

# Cryotherapy Simulator for Localized Prostate Cancer

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**Abstract.** Cryotherapy is a treatment modality that uses a technique to selectively freeze tissue and thereby cause controlled tissue destruction. The procedure involves placement of multiple small diameter probes through the perineum into the prostate tissue at selected spatial intervals. Transrectal ultrasound is used to properly position the cylindrical probes before activation of the liquid Argon cooling element, which lowers the tissue temperature below -40 degrees Centigrade. Tissue effect is monitored by transrectal ultrasound changes as well as thermocouples placed in the tissue. The computer-based cryotherapy simulation system mimics the major surgical steps involved in the procedure. The simulated real-time ultrasound display is generated from 3-D ultrasound datasets where the interaction of the ultrasound with the instruments as well as the frozen tissue is simulated by image processing. The thermal and mechanical simulations of the tissue are done using a modified finite-difference/finite-element method optimized for real-time performance. The simulator developed is a part of a comprehensive training program, including a computer-based learning system and hands-on training program with a proctor, designed to familiarize the physician with the technique and equipment involved.

## 1. Introduction

Prostate cryotherapy is a relatively new procedure for prostate cancer in which the prostate gland is treated in situ by freezing. The freezing and thawing process destroys the prostate glands, which are replaced by scar tissue following the procedure. This is accomplished by inserting several cylindrical cryoprobes into the gland under ultrasound guidance. Thermocouples are placed at strategic locations within and around the gland to monitor the formation of ice crystals around the cryoprobes which occurs when the cryoprobes are activated. The ability of a physician to deliver an efficacious freezing injury is largely dependent on clinical experience and the ability to create an area of treatment known as an 'iceball' that kills the target cancerous tissue without damaging surrounding tissues.

A prostate cryotherapy simulator has been developed to expedite the learning process associated with this technically demanding procedure. Three dimensional ultrasound images of the prostates from real patients are used. The physician can practice prostate cryotherapy in a clinically realistic manner by placing and operating the cryoprobes before actually treating a patient. During a clinical procedure the physician monitors the iceball growth on ultrasound and also uses the temperature measurements from the thermocouples

