Virtual Reality-Based Training for the Diagnosis of Prostate Cancer

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***Abstract*—Prostate malignancies are the second leading cause of cancer deaths among men. The most common method of detecting this disease is digital rectal examination (DRE). Current DRE training is inadequate, since the number of patients that students can practice on is limited. Furthermore, allied care personnel do not train in screening for prostate cancer. Finally, there is no objective way to follow the improvement in DRE skills for medical personnel. This paper presents a virtual reality-based simulator that addresses the above problems. The prototype consists of a PHANToM haptic interface which provides feedback to the trainee's index finger, a motion restricting board, and an SGI workstation, which renders the patient's anatomy. Four types of prostates were modeled—normal, enlarged with no tumor, incipient malignancy (single tumor), and advanced malignancy (tumor cluster). Human factors studies were conducted on both nonmedical students and urology residents in order to quantify the system usefulness. After only five minutes of training, nonmedical students had a 67% correct diagnosis rate of malignant versus nonmalignant cases. This compared with 56% for urology residents in the same trials. Subjective evaluation by the residents pointed out the need to improve the virtual prostate model realism. A control group formed of urology residents performed the same trials on a modified Merck Procar simulator. The control group scored significantly better (96% correct diagnosis of malignancies). We conclude that the virtual prostate palpation simulator, while promising, needs significant improvement in both model realism and haptic interface hardware.**

***Index Terms*— Digital rectal examination (DRE), haptic feedback, human factors, modeling, prostate cancer, training, virtual reality.**

I. INTRODUCTION

PROSTATE malignancies are the second leading cause of cancer death among men, with 25% of patients dying from the disease [1]. It has been estimated that there were 184 500 new cases of prostate cancer diagnosed in the United States in 1998 [5].

Early detection of prostate cancer is key to survival. Disease confined to the prostate has a high rate of cure, however 33% of patients have advanced disease on initial diagnosis [18]. Early detection of prostate cancer is, thus, key to survival. Currently prostate cancer screening methods commonly used are digital rectal examination (DRE), transrectal ultrasound and prostatic specific antigen (PSA). DRE in combination with PSA has been shown to be the most cost efficient screening method for prostate cancer [14], [19].

Many medical schools consider DRE a very important diagnostic tool, due to several factors. First, the technique is simple, inexpensive, and easily used at the primary medical care level. Second, detection of palpable nodules through DRE is a strong indication of cancer (up to 50% of palpable prostate nodules are malignant) [9]. In early years students train on DRE simulators, such as the Merck's "Procar" simulator. These have anatomically accurate rubber models of the prostate which have various beads inserted to simulate malignancies. A plastic cover is used to block the student's view of the phantom during diagnosis, while a rotating plate switches between prostate types.[1] These are simple mechanical systems without computer data gathering of student's actions or diagnosis outcome. An enhanced version of the Merck's mechanical simulator allows interfacing with a graphics workstation and tracking of the trainee's finger motions. This is done by placing a Polhemus three-dimensional (3-D) sensor on the trainee's index finger which measures his fingertip position/orientation up to 120 times/s [21]. The tactile sensation is produced by the mechanical model being palpated, while the computer displays a corresponding virtual finger and prostate model.[2]

Simulator-based training is followed in the senior year by training on patients. Finding patients willing to allow medical students to train on them is, however, difficult. DRE may be uncomfortable for the patient if performed by an inexperienced examiner. Furthermore, the doctor that is training the student (typically an urologist) has no way of evaluating the student's ability to palpate pathology within the rectum, so mistakes cannot be corrected. Rare or interesting cases may not be available for the student at the time he/she is doing the DRE training rounds. Evaluating the improvement of the student's DRE skill is difficult and subjective at best. Furthermore, there are no online error rate measurements, and no database to keep track of the student's learning curve. As a result of the current training inadequacies many general physicians, once graduated from

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[1] Heath Edco, "Prostate training kit," Waco, TX, 1997.

[2] J. Merril, Demonstration at the American Urologic Association Meeting, 1993.

medical schools, are not confident in their ability to perform DRE. Hennigan and colleagues studied the attitudes of medical students regarding digital rectal examination. They found that only 31% of students routinely perform rectal examinations and suggested that the general practitioners' confidence and frequency of performing DRE depend on medical school exposure [10]. This leads to expensive referrals to specialists for prostate evaluation [11].

A possible solution to the above problem is the use of virtual reality simulators to precede patient rounds. This training system could provide the same kind of benefits that flight simulators do [11]. There could be a sufficient number of virtual patients and types of malignant prostates to train on at any time. The student would be able to travel inside the patient's body and see the region of interest (rectum, intestine, prostate). Students training on such a simulator would also feel more comfortable because they are performing the examination on a virtual, rather than a real, patient. Expert DRE examples could easily be provided. As more senses are incorporated into the simulation (such as touch and force feedback), the simulation becomes more realistic [17], [24]. Studies done on similar tasks show up to 30% decrease in instructor time, up to 30% decrease in student time, and up to 30% increase in student outcome [16].

