

# ACR–ABS–ASTRO practice parameter for the performance of radionuclide-based high-dose-rate brachytherapy

Matthew M. Harkenrider<sup>1,\*</sup>, Kevin Albuquerque<sup>2</sup>, Derek Brown<sup>3</sup>, Mitchell Kamrava<sup>4</sup>, Martin King<sup>5</sup>, Firas Mourtada<sup>6</sup>, Peter Orio<sup>5</sup>, Rakesh Patel<sup>7</sup>, Michael Price<sup>8</sup>, Prema Rassiah<sup>9</sup>, Abhishek A. Solanki<sup>1</sup>, William Small Jr<sup>1</sup>, Naomi R. Schechter<sup>10</sup>

<sup>1</sup> Stritch School of Medicine, Loyola University Chicago, Maywood, IL

<sup>2</sup> UT Southwestern Medical Center, Simmons Comprehensive Cancer Center, Dallas, TX

<sup>3</sup> UC San Diego, La Jolla, CA

<sup>4</sup> Cedars Sinai Medical Center, Los Angeles, CA

<sup>5</sup> Brigham and Women's Hospital/Dana-Farber Cancer Institute, Boston, MA

<sup>6</sup> ChristianaCare, Newark, DE

<sup>7</sup> White Oak Cancer Center, Silver Spring, MD

<sup>8</sup> Columbia University Irving Medical Center, New York, NY

<sup>9</sup> Huntsman Cancer Institute, University of Utah, Salt Lake City, UT

<sup>10</sup> Keck Medical Center of USC, Norris Comprehensive Cancer Center, University of Southern California, Los Angeles, CA

## ABSTRACT

**PURPOSE:** This practice parameter aims to detail the processes, qualifications of personnel, patient selection, equipment, patient and personnel safety, documentation, and quality control and improvement necessary for an HDR brachytherapy program.

**METHODS AND MATERIALS:** This practice parameter was revised collaboratively by the American College of Radiology (ACR), the American Brachytherapy Society (ABS), and the American Society for Radiation Oncology (ASTRO).

**RESULTS:** Brachytherapy is a radiotherapeutic modality in which radionuclide or electronic sources are used to deliver a radiation dose at a distance of up to a few centimeters by surface, intracavitary, intraluminal, or interstitial application. Brachytherapy alone or combined with external beam radiotherapy plays an important role in the management and treatment of patients with cancer. High-dose-rate (HDR) brachytherapy uses radionuclides, such as iridium-192, at dose rates of  $\geq 12$  Gy/hr to a designated target point or volume, and it is an important treatment for a variety of malignant and benign conditions. Its use allows for application of high doses of radiation to defined target volumes with relative sparing of adjacent critical structures.

**CONCLUSIONS:** HDR brachytherapy requires detailed attention to personnel, equipment, patient and personnel safety, and continuing staff education. Coordination between the radiation oncologist and treatment planning staff and effective quality assurance procedures are important components of successful HDR brachytherapy programs. © 2021 Published by Elsevier Inc. on behalf of American Brachytherapy Society.

## Keywords:

HDR brachytherapy; High-dose-rate brachytherapy; Brachytherapy; Radiation oncology; Radionuclides

The American College of Radiology, with more than 30,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the

science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice parameters and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice parameters

Received 10 August 2021; accepted 17 August 2021

\* Corresponding author: Stritch School of Medicine, Loyola University Chicago, 2160 S 1<sup>st</sup> Ave, Maywood, IL 6015

E-mail address: [mharkenrider@lumc.edu](mailto:mharkenrider@lumc.edu) (M.M. Harkenrider).

and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

## Preamble

This document is an educational tool designed to assist practitioners in providing appropriate radiation oncology care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care<sup>1</sup>. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner in light of all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

<sup>1</sup> Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the *ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures* (Revised 2008) sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, *Stanley v. McCarver*, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of this document is to assist practitioners in achieving this objective.

## Introduction

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the American Brachytherapy Society (ABS), and the American Society for Radiation Oncology (ASTRO).

Brachytherapy is a radiotherapeutic method in which radionuclide or electronic sources are used to deliver a radiation dose at a distance of up to a few centimeters by surface, intracavitary, intraluminal, or interstitial application. This practice parameter refers only to the use of radionuclides for brachytherapy. Brachytherapy alone or combined with external beam radiotherapy plays an important role in the management and treatment of patients with cancer (1). High-dose-rate (HDR) brachytherapy uses radionuclides such as iridium-192 at dose rates of 20 cGy/min (12 Gy/hr) or more to a designated target point or volume. HDR brachytherapy is indicated for treating malignant or benign tumors where the treatment volume or targeted points are defined and accessible.

The use of brachytherapy requires detailed attention to personnel, equipment, patient and personnel safety, and continuing staff education.

The licensing of radioactive sources (radionuclides) and the safety of the general public and health care workers are regulated by the Nuclear Regulatory Commission (NRC) or by agreement states.<sup>2</sup> Medical use of radionuclides for therapeutic procedures must adhere to the constraints set forth by these regulatory agencies. Detailed descriptions of NRC licensing and safety issues can be found in the Code of Federal Regulations, Part 20 and Part 35. State requirements for the agreement states are found in the respective state statutes and regulations.

A literature search was performed and reviewed to identify published articles regarding practice parameters and technical standards in HDR brachytherapy.

<sup>2</sup> An agreement state is any state with which the U.S. Nuclear Regulatory Commission or the U.S. Atomic Energy Commission has entered into an effective agreement under Subsection 274.b of the Atomic Energy Act of 1954, as amended (73 Stat. 689).

## Process of brachytherapy

The use of HDR brachytherapy is a complex multi-step process involving trained personnel who must work in concert to carry out a variety of interrelated activities. Communication among brachytherapy team members and well-defined procedures are essential for accurate and safe treatment. See the ACR–ASTRO Practice Parameter for Communication: Radiation Oncology [2].

### *Clinical evaluation*

The initial evaluation of the patient includes history, physical examination, review of pertinent diagnostic studies and reports, and communication with the referring physician and other physicians involved in the patient's care. The extent of the disease must be determined and recorded for staging. Staging facilitates treatment decisions, determines the prognosis of the patient, and enables a comparison of treatment results. The brachytherapy treatment target and organs at risk (OARs) should be determined and documented as part of the clinical evaluation. See the ACR–ASTRO Practice Parameter for Radiation Oncology (3) and the ACR–ASTRO Practice Parameter for Communication: Radiation Oncology (2).

### *Establishing treatment goals*

The goals of radiotherapy should be clearly documented. Treatment options and their relative benefits and risks should be discussed with the patient. The role of integrating other therapies, such as external beam radiotherapy, chemotherapy, immunotherapies, or hormonal manipulation, with brachytherapy must be considered and discussed when defining the course of treatment. A summary of the evaluation should be communicated to the referring physician and other physicians involved in the patient's care.

### *Informed consent*

Informed consent must be obtained and documented. See the ACR Practice Parameter on Informed Consent – Radiation Oncology (4).

### *Applicator placement*

Oncologic practice, including brachytherapy, may require the interaction of multiple specialists. The choice and placement of afterloading applicators, treatment planning, and treatment delivery are the responsibility of the radiation oncologist who is a licensed authorized user of radionuclides for medical purposes (5).

