Gynecologic interstitial brachytherapy curriculum using a low-cost phantom with ultrasound workshop and a treatment planning workshop is effective

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ABSTRACT

PURPOSE/OBJECTIVE(S): Standardized simulation training geared towards interstitial brachytherapy (IS BT) for gynecologic malignancies is lacking in radiation oncology resident education. We developed and implemented a curriculum for IS BT training with (1) lecture on equipment, workflow, and guidelines, (2) hands-on ultrasound-guided IS BT workshop, and (3) treatment planning workshop.

METHODS AND MATERIAL: The cost in materials of each phantom was approximately $66. After a lecture, two alternating workshops were performed. The first session consisted of a hands-on ultrasound-guided IS BT workshop with one resident imaging the phantom with a transabdominal ultrasound probe and the other resident implanting the phantom with needles. A second session consisted of a hands-on treatment planning workshop using BrachyVision and an i-Q spreadsheet with the following objectives: coverage goal, meeting D2cc constraints, and minimizing V200. The primary outcome was improvement in knowledge assessed with Likert-style questions and objective knowledge-based questions (KBQs).

RESULTS: Four of the seven medical residents that participated in this curriculum had prior IS BT experience. Residents reported significantly improved knowledge regarding gynecologic IS BT equipment and procedure, evaluating gynecologic anatomy using ultrasound, CT simulation, contouring, and plan review (overall median pre-session subjective score 2 (1) − 3) versus post-session score 4 (3) − 4, p < 0.01). Residents demonstrated improvement in answering KBQs correctly from 44% correct at baseline to 88% after completion of the curriculum (p < 0.01). All residents “Agree” and “Strongly Agree” the session was an effective learning experience.

CONCLUSIONS: Residents participating in phantom training with an ultrasound curriculum and a treatment planning session is effective for improving knowledge and skills in IS BT for radiation oncology residents. © 2021 Published by Elsevier Inc. on behalf of American Brachytherapy Society.

Keywords: Interstitial brachytherapy; Ultrasound phantom; Cervical cancer; Treatment planning; Brachyvision; Cost-effective; Simulation training; Education curriculum; Gynecologic malignancies

Introduction

Standard of care curative intent treatment of cervical cancer consists of chemoradiation and brachytherapy (BT). In the 1991 Patterns of Care Study evaluating pretreatment and treatment factors associated with outcomes of cervical cancer, BT was the only treatment factor associated with improved pelvic control (1). Multiple additional significant studies have subsequently demonstrated the importance of BT during the treatment course to the outcomes in cervi-
cancer (2 − 4). BT has the ability to escalate dose to the tumor to optimize local control (5) and remains the best treatment modality to spare radiation to normal tissue and subsequently late radiation-related toxicities (6). Despite the clear benefit of this procedure, utilization rates for cervical cancer treatment have decreased from 1988 to 2009 (p < 0.001) according to a couple of Surveillance, Epidemiology, and End Results analyses (7, 8) which may lead to worse local control and survival outcomes. The decrease in BT utilization likely has many contributing causes, but procedural technique comfort is likely contributory. For example, in a survey of radiation oncology residents, 40% reported inadequate exposure of BT in their training (9).

A hallmark 1979 study noted that increasing physician experience with higher surgical volumes improve outcomes (10). While not necessarily a surgical procedure, BT procedures are hands-on and require higher volumes to optimize proficiency. In addition to volume, quality of the procedure is important. For example, BT implant quality has been examined in patients treated on clinical trials and inferior applicator placement is associated with worse local control and disease-free survival (11). Additionally, as proceduralists gain confidence using ultrasound guidance, cases of vaginal laceration and uterine perforation decrease (12, 13). Regarding cervical BT, 55 facilities were examined by volume and centers with less volume were associated with suboptimal doses to the tumor when evaluating dose to point A (14).

