Qualitative Analysis of Human Semen Using Microwaves

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Abstract—Microwave engineering now a days plays a vital tool in diagnostic and therapeutic medicine. A quality evaluation of human semen at microwave frequencies using the measurements made at different intervals of time by cavity perturbation technique in the S-band of microwave spectrum is presented in this paper. Semen samples were also examined in the microscopic as well as macroscopic level in clinical laboratory. It is observed that conductivity of semen depends upon the motility of sperm and it increases as time elapses, which finds applications in forensic medicine.

1. Introduction

Accurate information about the dielectric properties of tissues and biological liquids is important for studies on the biological effects at radio and microwaves frequencies. In macroscopic level, these electrical properties determine the energy deposition patterns in tissue upon irradiation by an electromagnetic field. In microscopic level, they reflect the molecular mechanisms, which underlie the absorption of electromagnetic energy by the tissue or liquids. Knowledge of the microwave dielectric properties of human tissues is essential for the understanding and development of medical microwave techniques. Microwave thermography, microwave hyperthermia and microwave tomography all rely on processes fundamentally determined by the high frequency electromagnetic properties of human tissues. Tissue temperature pattern retrieval in the microwave thermography is achieved using models of the underlying tissue structure, which depend particularly on the dielectric properties of the tissue [1]. A recent review of published data on animal and human dielectric parameters shows that for most tissue types animal measurements are good substitute for human tissues [2].

Gabriel et al., Cook and Land et al., reported the dielectric parameters of various human tissues at different RF frequencies. [3–6]. Microwave study of human blood using coaxial line and wave-guide methods was carried out by Cook [7]. Tissue samples of human brain at microwave frequencies were analysed using sample cell terminated transmission line methods [8]. Open-ended coaxial line method allows measurements of tissue samples over a wide range of frequencies [9].

Microwave medical tomography is emerging as a novel non-hazardous method of imaging for the detection of fracture, swelling and diagnosis of tumors. Active and passive microwave imaging for disease detection and treatment monitoring require proper knowledge of body tissue dielectric properties at the lower microwave frequencies [10–12]. Studies on the variation of dielectric properties of body fluids and urinary calcifications at microwave frequencies have revealed that diagnosis is possible through cavity perturbation technique [13–15]. The present paper reports dielectric properties of semen at microwave frequencies as well as the quantitative analysis in the clinical laboratory. It is observed that conductivity of semen depends upon the motility of sperm as well as the time elapses after ejaculation.

2. Materials and Methods

The experimental set-up consists of a transmission type S-band rectangular cavity resonator, HP 8714 ET network analyser. The cavity resonator is a transmission line with one or both ends closed. The resonant frequencies are determined by the length of the resonator. The resonator in this set-up is excited in the $TE_{10\rho}$ mode. The sample holder which is made of glass in the form of a capillary tube flared to a disk shaped bulb at the bottom is placed into the cavity through the non-radiating cavity slot, at broader side of the cavity which can facilitate the easy movement of the holder. The resonant frequency f_o and the corresponding quality factor Q_o of the cavity at each resonant peak with the empty sample holder placed at the maximum electric field are noted. The same holder filled with known amount of sample under study is again introduced into the cavity resonator through the non-radiating slot. The resonant frequencies of the sample loaded cavity is selected and the position of the sample is adjusted for maximum perturbation (i.e., maximum shift of resonant frequency with minimum amplitude for the peak). The new resonant frequency f_s and the quality factor Q_s are noted. The same procedure is repeated for other resonant frequencies.

3. Theory of Cavity Perturbation

When a material is introduced into a resonant cavity, the cavity field distribution and resonant frequency are changed which depend on shape, electromagnetic properties and its position in the fields of the cavity. Dielectric material interacts only with electric field in the cavity.