Each type of brachytherapy procedure has unique characteristics. The brachytherapy team should operate according to an established procedural system that has been

developed by the radiation oncologist and brachytherapy team members. This systematic approach to applicator insertion and source afterloading should include a description of preimplantation procedures, sedation or anesthesia needs, applicator option, and insertion techniques. Standard orders or care guidelines may enhance the systematic approach to the brachytherapy process. The physician should be responsible for applicator removal, including supervision or oversight of applicator removal if done by a trained member of the brachytherapy team.

### *Image acquisition*

In most applications, images of the implanted regions should be obtained. Imaging should be standardly performed for treatment planning and or to verify intended applicator position for intracavitary, interstitial, intraluminal, and complex surface brachytherapy. In certain instances (i.e., simple surface brachytherapy), clinical assessments without radiographic images may suffice for verification of applicator position, and clinical photography is encouraged in such situations. Images may be either 2-D (radiography based) or 3-D (ultrasound, computed tomography [CT], or magnetic resonance imaging [MRI] based). The authorized user should select the optimal imaging protocols for treatment planning. The purpose of these protocols is to acquire optimal images of the implant applicator, the treatment target, and the surrounding normal tissues. It is desirable to have 3-D spatial information so that the relationship of the target and surrounding critical organs can be visualized. The dose applied to the target and to the normal critical structures can then be determined and optimized. For instance, to help mitigate localization uncertainties, CT or MRI slice thicknesses on the order of 1 to 2 mm should be considered. Optimization of the diagnostic and functional imaging protocols in collaboration with diagnostic radiologists, nuclear medicine physicians, and imaging physicists is critical.

### *Treatment planning*

As the authorized user, the radiation oncologist must provide a signed and dated written directive (WD) to the planner (i.e., Qualified Medical Physicist, certified medical dosimetrist), as described in the regulations applicable to your state. The WD should include at least the treatment site, the radionuclide used, the dose per fraction, the total number of fractions, the planned total dose, and the dose specification (i.e., target volume, point, distance from lumen, or surface of applicator) as per NRC 10 CFR 35.40 (6). Based on anatomical targets and/or OARs as well as dose specifications, the planner creates a treatment plan. Computer-planning techniques to shape the dose distribution are widely available but should be used correctly to properly optimize the dosimetry in all

visualized planes. Verification of the resultant plan's dosimetric calculations must be performed using a secondary dose calculation prior to treatment delivery (see Section V). Once the radiation oncologist has reviewed and approved the plan and final adjustment to the WD (prescription) parameters has been made, the plan must be saved and locked using a unique user identification and password combination to prevent any unintended changes.

### *Treatment delivery*

Verification of patient identity is required prior to treatment delivery. A time-out should be performed and documented in the medical record prior to treatment delivery. At a minimum, the time-out should include patient identity, treatment site, laterality if applicable, dose per fraction, and fraction number of the total course.

Prior to each treatment, the radiation oncologist, Qualified Medical Physicist, or the radiation therapist should verify and document that the HDR afterloader transfer tubes are appropriately connected to each applicator channel. The patient and the room must be surveyed with pretreatment survey results documented in the patient records. The Qualified Medical Physicist should verify and document all treatment parameters at the HDR treatment console prior to source delivery, including the correspondence between planned source strength and afterloader source strength with appropriate corrections for source decay. In a multifraction treatment regimen using indwelling needles or catheters, where interfraction movement is possible, it is important to verify that the applicator is stable with regards to the target and OARs before delivery of subsequent fractions. In any single-fraction treatment it is also important to verify applicator positioning prior to treatment. Verification of applicator position can be performed by visualizing the applicator relative to the patient and/or with 2-D or 3-D imaging.

Radiation safety measures are mandatory for HDR procedures to ensure exposure is confined to the patient and that the source is properly delivered and returned to the radiation safe location within the afterloader. The radiation oncologist and the Qualified Medical Physicist must be in the immediate vicinity at all times while HDR brachytherapy is being administered. The patient must be continuously monitored by video and/or audio means during treatment, and the proper functioning of equipment directly must be supervised by the qualified personnel. Treatment delivery must be documented for each fraction and subject to detailed scrutiny as described in the patient and personnel safety section (see Section VI). At the end of each treatment, the patient and the room must be surveyed to confirm the source has been safely retracted into the afterloading device. The radiation survey results should be recorded and maintained per regulatory requirements.

### *Treatment summary*

At the conclusion of the course of treatment, a written treatment summary that includes a description of the brachytherapy technique and/or applicator(s), dose per fraction, number of fractions, total brachytherapy dose, cumulative dose to the target and OAR, and dose specification and total dose of external beam radiotherapy, if given, should be generated. There should also be a brief outline of the clinical course, acute toxicities or procedure complications, if any, and a plan for patient follow-up care. See the ACR–ASTRO Practice Parameter for Communication: Radiation Oncology (2).

### *Follow-up evaluation*

Patients treated with HDR brachytherapy should be evaluated at regular intervals for disease status, procedure-related side effects, and radiation complications. Information about the patient's clinical status should be communicated to the primary, referring, and other appropriate physician(s).

### *Emergency procedures*

Emergency procedures that outline the actions taken by the radiation oncologist, Qualified Medical Physicist, radiation safety officer, and any additional members of the treatment team in the event a radioactive source does not retract, as planned, from the patient at the end of a HDR administration must be defined. Emergency procedures should be reviewed and documented with each member of the brachytherapy team at least annually.

### **Qualifications of personnel**

The HDR brachytherapy team includes the radiation oncologist(s), Qualified Medical Physicist, dosimetrist, radiation therapist, and/or nurse. An individual serving in the role of radiation safety officer should provide an independent regulatory oversight. HDR brachytherapy requires close coordination between all members of the team as radiation is given in relatively large doses per fraction in a short period of time. Errors in treatment leading to radiation misadministration can happen quickly with serious consequences. Communication among team members and well-defined procedures for performing HDR brachytherapy are thus essential for accurate and safe treatment. Qualifications of the brachytherapy team include the credentials listed below.

#### *Radiation oncologist who also meets the requirements of the authorized user*

Certification in Radiation Oncology or Therapeutic Radiology by the American Board of Radiology, the American Osteopathic Board of Radiology, the Royal College of



Physicians and Surgeons of Canada (RCPSC), or the Collège des Médecins du Québec, or certification in Radiology by the American Board of Radiology of a physician who confines his/her professional practice to radiation oncology (5) or

Satisfactory completion of a residency program in radiation oncology approved by the Accreditation Council for Graduate Medical Education (ACGME), the RCPSC, the Collège des Médecins du Québec, or the American Osteopathic Association (AOA).

#### *Qualified medical physicist*

For the qualifications of the Qualified Medical Physicists, see the ACR–AAPM Technical Standard for the Performance of High-Dose-Rate Brachytherapy Physics (7).

#### *Medical dosimetrist*

Board certification by the Medical Dosimetrist Certification Board is recommended.

#### *Radiation therapist*

The radiation therapist must fulfill state licensing requirements and should have American Registry of Radiologic Technologists (ARRT) certification in radiation therapy.

#### *Nurse*

The nurse must fulfill state licensing requirements.

#### *Continuing education program*

Continuing medical education (CME) programs should include radiation oncologists, Qualified Medical Physicists, dosimetrists, radiation therapists, nurses, and radiotherapy staff. Radiation safety programs should also include hospital-based personnel who will be involved with brachytherapy patients. Educational programs used for both initial training and retraining must cover the following:

The safe operation, including emergency procedures, of HDR applicators and HDR remote afterloading equipment and sources as appropriate to the individual's responsibilities

Treatment techniques and new developments in radiation oncology and brachytherapy

The program should be in accordance with the ACR Practice Parameter for Continuing Medical Education (CME) (8).

