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Research Letter

Manufacture and evaluation of 3-dimensional printed sizing tools for use during intraoperative breast brachytherapy

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Abstract
Three-dimensional (3D) printing has emerged as a promising modality for the production of medical devices. Here we describe the design, production, and implementation of a series of sizing tools for use in an intraoperative breast brachytherapy program. These devices were produced using a commercially available low-cost 3D printer and software, and their implementation resulted in an immediate decrease in consumable costs without affecting the quality of care or the speed of delivery. This work illustrates the potential of 3D printing to revolutionize the field of medical devices, enabling physicians to rapidly develop and prototype novel tools.

Introduction

More than 234,000 new cases of breast carcinoma are expected in the United States in 2015, composing 29% of all new cancer diagnoses in women this year.[1] Two-thirds of these cases are localized disease at diagnosis. Practice patterns reveal nearly 60% of patients with early-stage breast cancer (stage I or II) receive breast-conserving therapy and should be evaluated for radiation therapy as part of their management.[2] The standard of care in whole-breast external beam radiation therapy has been to deliver 45 to 50 Gy with or without a 10 to 16 Gy boost over 5 to 6 weeks of treatment. However, this standard fractionation scheme can be burdensome for patients living in remote areas who may have to travel long distances to receive care. It is also less popular in closed systems, such as the Canadian and British health care systems, in which there are fewer facilities and greater pressure to control cost of care. The end result has been the development of both hypofractionated whole-breast radiation therapy and accelerated partial breast irradiation regimens, which are able to shorten treatment

Conflicts of interest: None.

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times further, from 3 weeks of treatment in the case of most hypofractionation regimens to a single treatment in the case of intraoperative radiation therapy (IORT).[3,4] There are a range of techniques currently in use to deliver accelerated partial breast irradiation, including external beam radiation therapy, interstitial brachytherapy, balloon brachytherapy, and IORT.

Intraoperative electronic brachytherapy has been used to deliver adjuvant IORT to 116 patients at our institution since December 2009. All treatments have been delivered using a Zeiss Intrabeam device, which generates 50 kV photons at the center of a spherical applicator. Applicator sizes range from 1.5 cm to 5 cm sphere diameter in 0.5 cm increments. The surface of the resection cavity receives 20 Gy over 20 to 35 minutes and the dose is attenuated to 5 to 7 Gy at a depth of 1 cm from the surface of the applicator. Patients eligible for IORT at our institution are based on the American Society for Radiation Oncology consensus guidelines: age ≥60 years, size ≤2 cm, pN0 by sentinel node biopsy or axillary dissection, estrogen receptor positive, resection margin negative by ≥2 mm, and unifocal disease.[3] This technique has proven invaluable in the treatment of well-selected patients, some of whom would have otherwise decided to forgo breast conservation or adjuvant radiation therapy because of geographic or personal constraints. We have experienced good results with regard to cosmesis and toxicity, experiencing a single incidence of skin necrosis during our 6 year experience. The Targeted Intraoperative Radiotherapy versus Whole Breast Radiotherapy for Breast Cancer trial revealed similar rates of local control when comparing standard fractionation whole-breast radiation therapy with IORT.[5,6]

Optimal use of the electronic brachytherapy system is dependent on selection of an appropriately sized applicator for each patient. Sizing of the applicators intraoperatively typically consists of serially testing multiple applicator diameters until one is identified that fills the surgical defect as precisely as possible. This cavity sizing is typically performed using functional brachytherapy applicators. However, our institutional experience revealed that a major cost associated with the program is the brachytherapy applicators themselves. There are 8 available applicator sizes, with a retail cost of $10,300 per applicator, and the individual devices have a useable lifespan of 100 sterilization cycles. One simple solution to minimize cost implemented early in our program was to sterilize each applicator individually. This enabled surgeons to request specific sizes of brachytherapy applicator to assess best cavity fit, without subjecting the entire set to a sterilization cycle unnecessarily. During 116 cases at our institution, there have been 529 sterilization cycles performed on individual applicators, averaging 4.6 sterilization cycles per IORT case. Based on the replacement cost of the IORT applicators, an average of $371 per procedure was wasted on IORT applicators used for sizing purposes alone. Over the past 6 years of our program, this has resulted in more than $43,000 worth of the useful life of IORT applicators being used on lumpectomy cavity sizing only and not to deliver radiation therapy.

There has been a proliferation of low-cost commercially available 3-dimensional (3D) printing systems. There are now many examples of 3D printing technology being used for medical modeling, devices, and, more recently, implants.[7-9] This technology has ushered in a new era in which it is possible to perform rapid prototyping and development of new medical devices, in many cases without having to undergo lengthy and costly development processes that previously hindered innovation. The most ubiquitous and lowest cost technology currently available is fused deposition modeling (FDM) printing, a process in which thermoplastic material is simultaneously heated and extruded through a nozzle onto a print bed, building the model in successive layers.[10] The quality of the finished product is dependent on the layer height and extruder nozzle diameter, which typically ranges between 20 and 200 μ for commercially available FDM printers.

