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Efficacy of Prostate Stabilizing Techniques during Brachytherapy Procedure

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Abstract—**During the prostate brachytherapy procedure, multiple needles are inserted into the prostate and radioactive seeds are deposited. Stabilizing needles are first inserted to provide some rigidity and support to the prostate, ideally this will provide better seed placement and an overall improved treatment. However, there is much speculation regarding the effectiveness of using regular brachytherapy needles as stabilizers. In this study, we explored the efficacy of (1) two types of needles – 18 gauge brachytherapy needle vs. 18 gauge hooked needle; and (2) parallel vs. angulated needle configurations to stabilize the prostate. Prostate phantom movement and needle insertion progression were imaged using ultrasound (US). The recorded images were analyzed and prostate displacement was computed from images using implanted artifacts. Experimentation allowed us to further understand the mechanics behind prostate stabilization. We observed superior stabilization by the hooked needles compared to the regular brachytherapy needles (more than 40% for parallel stabilization). Prostate movement was also reduced significantly when regular brachytherapy needles were in an angulated configuration as compared to the parallel configuration (approximately 40%). When the hooked needles were angled for stabilization, further improvement in decreased displacement was observed. In general, for convenience of dosimetric planning, all needles are desired to be in parallel and in this case, hooked needles are better suited to improve stabilization of the prostate. On the other hand, both regular and hooked needles appear to be equally effective in reducing prostate movement when they are in angulated configurations, which will be useful in robotic permanent seed implantation (PSI).**

I. INTRODUCTION

One of the most effective methods of treating the early stages of prostate cancer is by implanting radioactive seeds (d=0.8mm) such as Iodine 125 and Palladium 103 using 17G (1.47mm) or 18G (1.27mm) brachytherapy needles. The seed placement is pre-planned and specific for each patient. However, due to the non-rigid and heterogeneous properties of tissues, the prostate moves significantly (sometimes more than 2cm) [1] during the procedure. It is critical that this movement be minimized if not negated in order to deposit the seeds at their planned coordinates. The inability to do so typically causes an insufficient dose distribution within the prostate, resulting in an under-dosing of the desired treatment volume and a potential over-dosing of the surrounding healthy and/or critical organs.

Research has been conducted [2] to determine the causes of seed misplacement, some of which include; inability to accurately position the needle, motion and rotation of the prostate, edema, bleeding and seed migration after implantation. Methods have therefore been explored [3] to improve the efficacy of the brachytherapy procedure. Techniques have been devised to minimize movement and rotation of the prostate during implantation. Feygelman *et al* [4] discovered that by using three rather than two stabilizing needles to secure the prostate, the quality of treatment improved. By initially inserting stabilizing needles that would remain throughout the procedure, displacement and axial motion of the prostate were minimized, providing a more controlled environment for precise seed placement and prescribed dose distribution. Taschereau *et al* [5] conducted experiments to determine whether parallel stabilization helps to reduce seed misplacement and concluded that there is no evidence to support this theory. Dattoli *et al* [6] considered the possibility of crossing the stabilizing needles within a human prostate during surgery. They observed an 80% decrease in lateral motion compared to the clinically observed 1cm of prostate displacement. In addition, negligible craniocaudal motion was seen.

In this paper, we have investigated the effectiveness of parallel compared to angled stabilization techniques using two different types needles; 18G diamond tip (DT) brachytherapy needles (regular needles) and needles that possess a retractable hook (Fig. 2).

II. MATERIALS

In this experiment, a phantom box (22.5x22x12.5cm^3) seen in Fig. 1 was used to house and stabilize the prostate. In order to create the true prostate environment, our phantom consisted of 3 distinct regions of varying concentrations of Polyvinylchloride (a super soft plastic, also known as PVC, MF Manufacturer, TX) representing the perineum, prostate and surrounding fascia tissues. The concentrations of these

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layers were based on prior experimentation with PVC in an attempt to obtain the force and displacement seen in the OR during brachytherapy procedures [7]. The perineum was prepared by mixing 30% hardener with 70% plasticizer and has a thickness of 2cm; the prostate consisted of 20% hardener and 80% plasticizer with a diameter of 5.5cm and the fascia tissue surrounds the prostate and consists of 40% softener and 60% plasticizer.