Kaufman, at Dalhousie Medical School (Halifax, N.S., Canada) [13], reported on the concept design of a VR prostate palpation system using a PHANToM haptic interface [15]. This small robotic arm is used to provide forces to the user's index finger in response to interaction with the virtual anatomy of interest. The system is presently under development and a commercial version is planned in collaboration with Digital Image FX (Dartmouth, N.S., Canada). At the time of this writing, however, no data is available on the completion of the system, or any human factor trials to validate its usefulness [7].

Burdea and his colleagues at Rutgers University in collaboration with Robert Wood Johnson Medical School (UMDNJ) (New Brunswick, NJ) independently developed and tested a VR-based training system for prostate palpation [4]. This article reports on the prototype simulator and its human-factor evaluation for usefulness in DRE training. Section II describes the hardware (PHANToM arm) and software system components (OpenGL and GHOST libraries). Section III presents the training approach using four prostate cases (normal, benign enlarged, incipient malignancy, and advanced cluster malignancy). Human factor trials performed on nonmedical students and urology residents from the medical school are described in Section IV. Section V concludes this paper.

II. SIMULATOR COMPONENTS

A. Hardware Components

The key hardware component of the VR simulator is a PHANToM force feedback arm, as illustrated in Fig. 1 [15]. This is a back-drivable manipulator that measures fingertip position and orientation within the work envelope of the wrist. Its gravity compensation and low inertia allow the user to move freely and explore the virtual space, without feeling any unnecessary forces. During prostate palpation training a motion restricting board is placed between the user and the PHANToM. The trainee has to first place his/her index through a hole in the board and then into the haptic interface finger attachment. This setup attempts to replicate the reduction in finger mobility experienced by the physician performing a DRE.

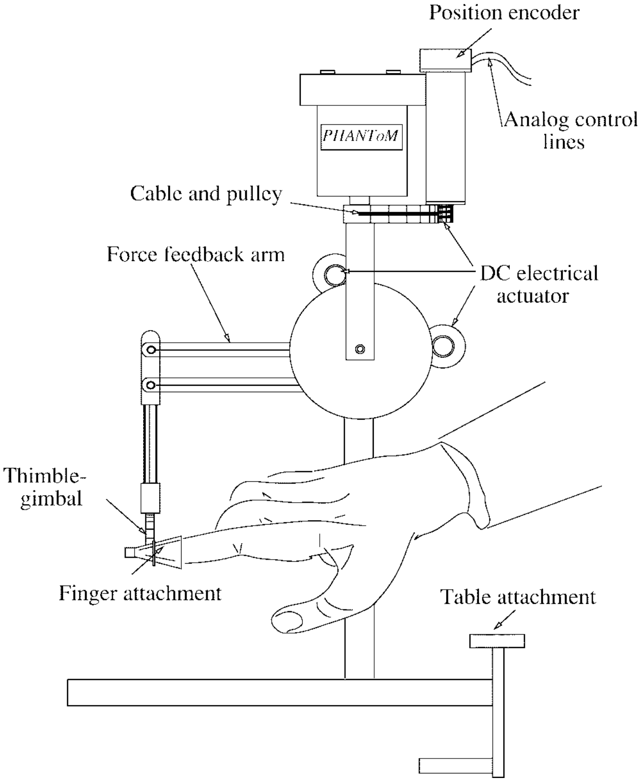

Fig. 1. The PHANToM master—standard configuration (adapted from [15]).©ASME. Reprinted by permission.

The PHANToM model used in our experiments had an interface box that was connected to a host computer (an SGI High-Impact workstation) through an ISA card, as illustrated in Fig. 2 [4]. This interface box held all the electronics necessary to servo control the PHANToM actuators at approximately 1000 Hz. Translational forces were produced by dc actuators within the PHANToM structure and felt by the user when there was interaction between virtual objects. The high dynamic bandwidth of this haptic interface allowed for the accurate physical simulation of surface hardness, rugosity, viscosity, and other similar sensations. A limitation of the current technology, however, was the lack of torques, which limited the complexity of the physical interaction to single-point contacts only [15]. Another limitation of the particular PHANToM available for our experiments was the lack of fingertip orientation data. This resulted in a virtual finger that had a fixed orientation during the palpation experiments. Finally, it is well known that electrical actuators overheat when subject to high torques. The PHANToM was no exception, such that large feedback forces were possible only for short durations.

B. Software Components

There are three software loops that run asynchronously as part of the DRE software environment. The first is the graphics

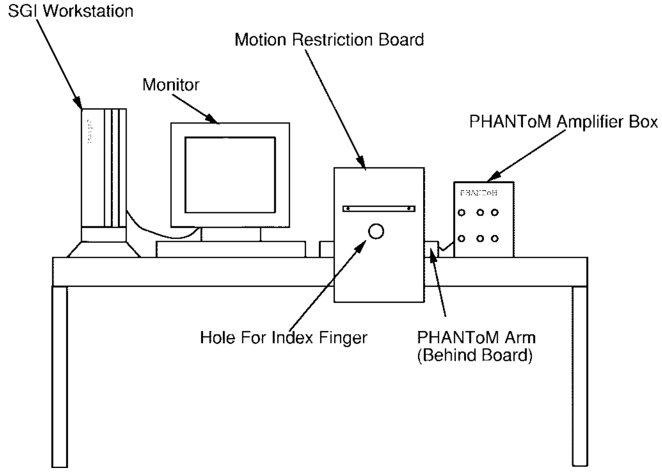

Fig. 2. Simulation hardware setup [4].

loop, which renders organ models in the area of interest on the SGI High-Impact workstation. When simulating human anatomy one has the choice of generic, or patient-specific models obtained from computed tomography or magnetic resonance imaging data. In this proof-of-concept research generic models were used, as they are easily available from various vendors.

