Magnetic Susceptibility of PAlNaGd doped with Europium Glasses and its effect on MR imaging

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Abstract. The effect of paramagnetic implant on magnetic resonance imaging (MRI) is important subjects in medical material studies. The purpose of this study is to investigate the effects of PAlNaGd doped with europium with the chemical composition of (60-x) P₂O₅: 10 Al₂O₃: 20 Na₂O: 10 Gd₂O₃: x Eu₂O₃, when x = 0.1 and 3.0 mol% on MR imaging. The glass was placed in phantom as to mimic in effect of material implant in human tissue. The results of this study show that artifacts severity depends on the europium ions (Eu³⁺) concentration and T2-weighted images is more effected than that of T1-images. The T2 relaxation time is also found to be affected by the Eu³⁺ concentration in the glass, causing the T2 relaxation time to become shorter. This current study found that PAlNaGd glass shows high magnetic susceptibility effects and modifies T2 relaxation time making it an interesting material for use as a medical implant and device.

1. Introduction
Bulk magnetic susceptibility is the effect from the field inhomogeneity that causes artifacts in magnetic resonance spectroscopy Imaging (MRI). The inhomogeneous magnetic field will result in the distortion or wrapped image that may impede the interpretation of MRI images. MRI is a powerful imaging technique for studying pathology of soft tissue with exceptional contrast. MRI acquired images with no radiation and also provided the tomography plane of organs of interest in one acquisition.

Europium ions (Eu³⁺) has been proposed as contrast agent for MRI from its properties as paramagnetic properties and low toxicity. It is also having photoluminescent properties that can emit strong fluorescent [1]. This is the reason why Eu³⁺ is gaining more and more attention in biomedical applications, particularly in biological probes and medical implants [2, 3]. However, the paramagnetic properties could be problematic for the images quality, because the magnetic properties can cause the inhomogeneity on MRI magnetic fields resulting in the image artifacts, especially around the edge adjacent to the implant or devices [4-6]. These artifacts depend on type and chemical composition of metal, the shape and size of metal, its orientation to the main magnetic field (B₀) of the machine, pulse sequence and parameters that were used in the study [7-9]. These artifacts could be in the form of a signal void on images, fringe or enhance area, and obscure areas of interest. However, very few studies on magnetic susceptibility of Eu³⁺ glass has been done so far.
In this study, the PAiNaGd glass formula of (60-x) P$_2$O$_5$: 10 Al$_2$O$_3$: 20 Na$_2$O: 10 Gd$_2$O$_3$: x Eu$_2$O$_3$ was studied, when x = 0.1 and 3.0 mol%. The glasses were placed in 3% agarose gel concentration to mimic properties of implanted devices in human tissue to study the effects of Eu$^{3+}$ concentration on MR imaging.

2. Material and methods

2.1. Agarose gel phantom preparation
The phantom of agarose gel was prepared with distilled water and polysaccharide agarose concentration at 3%. The mixture was boiled with magnetic stirrer until dissolved. The agarose gel was then poured into the plastic container of 20×20×25 cm$^3$. A glass sample was placed in the middle of phantom. The vertical line of sample glass was placed parallel to B$_0$ of MRI machine.

2.2. Glass Preparation
The PAiNaGd glass samples formula are (60-x) P$_2$O$_5$: 10 Al$_2$O$_3$: 20 Na$_2$O: 10 Gd$_2$O$_3$: x Eu$_2$O$_3$ when x = 0.1 and 3.0 mol% were doped with rare earth utilized quenching technique. All chemicals H$_2$BO$_3$, SiO$_2$, CaO and Gd$_2$O$_3$ used in this work were analytical grade. The total amounts of each batch of formulas were weighed to 30 g/melts, and were then placed in a high purity alumina crucible. Next, the prepared mixture was heated at 1773 K for 3 hours using an electrical furnace. The melt was then quickly poured into a preheated stainless steel mould, and quenched glasses were annealed at 773 K for 3 hours to reduce thermal stress. They were then left to cool down slowly to room temperature. The obtained glass samples were cut and polished into a proper shape for characterization.