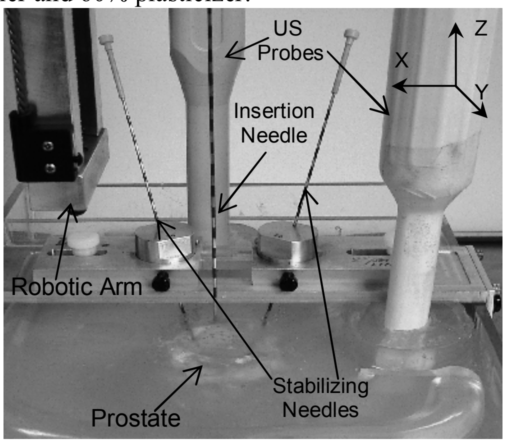

Fig. 1. Experimental phantom setup

Two types of 18-gauge needles were used to stabilize the prostate; an 18G regular diamond tip needle seen in Fig. 2a (Mick Radio-Nuclear Instruments, Inc., NY) and an 18G needle with a retractable hook seen in Fig 2b&c (Medical Device Technologies, Inc., FL).

We have designed and fabricated a 6 degree-of-freedom (DOF) robotic system for *in vitro* needle insertion experiments. All motions of the robot are actuated by stepper motors. Two linear optical encoders that allow for 10 micrometer resolution are mounted on the x and y-axes. The insertion of the needle into the prostate is monitored by a z-axis rotary optical encoder with 5 micrometer resolution.

A supporting structure was also fabricated to guide and secure the stabilization needles, as the template does in the operating room (OR) as seen in figure 1. It is fabricated from aluminum and contains interchangeable needle guides to provide stabilization in any reasonable vertical or horizontal plane.

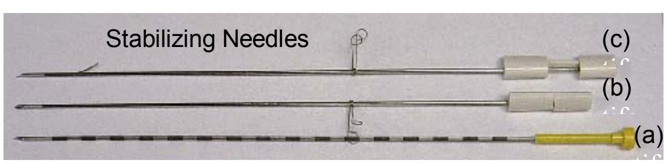

Fig. 2. (a) Diamond tip needle, (b) Needle with hook retracted and (c) Needle with hook extended

III. Procedure

In this study we considered the effects of different stabilization techniques on the movement of a prostate phantom when a 17-gauge diamond tip brachytherapy needle is inserted at 20mm/s. Insertions were conducted vertically to avoid initial displacement of the needle due to cantilever load. The phantom is initially positioned so that the tip of the needle is at the center of the prostate. The stabilizing needles (both regular and hooked) are then inserted into the prostate 1.75cm off-center to a depth of 5cm (length of the prostate). The first of 5 insertions starts at the center of the prostate, with the remaining 4 insertions occurring one centimeter in 4 adjacent positions (see Fig. 3a).

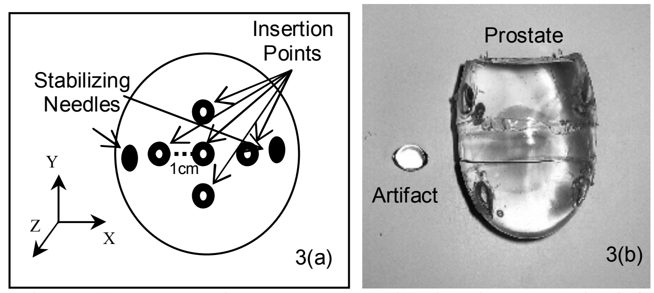

Fig. 3. (a) Prostate phantom set-up, 3(b) vitamin E capsule (left) and prostate with capsules embedded (right).

Once the 5 insertions were completed, the stabilizing needles were extracted; the prostate was removed from the phantom bed and replaced by a new prostate phantom. The stabilizing needles were then inserted into the new prostate and 5 more insertions were performed. Three prostates were used for each method of stabilization, providing us with a total of 15 insertions for displacement analysis.

In addition to experimenting with two different types of needles, we evaluated two stabilizing configurations as well; parallel and angulated ("no stabilization" was not measured due to the excessive motion of the prostate phantom and inability to visualize the artifacts throughout the entire insertion due to the limited range of the US probes). In order to capture the prostate movement we used two US machines; a LOGIQ 9 (General Motors, model #2404587, Wisconsin, IL) and an Acuson (128xP, Mountain View, CA) along with two probes placed orthogonally adjacent to one another. This arrangement provided us with appropriate angles to view prostate rotation and displacement in all axis of motion. Motion along the x-axis was captured by one US while motion on the y-axis was obtained by the second US machine. Z-axis motion was acquired from both ultrasound machines and all images were captured in sagittal view.

