A Computerized Physical Simulator for Training Clinical Prostate Palpation Skills

Sarah Rigsbee, Gregory J. Gerling*, Reba Moyer Childress and Marcus L. Martin, *Member, IEEE

Abstract—Cancer of the prostate is diagnosed at a high rate in American men and leads to a high number of deaths annually. Each of the three separate prostate diseases (benign prostatic hypertrophy, prostatitis, and cancer) has different palpable characteristics and requires different treatment. Therefore healthcare professionals must learn to correctly detect and diagnose each prostate abnormality. The digital rectal examination is a commonly employed method to detect prostate abnormalities. However, medical and nurse practitioner students often receive little to no training for this exam and trained clinicians often exhibit low agreement on findings. Both may be due, in part, to inadequacies of current training practices, particularly those involving simulation.

The purpose of this work is to improve the current training. In particular, current simulators might more adequately prepare trainees if they included design characteristics such as basic elements of lifelike anatomy, multiple and reconfigurable scenarios with graded levels of difficulty, and feedback on trainee technique and performance. Also, the simulator must train practitioners to detect prostate cancer and other diseases of the prostate. This work presents the implementation of these design characteristics. The Virginia Prostate Examination Simulator includes a freestanding torso structure, six instrumented prostates with embedded pressure sensors and controllable balloons, custom-built electronics to record sensor data and control balloon water pressure, and a user-interface display that presents technique and performance information to trainees.

I. INTRODUCTION

One in six men will develop prostate cancer during his lifetime, and one in thirty-four will die from the disease [1]. The digital rectal examination (DRE) is the most commonly employed method of prostate cancer detection because it is inexpensive, quick, and easy to perform. With the DRE, the practitioner uses his or her index finger to palpate the patient’s prostate and characteristics of the prostate, such as its size, stiffness, nodularity and constancy, are noted. Despite the wide-use and effectiveness of the DRE in cancer detection, the between-examiner agreement, even among experienced urologists, is rated only as fair (i.e. only between 21 to 40 percent agreement on a diagnosis [2, 3]). This disparity is due, in part, to little or inadequate training in the hands-on examination technique during medical school [4]. Studies in similar palpation examinations (breast) have shown that clinicians can improve examination accuracy with training that emphasizes tactile skills [5]. However, no quantitative means of measuring DRE proficiency currently exist, which impedes development of standardized training.

A. General Simulator Training Methods

All medical and nurse practitioner students, not just postgraduate oncology students, must be proficient in diagnosing and understanding the various forms of cancer. In addition to written curriculum, several types of simulators have been used to educate this large number of students, principally grouped as physical models, virtual reality devices, and hybrid devices (computerized physical models).

Physical models are silicone replicas which simulate anatomy via rubber-like replicas of external body contours, with tumors or anomalies made from hard plastics or erasers. Physical models provide training in a hands-on environment with abstracted anatomical structures. As compared to learning only with traditional lectures, physical models are known to improve the detection of simulated breast tumors, for example [6-8]. However, physical models typically present a small range of diseased states with obvious findings and little feedback to trainees in regards to their technique or performance.

Virtual reality (VR) simulation typically employs force feedback devices (such as the Sensible PHANTOM). Force feedback devices deliver realistic forces to a user’s hands via solid pens attached to a multiple degree of freedom robotic arm. Impact and vibration interaction with an object rendered in a 3D world may be presented, for example, to simulate contact with internal organs or the skin surface. Abdominal trauma surgery [9], incisions in congenital heart disease surgery [10], suturing [11] and neurosurgery [12] are a few applications. While VR simulators are useful in training the tasks mentioned above in a variety of diseased states and can provide technique and performance feedback, the pen-based interaction does not provide an appropriate range of tactile feedback [13] to train palpation tasks [14].

