Development of a dielectric equivalent gel for better impedance matching for human skin

H. Ikehra1, T. Sunaga1, T. Obata1, S. Furukawa1, M. Tamura1, E. Yoshitome1, S. Tanada1
1national institute of radiological sciences, Chiba-shi, Chiba-ken, Japan

Synopsis
In this study, solid-type water-based gelatin-honey gels were developed which have the electrical characteristics of skin tissue. It was demonstrated that a stable and homogeneous gel, with a relative dielectric constant \( \varepsilon \) chosen from desired ranges found in skin, can be made. Above 300 MHz, acquiring MR images of high quality is difficult because of the increase in operating RF (radio frequency). The main factor affecting image quality is a dielectric resonance phenomenon, which can cause distortion [1]. Electromagnetic wave impedance mismatching of the air/tissue interface may also cause dielectric in homogeneity, especially at the epidermal surface. We expect that three things will occur when an electromagnetic field propagating in the air encounters human tissue such as the dermis, the RF wave should be reflected, transmitted, and absorbed. Using suitable impedance-matched materials should reduce the dielectric mismatch between air and the human body. The simulation and the trial to form phantom for muscle tissue were reported previously [2,3]. We developed a bolus phantom gel which functions by suppressing the non-uniformity of RF due to impedance mismatching inside the skin at 200MHz up to 400MHz.

Methods
An open-ended coaxial probe method is used. This method is based on determination of the input reflection coefficient of an open-ended coaxial probe placed against the surface of each gel. The measurement method was reported in our previous article [4].

The each amount of gelatin powder was placed in a beaker with 100ml of distilled water. The water was heated slowly to 80°C. The general dielectric performance of human skin is also shown in our previous article [4]. Solidified gels were cut with a knife. Three points were measured to confirm the homogeneity: Figure 1 represents the gelatin concentration dependence of the relative dielectric constant. Dielectric constants at 64, 200, 300 and 400MHz are shown in this graph. Plots represent the average of three measurements at each frequency, while vertical bars represent the standard deviation among the three regions. Relative dielectric constant values decrease as the concentration of gelatin increases, and the gel becomes harder. By varying the amount of gelatin, it is possible to make gels of a desired hardness to some extent. Figure 2 shows changes in the relative dielectric constant dependent on the concentration of honey. Honey syrup was added to two base solutions; 28wt% gelatin solution (soft gels) and 50wt% gelatin solution (hard gels). Slender curves and broad curves represent 28wt% and 50wt% solutions, respectively. A reduction of relative dielectric constant values is observed as the honey concentration increases. It varies from 75 down to 40 at 64MHz and from 60 to 30 at 400MHz in soft gels.

Conductivity values are almost independent of both gelatin and honey concentrations. NaCl concentration dependence of the conductivity is shown in Figure 3. Variable amounts of salt are added to the three base solutions: 51, 68, and 76 wt% gelatin solutions shown in Figure 3 as circular, rectangular, and triangular plots, respectively. Conductivity values increase in proportion to the concentration of salt. In addition, conductivity rises in proportion to frequency as clearly shown in Figure 3 by the four plots arranged with even spaces. The tendency is that as the gelatin concentration increases, the slope becomes gentler. The 51 wt% based gels show a rapid increase in conductivity. A range of conductivity values from 0 to 1 is obtained by adding salt to the 51 wt% gelatin-concentrated base solution. The resultant gel, however, becomes softer, as the salt ratio increases. Finally, the composition by weight of most suitable skin equivalent phantom covered for 200 to 400MHz should be 55.7wt% gelatin, honey 15.2%, and NaCl 1.7%.

Conclusion
Solid-type water-based gelatin-honey gels were developed which have the electrical characteristic of skin tissue. It was demonstrated that stable and homogeneous gels can be made in which values of the relative dielectric constant \( \varepsilon \) can be chosen from desired ranges found in skin. Still, \( \varepsilon \) and \( \sigma \) can be varied almost independently, \( \varepsilon \) depending on gelatin and honey concentrations, and \( \sigma \) on the salt concentration. The usage of developed gels would not only improve diagnoses with high Tesla MRI, but also have potential for hyperthermia or the study of the safety of electromagnetic fields.

