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Contemporary image-guided cervical cancer brachytherapy: Consensus imaging recommendations from the Society of Abdominal Radiology and the American Brachytherapy Society

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ABSTRACT

PURPOSE: To present recommendations for the use of imaging for evaluation and procedural guidance of brachytherapy for cervical cancer patients.

METHODS: An expert panel comprised of members of the Society of Abdominal Radiology Uterine and Ovarian Cancer Disease Focused Panel and the American Brachytherapy Society jointly assessed the existing literature and provide data-driven guidance on imaging protocol development, interpretation, and reporting.

RESULTS: Image-guidance during applicator implantation reduces rates of uterine perforation by the tandem. Postimplant images may be acquired with radiography, computed tomography (CT), or magnetic resonance imaging (MRI), and CT or MRI are preferred due to a decrease in severe complications. Pre-brachytherapy T2-weighted MRI may be used as a reference for contouring the high-risk clinical target volume (HR-CTV) when CT is used for treatment planning. Reference CT and MRI protocols are provided for reference.

CONCLUSIONS: Image-guided brachytherapy in locally advanced cervical cancer is essential for optimal patient management. Various imaging modalities, including orthogonal radiographs, ultrasound, computed tomography, and magnetic resonance imaging, remain integral to the successful execution of image-guided brachytherapy. © 2022 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Image-guided brachytherapy; Cervical cancer brachytherapy; Magnetic resonance imaging; Computed tomography; Ultrasound; Structured reporting

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Abbreviations: ABS, American Brachytherapy Society; CT, computed tomography; CTV, clinical target volume; DWI, diffusion-weighted imaging; EBRT, external beam radiotherapy; FIGO, International Federation of Gynecology and Obstetrics; GEC-ESTRO, Gynaecological Groupe Européen de Curiethérapie-European Society for Radiotherapy & Oncology; HR-CTV, high-risk clinical target volume; ICRU, International Commission on Radiation Units and Measurements; IMRT, intensity modulated radiotherapy; MRI, magnetic resonance imaging; OAR, organ at risk; RT, radiotherapy; SAR, Society of Abdominal Radiology; TAUS, transabdominal ultrasound; TRUS, transrectal ultrasound; UOC DFP, Uterine and Ovarian Cancer Disease Focused Panel; US, ultrasound.

Summary: This document, generated by the Society for Abdominal Radiology and American Brachytherapy Society, provides guidance on imaging protocols, image interpretation and reporting for cervical cancer patients undergoing brachytherapy.

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Essentials

- Imaging is integral to optimal cervical cancer brachytherapy applicator placement and treatment planning. Images can be acquired in real time to guide the placement of applicators and interstitial needles, most frequently with ultrasound and, increasingly, with CT and/or MRI. Postimplant images obtained for the purposes of treatment planning and adjustment of applicator may be acquired with radiography, CT, or MRI.
- Ultrasound guidance for tandem insertion is recommended to reduce uterine perforation rates and to improve patient-specific tandem length and curvature selection.
- Once the tandem is inserted, MRI is preferred over CT for treatment planning, due to the superior soft tissue resolution of MRI that results in improved visualization of tumor and adjacent organs at risk. Axial and sagittal T2-weighted images, with the option of axial oblique images that align with the cervical anatomy or tandem, are recommended, with brachytherapy applicators in place, for treatment planning.
- When CT is used for treatment planning, the prebrachytherapy T2-weighted MRI should be used as a reference when contouring the high-risk clinical target volume (HR-CTV).
- Relative to radiography, image guided CT and MRI based treatment planning have been shown to improve patient outcomes, particularly when considering rates of ≥ Grade 3 genitourinary or gastrointestinal complications. CT and MRI are preferred for treatment planning over radiography if available.
- Radiologists should be aware of essential imaging findings if staffing ultrasound guided endocavitary implant placement and when interpreting postimplant CT and MRI in cervical cancer patients, to ensure appropriate applicator position and to exclude nontarget injury, including uterine perforation or injury to urinary bladder or rectum.

Introduction

Cancer of the uterine cervix is the second most common malignancy globally and the third most prevalent gynecologic malignancy in the United States (1,2). Cervical cancer has historically been staged based on histologic results from biopsy of the uterine cervix, with the most recent 2018 International Federation of Gynecology and Obstetrics (FIGO) guidelines incorporating findings from MRI, clinical exam and histopathology (3,4). The current FIGO staging criteria are summarized in Table 1, and example illustrations and MRI cases can be found in Fig. 1. Before the 2018 FIGO guidelines, cross-sectional imaging was not considered a factor in disease staging because clinical examination is the primary method employed for cervical cancer diagnosis worldwide. However, as emphasized in the updated FIGO staging, MRI is particularly valuable for accurate assessment of tumor size and extent of invasion, including presence of parametrial involvement (5,6).

