Biocompatibility study of Biphasic-Chitosan - Soya meal Composite Bioceramic Implants and their use as Phantoms for Medical Imaging Applications

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Abstract
Specific Absorption Rate (SAR) measurements of various ratios of Biphasic, Chitosan and Soya meal bioceramic composites at the S band of frequencies are presented. All of these composites have similar SAR behavior. This coincidence is very beneficial for making biomedical implants with higher biocompatibility. Dielectric properties of the composites are also presented. Dielectric parameter of the composites resembles with that of human muscle, liver, fat, bone etc. Thus they can also be used as phantom materials in medical imaging

Keywords- Bioceramics; Biphasic; Hydroxy Apatite (HA); beta tricalcium phosphate (b-TCP); dielectric properties, SAR, Microwave absorption, dielectric properties

1. Introduction
Specific-Absorption-Rate (SAR) measurements are critical for understanding the effects of nonionizing radiation on humans and other biological organisms. Here the SAR measurement is used to study the interaction of microwave with biomedical implants. Their dielectric properties are also studied to investigate their application as microwave phantom materials.

Bioceramics are alternatives for bone and are used to cure bony defects like osteomytitis, osteoporosis, fracture etc. Here biphasic bioceramic [1] is selected for the base material as they are reported to be more biocompatible. Pure forms of bioceramic are highly brittle in nature so can’t be implanted where strength is a major requirement. To overcome this drawback composites are used. Here composite biomaterials such as chitosan and soya meal are used instead of more common collagen composite. They add strength to bioceramics. SAR measurements of independent chitosan, soya meal and biphasic bioceramic samples show identical characteristics for a frequency range of 2-3GHz. This frequency range is selected to conveniently include the Industrial, Scientific and Medical Applications (ISM) band of 2.45GHz. This identical SAR nature can be utilized to develop their composites at various ratios. Since the combination does not alter the properties, these materials can be considered as appropriate constituents for the development of composite bioceramics with more strength and compatibility.

Developments of phantoms to simulate low water content biological tissues are an extensive research area. To study the interaction of electro magnetic energy with human tissue, it is necessary to use models that simulate the electrical properties of real tissue. A non hydrated phantom that overcomes inherent problems like decomposition and deterioration due to the invasion of bacteria or mold also be developed using various ratios of chitosan, soya meal and biphasic. The complex permittivity of the phantom can be controlled by adjusting the composition ratio.
2. Theory

From the measurement of S-parameters, absorption coefficient of the material can be found. Reflection coefficient $R$ and transmission coefficient $T$ are given as $R = |S_{11}|^2$ and $T = |S_{21}|^2$. The absorption coefficient $A$ can be obtained from the simple relation $A + R + T = 1$. **Specific Absorption Rate (SAR)** [2] can be defined as the ratio of the total microwave power absorbed by the sample to the total mass of weight of the sample and is expressed in Watts/Kilogram. The cavity perturbation technique [3] is employed for the study of dielectric parameters. The basic principle involved in the technique is that the field in the cavity resonator is perturbed by the introduction of dielectric sample through the non-radiating slot. The resonant frequency and the Q factor of the cavity are shifted by perturbation. The shift in the frequency is a measure of dielectric constant and that in the Q factor is representing the loss factor. The conductivity of the sample can be obtained from the loss factor. According to the theory of cavity perturbation [4], the complex frequency shift is related as

$$\varepsilon'_r - 1 = \frac{f_0 - f_s}{2f_s} \left( \frac{V_c}{V_s} \right),$$  \hspace{1cm} (1)

$$\varepsilon''_r = \frac{V_c}{4V_s} \left( \frac{Q_0 - Q_s}{Q_0Q_s} \right),$$  \hspace{1cm} (2)

Here, $\varepsilon = \varepsilon'_r + j \varepsilon''_r$ is the relative complex permittivity of the sample, $\varepsilon'_r$ is the real part of the relative complex permittivity (usually known as the dielectric constant), $\varepsilon''_r$ is the imaginary part of relative complex permittivity (associated with dielectric loss of the material). $V_c$ and $V_s$ are the volumes of the sample and the cavity resonator, respectively. The conductivity [4] can be related to the imaginary part of the relative dielectric constant as

$$\sigma = \omega \varepsilon'' = 2\pi f_0 \varepsilon''_r,$$  \hspace{1cm} (3)