For bulky tumors, tumors with extensive vaginal involvement, and tumors with parametrial or pelvic sidewall extension, interstitial (IS) BT can improve dose distribution when compared to intracavitary (IC) BT. IS BT is helpful to overcome shortcomings of IC BT and hybrid applicators such as the Vienna-style and Venezia (Elekta, Stockholm, Sweden) have been developed to allow for asymmetric dose delivery by differential weighting of different dwell positions in needles to help spare dose to normal structures (15, 16). Additionally, the American Brachytherapy Society (ABS) consensus guidelines states that vaginal lesions >0.5 cm thick at the time of BT should be treated with IS BT (17). To optimize local control for select locally advanced cases, IS BT may be the best option for treatment. However, in a query of the Accreditation Council for Graduate Medical Education (ACGME) for the caseloads of graduated radiation oncology residents, the average number of IS gynecologic cases has remained low from 2007 to 2018, with an average of 4.5 cases in 2018 per resident upon graduation raising concerns for residents receiving optimal training for IS BT (18).

Simulation training is crucial in medical education, as demonstrated by improved performance and knowledge in skills including arterial line placements, laparoscopic cholecystectomies, and cardiopulmonary resuscitation (19–21). Surgical residents trained in high-fidelity laparoscopic cholecystectomy performed better with significantly fewer errors in a randomized trial (21). Academic centers that have implemented simulation training has shown high levels of surgical skill retention (22) but in radiation oncology this remains underutilized. A literature search of BT training revealed a few promising simulation-based workshops for prostate and gynecologic malignancies using models, computer-based systems, cadavers, and virtual reality (23–28) demonstrating improvement in confidence and familiarity with procedures. Some publications on improving training of gynecologic BT have reported on the use of well-made phantom models or modification of anthropomorphologic ultrasound phantoms that can cost between $200 (29) to $7000 (29–31).

Given the lower caseloads of IS BT and the documented literature of the benefits of simulation training, we developed a curriculum utilizing didactics lectures and workshops consisting of hands-on simulation-based training to improve resident knowledge, understanding, and confidence regarding gynecologic IS BT. In the process, we developed an affordable phantom product that can be replicated for other institutions interested in building a simulation-based curriculum to supplement training on actual patient cases. We hypothesized that radiation oncology residents would benefit from a hands-on IS BT curriculum for cervical cancer to improve information retention, understanding, and confidence in IS BT procedures as assessed by subjective improvement through Likert-style questions and objective improvement through increase in correctly answered knowledge-based questions (KBQs).

**Methods and materials**

**Phantom production**

Phantoms were produced to mimic gynecologic anatomy, specifically the uterus and bladder. A uterus mold was produced by using a pear-shaped doll and modeling clay (Dixon Ticonderoga, Heathrow, FL, USA) (Fig. 1a). Once set, the pear-shaped doll was removed to create the negative of the mold. A homogeneous solution was produced using a mixture of agar (70 g/L; Sigma Aldrich, St. Louis, MO, USA) dissolved in water and glass microspheres (12 g/L; fiber Glast Developments Corp., Brookville, OH, USA). These materials were used based on agar’s tissue-mimicking properties (e.g., sound speed) and the use of microspheres to produce a hyperechoic uterus (30–33). The solution was poured into the uterus mold and removed after it solidified under refrigeration (~37°F). A second half was poured in the mold, the first half was attached while still molten, and then the uterus was allowed to fully bond under refrigeration. A thin-walled condom (Trojan Brand Condoms, Church & Dwight Co. Inc, Ewing, NJ, USA) was used to mimic the bladder by filling it with tap water. A 6×6×6-inch acrylic box (Royal Imports, Brooklyn, NY, USA) was used to assemble the contents of the phantom. An exterior vertical wall of
the box was drilled with 2-mm holes to mimic a Kelowna template (Varian Medical Systems, Paola Alto, CA, USA), defining the “front” face of the acrylic box using a stainless steel plate as guidance (Fig. 1b). A 1-inch diameter hollow, acrylic tube (FengWu, China) was cut to a length of 5 cm simulating a vaginal canal and cylinder and was filled with modeling clay to prevent floatation when pouring background material. The cylinder ran flush to and suspended the agar uterus. The condom bladder was suspended from the front face of the box with packing tape and rested upon the clay-filled cylinder. Using the same agar and concentration, a solution was made to fill the contents of the box to provide as background consistency mimicking soft tissue. Prior to pouring the agar solution, the drilled surfaces of the box were sealed with packing tape. This was performed to both prevent leaking of the background agar solution and create a penetrative barrier to mimic skin. The phantom was allowed to solidify under refrigeration. A Saran wrap layer (The Dow Chemical Co., Midland, MI, USA) was stretched tightly and placed over the top of the acrylic box to prevent desiccation and define the ultrasound scanning window, described below. In total, seven phantoms were produced. Components of phantom production are showcased in Figure 1c and Figure 1d and listed, with their costs, in Table 1.