Standard of care therapy for locally advanced cervical cancer

Surgery remains first line therapy for tumors measuring less than or equal to 4 cm which are confined to the uterine cervix. Locally advanced cervical cancer (Stage IB3 and greater) is treated with chemoradiotherapy, including external beam radiotherapy (EBRT) with concurrent platinum-based chemotherapy (7) followed by image-guided intracavitary brachytherapy with or without interstitial needles (8).

Brachytherapy

Current practice guidelines from the American Society for Radiation Oncology (ASTRO) recommend utilizing brachytherapy for women with Stage IB3 or greater cervical cancer as part of a definitive radiotherapy (RT) regimen and in women with a positive vaginal margin after postoperative external beam radiation (8,9,10). Of note, brachytherapy boost doses to residual tumor after cisplatin-based chemotherapy and EBRT significantly improve 4-year cause-specific-survival and overall survival in patients with locally advanced cervical cancer as compared to EBRT alone (11). This is attributed to the high radiation doses delivered to the high-risk clinical target volume (HR-CTV, defined as the entire cervix plus all palpable disease and gross disease visible on MRI). Optimal image-guided therapy allows for local tumor dose escalation whereas minimizing the dose to the following organs at risk (OARs): the bladder, rectum, small bowel, uninvolved vagina, and sigmoid colon. During treatment, a radioactive source, typically iridium-192, is guided into intracavitary applicators or interstitial implants that are positioned in or near the tumor. In locally advanced cervical cancer (stages ≥IB3), the total recommended EBRT and brachytherapy dose to the HR-CTV is over 8500 cGy to at least 90% of the target volume (D90) in equivalents of 2 Gy per fraction (EQD2) (12). Patients with poor initial EBRT response or a large volume of residual disease after initial chemotherapy and EBRT may benefit from increasing the HR-CTV D90 coverage up to 9000 cGy during brachytherapy, depending upon the tumor location and OAR dose. Primary cervix tumor control is approximately

Table 1
2018 cervical cancer staging guidelines developed by the International Federation of Gynecology and Obstetrics (FIGO) [4]

FIGO stage and substage		Largest tumor diameter	Location and organ invasion
Stage I	IA1	< 3 mm	Confined to cervix
	IA2	3–5 mm	
	IB1	0.5–2 cm	
	IB2	2–4 cm	
	IB3	≥ 4 cm	
Stage II	IIA1	≤4 cm	Confined to upper 2/3rd of the vagina without parametrial invasion
	IIA2	>4 cm	
	IIB	No limit on tumor size or extent	Parametrial invasion not extending to the pelvic wall
Stage III	IIIA	No limit on tumor size or extent	Invades lower 1/3rd of the vagina
	IIIB		Involvement of pelvic wall and/or hydronephrosis present
	IIIC1		Pelvic lymph node metastases
	IIIC2		Para-aortic lymph node metastases
Stage IV	IVA	No limit on tumor size or extent	Mucosal invasion of bladder or rectum
	IVB		Distant metastases to nodal sites, lungs, or skeleton

90% using concurrent chemoradiotherapy and MRI-based brachytherapy (13).

Gynecological brachytherapy applicators

Brachytherapy for gynecologic cancers, including cervical cancer, typically employs an intrauterine tandem with two intravaginal ovoids, an intravaginal ring, or a vaginal cylinder (Fig. 2a–c). These applicators are hollow, allowing placement of a radioactive source by a remote afterloader for high-dose-rate or pulsed-dose rate brachytherapy. After placement of an intrauterine tandem, ovoids or a vaginal ring are placed against the cervix. The dose distribution from proper placement of these types of applicators has traditionally been termed "pear-shaped," referring to a morphology encompassing the uterus, cervix, and upper part of the vagina. This distribution treats the anatomy that would otherwise be removed with a class II or greater modified radical hysterectomy. For cervical tumors with extensive parametrial involvement or eccentric or asymmetric tumors that would not receive sufficient dose to the HR-CTV with intracavitary brachytherapy alone, interstitial applicators may be used to provide additional channels for the source, adjusting the radiation dose distribution (14). Interstitial applicators may be inserted freehand, via a transperineal template, or through specialized fenestrated vaginal or ovoid applicators (Fig. 2d). This can be leveraged to achieve a higher dose to the HR-CTV, whereas minimizing dose to the OARs (Fig. 3).

Benefits of 2D and 3D brachytherapy treatment planning

Imaging guidance for brachytherapy applicator insertion enables verification of proper applicator position and reduces the risk of uterine perforation during insertion. Ultrasound (US) serves as a complementary modality to CT or MRI for intrauterine tandem placement, permitting real time image-guidance during tandem insertion and reducing the risk of uterine perforation (15,16). Transabdominal or transrectal US can also improve the distribution of interstitial applicators and minimize the number of needles placed in the bladder or rectum (17). Historically, orthogonal radiographs were acquired to visualize the position of the metallic implants relative to bony landmarks (18). The primary, significant limitation of two-dimensional radiography for postimplant dosimetric planning relates to its inability to delineate residual tumor, adjacent organs at risk and other key pelvic anatomical structures. As a result, radiographic planning has traditionally relied upon dose prescriptions based upon fixed distances from the intrauterine tandem and ovoids that cannot account for patient specific anatomical considerations and is not recommended for treatment planning unless CT and/or MRI are unavailable.