A 3-D model was purchased from Viewpoint DataLabs [26] consisting of an anatomically accurate adult male urinary tract and intestines. In order to allow realtime rendering on our SGI medium-range computer the model was subsequently simplified by eliminating the area above the waist and below the knees, as well as the kidneys and the intestine above the rectal region. The model was then shaded using OpenGL graphics libraries [20] and rendered at about 18 frames/s without noticeable latencies. In previous studies it was shown that this frame rate is sufficient for virtual object manipulation tasks [22].

A low-resolution model of a right virtual hand was also purchased from Viewpoint DataLabs. Subsequently it was configured in a fist gesture with the index extended at a fixed angle. This was needed since the PHANToM does not read hand gestures, and only measures the 3-D position of the trainee's index fingertip. This data was mapped to the index of the virtual hand, mimicking the motion of the user's index and haptic interface. Once the trainee's hand enters the rectal region of the virtual patient, and the prostate is in view, only the index finger is rendered, which further reduces the model graphics complexity.

The prostate and its malignancies were modeled by generating the vertices of a hemisphere and then connecting them into four-sided polygons. The prostate surface median groove was created by depressing all the vertices that lie on this longitudinal line. After the polygons have been constructed, the normals to the surfaces and vertices were calculated for graphics and haptics shading. A sample of the simulator graphics for an enlarged prostate is shown in Fig. 3 [4]. The complexity of the model for the prostate was 200 vertices, while each malignancy was constructed with an additional 100 vertices.

The prostate model (but not its malignancies) could be deformed graphically where compressed by the virtual fingertip. This was accomplished by detecting the "collision" between the surface vertex and the vertex of the fingertip. The magnitude of deformation was determined by the distance the finger penetrates the surface, with the surrounding vertices being deformed less, as the distance from the point of collision increased. This gave the illusion that the prostate was graphically compressed by the fingertip.

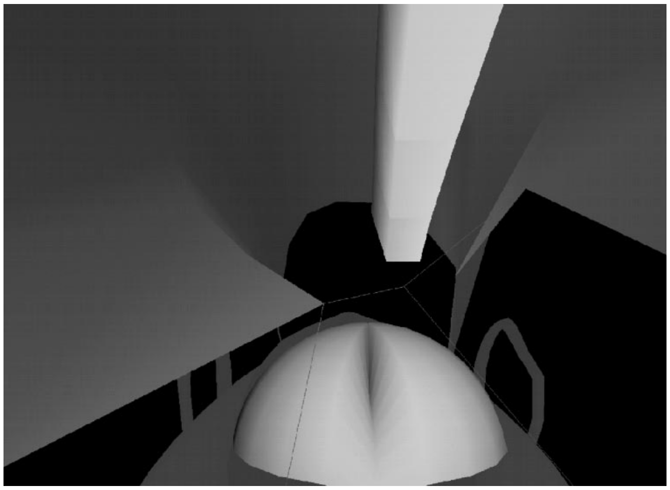

Fig. 3. Interior view of an enlarged benign prostate [4].

Graphics computations were only one part of the workstation load. The other important component of the software environment is the physical modeling, including contact detection and force feedback computation. The graphics and haptic loops run concurrently but asynchronously, as the haptics loop controlling the PHANToM has a much larger bandwidth (about 1000 Hz).

The physical modeling task takes advantage of the GHOST haptic library used to run the PHANToM arm [25]. In developing the prostate palpation simulation, speed had to be weighted against force feedback realism. These two opposing requirements called for optimization of the collision detection process, without which the model complexity would have been only 100 vertices (and not 200–500 vertices as described above).

The optimization takes advantage of the hemispherical shape of the prostate surface. It assumes that when projected onto a plane the prostate top surface has the shadow of concentric circles. This assumption transforms the previous two-dimensional search for collision location into two one-dimensional searches. This results in a reduction of the collision detection computation time by an order of magnitude. As illustrated in Fig. 4 [4], the search first finds the closest concentric circle to the fingertip vertex, then searches for the closest vertex on that circle.