2.3. MRI Acquisition
The Europium-doped glass samples at various concentrations were assessed for magnetic susceptibility using MRI 1.5 Tesla Phillips Ingenia provided by Department of Radiologic Technology, Faculty of Associated Medical Sciences, Chiang Mai University. CardiacQuant protocol available on MRI machine was used for T2* map generation. The T1-weighted images were acquired with a head coil fitted with foam to hold phantom in place throughout the study. T1-weighted Spin Echo sequence was acquired with TE = 8 ms and TR = 200, 300, 400, 500, 600, 700, 800, 900, 1000 and 1200 ms. T2-weighted images were obtained by using T2-weighted Spin Echo with TR = 2000 ms and TE = 20, 40, 60, 80, 100, 120, 140, 160 and 200 ms. Slice thickness for all sequence used in this study was 5 mm with FOV = 480 x 480 mm.

2.4. Magnetic susceptibility analysis
Signal to noise ratio (SNR) was measured using MIPAV (Medical Image Processing, Analysis, and Visualization) application. The region of interest (ROI) of 10×10 mm$^2$ was placed in the middle slice of the agar gel phantom. The measurement was measured at various distances of +0, +5, +10 and +15 from the center to the right side of phantom as shown in figure 1. The SNR was calculated from the average signal intensity (SI) multiplied by a correction factor of 0.655 and divided by the standard deviation of background image. The correction factor arose from Rician distribution of background noise in magnitude images [10].

3. Results and discussion
The images obtained from MRI are shown in figure 1. It is noticeable that the glass system that was placed in the phantom shows large artifacts in T2-weighted images. The T2-weighted images show that the signal void or enhancement effect also worsen with higher concentrations of Eu$^{3+}$. It can also be seen that the artifacts are potent in T2-weighted images, while the artifacts sizes in T1-weighted are independent of Eu$^{3+}$ concentration.
Figure 1. T1 and T2 weighted coronal plane image of phantom with ROI drawn at +0, +5, +10 and +15 from center to the right.

In figure 2, illustrates the relaxometry of T2 from each ROI. It can be seen that the T2 relaxation time of ROI decreases with the increasing of Eu$^{3+}$ concentration. The T2 value of phantom with glass of $x=0.1\text{mol\%}$ and $x=3\text{mol\%}$ at ROI = +10 is $T2=16.11\text{ms}$ and $11.56\text{ms}$ respectively.

![SNR vs. TE](image)

Figure 2. T2 relaxometry of each ROI from the phantom with (60-x) P$_2$O$_5$: 10 Al$_2$O$_3$: 20 Na$_2$O: 10 Gd$_2$O$_3$: x Eu$_2$O$_3$ glass when (left) $x = 0.1\text{ mol\%}$ (right) $x = 3\text{ mol\%}$.

The T2* map reveals the signal devoid in the middle of phantom at the area where the glass was placed. As seen in figure 3, the T2 value of reference phantom is $41.06\pm0.68\text{ms}$ which is close to the relaxation time of muscle and liver at 1.5T [11]. The phantom with glass system of $x=0.1$, 3 mol% have relaxation times that vary from reference values depending on the distance from the glass sample. It is also clear that higher concentrations of Eu$^{3+}$ composition contribute to the severity of artefacts. The T2* map also shows that the T2 relaxation time of the area around the glass embed is also affected.
4. Conclusion
Eu$^{3+}$ is a lanthanide element with paramagnetic properties. This current study shows that glass systems with Eu$^{3+}$ causes magnetic inhomogeneity and alteration of T2 relaxation time. The magnetic susceptibility caused by (60-x) P$_2$O$_5$: 10 Al$_2$O$_3$: 20 Na$_2$O: 10 Gd$_2$O$_3$: x Eu$_2$O$_3$ glass result in image artifacts in MR imaging. It is also shown that artifact severity also increases with concentration of Eu$^{3+}$ in PAINaGd glass. This study shows the magnetic susceptibility and its effects on the extent of artifacts in phantom to mimic glass implants or devices in humans. All in all, PAINaGd glass has a promising future as an MRI contrast agent and medical material to be used as magnetic materials for cancer therapy. Further investigation of PAINaGd glass for MR imaging is strongly recommended.

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