The advent of computed tomography (CT)-based planning allowed for 3D contouring of patient-specific CTVs and OARs for true three-dimensional (3D) treatment planning. This method enabled calculation of dose volume histograms, improved target coverage, and reduced risk of normal tissue toxicities (19–23). As compared to CT, the superior soft tissue contrast of magnetic resonance imaging (MRI), particularly with T2-weighted pulse sequences, has further improved 3D planning and is currently the preferred imaging modality for image-guided cervical cancer brachytherapy (24). The RetroEMBRACE multi-center retrospective analysis demonstrated that 3D treatment planning based on MRI or hybrid MRI/CT resulted in lower rates of local and regional recurrence compared to conventional brachytherapy (25).

Methodology

The literature search for this review and intersociety consensus consisted of English-language original publica-

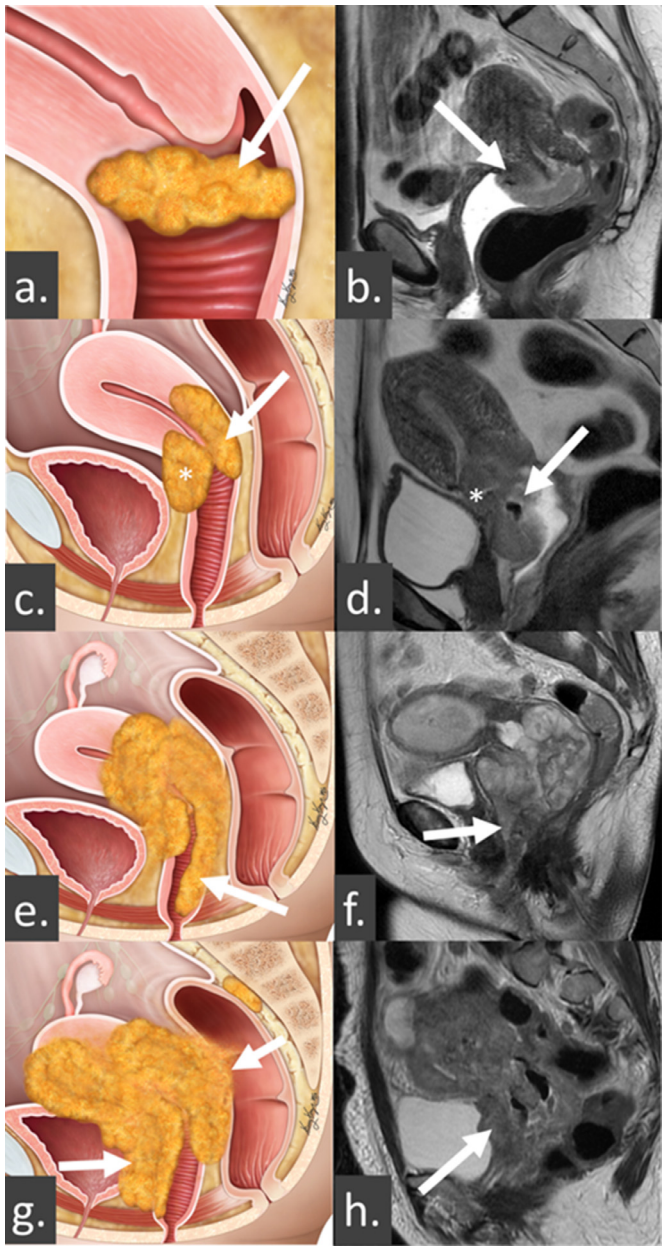

Fig. 1. FIGO stage-specific cervical cancer findings, with illustrations and corresponding MRI findings in patients treated with definitive chemoradiotherapy and brachytherapy (a): Sagittal illustration of the female pelvis with FIGO stage I disease, with tumor <4 cm in diameter (arrow), without extension beyond the cervix. (b): Corresponding sagittal T2-weighted MRI of Stage IB3 cervical cancer, demonstrating a 4.6 cm T2 intermediate signal mass arising from the cervix (arrow), without extension beyond the cervix. (c): Sagittal illustration of the female pelvis with FIGO stage II disease, with upper vaginal (arrow) and parametrial involvement (asterisk). (d): Corresponding findings on sagittal T2-weighted MRI in FIGO IIB cervical cancer, with upper vaginal (arrow) and parametrial (asterisk) involvement. (e): Sagittal illustration of the female pelvis with FIGO stage III disease, depicting tumor spread to the lower part of the vagina (arrow). (f) Corresponding sagittal T2-weighted MRI in FIGO stage IIIB with tumor extension to the lower 1/3 of vagina (arrows). (g): Sagittal illustration of the female pelvis with FIGO IV disease, including involvement of urinary bladder and rectal mucosa (arrows). (h): Corresponding findings on sagittal T2-weighted MRI in FIGO stage IV disease demonstrating parametrial tumor extension and involvement of the urinary bladder mucosa (arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tions on image-guided cervical cancer brachytherapy listed in PubMed as of February 2021 (Table 2). Publications were excluded if the study described was not original research or included fewer than ten patients with cervical cancer. The level of evidence and class of recommendation assigned to each study is as defined by the current American College of Cardiology-American Heart Association Clinical Practice Guideline Recommendation Classification System (26). Recommendation class is scored on a scale of I to III based on the strength of the recommen-

