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An insight into bone dielectric properties variation: a foundation for electromagnetic medical devices

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***Abstract*— Dielectric properties of bones have recently got significant attention to monitor bone quality. This paper reports *in-vitro* dielectric properties of human trabecular bone samples obtained from osteoporotic and osteoarthritic patients. The measurements were performed by using open-ended coaxial probe technique. The study further focuses on intra-femoral head variation of dielectric properties within two patients, and inter-disease comparison of bone dielectric properties between osteoporotic and osteoarthritic patients. The results suggest that dielectric properties significantly vary between different parts of femoral head within each patient and mean relative permittivity of osteoarthritic patient is higher in magnitude when compared to osteoporotic patient. The difference is observed more in relative permittivity profiles of each patient's bone samples than conductivity profiles.**

***Keywords*— dielectric properties; bones; osteoporotic; osteoarthritic.**

I. Introduction

The dielectric properties (namely relative permittivity and conductivity) of biological tissues characterize the interaction of electromagnetic (EM) waves with the tissue. The application of electrical stimulation in diagnosis and treatment of bone diseases such as fixing bone fracture and during bone surgeries (during total hip replacement) has been an active research area [1]. In order to better understand the bone remodeling process (formation of new bone tissue) during direct or induced electrical stimulation, characterization of electric field and current distribution in bone is of vital importance [2]. Dielectric properties can potentially be used for diagnosis of osteoporosis [3]. Clinically bone mineral density (BMD) is considered as key indicator of osteoporosis and is obtained via Dual X-ray Absorption (DXA) [3]. Recent studies have suggested a correlation between the dielectric properties of bone and the corresponding bone mineral density (BMD) [3]. Therefore, determination and understanding of bone dielectric properties is of paramount importance for implementation of electromagnetic medical devices for diagnosing osteoporosis [3]. Microwave tomography imaging (MTI) can potentially measure *in-vivo* dielectric properties of the bone and can be used for osteoporosis monitoring [3].

A number of studies have previously reported dielectric properties of human and animal bone samples. Some of these studies have also established relationship between bone dielectric properties and bone quality (in terms of BMD and bone volume fraction (BVF)) in microwave frequency range. However, no inter-disease comparison of dielectric properties of bones has been previously reported. Similarly, no previous study has measured dielectric properties of different parts of a single femoral head. The micro-structure of trabecular bone pattern within femoral head varies significantly, particularly in case of diseased bone. Consequently, the dielectric properties may also vary within a femoral head. Therefore, it is important to understand and quantify these variations for the development of a microwave-based osteoporosis monitoring device.

The objective of this work is to present preliminary findings of: dielectric properties of human bones in microwave frequency range (0.5 – 8.5 GHz); intra-femoral head variation of dielectric properties of bones; and inter-disease variation of dielectric properties of bones.

II. Methodology

Two diseased patients (one male osteoporotic patient age 63 year and one female osteoarthritic patient age 76 year) undergoing total hip replacement were considered in this study. Four trabecular bone samples were obtained from each patient's femoral head. The sample size was 8 (four samples were obtained from each patient's femoral head resulting in total 8 samples). After the surgical extraction bone samples were put into phosphate buffered saline (PBS) in order to prevent loss of moisture. The bone samples were frozen at -20 °C, until measurements were performed. The preservative procedure was followed as reported in literature. The bone samples were thawed and dried before measurement. Temperature of each sample was recorded before measurement and was found to be 21 °C ± 0.1. Open-ended coaxial probe measurement technique was employed to measure *in-vitro* bone dielectric properties. Measurements were performed in frequency range of 0.5 – 8.5 GHz over 101 linearly spaced points. The Keysight slim form probe 85070E was connected to Keysight E5063A vector network analyzer (VNA). Before measuring dielectric properties of bones, calibration of the measurement equipment was performed by verifying dielectric properties of 0.1 M NaCl (saline) [4]. The uncertainty of the equipment was found to be 0.41% and 2.5% for relative permittivity and conductivity respectively.