In order to accurately determine the extent of the prostate motion, vitamin E capsules seen in Fig. 3b were placed along the outer region of the prostate where they were sure not to obstruct needle insertion. These capsules were differentiated from the rest of the prostate as white spots on the US machines. Video was taken from both US machines during each insertion and with the assistance of an image processing algorithm developed by us; we computed the displacement of the visible artifacts within the phantom. The displacement is obtained by subtracting the end positions from the initial start positions of the implanted artifacts (seen as white spots on ultrasound) shown in Fig. 4.

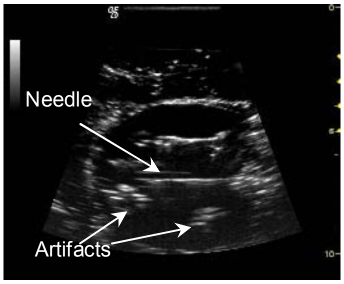

Fig. 4. Ultrasound Image of Prostate Phantom with Artifacts

IV. RESULTS & DISCUSSION

A. Experiment #1: 18G DT and Hooked Parallel Stabilization

The average displacement measurements of both stabilization methods during the insertion of the 17 gauge needle are presented in Table I. Here we have compared the x,y,z motion of a prostate phantom when stabilized by an 18G DT regular needle and an 18G hooked needle both inserted bilaterally.

TABLE I: PARALLEL STABILIZATION OF PROSTATE PHANTOM

Parallel Stabilization 0^oV&0^oH		Displacement (mm)
Z-Axis:	18G DT	11.4
	18G Hook	6.3
X-Axis:	18G DT	1.1
	18G Hook	0.7
Y-Axis:	18G DT	0.9
	18G Hook	1.4
Resultant Motion:		
18G DT		11.5
18G Hook		6.5
Improvement over Parallel DT		43.5 %

When comparing the ability of the hooked needle as opposed to the DT needle to stabilize the prostate, a significant decrease in z-motion (parallel to the stabilizing needles) was observed. This can most likely be attributed to the retractable hook and its ability to provide a more rigid and secure hold on the prostate. The x-motion was obtained during insertions near the 2 stabilizing needles. Here, we observe about 36% improved stabilization, also a result of the hook securing the prostate in place and preventing movement. Although we would expect the same improved stabilization to occur for the motion in the y-direction, our data indicates otherwise. Here we see an increase of about 0.5mm in motion when using the hooked needle for stabilization. This is most likely a side-effect of the significant stabilization along the z-axis, forcing the prostate to convert its desired z-axis motion into y-movement. In addition, more motion is expected along the y-axis as opposed to the x-axis due to the absence of stabilizing needles near the insertion path. However, when compared to the significant decrease in resultant motion where we observed about 43.5% reduction in overall displacement, allowing only 6.5mm of motion rather than 11.5mm. Thus, motion in y-direction becomes negligible. Also the seed diameter is 62.5% larger than the observed lateral movement, providing minimal deviation from the desired seed coordinates. It appears that the hooked needles are significantly more effective in stabilizing the prostate, providing an improved environment for accurate needle and seed placement.

B. Experiment #2: 18G DT and Hooked Angled Stabilization

In this set of experiments, the same analysis was conducted using 18G DT and 18G hooked needles to stabilize the prostate. However, the method of stabilization differed in that the needles were inserted at specified angles. In this case, the angles used were 20^o in the vertical plane (x-axis) and 30^o in the horizontal plane (y-axis), note that the stabilizing needles did not cross each other within the phantom. It was hypothesized that the presence of angled stabilization needles would improve stabilization of the prostate. This hypothesis is based on the fact that if the orientation of the stabilizing needles transverses the inserted needle, then the physical properties of the needle will play a significant role and thus improve stabilization. Table II presents the prostate displacement measurement for angulated stabilization.