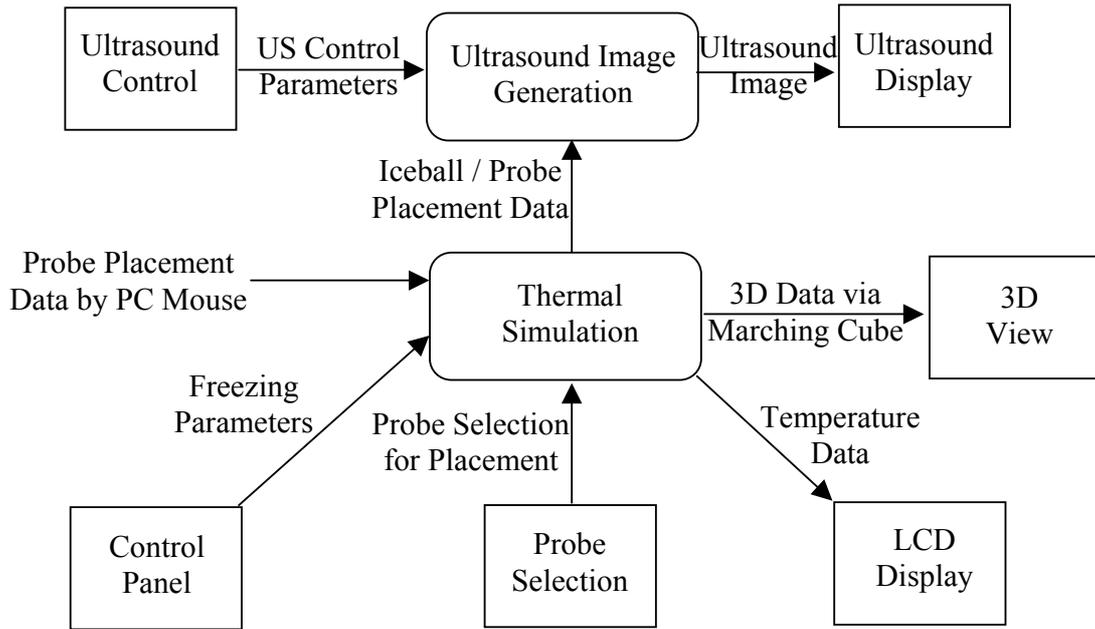


Figure 1: Diagram of Functional Modules

to assess the extent of the freezing injury. A mathematical cryotherapy simulation with verified accuracy is used to determine the temperatures surrounding the cryoprobes during the procedure simulation. Changes that occur in the ultrasound image when ice forms in tissue have been accurately reproduced. Combining this visual feedback with the thermocouple readings, the physician can judge the extent of freeze injury in both tissues targeted for destruction and tissues that must remain unfrozen.

This simulator allows a physician to gain a skill set previously attainable only with clinical experience. The simulation is being incorporated into the training process by Endocare Inc., a leader in the development of cryotherapy technologies. The current training process consists of a day of classroom instruction and the physician being proctored, on average, for their first six clinical cases. This is very inefficient from a cost perspective because of the need to provide an expert in cryotherapy as the proctor for each case. The simulator provides a physician an intuitive feel for the procedure and a solid understanding of how the freezing process will be visualized within the target tissue based upon placement and activation of the cryoprobes. Incorporation of the simulator into the training process is expected to reduce the number of cases that require oversight as the physician becomes comfortable with the procedure. Consequently, it is believed that this will result in a significant reduction of the cost associated with training [8].

## 2. System Design

The simulation system is composed of three main sub-systems:

- 1) the ultrasound image generator
- 2) the thermal simulator
- 3) the user interface components to control the simulation and the virtual instrumentation

Figure 1 shows the overall functional diagram of the simulator. In this figure, the rounded blocks denote internal function blocks, and rectangular blocks represent the



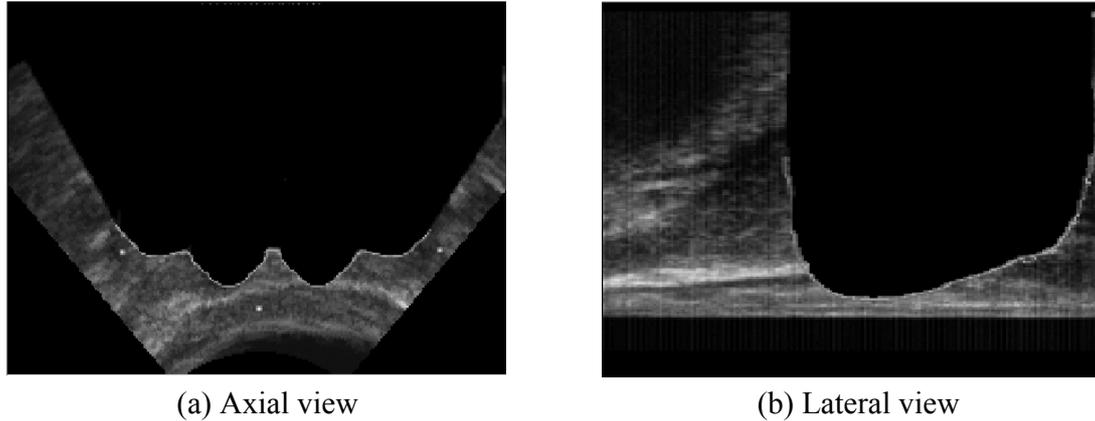


Figure 3: Ultrasound images during the simulation

becomes opaque to ultrasound. The resultant shadows and diffraction is simulated (Figure 3). The virtual ultrasound view is generated in real time [1,2,6].

