Control System for MR-Guided Cryotherapy: Automatic Segmentation and Short-Term Future Prediction of Therapy Region Using 3D Optical Flow

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Synopsis

During cryotherapy, it is extremely useful for the interventionalist to have available intra-operatively a 3D iceball visualization, to ensure the effectiveness and safety of the procedure. Additionally, it highly beneficial to provide the interventionalist with a best estimate of how the iceball will grow in the future, and an estimate of the extent to which the target region and the tissues around it will be ablated. In this study, we introduce a newly developed control system for cryotherapy using a novel approach for the real-time/future-predicted assessments of the treatment. The system has been validated using results from cryotherapy experiments.

Introduction

During cryotherapy, it is extremely useful for the interventionalist to have available intra-operatively a 3D iceball visualization in order to ensure the effectiveness and safety of the procedure. Additionally, it highly beneficial to provide the interventionalist with a best estimate of what will occur in near future so the progress of the procedure can be carefully controlled. That is, the aim is to provide a best estimate of how the iceball will grow and an estimate of the extent to which the target region and the tissues around it will be ablated. The quantitative analysis of ablation treatment is difficult during therapy due to the typically 2D representation of intra-operative MR image information, and the inhomogeneity of the iceball growth due to nearby vessels or other perturbing anatomy. Previously, we formally developed and evaluated a predictive method for estimating the extent and effectiveness of thermal therapies using 2D optical flow[1,2]. In this study, we introduce a newly developed computerized control system for cryotherapy using 3D visualization and a 3D optical flow computation along with other novel software tools. Our new control system provides intra-operatively for the real-time and future-predicted quantitative assessments of the cryotherapy treatment. System evaluation and validation was performed using animal cryotherapy experiments data..

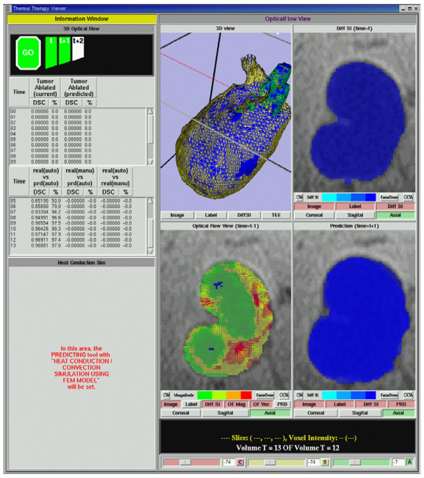

Fig.1 Overview of the control system for MR-monitored cryotherapy. 3D/2D representation of the iceball region (top), optical flow information (Bot L), and predicted iceball are shown on rendering windows. Results of quantitative assessment and visual status information are shown at top-left.

Method

This system consists of 3 main components: (1) an automatic iceball segmentation module; (2) a computation of the short-term future prediction of the iceball region; and, (3) a quantitative assessment and visual status/alarming module for the treatment. Iceball regions are automatically segmented based on the information of the differences of MR signal intensities from preoperative baseline images. We estimate the velocity field of the iceball region growth using Lucas & Kanade's optical flow (OF) calculation method [3] in 3D which makes use of the past 3 image datasets taken during an intra-therapy dynamic imaging series. The short-term future of the iceball region is predicted using the OF information, which is quantitative information about temporal changes in image sub-regions having uniform intensity .

Real-time quantitative assessment of the progress of the treatment is carried out by comparison between the target region of treatment and the auto-segmented/predicted iceball region using the Dice Similarity Coefficient (DSC) and % Target Coverage (%TC) calculations [4]. A key feature of our system is the status/alarming module that can signal an audible and visual alert when the auto-segmented/predicted iceball extends near to or into physician-defined protected regions, ie. regions designated to be protected from the ablative effects (Fig.2).

The performance of the system was evaluated using porcine cryotherapy experimental data. The validation process is performed, and system accuracy and effectiveness was confirmed, by comparing segmented iceball results estimated using the EM algorithm [5] to the set of iceball results obtained from hand-segmentation by 3 experts.

Result

The system computation including automatic segmentation, OF computation and prediction, therapy assessment calculation and 3D visualization had an update time of approx 2.5sec for a 256x256x20 voxel MRI slab dataset using a Dell Precision workstation with 2.2 GHz Pentium4 processor and 2 GB RAM.

3D optical flow computation results show dynamic information of the iceball growth during the procedure. This information is not only useful for the prediction of the future iceball but also supports the intuitive understanding of the trend of therapy progress.

DSC and % Coverage calculation results from auto-segmented iceballs and expert segmentation are over 0.9 and 90%, resp. Comparison results from predicted iceball (based on OF) and hand-segmented results also show good performance (DSC>0.6, %C>50%), with poorer performance of the prediction during the early phase of treatment when the speed of iceball expansion is large in magnitude with respect to the rate of image acquisition. In almost all cases, notably, this system demonstrates effectiveness of the control and monitoring of cryotherapy during the middle-to-end phase of treatment.

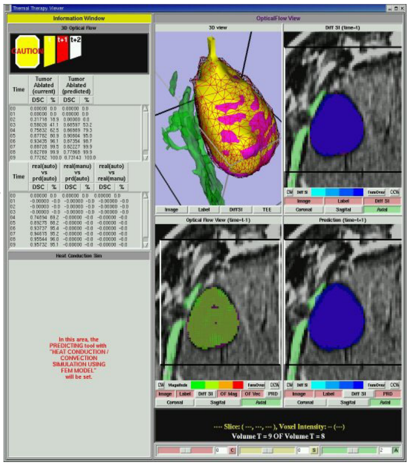

Fig.2: Status/Alarming module demonstration. Predicted iceball (mesh volume at top L) violates a predefined protected region (vessel, green). Forecasting damage in near future if the therapy continues. Status/Alarming module signals audible and visual alert to notify the interventionalist of impending danger before damage occurs.

Conclusion

We developed a novel MRI-based monitoring and control system for cryotherapy. The system shows the interventionalist rich visual and quantitative information of the treatment in real-time and provides highly beneficial predicted information regarding the course of the treatment. Results of animal experiments were used to demonstrate the good accuracy of the system. The results from using our system during animal crytotherapy experiments indicate the system's value in increasing the therapeutic effectiveness of the ablation and the safety of the procedure.

Acknowledgement

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