According to the theory of cavity perturbation, the complex frequency shift is related as [16]

$$-\frac{d\Omega}{\Omega} \approx \frac{(\bar{\varepsilon_r} - 1) \int\limits_{V_s} E.E_0^* dV}{2 \int\limits_{V_c} \mid E_0 \mid^2 dV} \tag{1}$$

But

$$\frac{d\Omega}{\Omega} \approx \frac{d\omega}{\omega} + \frac{j}{2}\left[\frac{1}{Q_s} - \frac{1}{Q_0}\right] \tag{2}$$

Equating (1) and (2) and separating real and imaginary parts results

$$\varepsilon_r' - 1 = \frac{f_o - f_s}{2 f_s}\left(\frac{V_c}{V_s}\right) \tag{3}$$

$$\varepsilon_r'' = \frac{V_c}{4 V_s}\left(\frac{Q_o - Q_s}{Q_o Q_s}\right) \tag{4}$$

Here, $\bar{\varepsilon_r} = \varepsilon_r' - j\varepsilon_r''$, $\bar{\varepsilon_r}$ is the relative complex permittivity of the sample, ε_r' is the real part of the relative complex permittivity, which is known as dielectric constant. ε_r'' is the imaginary part of the relative complex permittivity associated with the dielectric loss of the material. V_s and V_c are corresponding volumes of the sample and the cavity resonator. The conductivity can be related to the imaginary part of the complex dielectric constant as

$$\sigma_\varepsilon = \omega\varepsilon'' = 2\pi f \varepsilon_0 \varepsilon_r'' \tag{5}$$

4. Results and Discussion

Table 1: Variation of dielectric constant with frequency at different time intervals.

Frequency (MHz)	T = 5 minutes			
	M23	M24	M29	M33
2439.019	11.93	12.90	11.17	14.11
2683.882	11.91	12.44	10.93	12.52
2969.983	12.12	13.92	11.96	13.21
	T = 15 minutes			
2439.019	12.73	12.97	11.21	13.12
2683.882	11.87	12.76	12.53	11.77
2969.983	11.77	13.01	10.11	12.23
	T = 30 minutes			
2439.019	11.01	12.60	12.86	14.01
2683.882	12.37	12.56	12.38	13.81
2969.983	13.53	12.90	12.71	13.92
	T = 45 minutes			
2439.019	13.31	12.61	11.74	13.22
2683.882	13.80	12.11	11.82	13.71
2969.983	13.06	12.84	11.95	13.51

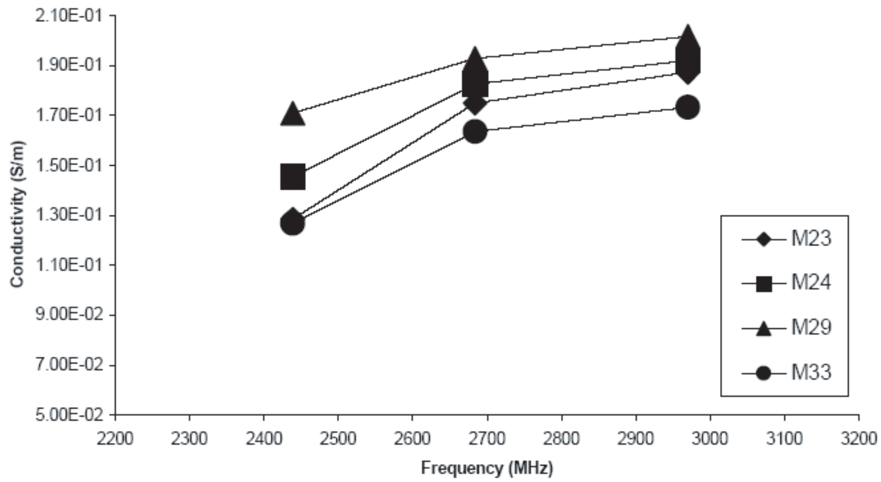

Figure 1: Conductivity of semen.