Once the vertices of the polygon the fingertip is in contact with have been determined, the palpation force vector is determined by the following formula:

$$F = k * f(b * d)$$

where k represents the tissue stiffness. This parameter was determined experimentally, based on the subjective evaluation of our urologist coauthor, such that the virtual models felt

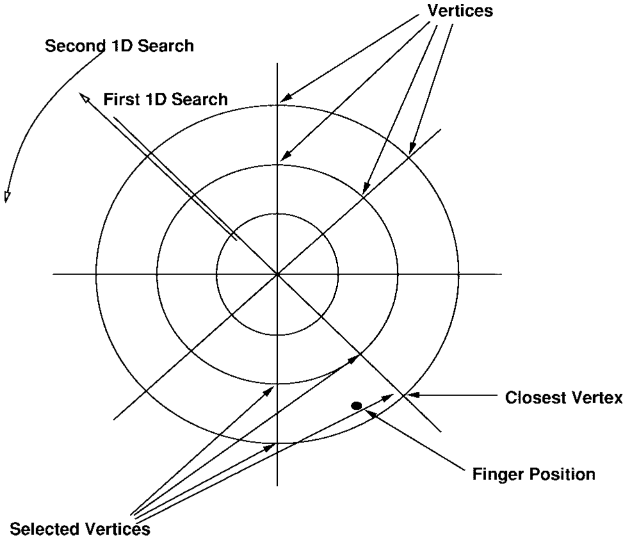

Fig. 4. Vertex search optimization [4].

"real." For example, the malignancies had a k that was 80% larger than that of the stiffness of the surrounding tissue.

In the above formula d is the penetration distance along the normal defined at the surface point

$$d = u\big(\langle(P_{\text{surface pt}} - P_{\text{fingertip}}),\, N_{\text{surface pt}}\rangle\big)$$

and u is the unity step function (forces are applied only when the surface is deformed by the fingertip).

The f function models a nonlinear deformation, instead of the customary Hooke's law ($F = kd$). The simulation uses an arctan function for the deformation model, with the slope of f controlled according to the desired object deformation model. Another useful aspect of the arctan function is that it produces bounded forces, avoiding a premature exit due to GHOST safeguards (overload condition). The normal vector at the point of contact on the surface is determined in a way similar to the Phong shading routine used in computer graphics [8]. In our simulation force shading is implemented by calculating a weighted average of the vertex normals closest to the point of contact. The normal vector obtained from this calculation is used to determine the direction of the force the surface exerts on the finger and it is also used as the projection vector for the calculation of the distance the finger penetrated the surface. The magnitude of the force calculated is subsequently averaged with the last force magnitude to get a smoother transition between subsequent forces. This reduces the effect of mechanical vibrations, or "buzzing," that would result from unsmoothed force transitions.

III. Training Simulation

The simulation can be run in "training mode" and "examination mode." The training mode allows for visual feedback of the patient's anatomy. It starts by showing the male patient bent in the usual DRE position. The trainee then positions the virtual finger on the screen such that it lines up with the rectal area. As the trainee pushes through the anus, the inertia effect produced by GHOST provides the feel of resistance. Once the finger has penetrated the rectum, the inertia effect stops and the graphics switches to an interior view of the patient.

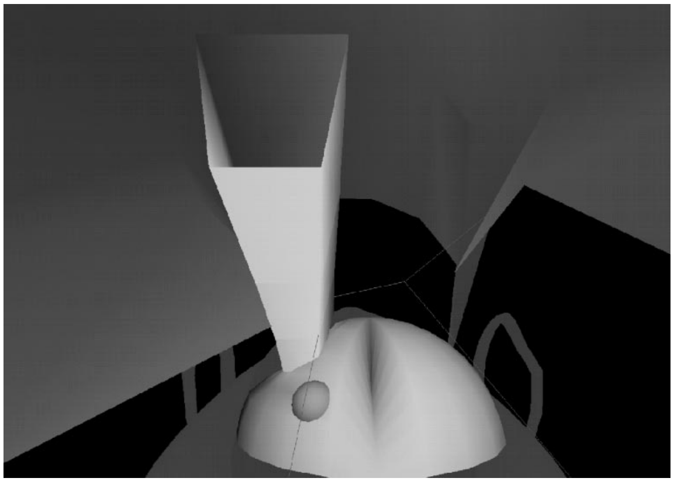

Fig. 5. Interior view of a prostate with a single tumor [4].

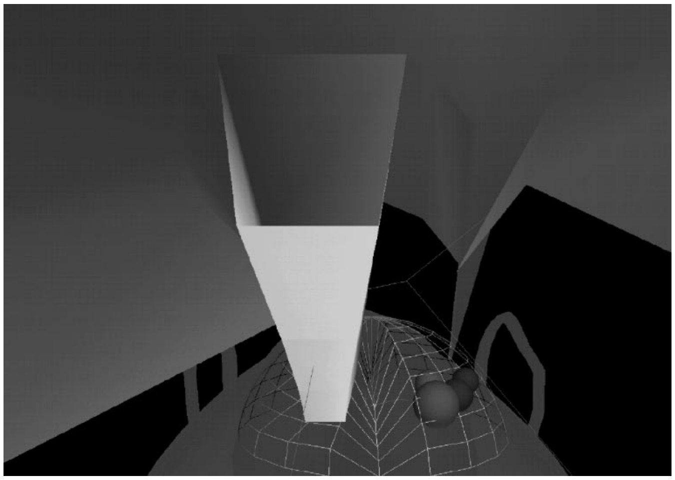

Fig. 6. Interior view of a transparent prostate with an advanced malignant cluster [4].