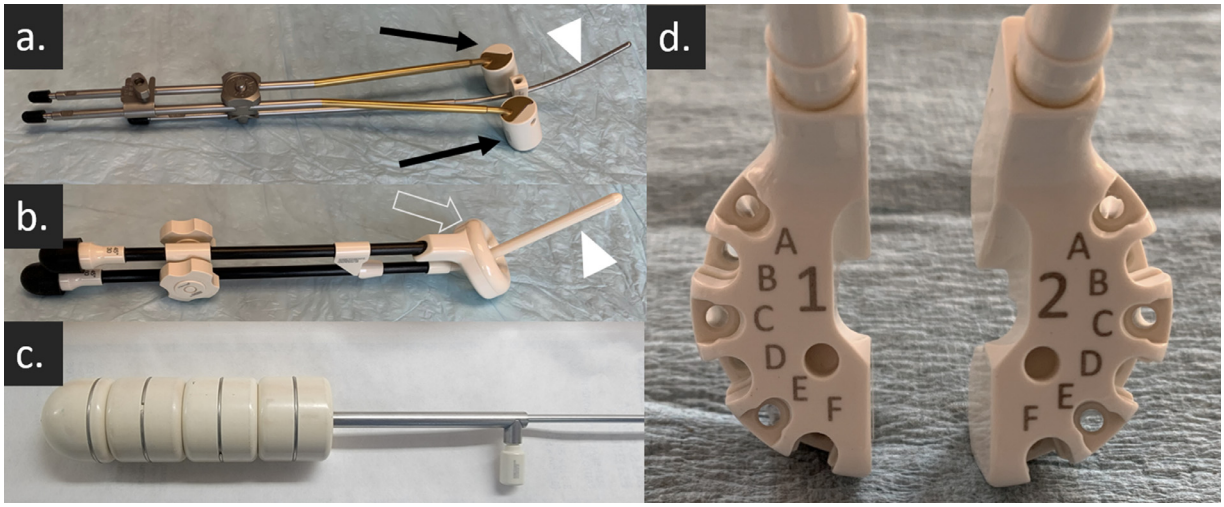

Fig. 2. Examples of four types of gynecologic brachytherapy applicators, including (a) tandem (arrowhead) and ovoids (black arrows) (Fletcher Williamson Applicator, Elekta, Stockholm, Sweden), (b) tandem (arrowhead) and ring (open arrow) (Ring CT/MR Applicator, Elekta), (c) cylinder (Vaginal Applicator, Elekta), and (d) fenestrated ovoids (Venezia Interstitial Lunar Ovoids, Elekta) which assist with interstitial needle placement. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