**Curriculum structure**

The participants of this curriculum included seven radiation oncology residents at different levels of training: two postgraduate year (PGY) 2, two PGY 3, one PGY 4, and two PGY 5 residents. The treatment lecture (1 h) and two workshops (1 h each) were conducted over 3 h during our dedicated resident education session. Two total sessions were conducted 3 weeks apart to accommodate for all residents to be able to attend. The primary objective of this curriculum was to improve the knowledge of IS BT for gynecologic malignancies for radiation oncology residents as assessed with subjective Likert-style questions and objective knowledge-based questions (KBQs).

**Interstitial brachytherapy treatment lecture**

At the beginning of this curriculum, a structured one-hour lecture was designed to teach radiation oncology residents the fundamentals of gynecologic IS BT. The lecture was reviewed by two radiation oncology attendings who specialize in gynecologic malignancies and routinely performed IS BT treatments, the medical physicist who primarily works with IS BT procedures, the medical physics resident, and the radiation oncology medical resident who...
designed this curriculum. The lecture was presented by the senior radiation oncology medical resident. The lecture consisted of: (1) indications for IS BT for gynecologic malignancies; (2) IS BT equipment; (3) procedure steps including applicator and needle placements; (4) basics of ultrasound terminology; (5) ultrasound artifacts; (6) evaluating a CT simulation scan for appropriate applicator and needle placement; and (7) contouring, coverage goals, and constraints. The lecture can be provided upon request.

Ultrasound phantom curriculum

A hands-on ultrasound-guided IS BT workshop was performed led by the senior medical physics resident. The workshop began with a short presentation, which described fundamental aspects of ultrasound imaging and equipment handling. Highlights of this presentation included basic physics of ultrasound image formation, common imaging artifacts observed during IS BT, image plane orientation, and basic, manipulable ultrasound scanner settings. Upon completion of the presentation, participants were broken into small groups of two and led through imaging the gynecologic phantoms (described above) using a transabdominal ultrasound probe on a Flex Focus 400 BK Ultrasound system (BK Medical, Peabody, MA, USA) (demonstrated in Fig. 1d). Participants were instructed on how to vary gain, time gain compensation, frequency, and depth on the ultrasound scanner. Once participants felt comfortable with scanner settings as the role of a sonographer, participants then switched roles as a brachytherapist, implanting the phantom using custom stainless steel needles machined in-house (Fig. 2a). Representative ultrasound images of the phantom are shown in Figure 2a for anatomy, and Figure 2b demonstrating implantation using the custom-made interstitial needles.

<table>
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<th>Item (Quantity, size)</th>
<th>Manufacturer</th>
<th>Cost ($)</th>
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<td>Royal Imports</td>
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</tr>
<tr>
<td>Rigid PETG tube (7, OD: 1-inch)</td>
<td>FengWu</td>
<td>9.50</td>
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<tr>
<td>Rigid PETG tube (7, OD: 0.5-inch)</td>
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<td>9.50</td>
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<tr>
<td>Modeling clay (2.2 lbs)</td>
<td>Dixon Ticonderoga</td>
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<tr>
<td>Plaster of Paris (5 lbs)</td>
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<td>Condoms</td>
<td>Trojan Brand Condoms</td>
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<td>Babushka micro doll</td>
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<td><strong>Total cost ($)</strong>:</td>
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<td><strong>Approximate cost per phantom ($)</strong>:</td>
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</table>

Abbreviations: OD=outer diameter.

**Treatment planning curriculum**

For this 1-h curriculum, an IS BT plan of a treated patient was copied and modified to create seven anonymized cases utilizing BrachyVision (Varian Medical Systems, Paola Alto, CA, USA) (Fig. 3b). These cases were modified so coverage goals and normal tissue constraints were not met. The workshop began with a demonstration showing the importance of needle spacing at approximately 1 cm versus 0.5 cm and 2 cm. Subsequently, this curriculum had four objectives: (1) Coverage goal of D90 (dose to 90% of the volume) > 100% prescription dose, (2) Meeting D2cc (maximum dose to 2cc) constraint of rectum, (3) Minimizing V200% to qualitatively involve a small volume (the volume to 200% of the dose does not exceed past the surface of the needle) (34), (4) Meeting D2cc constraint of bladder. For each step of the objectives, dwell times in pre-specified positions were modified so that the goal was met. Additionally, the L-Q spreadsheet was used to evaluate the EQD2 (equivalent total doses in 2 Gy fractions). The coverage goals were EQD2 D90 greater than 80 Gy, D2cc rectum < 75 Gy, D2cc bladder < 90 Gy according to ABS guidelines (34).