For training purposes the patient's interior view shows a portion of the rectum rendered in "wire frame" so the trainee can see the intestine wall, the top of the prostate, the bladder, and an index finger. If the trainee pushes the virtual finger against the rectum wall, he feels a small resistance to the motion. When the trainee starts palpating the prostate, the prostate model deforms and forces are fed back by the PHANToM, as described previously. The trainee can feel the median groove which helps orient him hapticly before starting the palpation process.

The simulator can display one of four models that are available for palpation. These are: 1) normal prostate, 2) benign enlarged prostate (prostatic hypertrophy), 3) early single malignant nodule (illustrated in Fig. 5), and 4) late invasive cluster tumors (illustrated in Fig. 6). The tumor locations are in turn randomized to four lobes of the prostate top surface, which results in 12 cases of virtual patients to train on. More could be created, such as rare cases, or patient-specific cases, but this was beyond the scope of the current research.

The trainee has the option of seeing through the prostate surface by turning the model to wire frame rendering (see Fig. 6). This forms a mental mapping of the anatomy/pathology with the haptic feedback the trainee receives when palpating the area of interest. After the trainee feels confident with the current case (model being palpated), he can switch to another case with a simple keystroke.

Once the trainee has palpated each type of 12 prostate cases, the simulation is switched to the "examination mode." During this mode the trainee has to diagnose each case presented without seeing the prostate on the screen, similar to real DRE's. The screen displays only a red sphere during "rest" and a green sphere during "palpate" periods. In examination mode, all cases are randomized by prostate type and by tumor location. The trainee inputs his diagnosis by pressing a key that corresponds to the prostate type being examined. The response time for diagnosis, as well as diagnosis errors, are recorded transparently for each trainee's response.

During the examination each of the four different prostate types are presented three times in random order. After the trainee gives his diagnosis, the trainee has a five-second break until the next case is presented. The trainee gets a three-minute break after every four cases presented. Once the examination is completed, the results can be viewed by reading a text file which lists what was recorded during the test. The trainee's actions can also be recorded for play-back at a later time. This file records the trajectory traced by the virtual finger during examination and the case presented at that time. This graphics playback provides a way to analyze the trainee's palpation technique, and what can be done to improve and correct any errors. The same software can be used to record and play back expert examinations to show the trainee exactly how DRE's should be done. To play-back a recorded file, the simulation simply changes the source of its input from the PHANToM to the data file.

IV. HUMAN FACTOR STUDIES

The VR-based DRE training system has some clear advantages over current training methods, however, it is essential to quantify its usefulness as a learning environment for medical students. This required human factors studies to quantify objective variables such as the trainee's learning curve over repeated cases. Other variables that were important to be measured include the diagnosis accuracy, the time taken to diagnose each case, and the case that proved hardest to diagnose. In order to measure these variables we performed a series of three studies. These studies involved two experimental groups and a control group.

A. Experimental Protocol

The first study used 22 nonmedical students as subjects, 16 male, and six female. All subjects were volunteers, and were not compensated for participation in the project. Each subject was given an overview of how to palpate the prostate correctly using rubber models of the prostate. These models are manufactured by Health Edco (Waco, TX) and differ from the models normally used by the Merck's Procar simulator. They were told to first identify the median groove and evaluate the size of the prostate. The subjects were then told to scan the prostate surface in small increments looking for nodules that signify tumors. Subsequently, each subject had five minutes of training using the PHANToM arm without the motion restriction board. During this time the wire-frame model of the prostate was made visible on the screen. Subjects were reminded of the correct way of palpating a prostate and presented with all four prostate types (normal, enlarged, single malignancy, and cluster malignancy) at least twice. During training, subjects were allowed to concentrate on the cases they felt were difficult.

Once the five-minute training period ended, the simulation would blank the screen and display a red sphere signifying the initiation of the test. From this point on, subjects were not instructed on palpation technique, as the simulation was in the "examination mode." Each subject was presented with 12 random cases with a three-minute break between every four cases. They were not given feedback on their performance until after the experiment was finished. The data recorded for each subject was the length of time to make a diagnosis (seconds), the diagnosis the subject chose, and the correct diagnosis for that case. No subjective assessment was done by the subjects in the first experimental group.

Subsequently, a second experimental group was selected from the urology residents at Robert Wood Johnson Medical School. These subjects were also volunteers, so they were not compensated for participation in the project. Due to the constraints of medical practice the second group was much smaller, consisting of only four subjects. Furthermore these subjects were in a high stress/high fatigue state, having just completed 24-h rounds in the hospital emergency room.

The protocol used on the second group was similar to that used on the first group, namely the same objective variables were measured and stored for analysis. The one exception, however, was that the residents had to use the motion restricting board, which made the test harder, but somewhat more realistic. Additionally, these subjects were asked to subjectively assess the simulator, based on their prior knowledge of how real normal and malignant prostates feel during DRE.