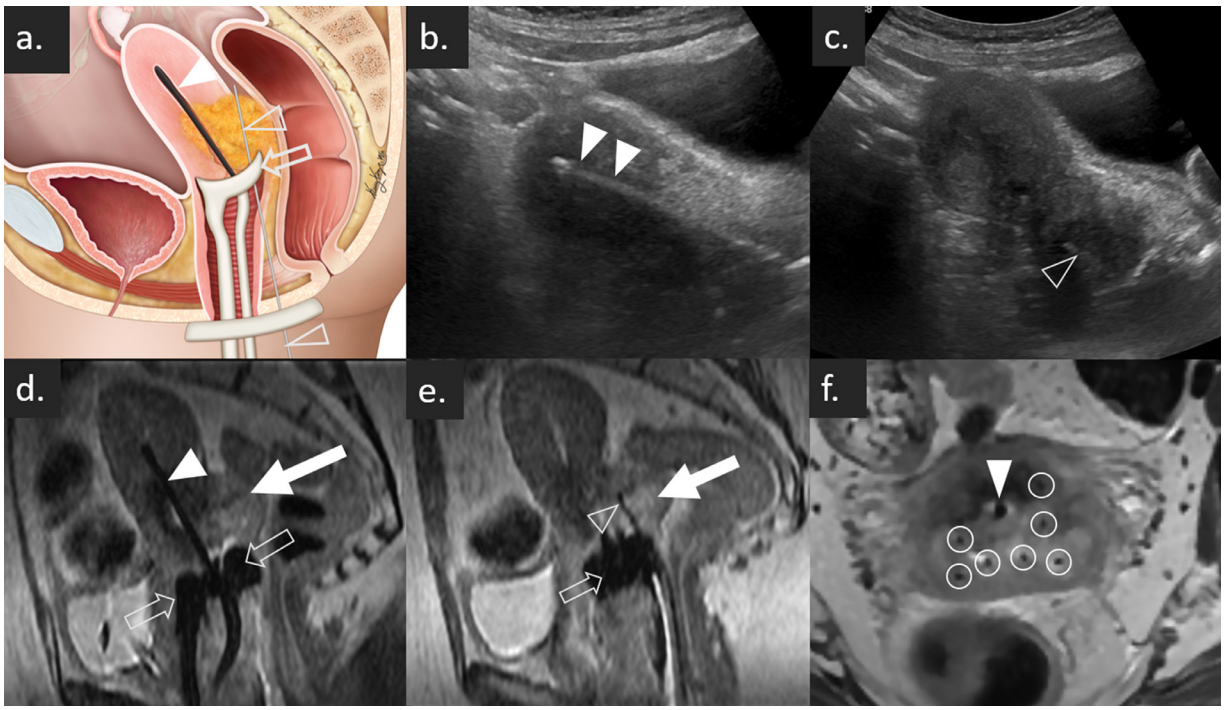

Fig. 3. Proper brachytherapy applicator positioning for cervical cancer treatment (a): Sagittal illustration of uterine tandem (filled arrowhead) and ring (open arrow) placement with interstitial needle (open arrowhead) in an eccentric tumor. The tandem tip should be near the uterine fundus, ring or ovoids in the upper vagina or vaginal fornices, and interstitial needles positioned through a guide and into the tumor. Clinical images of FIGO stage IIB cervical cancer include (b) intraoperative transabdominal ultrasound, verifying tandem (filled arrowheads) position in the uterus, (c) ultrasound verification of interstitial needle (open arrowhead) placement in the hypoechoic tumor, (d) sagittal T2-weighted MRI depicting the tandem (filled arrowhead) and ring (open arrow) placement adjacent to the tumor (white arrow), (e) sagittal T2-weighted MRI showing interstitial needle (open arrowhead) positioning in the tumor (white arrow), and (f) axial T2-weighted MRI confirming the final position of multiple interstitial needles (open circles) throughout the tumor in addition to the tandem (filled arrowhead). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
PubMed search terms by imaging modality

Imaging modality	Search terms
Radiography	("radiography*" OR "radiograph*") AND "brachy*" AND ("gyne*" OR "cervi*")
Ultrasound	("US-guid*" OR "ultrasound guid*" OR "ultrasound" OR "US" OR "sono*") AND "brachy*" AND ("gyne*" OR "cervi*")
CT	("CT-guid*" OR "CT guid*" OR "computed tomography" OR "CT") AND "brachy*" AND ("gyne*" OR "cervi*")
MRI	("MR-guid*" OR "MRI-guid*" OR "MR guid" OR "MRI guid" OR "magnetic resonance" OR "MR" OR "MRI") AND "brachy*" AND ("gyne*" OR "cervi*")

dation. Class I indicates that the recommendation should be applied whenever possible based on the high benefit-to-risk ratio, Class IIa represents a moderate recommendation, Class IIb is a weak recommendation, and Class III indicates that there is no evidence of benefit (26). Levels of evidence are similarly graded from A to C, with A ratings for evidence that includes several randomized clinical trials in which results are in agreement, B for moderate evidence from trials or meta-analyses with R and NR modifiers representing "randomized" and "nonrandomized", and C represents little published evidence modified by LD for limited data or EO for expert opinion (26). The qualitative weight of these articles is assembled into evidence tables by modality, for radiography, ultrasound, CT and MRI guidance (Supplemental Tables 1–4) to ensure that the written document contained evidence-based data.

Role of imaging for the brachytherapy workflow

Workflow

Standard brachytherapy workflow includes preimplant imaging or clinical exam to assess disease response to chemotherapy and EBRT before the initiation of brachytherapy. Ideally, treatment response is assessed using MRI, but CT is also an option for sites with limited access to MRI. Residual tumor burden must be assessed to choose the appropriate brachytherapy applicator. Using conventional source loading patterns and radiation source dwell times for a tandem and ovoid or tandem and ring applicator results in a pear-shaped dose distribution that may not provide sufficient coverage of the HR-CTV or may exceed dose tolerances of OARs. In patients with advanced disease or eccentric tumors, interstitial catheters may be inserted in addition to intracavitary applicators to achieve adequate dose coverage. Preoperative 3D imaging also allows the radiation oncologist to consider number and orientation of interstitial needles if necessary, to deliver optimal conformal brachytherapy to an eccentric tumor.