### 3.2 LCD Display and Control Pad

The freezing process in real cryotherapy is controlled by a remote control pad. The same interface is located in the lower right corner of the simulator's screen. With the control pad, the physician can set the operational mode for each of the cryoprobes. With the remote control, he/she can select a cryoprobe which is currently being operated. The operating mode can also be changed between stick, freeze, thaw, and off modes. The number denotes the duty factor which controls the amount of freezing for each cryoprobe.

The LCD display shows the information for the cryoprobes and current temperatures at the cryoprobes and thermocouples. The history of the temperatures for each thermocouple is shown on a graph. Figure 4 shows the LCD display with temperature graphs obtained during the simulation.

### 3.3 Cryoprobe Management

The interface shown in the middle-right area of Figure 2(a) enables the user to select a cryoprobe or thermocouple being currently controlled. Once the inserting position is determined, the operator can insert the probe by dragging the mouse. The probes are displayed in real time on the ultrasound display. The physician can practice the placement by dragging the probes while controlling the ultrasound device.

## 4. Thermal Simulation

The purpose of the simulator is to mimic the freezing process of real cryotherapy. In order to achieve this, thermal simulation is performed based on finite difference model. We use three dimensional grid structure to represent the thermal simulation elements. Each element contains current temperature, and interacts with nearby elements by giving and receiving thermal energy. The freezing process begins at the tips of the probes and neighboring elements are frozen as the simulation proceeds. The temperature information of the elements is always available so that it can be given to the user.



Figure 4: LCD Display

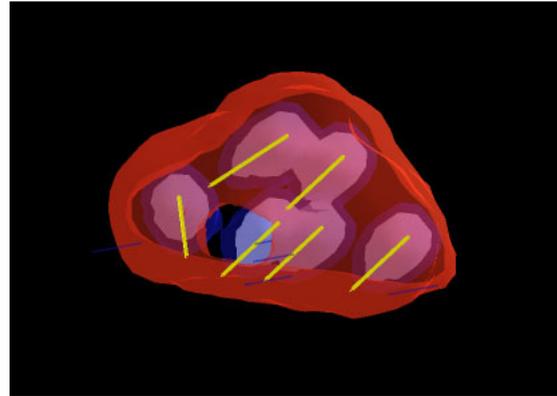


Figure 5: 3D View

The information about the current situation is given to the operator through the ultrasound image. During the simulation of cryotherapy, the ultrasound image is altered in order to reflect the changes made by the freezing process. Iceball regions are identified by the thermal simulation module as being opaque to ultrasound. Ultrasound shadows and reflection effects are added. Figure 3 shows the ultrasound display during the simulation of cryotherapy in axial and lateral views.

LCD display shows the current temperatures for all cryoprobes and thermocouples. The current operating modes of the cryoprobes are also provided. Figure 4 shows a screen shot of LCD display during the simulation. The graphs in the figure represent the temperature history for the cryoprobes.

The simulation status can also be seen in 3-D birds-eye-view. A typical result is shown in Figure 5. In this figure, the red object is a model of the prostate while yellow rods are cryoprobes. Iceballs are shown in two colors. The white iceballs are iso-surfaces for the temperature of -40 °C, and blue iceballs are for 0 °C. This view can be rotated or zoomed by simple mouse operations. The prostate model is obtained by segmentation before the simulation. The iceball objects are obtained by standard marching cube algorithm [5]. Once the user pauses the simulation, the marching cube algorithm extracts the iso-surface from thermal simulation grids and generates the iceball objects.

## 5. Conclusion

Despite the prevalence of surgical simulation systems, very few are actually being used routinely for training. The difficulty is not only technical but in engineering a system that fits the task. In this simulation system, we have taken the approach that many low-end flight simulators have taken in that we have concentrated on the intellectual learning component and left out the manual dexterity to be learned in actual procedures.

The simulation system has been developed and has gone through several iterations. Preliminary indications are that it is effective in training the user in the techniques and the instrumentation and is an important component in a coherent and comprehensive training program for the procedure.

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