**Pre- and Post- Curriculum Survey collection and evaluation**

All participating individuals filled out an anonymized survey containing both subjective and objective questions before and after completion of the curriculum. The surveys were anonymized and matched using the first name of the first pet (or favorite family member). Improvement in knowledge was assessed with Likert-style questions and objective knowledge-based questions (KBQs). The survey consisted of a total of 25 questions: the objective portion consisted of 13 knowledge based multiple choice questions and the subjective portion consisted of 12 questions.
evaluating the participants’ understanding of IS BT (see Supplementary Document). Themes targeted on the surveys included skills and knowledge regarding gynecologic IS BT equipment and procedure, skills and knowledge regarding evaluating gynecologic anatomy using ultrasound in the context of IS BT, and skills and knowledge regarding CT simulation, contouring, and plan review for gynecologic IS BT. Questions regarding subjective knowledge consisted of Likert-type responses evaluating confidence (1 = not at all, 2 = somewhat, 3 = moderately, 4 = quite, and 5 = extremely) as well as free text responses for feedback. The same questions were asked after the curriculum was completed to analyze change in understanding.

**Statistical analysis**

Wilcoxon signed ranks test was used to assess if there is any difference between pre-curriculum and post-curriculum subjective Likert-type paired data. McNemar’s test of paired proportions was used to assess pre-curriculum and post-curriculum knowledge-based responses. Due to the small sample size, we reported the McNemar mid-p test instead of the exact test due to the better performance (35). Free text responses regarding for feedback was aggregated from all participants and reported. All statistical analysis was performed using SPSS version 26 (SPSS, Chicago, IL, USA), with a 2-sided p-value at the 0.05 significance level.
Results

The curriculum was performed with 7 radiation oncology residents in two separate sessions. All residents filled out the pre- and post-curriculum paperwork completely. Four residents had prior experience with IS BT prior to this curriculum.

Subjective knowledge

At baseline, most residents felt “slightly” (2/7) or “moderately” (3/7) confident in their understanding of when IS BT is indicated. Majority felt they were either “not at all” (3/7) or “moderately” (3/7) confident to perform a template and IS BT procedure independently under minimal supervision. Majority felt “slightly” (3/7) or “moderately” (3/7) confident in their ability to identify gynecologic anatomy on ultrasound images in the presence of ultrasound imaging artifacts. Additionally, most residents felt “not at all” (2/7) or “slightly” (3/7) confident to evaluate a plan to optimize coverage of the high-risk CTV. The rest of the answers to the subjective questions is available in Figure 3.

After the curriculum, residents reported significant improvement in all subjective questions asked as demonstrated in Figure 3. After completing both the ultrasound phantom and treatment planning workshops, all residents reported that they either “agree” or “strongly agree”, with a median Likert score of 5 [IQR 4–5] that the session was an effective learning experience.

Objective knowledge

At baseline, the objective questions asked assessing radiation oncology knowledge was answered 44% correctly. After the curriculum, the overall percent correct was 88% (p < 0.0001) (Table 2). All questions increased in percent correct and were evaluated using McNemar’s mid-p except for questions 4: “Which of the following is NOT a component of a typical Varian Kelowna Interstitial Brachytherapy set?” and question 5: “For transabdominal ultrasound during brachytherapy procedures, what are the two different planes that are generally used for visualization of gynecologic anatomy?” Both of these questions had the same number correct before and after the curriculum. Four questions had over 70% absolute increase in percent correct after the curriculum with p-values<0.05 (see Table 2 for details). One question had an over 50% absolute increase in percent correct after the curriculum with a marginal significant p-value (p = 0.06).

Resident feedback

Following completion of the curriculum, free text responses to the following questions: “What addition or changes to this curriculum would help to better prepare you for interstitial brachytherapy?” are reported in Table 3. All participants provided comments.