After preimplant imaging, the patient undergoes applicator and tandem placement. Patients are anesthetized, a Foley catheter is placed, and if a tandem is being placed, the uterus will be sounded to determine the appropriate tandem length and curvature, with ultrasound guidance as needed. At this stage, it is optional to place a uterine Smit sleeve to aid tandem insertion during subsequent treatment fractions. The tandem tip should be located within the fundal (superior most) aspect of the endometrial cavity, without being embedded within or perforating the myometrium (Fig. 3a–c). After tandem insertion, the ovoids, ring, or cylinder are inserted into the vagina and positioned abutting the cervical os. Images may be acquired in real time to guide the placement of applicators and interstitial needles, most frequently with ultrasound and increasingly with CT or MRI and provide verification of proper applicator positioning. Postimplant images are acquired with CT or MRI to provide the basis for treatment planning. If CT or MRI is not available, radiography can be obtained postimplant placement, however radiography cannot determine precise tandem placement or exclude uterine perforation. The use of each imaging modality for image-guided brachytherapy is discussed in detail in the following sections.

Ultrasound

Ultrasound is the primary modality for intraprocedural guidance of intracavitary brachytherapy applicator and tandem insertion, as it is widely available and provides real time guidance (Fig. 3b). Ultrasound can determine intrauterine tandem positioning within the endometrial cavity, confirm the fundal location of the tip and exclude uterine perforation (Fig. 3b) (16,27). Multiple retrospective studies have demonstrated that the rate of uterine perforation by the tandem is significantly lower with ultrasound-guidance than for cases performed without ultrasound (Table 3). Reported perforation rates without image guidance range from 2.3% to 34% (15,16,28) per insertion compared to 0–1.4% with US guidance (15,16,29–31). A 2018 meta-analysis by Sapienza et al. found that US-guided tandem placement resulted in statistically significant decreases in uterine perforation rates on both a per-insertion and per-patient basis compared to procedures performed without US guidance (32). A recent prospective trial by Pareek et al., with patients randomized to either an arm with intraoperative US guidance or one without ultrasound guidance demonstrated a perforation rate of 1.25% (1/80) using US guidance compared to 12.5% (10/80) without ultrasound guidance (15). Pareek et al. also found that in 40% of cases (32/40), the tandem selected based upon initial uterine sounding was changed, on the basis of US imaging findings, to optimize tandem length and/or curvature for the patient (15). Repositioning or replacing a tandem

Table 3
Published studies summarizing uterine perforation rates in intracavitary brachytherapy with and without ultrasound guidance

Study	Year	Study type	US type	n*	Uterine perforation rate per insertion		Uterine perforation rate per patient	
					Without guidance	US-guided	Without guidance	US-guided
Sapienza et al. (32)	2018	Systematic review and meta-analysis	TAUS	766 (1757)	10.54%	1.06%	16.67%	2.54%
Pareek et al. (15)	2021	Prospective randomized trial	TAUS	160 (NR)	12.5% (10/80)	1.25% (1/80)	NR	NR
Kissel (107)	2019	Retrospective case series	None	172 (301)	6% (18/301)	NR	NR	NR
Petereit (28)	1998	Retrospective case series	None	169 (822)	2.3% (19/822)	NR	NR	NR
Barnes (108)	2007	Prospective observational	None	114 (124)	13.7% (17/124)	NR	NR	NR
Bachand (33)	2010	Retrospective case series	None	56 (256)	6.6% (17/256)	NR	21.4% (12/56)	NR
Onal (109)	2014	Retrospective case series	None	NR (133)	NR	NR	10.5% (14/133)	NR
Bahadur (34)	2015	Retrospective case series	None	82 (231)	6.1% (14/231)	NR	14.6% (12/82)	NR
Sapienza (110)	2016	Retrospective case series	None	46 (186)	21.5% (40/186)	NR	32.6% (15/46)	NR
Granai et al. (16)	1990	Prospective observational	TAUS	Guided: 28 (50) Nonguided: NR (73)**	34% (17/50)	0% (0/73)	NR	NR
Schaner et al. (31)	2013	Retrospective case series	TAUS	243 (356)	NR	1.4% (5/356)	NR	NR
Akbas (29)	2018	Retrospective case series	TAUS	Guided: 113 (412) Nonguided: 29 (NR)***	NR	0% (1/412)	6.9% (2/29)	0.9% (1/113)
Davidson (30)	2008	Prospective observational	TAUS	Guided: 21 (35) Nonguided: NR (59)	10.2% (6/59)	0% (0/34)	NR	0% (0/21)
Narayan (111)	2014	Retrospective case series	TAUS	127 (NR)	NR	NR	NR	0% (0/127)
Liu (112)	2016	Prospective observational	TAUS	52 (260)	NR	0.7% (2/260)	NR	3.8% (2/52)
Hallock (113)	2011	Retrospective case series	TAUS	57 (114)	NR	0% (0/114)	NR	0% (0/57)
Sharma (17)	2011	Prospective observational	TRUS	32 (NR)	NR	NR	NR	6.3% (2/32)

TAUS = transabdominal ultrasound; TRUS = transrectal ultrasound; NR = not reported.
* n: number of patients with number of insertions in parentheses.**Study featured an additional 73 insertions under TAUS guidance, but number of patients was not specified.***Study reported 29 non-US guided implants, but did not specify the number of patients in this study arm.

with suboptimal length and/or curvature can avert adverse events such as uterine perforation or unacceptable dosimetry to the HR-CTV and/or OARs (33,34). When uterine perforation due to tandem insertion occurs, posterior perforations result in higher rectal dose, whereas anterior perforations may increase bladder dose (35).