The Medical Director of Radiation Oncology is responsible for the institution and ongoing supervision of continuing quality improvement (CQI) as described in the ACR–ASTRO Practice Parameter for Radiation Oncology (3).

It is the responsibility of the Medical Director to identify problems, see that actions are taken, and evaluate the effectiveness of the actions. The Medical Director will designate appropriate personnel to constitute the CQI Committee that will review HDR brachytherapy as part of the CQI meeting agenda. Refer to the ACR–ASTRO Practice Parameter for Radiation Oncology (3) for a detailed description of CQI Committee functions.

### **Patient selection criteria**

#### *Cervical cancer*

Brachytherapy is an essential modality in the definitive treatment of cervical cancer as there is improved survival compared with advanced techniques of external beam radiotherapy (9,10). Brachytherapy is given in conjunction with external beam radiotherapy with or without concurrent chemotherapy for locally advanced cervical cancer. Omission of chemotherapy can be considered for patients with early-stage disease in whom radical hysterectomy is medically contraindicated. International randomized trials and meta-analyses have concluded that HDR brachytherapy is equivalent to low-dose-rate (LDR) brachytherapy for local control, survival, and toxicity. Treatment planning is an integral part of cervical cancer brachytherapy because of the need for high curative doses to the cervix and paracervical tumor and the close proximity of the normal pelvic organs. 3-D image-based brachytherapy should be performed with the applicator in place, preferably with incorporation of MRI given the superior soft tissue delineation of the clinical target volume (11). MRI may be performed at a time prior to applicator placement with incorporation of findings into a CT-based treatment plan, or, more ideally, MRI may be performed with the applicator in place. A high-risk clinical target volume (HR-CTV) is commonly generated for dose specification, which consists of residual gross disease, cervix, and regions of regressed disease with intermediate signal on T2-weighted MRI (grey zones) (12). If MRI cannot be performed proximate to the time of implant, then 3-D imaging with CT or ultrasound should be utilized to delineate the target volume. Cervical brachytherapy is most commonly delivered with intracavitary applicators with or without interstitial needles. For more advanced disease, brachytherapy may also be delivered with a perineal template or free-hand technique with interstitial needles and an intrauterine tandem. Intracavity or interstitial brachytherapy is used postoperatively in some patients following hysterectomy (12–25).

#### *Endometrial cancer*

Vaginal brachytherapy, with or without external beam radiotherapy, is frequently used following surgical staging in the treatment of patients with early endometrial carcinoma. Vaginal brachytherapy is an effective means of

reducing the risk of a vaginal recurrence with a low risk of morbidity. Brachytherapy is also used for patients with recurrent endometrial carcinoma and, in this setting, application may be intracavitary or interstitial based on tumor thickness and depth of invasion. Brachytherapy is routinely used following external beam radiotherapy in previously unirradiated patients with recurrent disease. Definitive radiotherapy with brachytherapy with or without external beam radiotherapy may be considered for patients with medically inoperable endometrial carcinoma (14,16–22).

#### *Vaginal cancer*

Brachytherapy is used alone or in combination with external beam radiotherapy with or without concurrent chemotherapy in the curative treatment of cancers of the vagina. Depending on the extent of initial disease and residual disease following external beam radiotherapy, brachytherapy may be either intracavitary or interstitial (13,15).

#### *Bile duct*

Postoperative radiotherapy may be helpful in patients with positive margins or positive nodes. Intraluminal or interstitial brachytherapy can be used as a boost following external beam radiotherapy to areas of close or positive margin. External beam radiotherapy plus brachytherapy can be effective palliation for patients with unresectable disease. There is evidence that radiotherapy can provide long-term local control and that dose escalation with brachytherapy may be important to yield improved outcomes. Intraluminal brachytherapy alone can be used to palliate biliary obstruction along with percutaneous drainage (26–28).

#### *Esophagus*

HDR intraluminal brachytherapy has been used in the treatment of esophageal cancer, both for palliation and as a component of a definitive regimen (29). In the definitive setting, HDR brachytherapy has most commonly been used in combination with external beam radiotherapy, though brachytherapy alone may be adequate in the subset of cancers confined to the mucosal layer of the esophagus (30–32). The improvement in local control with the addition of HDR brachytherapy must be balanced against the risk for treatment-related morbidity in each individual case.

#### *Lung/Bronchus/Trachea*

HDR brachytherapy has been used to treat malignancies involving the central lung, bronchus, and trachea. In definitive cases, it can be used alone or in conjunction with external beam radiotherapy (33–36). HDR brachytherapy also

has a well-established role in the palliation of primary and recurrent endobronchial lesions (37).

#### *Prostate*

HDR brachytherapy may be used as monotherapy or as a boost in combination with external beam radiotherapy for the treatment of prostate cancer. It may be used as monotherapy for low-risk and select patients with intermediate-risk disease (38–49) and as a boost in combination with external beam radiotherapy for unfavorable intermediate-risk or high-risk disease. In addition, HDR brachytherapy may be used to salvage local recurrence of disease after prior definitive radiotherapy (50–55). There is a separate ACR–ABS Practice Parameter for Transperineal Permanent Brachytherapy of Prostate Cancer (56).

#### *Breast*

HDR brachytherapy can be used as a boost to the tumor bed after conventional external beam radiotherapy, and it can also be used for delivering accelerated partial breast irradiation (APBI) as the sole postoperative radiation treatment (57–61). This approach treats a limited volume of breast tissue around the lumpectomy site over a short duration of time. Applicator insertion techniques include multicatheter interstitial tubes stabilized with buttons and various single-entry intracavitary devices (balloon catheters and other multichannel devices). Additionally, HDR brachytherapy can be noninvasively targeted to the lumpectomy bed by utilizing superficially placed applicators positioned according to mammographic image guidance (62–66). APBI is used for select patients with early breast cancer or in situ disease. The role of radionuclide-based intraoperative therapy in treating early-stage disease is being evaluated in clinical trials (67). In this approach, radiotherapy is administered to the tumor bed at the time of the lumpectomy procedure. Further information related to patient selection and indications is available from AS-TRO and ACR documents (68,69).

#### *Head and neck*

LDR brachytherapy has long played an important role in the treatment of head and neck malignancies. The same operative techniques may be used for HDR brachytherapy (70–81). Tumors in the head and neck affect important anatomic structures; therefore, careful attention to the preservation of normal tissue structure and function is needed. Multifraction regimens that avoid large doses per fraction have been recommended (82). Computer-based dose optimization, advances in radiation safety, and improved nursing care are important reasons why LDR brachytherapy is being supplanted by HDR brachytherapy, especially in head and neck brachytherapy where nursing

care is so important to patient comfort and quality outcomes (41,83–88). Interstitial, intracavitary, surface applications, and intraoperative techniques are applicable techniques. Head and neck brachytherapy may be applied as a boost treatment in combination with external beam radiotherapy as definitive therapy or as monotherapy for postoperative therapy in the event of close or positive margins. It may be used in any sites in the head and neck as primary curative treatment, salvage therapy, or reirradiation (89).