TABLE II: ANGLED STABILIZATION OF PROSTATE PHANTOM

Angled Stabilization 20^oV&30^oH		Displacement (mm)
Z-Axis	18G DT	6.8
	18G Hook	5.8
X-Axis:	18G DT	1.6
	18G Hook	1.0
Y-Axis	18G DT	2.3
	18G Hook	2.4
Resultant Motion		
18G DT		7.4
Improvement over Parallel DT		35.5%
18G Hook		6.3
Improvement over Parallel DT		44.8%

The hooked needle provided a better-quality of stabilization by limiting the overall prostate motion to 6.3mm (about 44.8%). Additionally, stabilization with a regular diamond tip needle restricted prostate motion to 7.4mm, providing a 35.5% improvement over the parallel stabilization method. It would appear that by minimizing z-axis motion we have in turn increased the lateral motion in both the x and y axes. This again is a direct result of the distribution of force/energy exerted on the prostate by the inserted needle. Normally the force would be converted to z-motion (movement with less resistant force); however with a more rigid support dampening movement in the z-direction, the prostate has no choice but to convert the energy into lateral motion. Nevertheless, this motion is insignificant in comparison to the tremendous reduction in z-displacement and ultimately the overall prostate motion. Additionally, the planning for the permanent seed implantation process is based on a three dimensional prostate, further emphasizing the importance of decreasing the resultant motion. The observed advantage in using the angulated stabilization technique confirms the hypothesis that needle orientation and similarly needle properties can play a significant role in restricting prostate motion and improving needle placement accuracy.

C. Experiment #3: Further Analysis of Angled Stabilization

Another experiment was conducted to corroborate the data collected in experiment 2. Table III contains the prostate displacement measurements collected while stabilizing the prostate at 30^o in the vertical plane and 30^o in the horizontal plane.

TABLE III: ANGLED STABILIZATION OF PROSTATE PHANTOM

Angled Stabilization 30^oV&30^oH	Displacement (mm)
Z-Axis: 18G DT	5.3
18G Hook	4.5
X-Axis: 18G DT	1.7
18G Hook	2.0
Y-Axis: 18G DT	2.6
18G Hook	2.8
Resultant Motion:	
18G DT	6.1
Improvement over Parallel DT	47%
18G Hook	5.7
Improvement over Parallel DT	51%

The experimental results above support the conclusions stated in experiment 2, confirming that angled stabilization does minimize overall prostate motion while inducing relatively insignificant lateral motion. When using a diamond tip stabilization needle, prostate movement is held to 6.1mm, a 47% improvement over DT parallel stabilization and a 17.5% improvement over DT angled stabilization (20^oV30^oH). The hooked needle offered the best means of stabilization by limiting prostate motion to 5.5mm, a 51% improvement over DT parallel stabilization as well as a 14.5% improvement over a lesser angulated stabilization (20^oV30^oH). Thus, it appears that the resultant motion of the prostate can be minimized by angling the stabilizing needles. However, more studies are required to find the optimal angle considering clinical scenarios

V. CONCLUSION

We have investigated the effects of conventional versus unconventional stabilization techniques in phantom. Both 18G regular needles and 18G hooked needles were used to stabilize the PVC prostate phantom during insertion of a 17G DT brachytherapy needle. From the experimental results, we observed significant decreases in prostate motion for all cases when compared to the conventional method of using an 18 gauge regular diamond tip brachytherapy needle in parallel configuration. In experiment 1, we saw the importance and significance of the retractable hook in providing a more rigid stabilization. It is crucial to maintain the original prostate positioning throughout the procedure in order to ensure the precise delivery of the radioactive seeds.

In experiments 2 and 3, we saw that as the angle of stabilization increases there was a related decrease in prostate motion. Additionally, with the stabilizing needles at an angle, they will not hinder the surgeon's insertion of the implant needles. By increasing the angle of stabilization, the needle properties tend to play a more significant role offering more support to the prostate. This is due to the prominent prostate motion occurring in the z-direction. When the stabilizers are in parallel, they do not obstruct z-displacement since insertion is along the same axis. However, in an angled configuration the orientation of the stabilizers will provide more resistance to z-displacement.

It appears as though the prostate motion may continue to decrease as the stabilization angle increases (becoming more perpendicular to the angle of insertion). Although this angle might be ideal, it may not be clinically practical for the current transperineal brachytherapy procedure due to the limited space available. Thus it appears that in order to effectively stabilize the prostate, one should either use needles possessing a retractable hook inserted in parallel or find the optimal angle for practical stabilization. Future experimentation will be conducted utilizing human prostates.

VI. ACKNOWLEDGEMENTS

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