Phantom usability

In general, the phantoms had a shelf life of approximately one month of stability from construction to utilization in the workshop. Each phantom was used by multiple residents in each workshop. Two phantoms were re-used in a second workshop three weeks after the first workshop. Two phantoms could not be re-used as the bladder (condom) was punctured accidentally during the workshop.

Discussion

This curriculum consisting of a didactics lecture and a couple of novel hands-on workshops: (1) simulation training of implanting a relatively low-cost gynecologic phantom with needles and assistance with transabdominal ultrasound guidance, and (2) treatment planning training for a gynecologic IS BT case. Training for BT procedures typically happens through repetition of actual procedures performed on patients with guidance and feedback from an expert radiation oncology brachytherapist. Training of this sort is conventionally implemented for surgical procedures as well but may affect patient outcomes as learning happens during patient care. Residents participating in this simulation training demonstrated significant improvements in objective knowledge (Table 1) and reported a median of ‘5’ on the Likert Scale for usefulness in the IS BT curriculum. Additionally, on targeted questions asked regarding IS BT, all residents reported a subjective increase in their knowledge of IS BT for gynecologic malignancies as demonstrated in Figure 3.

This curriculum provides educational consistency, is relatively low cost, is hands-on and interactive, and increases exposure to residents for a procedure that is typically infrequent in training. The phantoms we produced each cost approximately $66 (Table 1) with material that are readily purchasable. The overarching goal of this curriculum would be to improve understanding and knowledge of every step of the IS BT procedure and ultimately lead to better applicator placement and decreased time for the procedure that subsequently translates to less time under anesthesia, better tumor control, and fewer treatment-related complications. An additional goal of this curriculum would be the hope that increased familiarity would increase interest in IS BT amongst resident physicians so that utilization increases over time. This curriculum is cost-effective and easy to implement, with phantoms made from everyday materials that replicate gynecologic anatomy when visualized with a transabdominal ultrasound and cost significantly less than other available phantoms. These phantoms may possibly be replicated at other radiation oncology training programs or at ABS meetings in the future.
For programs with less exposure to gynecologic BT, especially IS BT, this curriculum consisting of multiple workshops may be increasingly beneficial.

Despite the significant role BT plays in the curative intent cervical cancer treatment, residency education for this procedure significantly varies between training institutions and is insufficient in many. The aforementioned ACGME case logs showed that the number of IC BT uterus/cervix procedures observed and/or performed across institutions by a graduating resident was wide-ranging from 0 to over 300 (18). For gynecologic IS BT, the median number of cases is low at 0 to 2 per resident and was stable from 2007 to 2018 (18). When analyzing the lower 30th percentile of residents from 2007 to 2018, no gynecologic IS cases were performed. When looking at the 70th percentile, amount of IS BT gynecologic cases performed was 2 to 6 cases, and at the 90th percentile, the amount of IS BT gynecologic cases performed ranged from 5 to 11 cases (18). According to a survey performed by the Association of Residents in Radiation Oncology (ARRO), the minority of residents (24%) thought the 5-case minimum for interstitial brachytherapy was adequate, and 31% “strongly agree” or “agree” to having a formal brachytherapy curriculum (36). Given the lower volume numbers, it is important to improve resident education as much as possible by supplementing with additional curriculums.

The insufficient training in BT has also been reported in other countries. A survey of French residents of radiation
oncology reported that 71% had performed at least one gynecologic BT procedure, however only 12% felt comfortable independently performing the procedure (37). Additionally, a survey of Canadian practicing radiation oncologists, residents, and fellows identified a lack of time and guidance for BT training (38). When looking at on-site training of a procedure performed on a patient in the operating room, all staff participating in the procedure have increased time involved in providing patient support, there is increased time for the patient under anesthesia, and subsequently increased costs (39). This suggests a need for hands-on dedicated training or simulation curriculum to improve resident understanding of BT and can potentially lead to decreased costs and improved patient outcomes. It is important to note that these surveys are directed at all gynecologic BT and there is no specific survey that we are aware of regarding IS BT.