The third (and last) subject group acted as a control. Subjects in this group were other volunteer urology residents from the R. W. Johnson Medical School. The protocol in their case involved palpation of rubber models as part of a Procar simulator. The Procar was modified by adding the same motion restriction board that was used with the PHANToM arm, however, the prostates were now rubber models, rather than virtual ones. The examination time, rest periods, and case randomization were the same as in the previous two experiments. Timing was measured with a stopwatch and responses given orally (as opposed to using a keyboard as the two previous groups did).

B. Experimental Results

Table I compares the overall diagnosis accuracy of the subjects in our study. The nonmedical students had con-

TABLE I
CORRECT DIAGNOSIS RATES (ADAPTED FROM [4])

Subject category	Exact Diagnosis (four cases)	Benign/Malignant Diagnosis
Nonmedical Students	46%	67%
Urology Residents	33%	56%
Control Group	92%	96%

sistently better diagnosis accuracy than medical residents (46% correct versus 33% correct) when using the PHANToM simulator. This may be explained by the use of the motion restriction board by the residents, which increased the task difficulty. Another factor that impacted the performance of the second group was fatigue when taking the test. A similar trend was observed when comparing the subject's ability to distinguish the malignant cases (incipient or advanced) from nonmalignant cases (normal or enlarged prostates). Here, again the performance of the first group was better (67% correct versus 56% correct). The control group using the Procar did significantly better than both groups with exact diagnostic rates at 92% and detection of malignancies at 96%. This may be explained in part by the richer tactile information provided by the rubber models, compared to the simplified virtual models used in the trials. Furthermore, the task for the control group was easier since the location of the malignancy was not randomized. There was only one incipient and one advanced malignant rubber models in the Procar, versus four each in the PHANToM simulator.

Table II details the subjects' diagnosis accuracy as a function of individual case type (benign, enlarged, single tumor, and cluster of tumors). The nonmedical students were most accurate in detecting single tumors (58% correct diagnosis), and had the worst performance when detecting a cluster of tumors (34% correct diagnosis). The urology residents in the second group of subjects were similarly most accurate in detecting single tumors (50% correct diagnosis), with their worst performance when diagnosing benign prostates (25% accurate). This poor performance may be explained by the residents' subjective evaluation. Here, they complained that the normal prostate model did not feel sufficiently realistic, based on their prior mental model, and the median groove was not sufficiently delineated. The control group had 100% accuracy for normal prostates. Their subjective evaluation indicated that the median groove in the EDCO rubber models was too delineated, making it too easy to find. Similarly, results show a much larger correct diagnosis rate for the control group in the other three cases (benign enlarged, incipient, and advanced malignancies). The correct diagnosis rates were in this case 92%, 92%, and 83%, respectively.

The above experimental results gave a measure of confidence in the simulator ability to model various prostate cases, even though the sample population was small. If the haptic models were poor, then all percentages in Table II would have been 25%, meaning chance probability. Another important variable is the learning curve, namely the increase in diagnosis accuracy over repeating trials of the same case. As illustrated in Fig. 7 [4], both experimental groups using the PHANToM simulator learned during the trials. However, the nonmedical students had a steeper learning curve between the first and second trials, as they had no prior knowledge or experience with DRE's. The learning curve of the subjects in the second group was different, with the steepest slope between the second and third trials. The residents had to first adapt to the simulator, and its limited realism. Once they learned the simulator, they improved performance in the third trial. There was no learning for the control group, a clear indication that the task was too easy for them. These controls all had prior experience with the Procar, the models did not have the same randomization as the PHANToM simulator had, and the rubber models provided more tactile realism.

Fig. 7 also shows the variation in the standard deviation in the correct diagnosis percentage over repeated trials. There was a small reduction in the standard deviation of nonmedical students' responses, which meant that as subjects learned, they behaved more uniformly as a group. A similar, but more dramatic, trend was displayed by urology residents in the second group. These subjects had a very large standard deviation of the correct diagnosis percentage in their first trial. This large variability may be attributed in part to the lack of sufficient realism of the virtual prostate cases, because of the limited computing power of the workstation used for testing. The large variability may also have been due in part to fatigue, as discussed previously. Subjects in the control group have better uniformity of response (smaller standard deviation) than either of the experimental groups. Again, this is an indication of a familiarity with the task.

Table III shows the overall time taken by each subject group to diagnose individual cases. The nonmedical students were consistently slower to diagnose than the residents, which is in no doubt a result of prior experience. Students took longest to diagnose enlarged prostates (60 s) and the least amount of time to detect single tumors (48 s). The residents had similarly the shortest time overall in detecting incipient tumors (39 s). Their difficulty was in diagnosing normal prostates (53 s), again due to the model geometry which was not what they had expected. The control group was three to five times faster than the residents in the second group. They took the least amount of time to detect a normal prostate (9 s) and the most time to diagnose advanced malignancies (16 s on average).

Residents which were subjects in the second and third groups were asked subjective questions as to the usefulness and realism of the simulation, as well as perceived problems or difficulties they may have had. The second group responses were optimistic in terms of eventual usefulness of the PHANToM system as a teaching aid, provided more realism in the modeling was achieved. One resident had shorter fingers which prevented him from fully palpating the prostate, which we suspect may have happened also in actual DRE's. Subjects in the third (control) group were asked to subjectively rate the realism of the rubber models they palpated, as well as the task difficulty when using the modified Procar with the added motion restriction board. They felt that the model for the normal prostate was too soft and too delineated. Furthermore, they rated the board as too restrictive in terms of finger motion when compared to the anal orifice.