Hybrid (computerized and physical) simulators combine the use of rubber-like materials to simulate the feel of the tissue while using a computer to generate reconfigurable scenarios and capture and present feedback to users. For
example, Gerling and Thomas’s breast cancer simulator enables reconfigurable scenarios, as well as augmented pulsating feedback [15, 16]. Pugh’s pelvic simulator utilizes sensors embedded in a rubber material to provides visual feedback to the trainee [17]. This physical nature of the simulators provides a tactile feel which is difficult to achieve with a virtual reality device.

II. CURRENT PROSTATE GLAND SIMULATORS IN USE

Two physical simulators (Nasco, Inc., Fort Atkinson, WI) are used to teach clinical palpation of the prostate at the University of Virginia. The Static With Torso (SWT) simulator represents a man's posterior section from naval to mid-thigh, with a rectal wall and four insertable prostate glands. The Static Without Torso (SWOT) simulator utilizes five simulated prostate glands, with no posterior section or rectal wall. The simulated prostates are built from a silicone-elastomer material and embedded with hard plastic or eraser-like materials that represent cancerous tumors. While they permit hands-on practice, these physical simulators: a) lack the basic elements of lifelike anatomy, b) encourage memorization of abnormality scenarios, and c) lack feedback on trainee technique and performance.

First, the simulators lack the basic elements of lifelike anatomy. In either simulator, four anatomical elements are either missing or misrepresented: posterior section, rectal wall, prostate anatomy, and most importantly disease states. A posterior section is needed to block the trainees’ view of the prostate, fix prostates in space, and attach the rectal wall for palpation. The absence of a rectal wall means that trainees palpate with no physical barrier between the finger and prostate, which can affect sensitivity [18]. The simulated normal prostate state is too firm and abnormally large in size, providing trainees a false baseline against which to judge subsequent non-normal prostates. Neither model provides the entire range of disease states; this therefore limits the trainees’ exposure to the various forms of prostate disease.

Second, because only a few abnormality scenarios are simulated, those presented can be easily memorized. For example, the SWOT presents five simulated prostates and the SWT only four. The ability to memorize the physical landmarks encourages trainees to exhibit a false level of proficiency [15] and enables little repetitive practice. Both may ultimately inhibit skill improvement and transfer of skills to the actual exam.

Finally, technique and performance feedback is not provided to trainees. Trainees gain no insight on the effectiveness of their technique (e.g., adequate area coverage and appropriate finger pressure applied) and proficiency of performance (e.g., correct number of tumors found). The only type of feedback in either simulator is visual feedback with SWOT simulator. This form of feedback, unfortunately, gives students a visual of the physical landmarks (inflammation, tumors) and size of prostate.

III. VIRGINIA PROSTATE EXAMINATION SIMULATOR

We designed and built a hybrid (computerized and physical) simulator to address the three issues identified with the current simulators. First, to address the lack of basic elements of lifelike anatomy, we included a posterior section and rectal wall, in addition to ensuring accurate prostate stiffness and size, and oncologically accurate disease states. Second, to address memorization of the few abnormality scenarios, we developed a concept of multiple and reconfigurable scenarios with graded levels of difficulty. Finally, to address the issue of lack of technique and performance feedback, sensors embedded within each prostate capture finger pressure information for presentation to users.

A. Basic Elements of Lifelike Anatomy

To promote a realistic training environment, a posterior section was constructed with an exterior skin made of a pigmented silicone-elastomer, and internal support structure made from PVC piping, foam, and a steel plate (Fig. 1). The rectal wall is made of a silicone-elastomer. Three prostates with accurate size and stiffness (Shore A, durometer value of 16 as compare to Shore A, durometer value of 19 for SWT and Shore A, durometer value of 26 for SWOT) are attached to a track system internal to the posterior section, upon which the one prostate under test can be rotated into position beneath the rectal wall.