Interstitial needles may be placed under ultrasound guidance (Fig. 3c) to provide real-time feedback regarding needle positions, avoid perforation of OARs, and to verify or adjust preplanned needle depths (44,45). Ultrasound guidance has also been used in to measure distances between the tandem and interstitial needles (46,47), and Doppler ultrasound has been used to identify blood vessels before interstitial needle placement (48). Knoth et al. recently found that 79.3% (149/188) interstitial needles in 24 patients were well visualized on TRUS (47). Drawbacks to using TRUS for needle placement include a limited field-of-view, masking of needles from other pathology (e.g., myomas), poor image quality, and insufficient bowel preparation (47). TAUS is also routinely used for image

guidance of interstitial needle placement, but the accuracy of needle visualization has not been evaluated in the literature (49).

When possible, a radiologist or radiation oncologist trained in the use of intraoperative pelvic ultrasound should perform the image guidance. Training guidelines for the use of point-of-care ultrasound are published by the American Institute of Ultrasound in Medicine and include minimum standards for the didactic training, number of cases performed and reported during hands-on training, and maintenance of competency recommendations (50).

Ultrasound-based treatment planning for gynecologic brachytherapy using both TAUS and TRUS has been reported in the literature (36–38), but OAR definition for dosimetry purposes has not been investigated. In general, ultrasound-based dosimetry is two-dimensional and comparable to radiography. Uterine and cervical sizes measured relative to the tandem on US correlate well with MRI, with distances generally agreeing to within 3 mm in the sagittal plane (39–43), so point-based dosimetry is comparable to radiography. However, three-dimensional dosimetry methods using CT or MRI are preferred over ultrasound to minimize toxicities and improve tumor coverage.

Recommendations

- Ultrasound guidance for tandem insertion is recommended to reduce uterine perforation rates. (Class I recommendation, Level of evidence: B-R)
- Ultrasound guidance can improve tandem selection to achieve the appropriate tandem length and curvature. (Class I recommendation, Level of evidence: B-R)
- Real-time ultrasound guidance of interstitial needle placement is feasible with either transabdominal or transrectal probes, and preferred when other image guidance modalities are unavailable. Postimplant 3D imaging remains recommended for treatment planning. (Class IIa recommendation, Level of evidence: C-EO)

Radiography

In conventional intracavitary brachytherapy, orthogonal radiographs of the pelvis have historically been acquired after implant placement to both verify proper positioning of the applicators relative to bony landmarks and to perform 2D dosimetry. The use of radiographs alone to verify proper applicator placement has been shown to be inadequate for reducing rates of uterine perforation with the tandem as demonstrated by follow-up CT, and ultrasound-guidance during tandem placement is recommended to reduce rates of uterine perforation (Table 3).

Because residual tumor cannot be visualized on orthogonal radiography, post implant dosimetric planning based upon radiographic images has been calculated using anatomical reference points defined at fixed distances from the uterine tandem. Points A and B were originally defined as part of the Manchester system, with Point A defined as 2 cm lateral to the central canal of the uterus and 2 cm cranial to the lateral fornices in the axis of the uterus. Point A was subsequently revised so that the point could be located on radiography and defined as 2 cm cranial to the tandem flange and 2 cm lateral from the center of the tandem (Fig. 4a). Point B was defined as 5 cm from the midline and 2 cm cranial to the lateral fornices, meant as a surrogate for dose in the vicinity of the obturator nodes (51,52). The International Commission on Radiation Units and Measurements (ICRU) reports 38 recommendations are used for assessment and reporting of the absorbed dose to bladder and rectum, estimated at single points on radiographic imaging (51). The ICRU (bladder) point is located at the most posterior point of a Foley catheter balloon seated at the base of the bladder filled with 7 cc contrast as seen on a lateral radiograph (51). The ICRU rectum point is located along an anteroposterior line from the lower end of the tandem 5 mm from the posterior vaginal wall (51). In contemporary practice, these dosimetric approximations are far from optimal, given the lack of direct imaging visualization and inability to account for patient specific anatomical considerations (53). In addition to the lack of direct visualization of residual tumor and OARs, point doses are frequently located in areas with a high dose gradient. As a result, they do not correlate as well with OAR complication rates as compared to 3D contoured volumes obtained on post implant CT or MRI (22,54,55).

Recommendations

- Orthogonal radiography is recommended for treatment planning at centers without access to CT or MRI (Class I recommendation, Level of evidence: B-NR).

