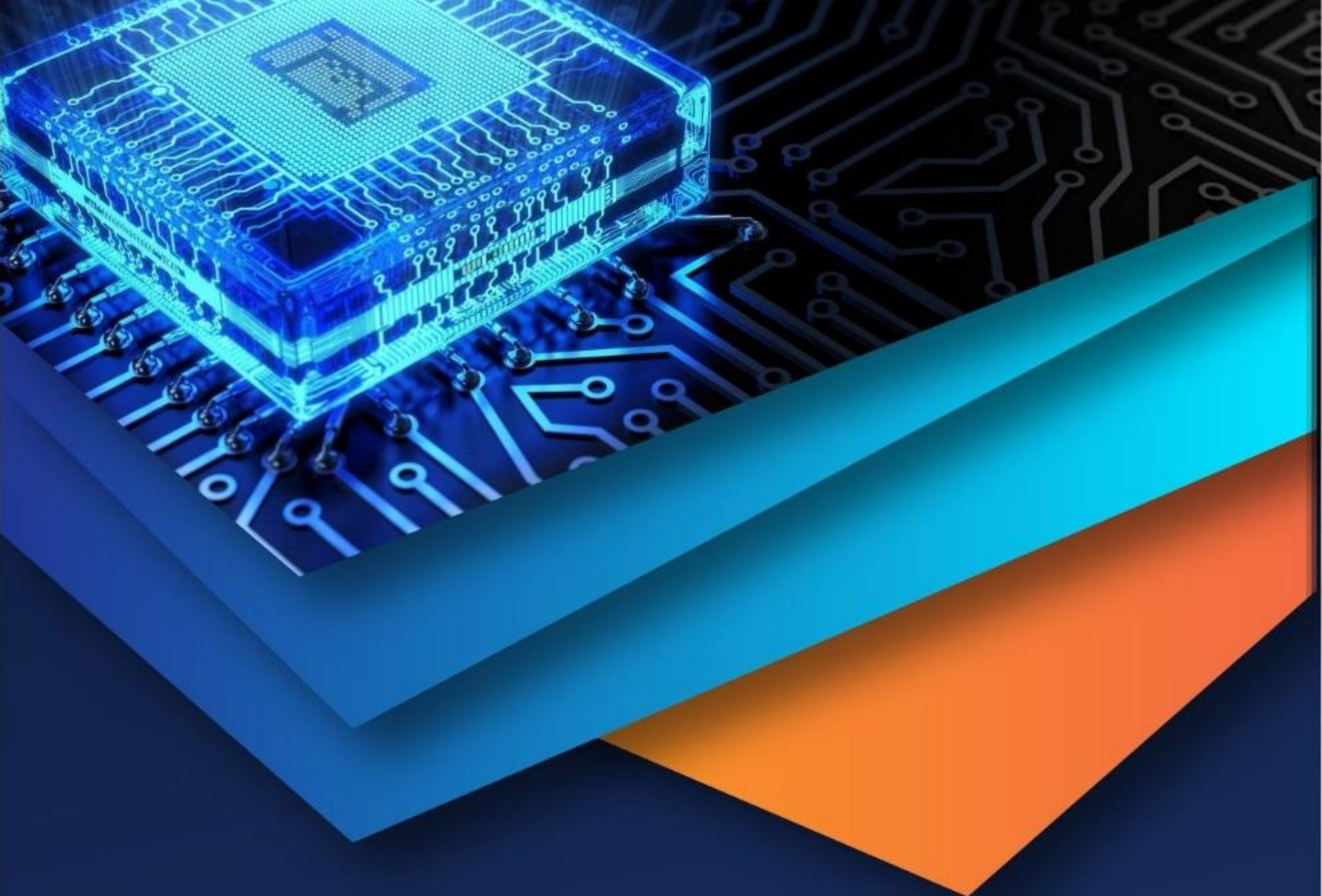

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