#### *Soft-tissue sarcoma*

HDR brachytherapy has a role in the treatment of soft-tissue sarcoma, typically as part of a multidisciplinary management plan with surgery as the primary intervention. It can be a part of definitive therapy (90–98), postoperative adjuvant therapy (99–101), intraoperative radiotherapy (91,102–104), and palliative treatment.

#### *Pediatric tumors*

HDR brachytherapy can be useful in managing pediatric tumors. There are potential long-term consequences of irradiation in the pediatric patient, which should be a primary consideration in treatment planning along with local disease control. There are major advantages to brachytherapy for avoiding irradiation to normal tissue and growth centers.

#### *Skin*

Although skin cancer can be treated using a variety of radiotherapy techniques, HDR brachytherapy offers unique dosimetric properties that may be useful for treating skin cancer over irregularly shaped and difficult to access skin surfaces (105–109). Both interstitial and plesiotherapy (surface applicators) techniques can be used and allow for safe hypofractionation of the treatment course. HDR brachytherapy can be used in combination with surgery for keloids (110–112).

#### *Intraoperative brachytherapy*

HDR brachytherapy catheters and/or other devices can be inserted at the time of open or minimally-invasive surgery. Such devices can be left in place for postoperative simulation dosimetry and fractionated treatment delivery in a brachytherapy suite or shielded room. The advantages of the fractionated approach are time allocation for wound healing, obtaining simulation imaging, achieving good dosimetry, and the dose fractionation for normal tissue tolerance. Alternatively, in a shielded operating room, applicators can be inserted after maximum tumor resection, and a single HDR fraction can be given to the surgical margin while the tumor bed is accessible and normal tissues can be displaced or shielded from the site of

treatment. Special intraoperative applicators have been developed that conform to various tumor bed configurations. These techniques may be used in a variety of tumor types and body sites (113,114).

#### *Anorectal*

Interstitial, intraluminal, or intraoperative HDR brachytherapy may be used in the treatment of anal and rectal cancers. This modality can be part of a preoperative approach for resectable or locally advanced rectal cancers (115,116) or for unresectable, inoperable, and recurrent disease. For anal cancers, HDR brachytherapy can be used as a boost after external beam radiotherapy (117) or as definitive treatment in selected cases. Both interstitial and intracavitary techniques have been used.

#### *Other indications*

The list of indications above is not comprehensive or exclusive. Brachytherapy can be applied and radiation accurately delivered to any site where there is localized disease. The indication may be curative or palliative. The individual radiation oncologist may find HDR brachytherapy beneficial in a variety of other tumor types and specific clinical situations (i.e., penis, bladder, urethra, vulva, central nervous system, ocular).

#### *Equipment*

HDR brachytherapy treatment is delivered with computerized robotic devices (remote afterloading devices) for reasons of radiation safety and precision of treatment delivery. They consist of a small radiation source of high specific activity attached to the end of a fine cable, a radiation-safe container, a motor drive, and sophisticated computer equipment for reliable execution of complex radiation treatment plans (i.e., instructions for where and how long the radiation source should be deployed). Equipment manufacturers offer a wide range of applicators for interstitial, intracavitary, intraluminal, and surface brachytherapy. The radiation source must be changed routinely (usually quarterly) to account for radioactive decay, and a maintenance contract is essential to ensure the equipment functions safely and correctly. A schedule of updating and replacing the applicators and transfer tubes should be implemented to address issues of wear and aging equipment. Computerized treatment planning is accomplished with specialized hardware and highly technical software compatible with the respective HDR brachytherapy system being used.

Periodic scheduled preventive maintenance is essential. The Qualified Medical Physicist supervising the quality improvement program is responsible for documenting the maintenance and repair of remote afterloading units, applicators, transfer tubes, and other equipment (see the ACR–

AAPM Technical Standard for the Performance of High-Dose-Rate Brachytherapy Physics) (7).

### Patient and personnel safety

Patient protection measures include those related to medical safety and radiation protection.

*Patient protection measures should include the following*

- 1 A radiation exposure monitoring program as required by the NRC or appropriate state agencies
- 2 Annual (re)training of staff in emergency procedures in case of equipment malfunction and in brachytherapy-specific quality management procedures
- 3 Charting systems for dose specification, definition, and delivery of treatment parameters and recording and summation of HDR brachytherapy and external beam radiotherapy treatment
- 4 A physics quality assurance program for ensuring accurate dose delivery to the patient
- 5 A system for the radiation oncologist and Qualified Medical Physicist to verify independently (by another person or another method) all brachytherapy parameters to be used in each procedure (source model, radionuclide source strength (activity), total dose, treatment duration, etc) prior to HDR brachytherapy treatment delivery
- 6 Routine leak testing of all sealed sources as required by regulatory agencies
- 7 Use of a hand-held radiation survey meter when initially entering the room before and after a source run

*Personnel safety measures should include the following*

1. A radiation exposure monitoring program as required by the NRC or appropriate state agencies
2. Routine leak testing of all sealed sources as required by regulatory agencies
3. Use of a hand-held radiation survey meter when initially entering the room before and after a source run
4. Appropriate safety equipment for use of sealed sources

### Documentation

Reporting should be in accordance with the ACR–ASTRO Practice Parameter for Communication: Radiation Oncology (2).

### Quality control and improvement, safety, infection control, and patient education

Policies and procedures related to quality, patient education, infection control, and safety should be developed and

implemented in accordance with the ACR Policy on Quality Control Improvement, Safety, Infection Control, and Patient Education appearing under the heading *ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education* on the ACR website (<https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement>).

### Summary

HDR brachytherapy is an important modality in the treatment of a variety of different malignancies. Its use allows for application of high doses of radiation to defined target volumes and allows relative sparing of adjacent critical structures. Coordination between the radiation oncologist and treatment planning staff and effective quality assurance procedures are important components of successful HDR brachytherapy programs.

### Reprint requests

[permissions@acr.org](mailto:permissions@acr.org)

### Disclosures

Dr. Harkenrider reports personal fees from Astra Zeneca, personal fees from American College of Radiation Oncology, from American Society of Radiation Oncology, non-financial support from Chicago Radiological Society, outside the submitted work; Dr. Brown reports personal fees and grants from Varian Medical Systems, outside the submitted work; Dr. Kamrava reports personal fees from Springer, outside the submitted work; Dr. Orio reports personal fees from Palette Life Sciences, outside the submitted work; Dr. Small Jr reports personal fees from Carl Zeiss Meditech, personal fees from Merck, personal fees from Varian, grants from University of Utah, other from NRG Oncology, outside the submitted work.