3. Methods of Preparation and Experimental Techniques

Biphasic bioceramic (BCP) is obtained by the calcinations of beta tricalcium phosphate (b-TCP) and hydroxyapatite (HA). It consists of 20% HA and 80% b-TCP. Chitosan (Ch) powder is obtained by the deacetylation of chitin, extracted from crustaceans (shrimp, prawn etc.). Soya meal (Soy) is the residue of oil extraction from dry soya beans. These three samples are taken individually and also as mixtures (BCP:Ch- 40:60, 60:40, 80:20, BCP:Soy-50:50, BCP:Ch:Soy-33:33:33) for conducting SAR measurements. For absorption measurements a holder is designed with the inner dimension of the S-band wave-guide and which can hold a fixed weight independent of the sample used. The holder is kept between two coaxial to wave guide adapters and tightened. Using the HP 8714 ET vector network analyzer, the S-parameters $S_{11}$ and $S_{21}$ are measured. From the knowledge of S-parameters, $S_{11}$ and $S_{21}$ the microwave absorption coefficient the SAR are deduced. Experimental setup for the determination of dielectric properties consists of a transmission type rectangular S-band cavity resonator and network analyzer. The S band cavity is perturbed using pellets formed by pressing powder samples. The samples used for the study are replicas of original biomedical implant materials.

4. Results and Discussion

All of the bio materials show their identity when they are exposed to microwaves, in terms of Specific absorption rate. If two different bio samples are showing similarity in their SAR there
will be resemblance in their biological characteristics also. The SAR measurement is taken for a range of 2-3GHz. The results are shown in Fig.1. SAR values are highly frequency dependent. For a frequency range from 2-2.3GHz and from 2.4-3GHz biphasic, Chitosan and soya meal show similar SAR characteristic. From 2.3-2.4GHz it can be seen that there is no much large variation. It is inferred that all the three materials show more or less identical behavior towards microwave exposure. Also the SAR of different compositions did not drift away from their base constituents. It can be noted that the mixtures 80:20 (80% biphasic and 20% Chitosan) and BCP:Ch:Soy (33:33:33) are showing identical characteristics as that of Biphasic bioceramics. Since the compounds used for the study are non toxic and bio degradable they can be used as composite materials to supplement strength to innately brittle biphasic bioceramic. Particularly 80:20 and BCP:Ch:Soy can be used for the manufacture of more effective bioceramics as they are in best agreement with the biocompatibility requirement. The conductivity and loss factor of these materials are high similar to that of human organs (Fig.2&4). The dielectric loss is a direct function of relaxation process, which is due to local motion of polar groups. The friction between molecular chain increases at high frequencies which leads to higher dielectric loss. The conductivity relaxations are caused by this dielectric loss factor. At this relaxation region, polarization acquires a component out of phase with the field and displacement current in phase with the filed, resulting in thermal dissipation of energy, this generates dielectric loss which in turn generates conductivity. The dielectric parameters of BCP:Ch and BCP:Ch:Soy composite are the same as that of certain biological constituents of human body. A comparative study of dielectric parameters of human organs and their phantoms are given in Fig.3 and table.1.
The Biphasic-chitosan composite having ratios, 40:60, BCP:Ch:Soy, 80:20, BCP, Ch and Soya meal, and liver, tibia, eye vitreous body, human abdominal wall fat and human muscle, respectively falls in the same dielectric range. These materials are reproducible, Long Lasting, non corrosive, easy to make and cost effective. And can be used as suitable phantom for low water content biological tissue in microwave medical imaging.

<table>
<thead>
<tr>
<th>Human [4] Organs</th>
<th>Permittivity at 3GHz</th>
<th>Equivalent phantom</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver in vitro</td>
<td>12-12.2</td>
<td>80:20</td>
<td>Biphasic : Chitosan - pellet</td>
</tr>
<tr>
<td>Tibia</td>
<td>8.35</td>
<td>40:60</td>
<td></td>
</tr>
<tr>
<td>Radius</td>
<td>9-11</td>
<td>60:40</td>
<td></td>
</tr>
<tr>
<td>Abdominal wall fat/ Bone marrow</td>
<td>4.92</td>
<td>Ch</td>
<td>Chitosan Powder</td>
</tr>
<tr>
<td>Muscle in Vitro</td>
<td>12-16</td>
<td>Soy</td>
<td>Soya meal powder</td>
</tr>
</tbody>
</table>

Table. 1 Dielectric constants of human organs and their phantoms

5. Conclusion

The SAR and dielectric properties of biphasic-Chitosan-Soya meal composite bioceramic are studied and variations in their absorption characteristics are discussed. Soya meal and chitosan are proposed as constituents for bioceramic composites. The dielectric constant and conductivity of samples exhibit good matching with available literature data on biological tissues. High value of absorption coefficients of the samples suggest their another application as microwave absorbing material in microwave imaging.

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7. References