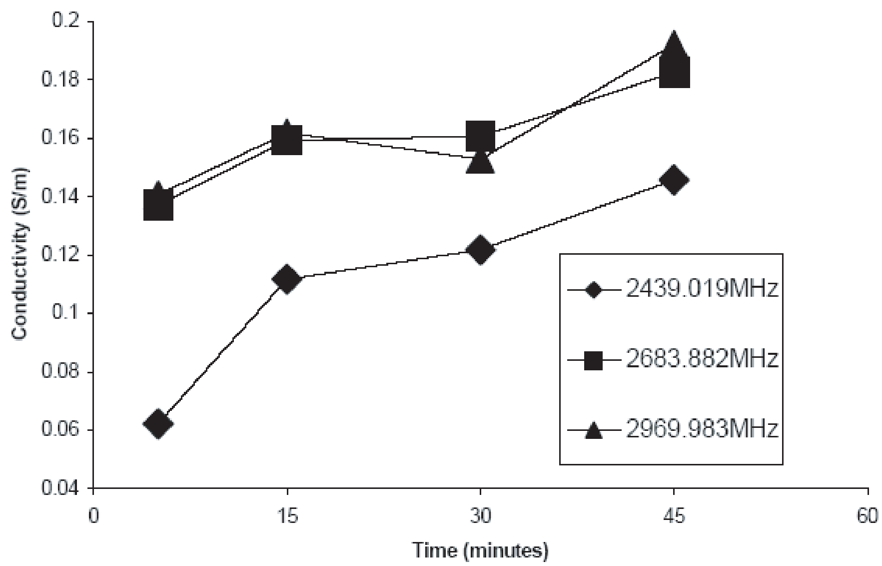

Figure 2: Temporal behaviour of conductivity of M24.

The microwave studies on the samples are done by cavity perturbation technique and the results are shown in Table 1 and in Figures 1 and 2. The clinical evaluation of the semen samples are done and the results are tabulated in Table 2. Table 1 indicates the variation of dielectric constant of different semen samples at different time intervals after ejaculation. It is observed that the dielectric constant is consistent at all frequencies at different intervals of time after ejaculation. From Figure 1, it is observed that the conductivity of the semen samples increases as frequency increases. This indicates that semen is lossier at higher frequencies due to the presence of the high motile quick sperms and its absorption of electromagnetic energy. The conductivity of the sample is more for high motile quick sperms and low conductivity for the dead sperms. From Figure 2, it is observed that the conductivity of semen increase as time elapses. This is due to the clotting enzyme of the prostatic fluid, which forms a coagulum in early stages after ejaculation, which makes the sperm remain relatively immobile, because of the viscosity of the coagulum [17]. The conductivity is relatively low due to this effect in early stages. As coagulum dissolves during the next 5 to 15 minutes, sperms become highly motile, which causes an increase in the conductivity.

This has potential application in forensic medicine in that the elapsed time after ejaculation is directly related to the conductivity of semen.

Table 2: Quantitative analysis of semen in the clinical laboratory.

SEMEN ANALYSIS				
	M23	M24	M29	M33
Time of collection	12.00 PM	12.15 PM	12.30 PM	12.35 PM
Time of liquefaction	12.30 PM	12.45 PM	1.00 PM	1.05 PM
MACROSCOPIC EXAMINATION				
Volume	1 ml	1.5 ml	0.5 ml	1 ml
Colour	Opaque grey	Opaque grey	Opaque grey	Opaque grey
Viscosity	Normal	Normal	Normal	Normal
pH	8.0	8.0	8.0	8.0
Liquefaction	Within 30 minutes	Within 30 minutes	Within 30 minutes	Within 30 minutes
MICROSCOPIC EXAMINATION				
Motility				
Quick	55 %	60 %	70 %	45 %
Sluggish	15 %	15 %	10 %	15 %
Dead	30 %	25 %	20 %	40 %
Sperm count	85million/ml	95 million/ml	100 million/ml	75million/ml
Pus cells	2-3/hpf	2-4/hpf	1-2/hpf	1-2/hpf
Morphology				
Normal	85 %	90 %	88 %	89 %
Giant Head	3 %	2 %	3 %	3 %
Round head	4 %	4 %	2 %	2 %
Pin head	5 %	2 %	4 %	5 %
Double head	3 %	2 %	3 %	1 %

5. Conclusion

The microwave study of the semen samples is done using cavity perturbation technique. This technique requires very small volume of sample and it is particularly applicable to biological samples like semen. The study shows that the dielectric constant of given semen sample does not show appreciable variation with time or with frequency. But it is observed that the conductivity of the semen sample increases as frequency increases, which shows that semen is lossier at higher frequencies. Samples with high conductivity indicates the presence of more high motile quick sperms and low conductivity indicate the more dead sperms. The conductivity of semen increases as time elapses and this finds application in forensic medicine to find the elspsed time after ejaculation.

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