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K. Chand
Pratik Mehta
Daryl G. Beetner
Missouri University of Science and Technology, daryl@mst.edu
R. Zoughi
Missouri University of Science and Technology, zoughi@mst.edu
William V. Stoecker
Missouri University of Science and Technology, wvs@mst.edu

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Microwave Reflectometry as a Novel Diagnostic Method for Detection of Skin Cancers

K. Chand¹, P. Mehta¹, D.G. Beetner¹, R. Zoughi¹ and W.V. Stoecker²

¹Electrical and Computer Engineering Department
University of Missouri-Rolla
Rolla, MO 65409

²The Dermatology Center
Rolla, MO 65401

Abstract- More than one million people are diagnosed with skin cancer each year in the United States and more than ten thousand people die from the disease. Currently, there are some methods for early detection of skin cancers, like visual inspection, but improvements are needed. This paper presents a method involving microwave reflectometry as a diagnostic tool for detection of skin cancers. The results of measurements and simulations for normal and wet skin have been shown to distinguish among skin samples with different properties. Microwave measurements from lesions have also been presented which are used to distinguish between cancerous and benign lesions.

Keywords – basal cell carcinoma, melanoma, relaxation frequency, microwave reflectometry

I. INTRODUCTION

The American Cancer Society estimates that skin cancer will affect more than 1 million people across the United States in 2005 [1]. Most of the deaths from skin cancer will come from melanoma, with 7770 deaths predicted for melanoma in 2005 [1]. Melanoma and other skin cancers are curable in almost all cases if diagnosed in the early stages. Most dermatologists today diagnose skin cancer by sight. Diagnosis is made using factors such as size, shape, color, border irregularities, presence of an ulcer, tendency to bleed and whether the lesion is raised, hard or tender to the touch. A biopsy is suggested in cases where the dermatologist suspects cancer. A major disadvantage of visual inspection is that it is subject to human error. Physicians’ accuracy in diagnosis of melanoma by unaided visual inspection is low, with diagnostic accuracy or sensitivity variously estimated at 55% for surgeons to about 66-82% for dermatologists [2-5]. The less common types of skin cancer, such as Merkel cell carcinoma, are almost always misdiagnosed in the clinic.

Other alternatives for diagnosis include bioelectrical methods where electrical properties of the skin, e.g. impedance, conductivity and permittivity, are used to differentiate between malignant and benign skin lesions, but research on these methods is still in progress [6]. There is an urgent need for non-invasive methods that allow early detection of skin cancers. One potential method involves using microwave reflectometry to exploit the differences in dielectric properties among normal skin and malignant lesions for diagnosis.

A literature search of microwaves and their use with cancer diagnosis shows a number of articles dating as far back as the 1920s. Substantial research has been directed toward detecting breast cancer using microwave signals [7-8]. Fundamental differences exist between breast and skin cancer and these differences need to be considered before a method for detecting skin cancer using microwaves is ready for use. The dielectric properties of skin are directly related to parameters such as water, sodium, and protein content, which differ between normal skin and benign and malignant lesions. The water content for normal skin is around 60.9% and that for cancerous lesions is 81.7% [9]. This difference in water content is expected to be readily detected in microwave measurements. At microwave frequencies, the dielectric properties of normal skin can be distinguished from those of lesions by measuring their reflection properties. The reflection properties that are measured are directly influenced by the dielectric properties of the material being interrogated [10]. Additionally, different types of probes may be used for microwave reflectometry which expand the potential for material characterization including detection of abnormal skin. This paper presents the results of measurements and simulations when using an open-ended coaxial probe to distinguish among skin with different properties.

II. APPROACH

In this investigation the reflection properties of skin were measured using an open-ended coaxial probe [11]. The Teflon-filled probe used here had an outer conductor diameter of 3.62 mm and inner conductor diameter of 1.08 mm. Figure 1 shows the side and plan schematic views of the probe. The measurements were conducted using a calibrated network analyzer (Agilent 8753ES) in the frequency range of 300 MHz - 6 GHz. The probe was pressed lightly against the skin under investigation. Enough pressure was applied to ensure that no air pockets remained between the tip of the probe and the skin since this might adversely affect the measurements. Preliminary measurements were conducted on moist and dry skin on volunteers who gave their consent to participate in the study.
Measurements were also conducted at different locations (i.e., forearm, cheek, palm and chest) to investigate the influence of skin properties, which vary from location to location, on measured reflectance. Benign lesions on several patients were also investigated with this method and the results were compared to those from normal skin and subsequent simulations. The simulations were performed to correlate measured results with a limited set of theoretical results. These simulations were conducted using an electromagnetic formulation that gives the reflection coefficient at the tip of the open-ended coaxial probe as a function of the frequency of operation, probe size, and the dielectric properties of the tissue under study [12-13]. The formulation used for these simulations predicts the magnitude and phase of the reflection coefficient for a two-layer model where the first layer is skin and the second layer consists of an infinite half-space of fat or muscle [14].

