Analysis of pediatric corpulence via adipose tissue characterization using ultra-wideband radar system

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***Abstract*— This projects proposes an ex-vivo method to estimate the dielectric properties and thickness of adipose tissue in the human body. Based on the electrical properties of adipose tissue, obesity levels will be assessed. This approach consists of two steps: 1) data acquisition by an ultrawideband (UWB) time-domain radar; 2) genetic algorithm optimization of the intended goal function. This study considers a three-layered tissue model to mimic the human abdomen surface. The experimental phantom consists of a pork skin layer followed by pork fat, then ground pork to emulate the muscle tissue. The technique is also applied to human voxel tissue models, including babies, children, and adults, available in CST software. This technique is a noninvasive, safe, cost-effective method to determine the type of fat tissue in the human body and the level of obesity.**

***Index Terms*— Ex-vivo, brown fat, white fat, specific absorption rate, genetic algorithm, ultrawide-radar**

I. Introduction

Leptin and resistin play important roles in glucose metabolism and regulating weight. Their levels are controlled by the nutritional condition in the body: increased by feeding and reduced by fasting [1]. Adipose tissue produces a bioactive product known as Adipocytokine that includes leptin as a metabolic regulator [2]. Leptin and resistin levels show a good correlation with anthropometric parameters of childhood obesity and its comorbidity. Hence, adipocytokines can be considered as a biomarker of childhood obesity [3]. A newborn baby generally has brown fat, which keeps the baby's body warm from cold weather. When baby age increases, some of the brown fat changes to white adipose tissue, resulting in a change in the electrical properties of the tissue. Recent studies show that in North America, many babies are born fat, and doctors are concerned about the problem [4]. The method to diagnose the type of fat is a biopsy, which is an invasive procedure. Doctors are looking for a non-invasive method to determine the type of fat underlying the skin tissue of newborn babies. Magnetic resonance imaging (MRI), Ultrasound, and computerized resonance imaging (CTS) are expensive methods to evaluate the properties of skin, fat, and muscle; hence, UWB radar techniques are of growing interest among researchers for non-contact measurements. Radar methods can measure the permittivity and thickness of unknown adipose tissues: white and brown fat, skin, and muscle properties. The white adipose tissue (WAT) and brown adipose tissue (BAT) are present in different parts of the human body, but we are concentrating on the abdomen of the anthropoid. In this project a free-space technique is proposed, which is a non-invasive contactless and ex-vivo method to measure the content of white/brown adipose tissue in the abdomen area. The measurements considerably correlate with the development of obesity. The UWB radar system with two antennas measures the multilayer tissue's transit time response. The proposed analysis is carried out on pork tissue samples that impersonate the properties of the human tissue.

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II. Simulation Setups

A. Setup for measurement using the proposed technique on a planar structure tissue model

The proposed technique is investigated using a planar structure of the pork tissue sample. As shown in Fig.1, the simulations setup is proposed in the CST microwave studio. Three metal

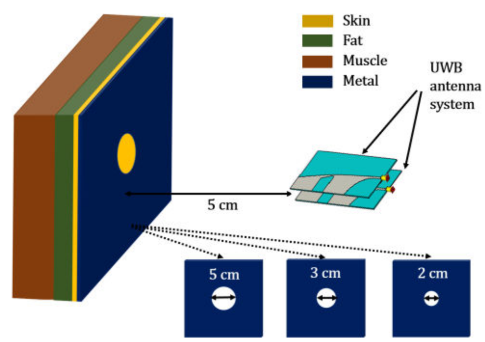

Fig.1 Measurement setup for pork tissue layers

plates with a circular aperture of 2 cm, 3 cm, and 5 cm are used for the experiments to precisely identify tissue properties in a specific area. The UWB antenna system consisting of two Vivaldi antennas is placed 5 cm apart from the metal, followed by pork tissue consisting of skin, fat, and muscle layers. The literature presents that these layers have specified permittivity and conductivity properties.The thickness of skin and fat layers are assigned with average values of 2.2 mm and 10.8 mm, respectively. First, three simulations are performed using just metal plates to extract the ambient signal occurring due to the mutual coupling of antennas and the metal plates.Then, other simulations are conducted by introducing skin, fat, and muscle layers with the metal plate and antenna structures. The time-domain signals are recorded for each case, and genetic optimization is applied to estimate the complex permittivity and thickness. The error for each layer permittivity is also estimated that lies within 11%, where a 3 cm aperture metal sheet shows the maximum error for fat assessment. In the case of 3 cm and 2 cm apertures, the error is around 8.3% for fat, while 0% and 4.5% for skin thickness, respectively. The maximum error for fat thickness is around 12.9% for a 5 cm aperture case.