Collaborative Committee – members represent their societies in the initial and final revision of this practice parameter

<u>ACR</u>	<u>ASTRO</u>
Matthew M. Harkenrider, MD, Chair	Kevin Albuquerque MD, MS, FRCS
Mitchell Kamrava, MD	Derek Brown, PhD
Rakesh Patel, PhD	Michael Price, PhD
Premavathy Rassiah, PhD	Abhishek Solanki, MD

### ABS

Martin King, MD, PhD  
Firas Mourtada, MSE, PhD,  
DABR, FAAPM  
Peter Orio, DO, MS



Committee on Practice Parameters – Radiation Oncology  
(ACR Committee responsible for sponsoring the draft through the process)

Naomi R. Schechter, MD, Chair	Join Y. Luh, MD
Nathan H. J. Bittner, MD	Matthew Poggi, MD
Samuel T. Chao, MD	Helen A. Shih, MD
Neil B. Desai, MD	Paul E. Wallner, DO, FACR
Beth A Erickson-Wittmann, MD	Kristina L. Woodhouse, MD
Matthew Harkenrider, MD	Ying Xiao, PhD
Mark Hurwitz, MD	Sue S. Yom, MD, PhD

William Small, Jr, MD, FACR, Chair of the Commission on Radiation Oncology

#### Comments Reconciliation Committee

David C. Beyer, MD, FACR, Chair	Amy L. Kotsenas, MD, FACR
Kurt Schoppe, MD, Co-Chair	Firas Mourtada, MSE, PhD, DABR, FAAPM
Kevin Albuquerque MD, MS, FRCS	Peter Orio, DO, MS
Sushil Beriwal, MD	Rakesh Patel, Ph.D.
Derek Brown, PhD	Michael Price, PhD
Richard Duszak Jr., MD, FACR	Premavathy Rassiah, PhD
Matthew Harkenrider, MD	Naomi R. Schechter, MD
Christina E. Henson, MD	William Small, Jr., MD, FACR
Mitchell Kamrava, M.D.	Abhishek Solanki, MD
Martin King, MD, PhD	

\*As of May 2010, all radiation oncology collaborative parameters are approved by the ACR Council Steering Committee and the ACR Board of Chancellors and will not go through the ACR Council (ACR Resolution 8, 2010). The effective date is displayed below:

#### Development chronology for this practice parameter

1996 (Resolution 15)  
Revised 2000 (Resolution 23)  
Revised 2005 (Resolution 15)  
Amended 2006 (Resolution 16g, 36)  
Revised 2010 (Resolution 3)  
Amended 2014 (Resolution 39)  
Revised 2015 (CSC/BOC)  
Revised 2020 (CSC/BOC)

#### Acknowledgments

This practice parameter was revised according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (<https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards>) by the Committee on Practice Parameters – Radiation Oncology of the ACR Commission on Radiation Oncology in collaboration with the ABS.

#### References

- [1] Devlin PM. Brachytherapy applications and techniques. Lippincott Williams & Wilkins, Philadelphia, PA, 2006.
- [2] American College of Radiology. ACR-ASTRO practice parameter for communication: radiation oncology July 11, 2019. Available at <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Communication-RO.pdf?la=en> Accessed.
- [3] American College of Radiology. ACR-ASTRO practice parameter for radiation oncology July 11, 2019. Available at <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/RadOnc.pdf?la=en> Accessed.
- [4] American College of Radiology. ACR practice parameter on informed consent - radiation oncology July 11, 2019. Available at <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/InformedConsent-RO.pdf?la=en> Accessed.
- [5] United States Nuclear Regulatory Commission. Part 35 - medical use of byproduct material August 5, 2014. Available at <http://www.nrc.gov/reading-rm/doc-collections/cfr/part035/> Accessed.
- [6] United States Nuclear Regulatory Commission. § 35.40 Written directives August 5, 2014. Available at <http://www.nrc.gov/reading-rm/doc-collections/cfr/part035/> Accessed.
- [7] American College of Radiology. ACR-AAPM technical standard for the performance of high-dose-rate brachytherapy physics July 11, 2019. Available at <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/HDR-BrachyTS.pdf?la=en> Accessed.
- [8] American College of Radiology. ACR practice parameter for continuing medical education (CME) July 11, 2019. Available at <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CME.pdf?la=en> Accessed.
- [9] Gill BS, Lin JF, Krivak TC, et al. National Cancer Data Base analysis of radiation therapy consolidation modality for cervical cancer: the impact of new technological advancements. *Int J Radiat Oncol Biol Phys* 2014;90:1083–1090.
- [10] Karlsson J, Dreifaldt AC, Mordhorst LB, Sorbe B. Differences in outcome for cervical cancer patients treated with or without brachytherapy. *Brachytherapy* 2017;16:133–140.
- [11] Viswanathan AN, Dimopoulos J, Kirisits C, et al. Computed tomography versus magnetic resonance imaging-based contouring in cervical cancer brachytherapy: results of a prospective trial and preliminary guidelines for standardized contours. *Int J Radiat Oncol Biol Phys* 2007;68:491–498.
- [12] Haie-Meder C, Potter R, Van Limbergen E, et al. Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group (I): concepts and terms in 3D image based 3D treatment planning in cervix cancer brachytherapy with emphasis on MRI assessment of GTV and CTV. *Radiation Oncol* 2005;74:235–245.
- [13] Beriwal S, Demanes DJ, Erickson B, et al. American Brachytherapy Society consensus guidelines for interstitial brachytherapy for vaginal cancer. *Brachytherapy* 2012;11:68–75.
- [14] Fayed A, Mutch DG, Rader JS, et al. Comparison of high-dose-rate and low-dose-rate brachytherapy in the treatment of endometrial carcinoma. *Int J Radiat Oncol Biol Phys* 2007;67:480–484.
- [15] Frank SJ, Jhingran A, Levenback C, Eifel PJ. Definitive radiation therapy for squamous cell carcinoma of the vagina. *Int J Radiat Oncol Biol Phys* 2005;62:138–147.
- [16] Harkenrider MM, Block AM, Alektiar KM, et al. American brachytherapy task group report: adjuvant vaginal brachytherapy for early-stage endometrial cancer: a comprehensive review. *Brachytherapy* 2017;16:95–108.
- [17] Harkenrider MM, Grover S, Erickson BA, et al. Vaginal brachytherapy for postoperative endometrial cancer: 2014 Survey of the American Brachytherapy Society. *Brachytherapy* 2016;15:23–29.
- [18] Klopp A, Smith BD, Alektiar K, et al. The role of postoperative radiation therapy for endometrial cancer: executive summary of an American Society for Radiation Oncology evidence-based guideline. *Practical radiation oncology* 2014;4:137–144.
- [19] Pearcey RG, Petereit DG. Post-operative high dose rate brachytherapy in patients with low to intermediate risk endometrial cancer. *Radiation Oncol* 2000;56:17–22.
- [20] Schwarz JK, Beriwal S, Esthappan J, et al. Consensus statement for brachytherapy for the treatment of medically inoperable endometrial cancer. *Brachytherapy* 2015;14:587–599.