TABLE II
Correct Diagnosis of Individual Prostate Cases (Adapted from [4])

Subject category	Benign normal size	Benign Enlarged	Malignant (incipient)	Malignant (advanced)
Nonmedical Students	48%	43%	58%	35%
Urology Residents	25%	25%	50%	33%
Control Group	100%	92%	92%	83%

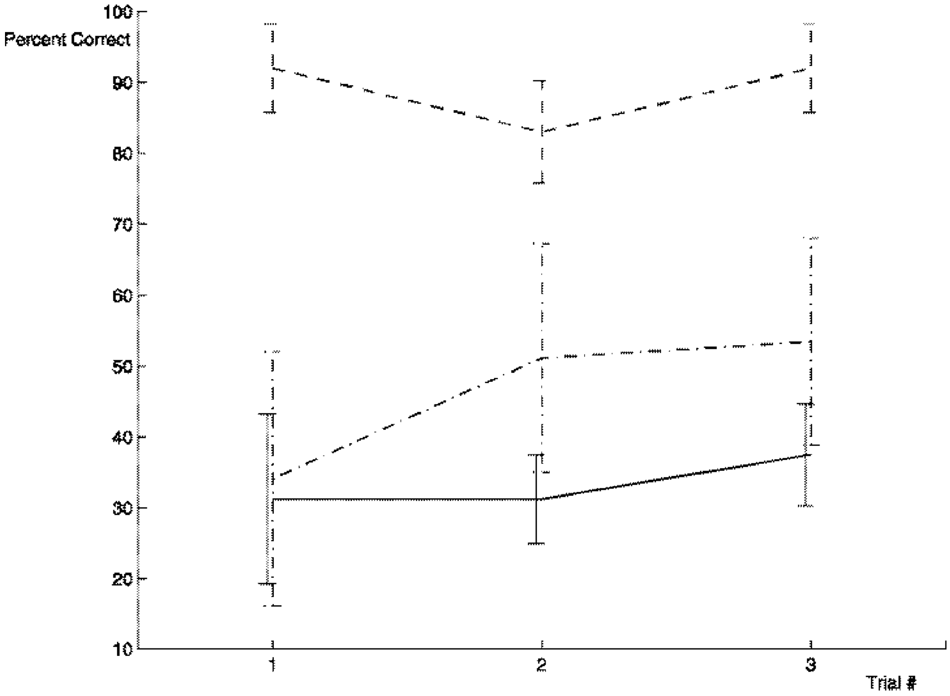

Fig. 7. Subjects' learning curves: — · — · — nonmedical students; — urology residents; and - - - control group (adapted from [4]).

TABLE III
Average Time to Diagnose for All Cases (Adapted from [4])

Subject category	Benign normal size	Benign Enlarged	Malignant (incipient)	Malignant (advanced)
Nonmedical Students	55 s	60 s	48 s	54 s
Urology Residents	53 s	45 s	39 s	48 s
Control Group	9 s	10 s	13 s	16 s

V. CONCLUSIONS AND FUTURE WORK

The present research was aimed to determine if VR-based simulators are useful as a means of improving training in prostate palpation through DRE. The prototype differs from current teaching methods since it uses virtual as opposed to mechanical (rubber) phantoms of the prostate in various disease stages. Diagnosis on 12 virtual patients was done using a PHANToM haptic interface providing realtime force feedback to the trainee's index finger. Initial human factors tests were performed on both nonmedical students and urology residents. Both groups were able to palpate and correctly diagnose the virtual cases presented to them, with accuracy rates above chance levels. Learning was evident in both groups over repeated trials. Both groups, however, scored less than the control group which palpated rubber models in a Procar. The rubber models were more realistic than the simplified virtual ones, and the tactile sensation richer than that provided by the PHANToM simulator.

The experimental results are encouraging with regard to the feasibility of a VR-based DRE simulator. At the same time it became clear that improvements are needed in both simulator hardware and software. Future research should develop a wider variety of more realistic virtual prostate models, based on real patient data. Improvements in the haptic interface are needed to be able to measure the index orientation and possibly add torques to the present translational-only force feedback. Funding is needed to perform a long-range study of the efficacy of the simulator in an actual teaching curriculum. Diagnosis accuracy (and time to diagnose) should continue to be the objective variables to be measured. However, the subjects should be only medical students, some doing training on Procars and some on the new simulator. The true measure of success will be the overall accuracy levels obtained once both groups palpate real patients.

A promising device—the Mechanical Imaging probe—is being developed by Artann Laboratories (New Brunswick, NJ) in collaboration with physicians at Robert Wood Johnson Medical Center. The probe has microsensors on its tip which record stress and strain patterns over the prostate surface. It creates a 3-D computer image which correlates with DRE. This device will give an objective, reproducible image which will increase the realism of the haptic simulation [6].

