Subzero temperature mapping in a cryosurgery ice ball by using MR signal time course

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Introduction

Cryosurgery is a technique for freezing and killing tumors by cooling the cryoprobe inserted subcutaneously. The frozen area appears dark in MR monitoring because the water of ice is MR-invisible. The malignant tumor becomes necrotic at freezing temperatures below –20ºC. However, it is hard to discern the necrotic area below –20ºC in the frozen area, so-called ice ball. To visualize the necrotic area, we developed a method to map subzero temperatures in a black ice ball.

Materials and Methods

An agar phantom was imaged using a 0.3-T MRI (AIRIS, Hitach Medical Corp.) every 20 s during the cooling of the cryoprobe of a cryotherapy system (CryoHit, Galil Medical) using a gradient echo pulse sequence with scan parameters as follows: TR/TE = 100/12 ms, flip angle = 30°, slice thickness = 8 mm, FOV = 256 × 256 mm^2, matrix size = 256 × 256. The temperature at ten points around the cryoprobe was monitored by using thermocouples, the positions of which are shown in Fig. 1. The MR signal in each pixel decreased rapidly during the phase transition of water to ice at 0ºC. Its rate of decrease (g) reflects the speed at which the latent heat of each voxel is absorbed. Providing this thermal absorption speed continued during the time (τ) after freezing until the end of cooling, the product $g\tau$ of each voxel is proportional to the amount of freezing calories (Q) absorbed. And Q is given by $mc\Delta T$ where m is the mass, c is the specific heat and ΔT is the temperature decrease from 0ºC, ΔT is proportional to Q ($g\tau$) whenever c is constant. Therefore, $g\tau$ represents the subzero temperature attained.

Results and Discussion

Since freezing commences from the cryoprobe-side of the voxel, the partial volume effect occurs. This effect becomes stronger and g becomes larger approaching to the cryoprobe. Then, the partial volume effect was corrected by using the power of g. The relationship between $g^{2.82}\tau$ and the decrease in temperature was unique for all voxels monitored by thermocouples (Fig. 2). The curvature of the relationship in Fig. 2 reflects differences from the assumption in the aforementioned idea, but the data on the same line indicates that the relationship in Fig. 2 is reliable to derive the subzero temperature. Based on this relationship, the value $g^{2.82}\tau$, which corresponds to –20ºC, was obtained to map a –20ºC line in an ice ball (Fig. 3). The thickness of the marginal area where the temperature is above –20ºC in an ice ball was 5 mm in the top and 3.5 mm in the side direction of the cryoprobe.

Conclusion

The necrotic area below –20ºC can be mapped in an ice ball in cryosurgery.

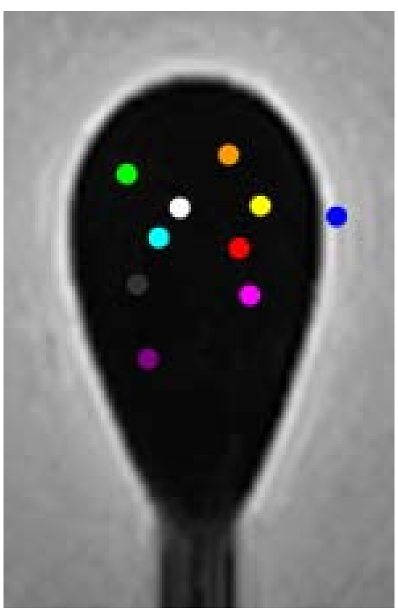

Figure 1

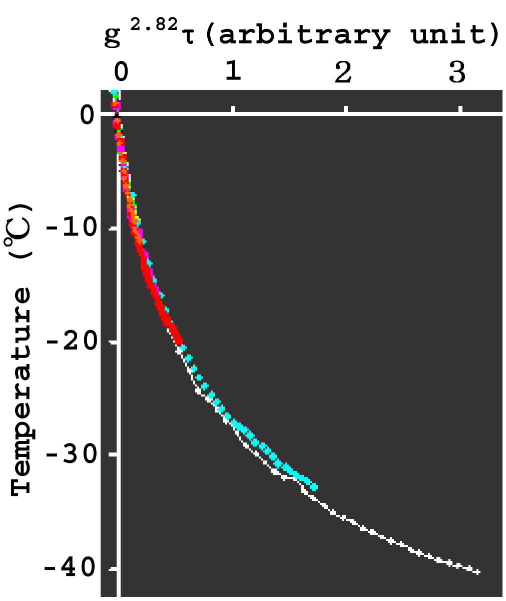

Figure 2

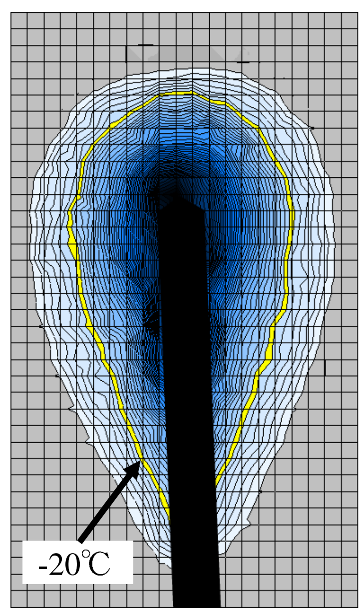

Figure 3