![Fig. 1. Virginia Prostate Examination Simulator (top), instrumented prostate (left) and internal track system (right)](image)

There are two different forms of prostate disease (prostatitis and benign prostatic hypertrophy), and one form of cancer of the prostate (carcinoma) [19]. Prostatitis is an acute inflammation of the prostate gland, is swollen asymmetically and typically tender, firm, or possibly enlarged with a boggy feel (if chronically inflamed). In contrast, benign prostatic hypertrophy (BPH) is symmetrical inflammation of the prostate. With carcinoma, either a) small and firm isolated nodules form in the prostate or b) the entire prostate is enlarged and feels hard. Following is a
comparison between the VPES, SWT and SWOT simulators, where a “yes” indicates the respective simulator can present that condition, and a “no” indicates the simulator cannot present that condition. The VPES simulates all four states (Fig. 2): normal (SWT, SWOT, VPES = yes), prostatitis (SWT, SWOT = no, VPES = yes), BPH (SWT = no, SWOT, VPES = yes), and cancer (SWT, SWOT, VPES = yes).

Prostatitis and BPH conditions are simulated through the use of medium (1.75 cm x 2.75 cm) and large (2.75 cm x 3.0 cm) balloons. Cancerous conditions are simulated through the use of four smaller balloons (0.5 cm x 0.5 cm, 0.75 cm x 0.75 cm, 1.0 cm x 1.0 cm, and 1.25 cm x 1.25 cm). While the balloons are deflated, they cannot be detected via palpation. However, once the balloons are inflated with water, they simulate abnormalities that can be detected through palpation. The medium balloon is located under the median sulcus (vertical groove), and when inflated can partially or totally inflame the median sulcus (see Fig. 2). Inflating the medium balloon can also simulate a boggy feeling. The large balloons are located on each side of a disease prostate. When inflated either individually or in tandem, they are able to simulate inflammation of the prostate (asymmetric and symmetric inflammation, respectively). The four smaller balloons are located in various locations within the prostate, and when inflated simulate small, discrete nodules.

B. Multiple, Reconfigurable, and Graded Scenarios

Multiple scenarios are prostate gland configurations of more than one tumor location, stiffness, and size for each cancerous state. Three of the silicone prostates simulate both BPH (SWT = 0, SWOT = 2, VPES = 4) and prostatitis (SWT, SWOT = 0, VPES = 4) (both with and without tumors), while the other three prostates simulate carcinoma conditions (SWT, SWOT = 3, VPES = 96) (single and multi-nodule).

A reconfigurable scenario is where within a single prostate, tumor locations change dynamically. Since the deflated plastic balloons have been embedded in various locations and depths within the prostate, they can be inflated and deflated via custom built electronics (Fig 3) in different combinations to produce the 96 unique cancer scenarios.

In addition to the multiple and reconfigurable scenarios, a graded difficulty of tumor can be presented whereby the simulator can also inflate each balloon to a different stiffness to give a more difficult case to discriminate from surrounding tissue. In addition to the cancer scenarios, the medium and large balloons can be inflated and deflated to simulate different inflammation severity.

Fig. 2. Four states simulated by VPES [20]

Prostatitis and BPH conditions are simulated through the use of medium (1.75 cm x 2.75 cm) and large (2.75 cm x 3.0 cm) balloons. Cancerous conditions are simulated through the use of four smaller balloons (0.5 cm x 0.5 cm, 0.75 cm x 0.75 cm, 1.0 cm x 1.0 cm, and 1.25 cm x 1.25 cm). While the balloons are deflated, they cannot be detected via palpation. However, once the balloons are inflated with water, they simulate abnormalities that can be detected through palpation. The medium balloon is located under the median sulcus (vertical groove), and when inflated can partially or totally inflame the median sulcus (see Fig. 2). Inflating the medium balloon can also simulate a boggy feeling. The large balloons are located on each side of a disease prostate. When inflated, either individually or in tandem, they are able to simulate inflammation of the prostate (asymmetric and symmetric inflammation, respectively). The four smaller balloons are located in various locations within the prostate, and when inflated simulate small, discrete nodules.

B. Multiple, Reconfigurable, and Graded Scenarios

Multiple scenarios are prostate gland configurations of more than one tumor location, stiffness, and size for each cancerous state. Three of the silicone prostates simulate both BPH (SWT = 0, SWOT = 2, VPES = 4) and prostatitis (SWT, SWOT = 0, VPES = 4) (both with and without tumors), while the other three prostates simulate carcinoma conditions (SWT, SWOT = 3, VPES = 96) (single and multi-nodule).