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REFERENCES

[1] C. Bohring and T. Squires, "Cancer statistics," *CA Cancer J. Clin.,* vol. 43, pp. 7–26, 1993.

[2] G. Burdea, *Force and Touch Feedback for Virtual Reality.* New York: Wiley, 1996.

[3] G. Burdea and P. Coiffet, *Virtual Reality Technology.* New York: Wiley, Inc., 1994.

[4] G. Burdea, G. Patounakis, V. Popescu, and R. Weiss, "Virtual reality training for the diagnosis of prostate cancer," in *Proc. IEEE Int. Symp. Virtual Reality and Applications (VRAIS'98),* Atlanta, GA, Mar. 1998, pp. 190–197.

[5] *CA Cancer J. Clin.,* vol. 48, p. 10, 1998.

[6] R. E. Weiss, A. P. Sarvazyan, P. Niemczyk, W. S. Ward, and K. B. Cummings, "Mechanical imaging: A novel device for prostate imaging," *Surgical Forum,* vol. XLIX, pp. 684–685, 1998.

[7] Digital Image Co., "Virtual reality prostate exam," Canada, 1997. [On–line]. Available: http://209.29.38.6/vr/vr-prostate.html.

[8] J. Foley, A. van Dam, S. Feiner, and J. Hughes, *Computer Graphics: Principles and Practice,* 2nd ed. Reading, MA: Addison-Wesley, 1990.

[9] L. Gomella and J. Stephanelli, "Malignancies of the prostate," *Practical Oncol.,* pp. 325, 1993.

[10] T. Hennigan, J. Franks, D. Hocken, and T. Allen-Mersh, "Rectal examination in general practice," *Br. Med. J.,* vol. 30, no. 1, pp. 478–480, 1990.

[11] G. Higgins, G. Merrill, L. Hettinger, C. Kaufmann, H. Champion, and R. Satava, "New simulation technologies for surgical training and certification: Current status and future projections," *Presence-Teleoperators Virtual Environ.,* vol. 6, no. 2, pp. 160–172, Apr. 1997.

[12] D. Irby, F. Lippert, and D. Schand, "Psychomotor skills for the general professional education of the physician," *Teaching Learning Med.,* vol. 3, pp. 2–5, 1991.

[13] D. Kaufman and W. Bell, "Teaching and assessing clinical skills using virtual reality," *Studies in Health Technol. Informatics: Med. Meets Virtual Reality,* vol. 39, pp. 467–472, 1997.

[14] P. Littrup, A. Goodman, and C. Mettlin, "The benefit and cost of prostatic cancer early detection," *CA Cancer J. Clinicians,* vol. 43, pp. 134–149, 1993.

[15] T. Massie and J. Salisbury, "The PHANToM haptic interface: A device for probing virtual objects," in *Proc. ASME Winter Annu. Meeting Symp. Haptic Interfaces for Virtual Environment and Teleoperator Systems,* NY, 1994, vol. DSC-55-1, pp. 295–300.

[16] K. McGovern and R. Johnston, "The role of computer-based simulation for training surgeons," *Studies in Health Technology and Informatics: Medicine Meets Virtual Reality: Health Care in the Information Age,* vol. 29, pp. 342–345, 1996.

[17] G. Merril, R. Raju, and J. Merril, "Changing the focus of surgical training," *VR World,* pp. 56–61, Mar./Apr. 1995.

[18] C. Mettlin, G. Jones, and G. Murphy, "Trends in prostate care in the United States, 1974–1990: Observations from the Patient Care Evaluation Studies of the American College of Surgeons Commission on cancer," *CA Cancer J. Clin.,* vol. 43, pp. 83–91, 1993.

[19] C. Mettlin, G. Jones, H. Averette, S. Gusberg, and G. Murphy, "Defining and updating the American Cancer Society guidelines for the cancer-related check-up: Prostate and endometrial cancers," *CA Cancer J. Clin.,* vol. 43, pp. 42–46, 1993.

[20] *OpenGL Programming Guide: The Official Guide to Learning OpenGL, Release 1.* Reading, MA: Addison-Wesley, 1996.

[21] Polhemus Navigation Sciences Division, *Fastrack User's Manual.* Colchester, VT: McDonnell Douglas Electronics Co., 1992.

[22] P. Richard, G. Birebent, P. Coiffet, G. Burdea, D. Gomez, and N. Langrana, "Effect of frame rate and force feedback on virtual object manipulation," *Presence,* vol. 5, no. 1, pp. 95–108, 1996.

[23] R. Satava, "Medicine 2001: The king is dead," *Studies in Health Technol. Informatics: Interactive Technology and the New Paradigm for Healthcare,* vol. 18, pp. 334–339, 1995.

[24] R. Satava and S. Jones, "Virtual environments for medical training and education," *Presence,* vol. 6, no. 2, pp. 139–146, 1997.

[25] *GHOST User's Manual,* SensAble Technologies, Cambridge MA, 1997.

[26] Viewpoint DataLabs International, *Viewpoint Catalog,* 3rd ed., Orem, UT, 1994.

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