B. Setup for measurement using the proposed technique on the human voxel tissue model

After successfully determining the planar pork tissue properties, the proposed technique is tested on human voxel tissue models available in the CST microwave studio. Further, the baby human voxel tissue model available in CST is examined. Fig.2 shows the graphical representation of the selected abdomen baby tissue model with a metal sheet of 2 cm aperture placed at a distance of 5 cm from the UWB antenna system. The voxel model is 0.85 x 0.85 x 0.8 mm^3 in resolution, and all other body parts in the abdomen are present.

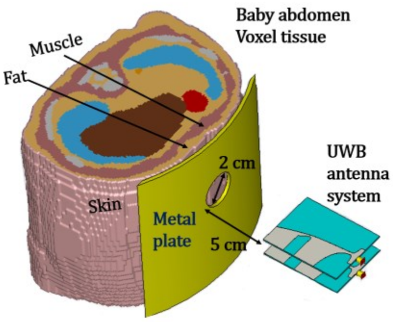

Fig.2 Graphical representation of baby abdomen voxel tissue model with the antenna system and a metal plate having 2 cm aperture

The abdomen tissue properties are assigned manually to test the proposed technique in the 5-10 GHz frequency range. The skin and muscle complex permittivity is assigned with actual average human tissue properties. Here, six models with fat values from 4 to 9 are proposed. The error calculated varies from 0.3% to 2% for fat tissue, 3.1% to 7.2% for skin tissue, and 0.2% to 9.5% for muscle tissue. The true thickness of fat for baby voxel tissue is the measured average thickness of 10 locations; states the reason for the maximum acquiring error of 31% in the case of fat dielectric constant is four.

III. MEASUREMENT SETUP AND RESULTS

The pork sample consists of skin, fat, and muscle, as shown in fig.3. Pork is used for evaluation purposes as pig tissue properties are alternative to human tissue properties and almost resemble complex permittivity and thickness. Human skin can be substituted by pork skin; human fat corresponds to pork lard and human muscle analogs with ground pork with 12% fat. For the measurements, the dimension of pork material having skin, fat, and muscle layer is approximately 15 cm in length and 17 cm in breadth. The UWB system is placed at a distance of 15 cm away from the sample surface. Each experiment with different metal plates is performed three times at three different locations to check the accuracy of the proposed technique and measurement setup. Then, the minimization problem was solved to estimate the complex permittivities and thickness of the tissue. The results highlight a considerable agreement in permittivity and loss tangent values in all six cases with minor errors. Quantitative differences are perceived between the overall permittivity and the viable conductivity obtained in this investigation, and values are compared with actual properties. The medical device equipped with the UWB system and the gaussian pulse wave generator circuit can be proposed in the future and utilized to estimate the fat tissue type in humans.

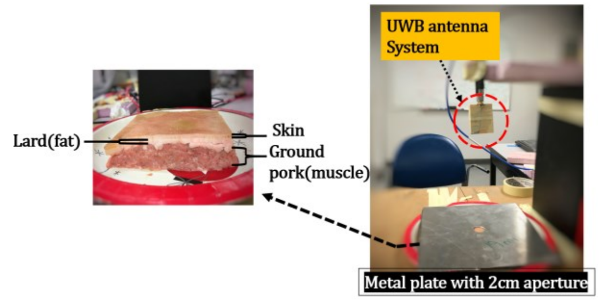

Fig.3 Laboratory measurement setup for pork tissue sample with 2 cm aperture metal plate

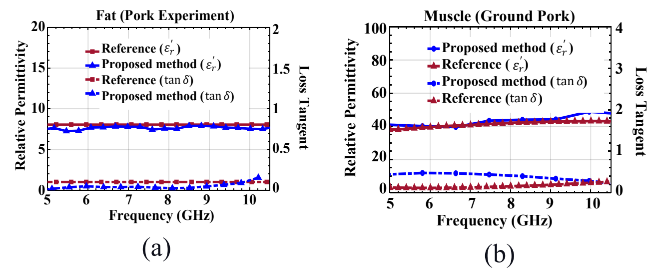

Fig.4 Plot of permittivity and loss tangent value for a) pork fat, b) muscle (ground pork)

IV. FUTURE CAREER PLAN AND FELLOWSHIP IMPACT

My primary career goal is to work on biomedical problems and develop techniques to overcome the bottlenecks of biomedical imaging, such as breast cancer detection, lung cancer diagnosis, and brain and cardiac imaging. It will help in the diagnosis process and bring down the diagnosis cost for those who cannot afford expensive imaging modalities. In the future, I plans to open a biomedical research lab related to microwave and RF technologies along with the teaching profession and will provide a free diagnosis to the people who are in need. Here, I would like to immensely express my gratitude to the MTT-S society for supporting me with this prestigious scholarship to work on this project. Since I was awarded the IEEE MTT-S Undergraduate Scholarship, I have started my Ph.D. in the Department of Electrical Engineering at Cornell University with a focus on RF technologies for biomedical appliactions.

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