- [21] Small W Jr, Beriwal S, Demanes DJ, et al. American Brachytherapy Society consensus guidelines for adjuvant vaginal cuff brachytherapy after hysterectomy. *Brachytherapy* 2012;11:58–67.
- [22] Small W Jr, Erickson B, Kwakwa F. American Brachytherapy Society survey regarding practice patterns of postoperative irradiation for endometrial cancer: current status of vaginal brachytherapy. *Int J Radiat Oncol Biol Phys* 2005;63:1502–1507.
- [23] Harkenrider MM, Alite F, Silva SR, Small W Jr. Image-Based Brachytherapy for the Treatment of Cervical Cancer. *Int J Radiat Oncol Biol Phys* 2015;92:921–934.
- [24] Potter R, Tanderup K, Kirisits C, et al. The EMBRACE II study: the outcome and prospect of two decades of evolution within the GEC-ESTRO GYN working group and the EMBRACE studies. *Clin Transl Radiat Oncol* 2018;9:48–60.
- [25] Sturdza A, Potter R, Fokdal LU, et al. Image guided brachytherapy in locally advanced cervical cancer: improved pelvic control and survival in RetroEMBRACE, a multicenter cohort study. *Radiother Oncol* 2016;120:428–433.
- [26] Crane CH, Macdonald KO, Vauthey JN, et al. Limitations of conventional doses of chemoradiation for unresectable biliary cancer. *Int J Radiat Oncol Biol Phys* 2002;53:969–974.
- [27] Czito BG, Anscher MS, Willett CG. Radiation therapy in the treatment of cholangiocarcinoma. *Oncology (Williston Park)* 2006;20:873–884 discussion 86–8, 93–5.
- [28] Erickson B, Subir N. Extrahepatic bile duct and liver cancer. In: Nag S, editor. Principles and practice of brachytherapy. Armonk, NY: Futura Publishing Co.; 1997. p. 367–91.
- [29] Sur RK, Levin CV, Donde B, et al. Prospective randomized trial of HDR brachytherapy as a sole modality in palliation of advanced esophageal carcinoma—an International Atomic Energy Agency study. *Int J Radiat Oncol Biol Phys* 2002;53:127–133.
- [30] Brunner TB, Rupp A, Melzner W, et al. Esophageal cancer. A prospective phase II study of concomitant-boost external beam chemoradiation with a top-up endoluminal boost. *Strahlentherapie und Onkologie: Organ der Deutschen Röntgengesellschaft ... [et al]* 2008;184:15–22.
- [31] Murakami Y, Nagata Y, Nishibuchi I, et al. Long-term outcomes of intraluminal brachytherapy in combination with external beam radiotherapy for superficial esophageal cancer. *International journal of clinical oncology* 2012;17:263–271.
- [32] Yamada K, Murakami M, Okamoto Y, et al. Treatment results of chemoradiotherapy for clinical stage I (T1N0M0) esophageal carcinoma. *Int J Radiat Oncol Biol Phys* 2006;64:1106–1111.
- [33] Aumont-le Guilcher M, Prevost B, Sunyach MP, et al. High-dose-rate brachytherapy for non-small-cell lung carcinoma: a retrospective study of 226 patients. *Int J Radiat Oncol Biol Phys* 2011;79:1112–1116.
- [34] Hennequin C, Bleichner O, Tredaniel J, et al. Long-term results of endobronchial brachytherapy: a curative treatment? *Int J Radiat Oncol Biol Phys* 2007;67:425–430.
- [35] Kawamura H, Ebara T, Katoh H, et al. Long-term results of curative intraluminal high dose rate brachytherapy for endobronchial carcinoma. *Radiat Oncol* 2012;7:112.
- [36] Niemoeller OM, Pollinger B, Niyazi M, et al. Mature results of a randomized trial comparing two fractionation schedules of high dose rate endoluminal brachytherapy for the treatment of endobronchial tumors. *Radiat Oncol* 2013;8:8.
- [37] Ozkok S, Karakoyun-Celik O, Goksel T, et al. High dose rate endobronchial brachytherapy in the management of lung cancer: response and toxicity evaluation in 158 patients. *Lung Cancer* 2008;62:326–333.
- [38] Corner C, Rojas AM, Bryant L, et al. A Phase II study of high-dose-rate afterloading brachytherapy as monotherapy for the treatment of localized prostate cancer. *Int J Radiat Oncol Biol Phys* 2008;72:441–446.
- [39] Demanes DJ, Ghilezan MI. High-dose-rate brachytherapy as monotherapy for prostate cancer. *Brachytherapy* 2014.
- [40] Hoskin P, Rojas A, Ostler P, et al. High-dose-rate brachytherapy with two or three fractions as monotherapy in the treatment of locally advanced prostate cancer. *Radiother Oncol* 2014.
- [41] Yamazaki H, Inoue T, Yoshida K, et al. Brachytherapy for early oral tongue cancer: low dose rate to high dose rate. *J Radiat Res (Tokyo)* 2003;44:37–40.
- [42] Demanes DJ, Rodriguez RR, Schour L, et al. High-dose-rate intensity-modulated brachytherapy with external beam radiotherapy for prostate cancer: California endocurietherapy's 10-year results. *Int J Radiat Oncol Biol Phys* 2005;61:1306–1316.
- [43] Galalae RM, Zakikhany NH, Geiger F, et al. The 15-year outcomes of high-dose-rate brachytherapy for radical dose escalation in patients with prostate cancer - a benchmark for high-tech external beam radiotherapy alone? *Brachytherapy* 2014;13:117–122.
- [44] Rogers CL, Alder SC, Rogers RL, et al. High dose brachytherapy as monotherapy for intermediate risk prostate cancer. *The J urol* 2012;187:109–116.
- [45] Yoshioka Y, Suzuki O, Otani Y, et al. High-dose-rate brachytherapy as monotherapy for prostate cancer: technique, rationale and perspective. *J contemporary brachytherapy* 2014;6:91–98.
- [46] Zamboglou N, Tselis N, Baltas D, et al. High-dose-rate interstitial brachytherapy as monotherapy for clinically localized prostate cancer: treatment evolution and mature results. *Int J Radiat Oncol Biol Phys* 2013;85:672–678.
- [47] Jawad MS, Dilworth JT, Gustafson GS, et al. Outcomes associated with 3 treatment schedules of high-dose-rate brachytherapy monotherapy for favorable-risk prostate cancer. *Int J Radiat Oncol Biol Phys* 2016;94:657–666.
- [48] Frank SJ, Pugh TJ, Blanchard P, et al. Prospective Phase 2 trial of permanent seed implantation prostate brachytherapy for intermediate-risk localized prostate cancer: efficacy, toxicity, and quality of life outcomes. *Int J Radiat Oncol Biol Phys* 2018;100:374–382.
- [49] Kukiela AM, Dabrowski T, Walasek T, et al. High-dose-rate brachytherapy as a monotherapy for prostate cancer—Single-institution results of the extreme fractionation regimen. *Brachytherapy* 2015;14:359–365.
- [50] Chen CP, Weinberg V, Shinohara K, et al. Salvage HDR brachytherapy for recurrent prostate cancer after previous definitive radiation therapy: 5-year outcomes. *Int J Radiat Oncol Biol Phys* 2013;86:324–329.
- [51] Yamada Y, Kollmeier MA, Pei X, et al. A Phase II study of salvage high-dose-rate brachytherapy for the treatment of locally recurrent prostate cancer after definitive external beam radiotherapy. *Brachytherapy* 2014;13:111–116.
- [52] Jiang P, van der Horst C, Kimmig B, et al. Interstitial high-dose-rate brachytherapy as salvage treatment for locally recurrent prostate cancer after definitive radiation therapy: Toxicity and 5-year outcome. *Brachytherapy* 2017;16:186–192.
- [53] Murgic J, Morton G, Loblaw A, et al. Focal salvage high dose-rate brachytherapy for locally recurrent prostate cancer after primary radiation therapy failure: results from a prospective clinical trial. *Int J Radiat Oncol Biol Phys* 2018;102:561–567.
- [54] Resch A, Potter R, Van Limbergen E, et al. Long-term results (10 years) of intensive breast conserving therapy including a high-dose and large-volume interstitial brachytherapy boost (LDR/HDR) for T1/T2 breast cancer. *Radiother Oncol* 2002;63:47–58.
- [55] Schroeder TM, Liem B, Sampath S, et al. Early breast cancer with positive margins: excellent local control with an upfront brachytherapy boost. *Breast Cancer Res Treat* 2012;134:719–725.
- [56] American College of Radiology. *ACR-ABS practice parameter for transperineal permanent brachytherapy of prostate cancer* July 11, 2019. Available at <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Brachy-Prostate.pdf?la=en> Accessed.
- [57] Benitez PR, Keisch ME, Vicini F, et al. Five-year results: the initial clinical trial of MammoSite balloon brachytherapy for partial breast irradiation in early-stage breast cancer. *Am J Surg* 2007;194:456–462.