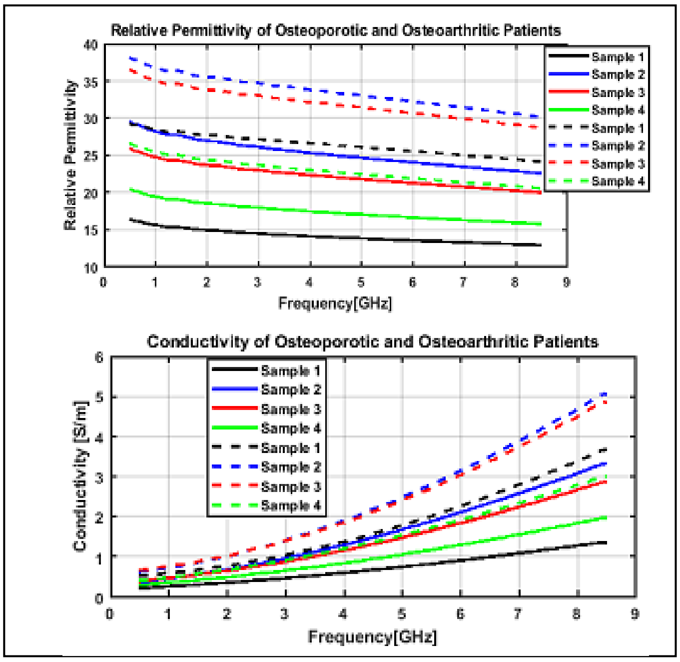

Fig. 1. Dielectric Properties of Osteoporotic (solid lines) and Osteoarthritic Patients' (dotted lines) bone samples.

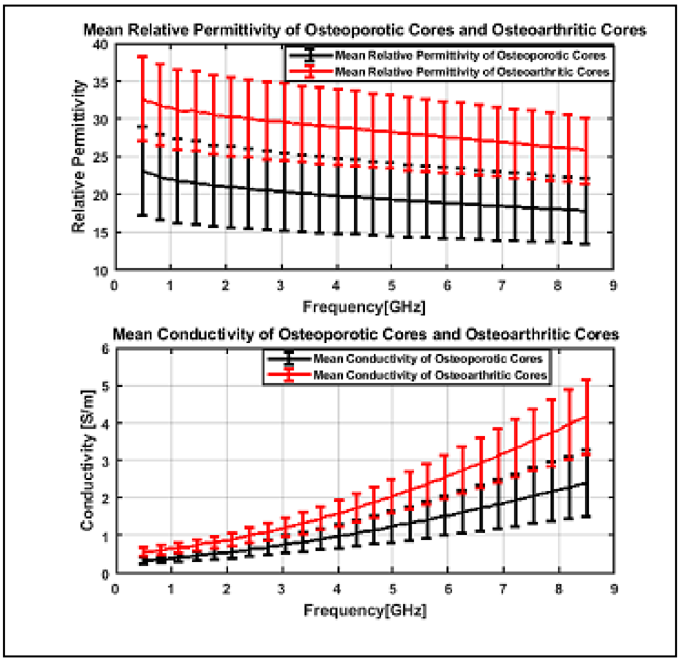

Fig. 2. Mean Dielectric Properties of Osteoporotic and Osteoarthritic Patients' bone samples.

III. RESULTS AND DISCUSSION

The relative permittivity and conductivity of each bone sample obtained from osteoporotic and osteoarthritic patient are shown in Fig. 1, the mean relative permittivity and mean conductivity of each patient are shown in Fig. 2. It can be observed from Fig. 1 that dielectric properties of bone samples obtained from one patient's femoral head vary from each other. The variations are observed mainly due to heterogeneity of micro-structure of femoral head. The relative permittivity values for each patient vary by mean standard deviation of ±5. The inter-disease variation of dielectric properties of both patients is significant. The mean dielectric properties of osteoarthritic patient's bone samples are higher in magnitude than osteoporotic patient's bone samples with overall mean percentage difference of 9% for relative permittivity. The conductivity values of bone samples obtained from osteoarthritic patient are also higher in magnitude than conductivity values of osteoporotic patients. The inter-disease variation is mainly due to the fact that micro-structure of trabecular bone pattern of osteoarthritic patient is much more compact and denser, as compared to osteoporotic patient. Similarly, studies have reported that the BMD values of osteoarthritic patients are higher as compared to osteoporotic patients. Further, the BMD values of osteoarthritic patients are similar to healthy bones, which makes fractures less likely. However, osteoarthritic causes pain, stiffness, bone spurs and loss of flexibility. These micro-structural variations significantly impact the bone dielectric properties, hence can be used to monitor bone quality.

IV. CONCLUSION

In this paper dielectric properties of human trabecular bones were measured over frequency range of .050 – 8.5 GHz. This study presented intra-femoral head variation and inter disease variation of dielectric properties of each patient. The measurement results reveal significant intra-femoral head variation of bone dielectric properties. Similarly, variations were observed between inter-disease dielectric properties as well. The mean dielectric properties of osteoarthritic patient are higher in magnitude than osteoporotic patient. These preliminary findings are stepping stones towards establishing and analyzing; relationship between bone dielectric properties with bone quality. These findings will support the design and development of microwave imaging based therapeutic device to monitor and to diagnose osteoporosis.

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