Methods and results

At Oregon Health & Science University, two breast-conserving therapy patients have been successfully treated with intra-operative radiation therapy after using 3D printed thermoplastic tools to determine lumpectomy cavity size. These tools were designed with dimensions identical to functional IORT applicators, allowing us to eliminate the need to use functional brachytherapy applicators for sizing purposes alone. We used computer aided design software (Autocad 2015, Autodesk, San Rafael, CA) to design sizing tools with sphere sizes identical to functional IORT applicators (Fig 1A). A low-cost FDM printer (Ultimaker 2, Ultimaker, Geldermalsen, Netherlands) was then used to make the sizing tools out of polylactic acid thermoplastic material (Fig 1B). To ensure accurate replication of functional IORT applicators, some postprocessing of the sizing tools is required to remove support structures needed during printing and sanding to remove minor surface imperfections. Sizing tools used in this publication were printed using a layer height of 40 μ, and final dimensions of the devices were within 0.3 mm, or a maximum of 2%, of the functional applicator and planned computer aided design dimensions.

The brachytherapy sizing tools used in this study were manufactured in fewer than 5 days using less than $20 in consumable materials. The total cost of manufacturing a complete set of sizing tools, inclusive of 3D printer purchase, material costs, and labor, is less than $2500. This was compared with traditional manufacturing methods, and 3D printing the sizing tools was found to be

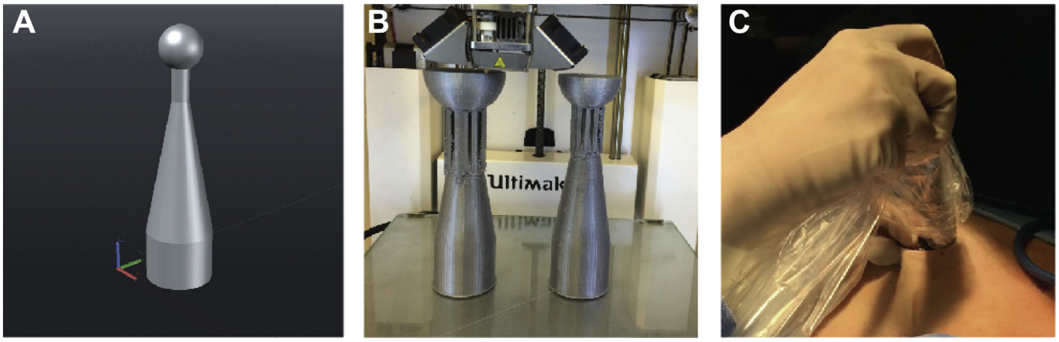

Figure 1 Illustration of the computer-aided design file for a 2.5 cm sizing tool (A); intraoperative radiation therapy sizing tools being printed with support structures in place that are removed during postprocessing (B); a 2.5 cm sizing tool being used intraoperatively (C).

30% to 50% of the cost of having them produced by specialty surgical tool manufacturers. Based on the previously discussed savings estimates of $371 per procedure after introduction of the sizing tools, we estimate that our per-procedure savings will exceed the amount spent to manufacture the tools after as few as 7 brachytherapy procedures. Others performing cost analysis have demonstrated that functional sterile surgical tools are able to be produced using 3D printing at one-tenth the cost of traditional manufacturing techniques.[11] Three-dimensional printing is considered by many to be a "slow" manufacturing technique because of the time required to produce individual parts using additive manufacturing; however, by 3D printing the sizing tools used in this publication we were able to obtain them in a fraction of the time required to obtain custom milled part from traditional manufacturers.

The polylactic acid material used to produce the sizing tools in this publication is not approved for high temperature sterilization or for direct contact with patient tissue. To implement their use in the operating room, the 3D printed sizing tools were sheathed in sterile disposable plastic bags similar to what is used for ultrasound probes intraoperatively (Fig 1C), allowing for reuse of the devices. Before their use, a surgical nurse can prepare a full set of sizing tools in this manner, allowing the surgeon to test multiple applicator sizes quickly before selecting an appropriate one and requesting a functional IORT applicator of the same dimensions. This technique has allowed our IORT team to eliminate the use of functional applicators for sizing purposes and eliminate the wasted sterilization cycles previously required to determine resection cavity size. Both patients treated thus far using these 3D printed sizing tools have then gone on to receive IORT without having to use more than a single IORT applicator during the procedure, and use of the devices did not add significant time to the procedure. The change in the dimensions of the sizing tool after placing it in a sterile bag for use in the sterile field did not pose a significant hindrance, and the operating surgeons were satisfied with the manner in which the tools approximated lumpectomy cavity size before proceeding with IORT.

Discussion

This work demonstrates that a low-cost, commercially available, 3D printer can now be used to design and produce functional tools capable of being incorporated into surgical and radiation therapy practice in a matter of weeks. The tools produced in this study are now saving our IORT program more than $300 per breast brachytherapy procedure in consumable costs. For larger IORT programs, this could amount to tens of thousands of dollars per year in savings. We are now experimenting with additional materials, such as nylon, which will ultimately allow for high-temperature sterilization of these tools in the future, further streamlining their use. As 3D printing becomes more pervasive and additional materials become available that are specifically designed for clinical use, we anticipate this technology will remove many barriers that previously existed to physicians developing and implementing tools for use in their own practice. This technology will also enable clinicians and researchers to develop publicly available databases of tools that can be produced and modified by others. In this spirit, the devices described in this publication have been made available at this URL: www.shapeways.com/shops/radmed.

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