A reconfigurable scenario is where within a single prostate, tumor locations change dynamically. Since the deflated plastic balloons have been embedded in various locations and depths within the prostate, they can be inflated and deflated via custom built electronics (Fig 3) in different combinations to produce the 96 unique cancer scenarios.

In addition to the multiple and reconfigurable scenarios, a graded difficulty of tumor can be presented whereby the simulator can also inflate each balloon to a different stiffness to give a more difficult case to discriminate from surrounding tissue. In addition to the cancer scenarios, the medium and large balloons can be inflated and deflated to simulate different inflammation severity.

Fig. 2. Four states simulated by VPES [20]

Fig. 3. Custom built electronics for balloon inflation

C. Technique and Performance Feedback

Technique feedback informs the user about finger location and applied magnitude of pressure during palpation, for both current and recent past. This data is captured by multiple FlexiForce (Tekscan, South Boston MA, 0-1 lb range) pressure sensors and then is presented on a graphical user interface. Voltage from these sensors is amplified and filtered through a custom designed circuit, then measured and displayed with an A/D converter (NI DAQCARD-6036E, Austin TX) and Labview (Version 8.0). We designed the graphical user interface to visually display immediate feedback of the magnitude of finger pressure exerted: a) via colored tanks that correspond to pressure sensor locations in four regions of the prostate (Fig. 4, “Palpation Pressure by Region”), and b) via continuous pressure plotting in an analog view (Fig. 4, “Magnitude Display”). All information is displayed in real time.

Performance feedback is used both to denote whether or not a user has palpated a tumor and to augment the trainee’s experience with non-natural feedback. First, when a trainee applies finger pressure to a water-filled balloon, the change in water pressure is captured and recorded. This information is used to determine if a trainee has palpated the simulated tumor and/or disease state, and is displayed on the feedback screen (Fig. 4, “Balloon Pressure Display”). This analog display of water-pressure for all inflated balloons indicates the finger pressure a trainee is exerting on an inflated balloon.
Second, as part of our design choice to use balloons that allow water to be pumped into one end, the water pressure in the balloons may be pulsated to provide a form of non-natural augmented feedback via the tactile modality [16]. Training of this sort can help draw a user’s attention to the tumor where they can focus in on specific stimulus dimensions, similar to visual search and detection techniques [21], which can lead to increased tumor detection and decreased false alarms.

**TABLE I**

<table>
<thead>
<tr>
<th>Simulator Features</th>
<th>SWT</th>
<th>SWOT</th>
<th>VPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Elements of Lifelike Anatomy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior section</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rectal Wall</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Accurate Prostate Size/Stiffness</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Entire Range of Disease States</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Reconfigurable</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Graded</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technique</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

IV. SIMULATOR CRITERIA COMPARISON TABLE

Table I shows a comparison table for a training apparatus and its corresponding simulator features (basic elements of lifelike anatomy, multiple and reconfigurable scenarios of graded levels of difficulty, and performance and technique feedback). An “X” indicates the training apparatus has the specified feature.

V. FUTURE WORK

An experiment is currently being designed to validate the VPES’s training capability. We intend to test if skills learned via the Virginia Prostate Examination Simulator improve trainee examination performance, specifically by considering numbers of true positive and false positive detections. We will be testing the simulator’s training effectiveness against the other simulators mentioned in this paper.

ACKNOWLEDGMENTS

This work was supported in part from a grant by the Academy of Distinguished Educators at the University of Virginia, School of Medicine. The authors wish to thank Dr. Dan Theodorescu, Professor of Urology and Molecular Physiology at the University of Virginia for providing valuable feedback on the disease states and subjective test of simulated prostate realism, as well as Mr. Curtis Myzie for his construction of the electronics box, initial graphical user interface and other valuable technical support.

REFERENCES