References

Results and Discussion
The general dielectric performance of human skin is also shown in our previous article [4]. Solidified gels were cut with a knife. Three points were measured to confirm the homogeneity: Figure 1 represents the gelatin concentration dependence of the relative dielectric constant. Gels were made of three different gelatin concentrations. Dielectric constants at 64, 200, 300 and 400MHz are shown in this graph. Plots represent the average of three measurements at each frequency, while vertical bars represent the standard deviation among the three regions. Relative dielectric constant values decrease as the concentration of gelatin increases, and the gel becomes harder. By varying the amount of gelatin, it is possible to make gels of a desired hardness to some extent. Figure 2 shows changes in the relative dielectric constant dependent on the concentration of honey. Honey syrup was added to two base solutions; 28wt% gelatin solution (soft gels) and 50wt% gelatin solution (hard gels). Slender curves and broad curves represent 28wt% and 50wt% solutions, respectively. A reduction of relative dielectric constant values is observed as the honey concentration increases. It varies from 75 down to 40 at 64MHz and from 60 to 30 at 400MHz in soft gels.

Conductivity values are almost independent of both gelatin and honey concentrations. NaCl concentration dependence of the conductivity is shown in Figure 3. Variable amounts of salt are added to the three base solutions: 51, 68, and 76 wt% gelatin solutions shown in Figure 3 as circular, rectangular, and triangular plots, respectively. Conductivity values increase in proportion to the concentration of salt. In addition, conductivity rises in proportion to frequency as clearly shown in Figure 3 by the four plots arranged with even spaces. The tendency is that as the gelatin concentration increases, the slope becomes gentler. The 51 wt% based gels show a rapid increase in conductivity. A range of conductivity values from 0 to 1 is obtained by adding salt to the 51 wt% gelatin-concentrated base solution. The resultant gel, however, becomes softer, as the salt ratio increases. Finally, the composition by weight of most suitable skin equivalent phantom covered for 200 to 400MHz should be water 34.7%, honey 50.1%, gelatin 13.5% and NaCl 1.7%.

Conclusion
Solid-type water-based gelatin-honey gels were developed which have the electrical characteristic of skin tissue. It was demonstrated that stable and homogeneous gels can be made in which values of the relative dielectric constant \( \varepsilon \) can be chosen from desired ranges found in skin. Still, \( \varepsilon \) and \( \sigma \) can be varied almost independently, \( \varepsilon \) depending on gelatin and honey concentrations, and \( \sigma \) on the salt concentration. The usage of developed gels would not only improve diagnoses with high Tesla MRI, but also have potential for hyperthermia or the study of the safety of electromagnetic fields.


dielectric constant and conductivity of skin tissue equivalent phantom for 200 to 400 MHz

<table>
<thead>
<tr>
<th>Frequency MHz</th>
<th>Dry skin tissue</th>
<th>Phantom skin tissue</th>
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<tbody>
<tr>
<td></td>
<td>Dielectric constant ( \varepsilon )</td>
<td>Dielectric constant ( \varepsilon )</td>
</tr>
<tr>
<td>400</td>
<td>46.8</td>
<td>49.5</td>
</tr>
<tr>
<td>300</td>
<td>49.8</td>
<td>50.5</td>
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<td>52.2</td>
</tr>
<tr>
<td>64</td>
<td>92.2</td>
<td>56.3</td>
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</table>

Figure 1: Dependence of the relative dielectric constant on gelatin concentration.

Figure 2: The changes in relative dielectric constant dependent on honey concentration.

Figure 3: Dependence of conductivity on NaCl concentration.

Salt are added to 51, 68, and 76 wt% gelatin solutions.