III. RESULTS

Since the water content of malignant lesions is much higher than that of the normal skin [9], an experiment was performed to test the effect of skin hydration on reflection properties. A piece of cotton wool soaked in water was placed on the skin for approximately 20 minutes. Later the skin was lightly dried using a paper towel to remove the excess water from the surface. Measurements of the reflection coefficient were conducted and compared to those measured on adjacent skin that was not moistened. Figures 2 and 3 show the measured magnitude and phase of reflection coefficient for these two cases, respectively, averaged over three measurements. As shown in Fig. 2, the magnitude of reflection coefficients for wet skin differs by approximately 14% at 3 GHz from that of normal skin. One would expect that wetter skin should produce a higher reflection coefficient at microwave frequencies. That is only true if the skin is an infinite half-space. However, in this case some of the microwave signal penetrates beyond the thin skin layer and interacts with fat or muscle beneath the skin. This causes a reflection at the boundary of skin and this second layer and since reflection is a coherent parameter (i.e., it has phase associated with it), the reflected signals from the skin-probe and skin-fat/muscle boundaries may coherently combine and result in a lower reflection coefficient magnitude. Soaking skin for a longer period of time would more appropriately approximate a mixture of skin and water, simulating a situation similar to that in malignant lesions.

![Fig. 1. Cross-sectional and plan views of an open-ended coaxial probe.](image)

To show these measurements may be reasonably simulated using the electromagnetic formulation mentioned earlier, computer simulations were performed in which water was considered to be a very thin separate layer (0.1 mm) on top of an infinite layer of normal skin. As shown in Fig. 4, the simulated magnitude of the reflection coefficient was lower than that of normal skin which follows the trend of the measurement results for wet skin. The dielectric values used for skin were given by Gabriel et al [14].

![Fig. 2. Effect of prolonged skin soaking on the magnitude of reflection coefficient.](image)

![Fig. 3. Effect of prolonged skin soaking on the phase of reflection coefficient.](image)

![Fig. 4. Simulated magnitude of the reflection coefficient when a virtual thin layer of water was backed by normal skin. This simulation predicts a magnitude change that varies inversely with frequency, unlike Fig. 2.](image)
It is also important to investigate the influence of location on the measurements. Skin properties vary significantly over the body surface and are therefore expected to affect the microwave measurements. To this end, Figs. 5 and 6 show the magnitude and phase of reflection coefficient on wet (in the same manner as before) and dry forearm. Figures 7 and 8 show the results of a similar measurement but on the same person’s cheek. The results clearly show the influence of skin properties on the measurements (e.g., the results for dry forearm and cheek are not exactly the same). Therefore, when making this type of microwave measurements on a suspected region it is important to calibrate or compare the results from those conducted on skin adjacent to a suspect region.

Finally, a set of measurements were conducted on a patient. The reflection properties of a pathologically confirmed benign skin lesion, a normal adjacent skin region, and a region away from the benign area. Figures 9 and 10 show the magnitude and phase of reflection coefficient for these three regions. The results show that the reflection properties of these three regions are similar and the slight variations in the measured results do not constitute significant skin property variations among these three regions. This fact corroborates the results shown in Figs. 9 and 10. Differences between a benign lesion and normal skin are not expected to be as significant as differences between a malignant lesion and normal skin. Currently, additional measurements are being conducted on patients and the results of these measurements will be provided in a follow up publication.
IV. SUMMARY

The results of these preliminary investigations show the promise of using open-ended coaxial probes for measuring the variation of properties of skin that might allow the detection of skin cancer. The theoretical and experimental results suggest that water content, either in pure or bound form, is the largest contributor to the difference in reflection coefficient among normal skin and benign and malignant lesions, as expected [15]. This is important and promising since normal skin and cancerous lesions differ in their water content as well as salt content. Microwave signals are sensitive to both of these parameters making these measurements ideal for the purpose of skin cancer detection. Currently, multiple measurements are being conducted on patients with malignant melanoma to fully assess the applicability of the method to diagnose skin cancers with high level of accuracy. Additional results reported in the final paper will include the measured reflection coefficients for benign and malignant lesions measured in-vivo and their comparison with simulated values. These studies will also include the choice of optimal measurement parameters such as probe dimensions and the operating frequency.

REFERENCES