- [58] Shah C, Vicini F, Shaitelman SF, et al. The American Brachytherapy Society consensus statement for accelerated partial-breast irradiation. *Brachytherapy* 2018;17:154–170.
- [59] Coles CE, Griffin CL, Kirby AM, et al. Partial-breast radiotherapy after breast conservation surgery for patients with early breast cancer (UK IMPORT LOW trial): 5-year results from a multicentre, randomised, controlled, phase 3, non-inferiority trial. *Lancet* 2017;390:1048–1060.
- [60] Schafer R, Strnad V, Polgar C, et al. Quality-of-life results for accelerated partial breast irradiation with interstitial brachytherapy versus whole-breast irradiation in early breast cancer after breast-conserving surgery (GEC-ESTRO): 5-year results of a randomised, phase 3 trial. *Lancet Oncol* 2018;19:834–844.
- [61] Strnad V, Hildebrandt G, Potter R, et al. Accelerated partial breast irradiation: 5-year results of the German-Austrian multicenter phase II trial using interstitial multicatheter brachytherapy alone after breast-conserving surgery. *Int J Radiat Oncol Biol Phys* 2011;80:17–24.
- [62] Hamid S, Rocchio K, Arthur D, et al. A multi-institutional study of feasibility, implementation, and early clinical results with non-invasive breast brachytherapy for tumor bed boost. *Int J Radiat Oncol Biol Phys* 2012;83:1374–1380.
- [63] Leonard KL, Hepel JT, Styczynski JR, et al. Breast boost using noninvasive image-guided breast brachytherapy vs. external beam: a 2:1 matched-pair analysis. *Clin Breast Cancer* 2013;13:455–459.
- [64] Hepel JT, Hiatt JR, Sha S, et al. The rationale, technique, and feasibility of partial breast irradiation using noninvasive image-guided breast brachytherapy. *Brachytherapy* 2014;13:493–501.
- [65] Hepel JT, Yashar C, Leonard KL, et al. Five fraction accelerated partial breast irradiation using noninvasive image-guided breast brachytherapy: Feasibility and acute toxicity. *Brachytherapy* 2018;17:825–830.
- [66] Schuster J, Chipko C, Kasper M, et al. Updated feasibility and reproducibility results of multi-institutional study of noninvasive breast tumor bed boost. *Brachytherapy* 2016;15:804–811.
- [67] Orecchia R, Leonardo MC. Intraoperative radiation therapy: is it a standard now? *Breast* 2011;20(Suppl 3):S111–S115.
- [68] Smith BD, Arthur DW, Buchholz TA, et al. Accelerated partial breast irradiation consensus statement from the American Society for Radiation Oncology (ASTRO). *Int J Radiat Oncol Biol Phys* 2009;74:987–1001.
- [69] White JR, Halberg FE, Rabinovitch R, et al. American College of Radiology appropriateness criteria on conservative surgery and radiation: stages I and II breast carcinoma. *J Am Coll Radiol* 2008;5:701–713.
- [70] Harrison LB, Lee HJ, Pfister DG, et al. Long term results of primary radiotherapy with/without neck dissection for squamous cell cancer of the base of tongue. *Head Neck* 1998;20:668–673.
- [71] Harrison LB, Zelefsky MJ, Armstrong JG, et al. Performance status after treatment for squamous cell cancer of the base of tongue—a comparison of primary radiation therapy versus primary surgery. *Int J Radiat Oncol Biol Phys* 1994;30:953–957.
- [72] Cano ER, Lai SY, Caylakli F, et al. Management of squamous cell carcinoma of the base of tongue with chemoradiation and brachytherapy. *Head Neck* 2009;31:1431–1438.
- [73] Levendag P, Nijdam W, Noever I, et al. Brachytherapy versus surgery in carcinoma of tonsillar fossa and/or soft palate: late adverse sequelae and performance status: can we be more selective and obtain better tissue sparing? *Int J Radiat Oncol Biol Phys* 2004;59:713–724.
- [74] Levendag PC, Nijdam WM, van Moolenburgh SE, et al. Interstitial radiation therapy for early-stage nasal vestibule cancer: a continuing quest for optimal tumor control and cosmesis. *Int J Radiat Oncol Biol Phys* 2006;66:160–169.
- [75] Martinez-Monge R, Pagola Divasson M, Cambeiro M, et al. Determinants of complications and outcome in high-risk squamous cell head-and-neck cancer treated with perioperative high-dose rate brachytherapy (PHDRB). *Int J Radiat Oncol Biol Phys* 2011;81:e245–e254.
- [76] Matsumoto K, Sasaki T, Shioyama Y, et al. Treatment outcome of high-dose-rate interstitial radiation therapy for patients with stage I and II mobile tongue cancer. *Japanese journal of clinical oncology* 2013;43:1012–1017.
- [77] Mazon JJ, Ardiet JM, Haie-Meder C, et al. GEC-ESTRO recommendations for brachytherapy for head and neck squamous cell carcinomas. *Radiother Oncol* 2009;91:150–156.
- [78] Pernot M, Hoffstetter S, Peiffert D, et al. Role of interstitial brachytherapy in oral and oropharyngeal carcinoma: reflection of a series of 1344 patients treated at the time of initial presentation. *Otolaryngology-head and neck surg: off j Am Academy of Otolaryngol-Head and Neck Surg* 1996;115:519–526.
- [79] Takacs-Nagy Z, Oberna F, Koltai P, et al. Long-term outcomes with high-dose-rate brachytherapy for the management of base of tongue cancer. *Brachytherapy* 2013;12:535–541.
- [80] Yamazaki H, Inoue T, Yoshida K, et al. Comparison of three major radioactive sources for brachytherapy used in the treatment of node negative T1-T3 oral tongue cancer: influence of age on outcome. *Anticancer res* 2007;27:491–497.
- [81] Yamazaki H, Yoshida K, Yoshioka Y, et al. High dose rate brachytherapy for oral cancer. *J radiation res* 2013;54:1–17.
- [82] Nag S, Cano ER, Demanes DJ, et al. The American Brachytherapy Society recommendations for high-dose-rate brachytherapy for head-and-neck carcinoma. *Int J Radiat Oncol Biol Phys* 2001;50:1190–1198.
- [83] Glatzel M, Buntzel J, Schroder D, Kuttner K, Frohlich D. High-dose-rate brachytherapy in the treatment of recurrent and residual head and neck cancer. *Laryngoscope* 2002;112:1366–1371.
- [84] Inoue T, Inoue T, Teshima T, et al. Phase III trial of high and low dose rate interstitial radiotherapy for early oral tongue cancer. *Int J Radiat Oncol Biol Phys* 1996;36:1201–1204.
- [85] Kakimoto N, Inoue T, Inoue T, et al. Results of low- and high-dose-rate interstitial brachytherapy for T3 mobile tongue cancer. *Radiother Oncol* 2003;68:123–128.
- [86] Leung TW, Wong VY, Kwan KH, et al. High dose rate brachytherapy for early stage oral tongue cancer. *Head Neck* 2002;24:274–281.
- [87] Patra NB, Goswami J, Basu S, et al. Outcomes of high dose rate interstitial boost brachytherapy after external beam radiation therapy in head and neck cancer—an Indian (single institutional) learning experience. *Brachytherapy* 2009;8:248–254.
- [88] Pellizzon AC, dos Santos Novaes PE, Conte Maia MA, et al. Interstitial high-dose-rate brachytherapy combined with cervical dissection on head and neck cancer. *Head Neck* 2005;27:1035–1041.
- [89] Hepel JT, Syed AM, Puthawala A, et al. Salvage high-dose-rate (HDR) brachytherapy for recurrent head-and-neck cancer. *Int J Radiat Oncol Biol Phys* 2005;62:1444–1450.
- [90] Goodman KA, Wolden SL, LaQuaglia MP, et al. Intraoperative high-dose-rate brachytherapy for pediatric solid tumors: a 10-year experience. *Brachytherapy* 2003;2:139–146.
- [91] Martinez-Monge R, Garran C, Cambeiro M, et al. Feasibility report of conservative surgery, perioperative high-dose-rate brachytherapy (PHDRB), and low-to-moderate dose external beam radiation therapy (EBRT) in pediatric sarcomas. *Brachytherapy* 2004;3:196–200.
- [92] Nag S, Tippin D, Ruymann FB. Intraoperative high-dose-rate brachytherapy for the treatment of pediatric tumors: the Ohio State University experience. *Int J Radiat Oncol Biol Phys* 2001;51:729–735.
- [93] Itami J, Sumi M, Beppu Y, et al. High-dose rate brachytherapy alone in postoperative soft tissue sarcomas with close or positive margins. *Brachytherapy* 2010;9:349–353.
- [94] Laskar S, Bahl G, Puri A, et al. Perioperative interstitial brachytherapy for soft tissue sarcomas: prognostic factors and long-term results of 155 patients. *Ann surg oncol* 2007;14:560–567.