As previously mentioned, there are a few encouraging simulation-based workshops for prostate and gynecologic malignancies developed at other academic centers (23–28), (40). Among the programs for gynecologic brachytherapy, there are curriculums that have been developed that are MR-based (41), virtual reality-based (42), and cadaver-based (26). This initiative builds on the foundation already developed at other institutions with the hopes to increase the training specifically for gynecologic IS BT. According to a survey performed of the ABS, 50% of physicians sometimes or always use ultrasound for applicator placement, and ultrasound was the most common modality used (43). Given the utility, a dedicated ultrasound curriculum is needed to understand ultrasound terminology and also identify artifacts that affect image quality.

Furthermore, a targeted needs assessment of US radiation oncology residents demonstrated that treatment planning education is limited, with 60% reporting insufficient exposure (44). Additionally, the further on in training, the less likely senior residents would be interested in treatment planning for BT, suggesting that residents do not find it useful given the lack of training and/or job prospects regarding BT (44). Approximately 19% of the time in clinic, radiation oncologists are spending on treatment planning, suggesting a heavier emphasis needs to be made for this clinical skill, and that experience with brachytherapy treatment planning is extremely lacking (45). As evidenced by our survey, no residents responded that they were “quite” or “extremely” confident with evaluating a plan to optimize coverage of high-risk CTV and to meet normal tissue constraints prior to this curriculum, yet treatment planning is a required and integral part of brachytherapy treatment planning.

There are some limitations inherent to this IS BT Curriculum for Gynecologic BT, which primarily include small sample size and measurements of the curriculum based on a subjective survey and knowledge-based questions. Only seven residents were available to participate in the study (as these are all the radiation oncology residents at our institution), but the benefits as illustrated in the improvement in subjective knowledge (Fig. 4) and objective knowledge questions (Table 2) could be provided and replicated at
other institutions, at ABS meetings, or other brachytherapy schools. In fact, residents at programs with a lower volume of brachytherapy, and for residents and/or early career radiation oncologists interested in establishing a program, this curriculum may prove even more beneficial. This curriculum is a pilot program that was implemented with success, and although only completed once, the low-cost of the phantom and ease of implementation should make it easy to standardize and replicate at other programs. At our institution, we plan to make this a standard part of the gynecologic radiation oncology education block and will likely increase the amount of time spent on treatment planning given the qualitative feedback we received.

Other limitations include the variable timing of the sessions, residents have differing levels of knowledge, and lack of the ability to evaluate accurate interstitial needle placement. The phantom was created based on normal gynecologic anatomy and pathology was not included. Implanting a phantom with tumor anatomy to simulate a real case, and incorporating other normal structures, like small bowel, into the phantom can be further beneficial for education learning. There is room for improvement in this curriculum that we can include incorporating phantoms with gynecologic tumors, incorporating training involving CT simulation planning, and involving a workshop that involves hands-on contouring. We also realize that our program uses the Kelowna template and transabdominal ultrasound for our procedures, which may be different than other institutions that use other templates with or without transvaginal or transrectal ultrasound. Therefore, the heterogeneity of IS BT procedures may make our curriculum not as applicable to education training at other institutions. Moving forward, we hope to perform a similar training workshop annually, and given the feedback from residents, we intend to incorporate improvements in phantoms and longer sessions with contouring and treatment planning. It is also important to note that to combat the decline in BT utilization (7,8) and perceived lack of adequate experience, the ABS has begun initiatives to increase training. One of these initiatives is the “300 in 10” project, where the goal is to train 300 competent brachytherapists in the next 10 years.

Finally, the robustness of the phantom is limited by the shelf life of weeks to months. We did not incorporate a cosmetic preservative to retain the structure and integrity of the phantom (30), given that we were intending them for one time use, but can do so if the program expands to a longer period of time.

Conclusions

Residents participating in IS BT training for gynecologic malignancies with an ultrasound curriculum utilizing a low-cost phantom and a treatment planning session is relatively low-cost, easy to implement, and effective. There are other promising curriculums that have been developed for gynecologic BT and this curriculum specifically designed for training of gynecologic IS BT can supplement the benefits of these other curriculums. Additional strategies to this initiative should be considered to standardize radiation oncology education initiatives for gynecologic IS BT training. This low-cost and effective training curriculum can be replicated at other programs or ABS meetings. This curriculum will likely be particularly helpful for institutions that have a lower volume of IS BT gynecologic cases. Overall, gynecologic BT hands-on training would benefit training radiation oncology residents, instructors, and most of all, our patients.

References