- [95] Nag S, Tippin D, Ruymann FB. Long-term morbidity in children treated with fractionated high-dose-rate brachytherapy for soft tissue sarcomas. *J pediatric hematology/oncology* 2003;25:448–452.
- [96] Petera J, Soumarova R, Ruzickova J, et al. Perioperative hyperfractionated high-dose rate brachytherapy for the treatment of soft tissue sarcomas: multicentric experience. *Annals of surgical oncology* 2010;17:206–210.
- [97] Raut C, Albert M. Soft tissue sarcoma brachytherapy. Brachytherapy applications and techniques. Devlin PM, editor. 1st ed.. Lippincott Williams & Wilkins, Philadelphia, PA, 2006.
- [98] Viani GA, Novaes PE, Jacinto AA, et al. High-dose-rate brachytherapy for soft tissue sarcoma in children: a single institution experience. *Radiat Oncol* 2008;3:9.
- [99] Bolling T, Schuller P, Distelmaier B, et al. Perioperative high-dose rate brachytherapy using a bendy applicator (flab): treatment results of 74 patients. *Anticancer res* 2008;28:3885–3890.
- [100] Koizumi M, Inoue T, Yamazaki H, et al. Perioperative fractionated high-dose rate brachytherapy for malignant bone and soft tissue tumors. *Int J Radiat Oncol Biol Phys* 1999;43:989–993.
- [101] Pohar S, Haq R, Liu L, et al. Adjuvant high-dose-rate and low-dose-rate brachytherapy with external beam radiation in soft tissue sarcoma: a comparison of outcomes. *Brachytherapy* 2007;6:53–57.
- [102] Alektiar KM, Hu K, Anderson L, et al. High-dose-rate intraoperative radiation therapy (HDR-IORT) for retroperitoneal sarcomas. *Int J Radiat Oncol Biol Phys* 2000;47:157–163.
- [103] Dziewirski W, Rutkowski P, Nowecki ZI, et al. Surgery combined with intraoperative brachytherapy in the treatment of retroperitoneal sarcomas. *Ann surgical oncology* 2006;13:245–252.
- [104] Rachbauer F, Sztankay A, Kreczy A. High-dose-rate intraoperative brachytherapy (IOHDR) using flab technique in the treatment of soft tissue sarcomas. *Strahlentherapie und Onkologie: Organ der Deutschen Röntgengesellschaft ... [et al]* 2003;179:480–485.
- [105] Fabrini MG, Perrone F, De Liguoro M, Cionini L. High-dose-rate brachytherapy in a large squamous cell carcinoma of the hand. *Brachytherapy* 2008;7:270–275.
- [106] Somanchi BV, Stanton A, Webb M, et al. Hand function after high dose rate brachytherapy for squamous cell carcinoma of the skin of the hand. *Clin Oncol (R Coll Radiol)* 2008;20:691–697.
- [107] Lipman D, Verhoef LC, Takes RP, Kaanders JH, Janssens GO. Outcome and toxicity profile after brachytherapy for squamous cell carcinoma of the nasal vestibule. *Head Neck* 2015;37:1297–1303.
- [108] Pop LA, Kaanders JH, Heinerman EC. High dose rate intracavitary brachytherapy of early and superficial carcinoma of the nasal vestibule as an alternative to low dose rate interstitial radiation therapy. *Radiother Oncol* 1993;27:69–72.
- [109] Vavassori A, Riva G, Durante S, et al. Mould-based surface high-dose-rate brachytherapy for eyelid carcinoma. *J contemporary brachytherapy* 2019;11:443–448.
- [110] Guix B, Henriquez I, Andres A, et al. Treatment of keloids by high-dose-rate brachytherapy: a seven-year study. *Int J Radiat Oncol Biol Phys* 2001;50:167–172.
- [111] Hoang D, Reznik R, Orgel M, et al. Surgical excision and adjuvant brachytherapy vs external beam radiation for the effective treatment of keloids: 10-year institutional retrospective analysis. *Aesthet Surg J* 2017;37:212–225.
- [112] Veen RE, Kal HB. Postoperative high-dose-rate brachytherapy in the prevention of keloids. *Int J Radiat Oncol Biol Phys* 2007;69:1205–1208.
- [113] Hu KS, Enker WE, Harrison LB. High-dose-rate intraoperative irradiation: current status and future directions. *Semin Radiat Oncol* 2002;12:62–80.
- [114] Nag S, Gunderson LL, Willett CG, et al. Intraoperative irradiation with electron-beam or high-dose-rate brachytherapy. In: Gunderson LL, Willett CG, Harrison LB, Calvo FA, editors. Intraoperative irradiation: techniques and results. Totowa, NJ: Humana Press; 1999. p. 111–30.
- [115] Vuong T, Belliveau PJ, Michel RP, et al. Conformal preoperative endorectal brachytherapy treatment for locally advanced rectal cancer: early results of a phase I/II study. *Dis Colon Rectum* 2002;45:1486–1493 discussion 93–5.
- [116] Vuong T, Devic S, Podgorsak E. High dose rate endorectal brachytherapy as a neoadjuvant treatment for patients with resectable rectal cancer. *Clin Oncol (R Coll Radiol)* 2007;19:701–705.
- [117] Oehler-Janne C, Seifert B, Lutolf UM, et al. Clinical outcome after treatment with a brachytherapy boost versus external beam boost for anal carcinoma. *Brachytherapy* 2007;6:218–226.