Computed tomography

CT is commonly used for postimplant imaging and subsequent simulation for treatment planning as well as near real-time guidance of interstitial BT needle placement (56). The anatomical visualization and 3D nature of CT has been shown to improve patient outcomes, particularly when considering rates of ≥ Grade 3 genitourinary or gastrointestinal complications (Table 4). Additionally, postimplant CT can identify suboptimal positioning of applicators relative to the HR-CTV such as air gaps or misplaced packing which may decrease the delivered dose to the tumor or increase dose to OARs (57). Use of CT imaging, thus allows for adjustment of applicator position when used while patients are under anesthesia. As cervical tumors are typically isointense relative to normal tissue on both noncontrast and contrast-enhanced exams, however, delineation of tumor burden may be difficult to assess with CT (3,6,58). Wires with dummy markers representing source dwell positions allow for accurate reconstruction of the applicator source channel and ensure that the applicators and any

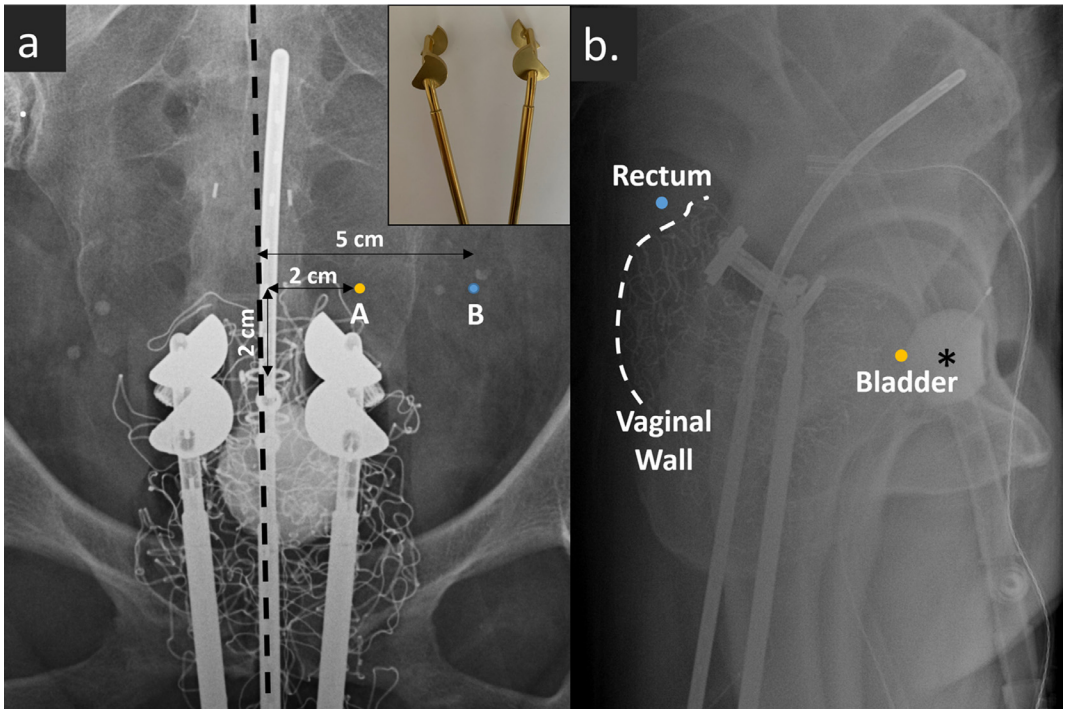

Fig. 4. Orthogonal pelvic radiographs of a female pelvis with a tandem and ovoids (Fletcher Williamson Applicator, Elekta). (a) Manchester system points A and B demonstrated on an anteroposterior radiograph with the dotted line representing the patient midline for estimation of the Point B location. Inset image of the ovoids without caps in a similar orientation demonstrate the expected bladder and rectal shield orientations in the radiograph. (b) Lateral radiograph demonstrating the ICRU bladder point (yellow dot) at the most posterior point of a Foley catheter (*). The vaginal wall (white dotted line) is delineated by the edge of the vaginal packing, and the ICRU rectal point (blue dot) is positioned 0.5 cm from the vaginal wall along the midline of the ovoids. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Summary of published studies comparing genitourinary and gastrointestinal toxicity outcomes of grade 3 or greater between cervical cancer intracavitary brachytherapy treatment planning using 2D point doses versus 3D contoured volumes on CT

Study	Year	Study type	2D radiographic planning		3D CT-guided planning	
			Toxicity rates ≥ Grade 3		Toxicity rates ≥ Grade 3	
			GU	GI	GU	GI
Charra-Brunaud et al. (55)	2012	Nonrandomized multicenter prospective observational**	9.2%	9%	1.2%	0.0%
Thomas et al. (114)	2017	Retrospective case series	0% (0/37)	13.5% (5/37)	2.9% (1/34)	2.9% (1/34)
Chen et al. (115)	2019	Retrospective case series	4.4% (6/136)	10.3% (14/136)	0.9% (1/117)	1.7% (2/117)
Kobayashi et al. (116)	2019	Retrospective case series	5.6% (4/71)	2.8% (2/71)	5.8% (2/34)	0.0% (0/34)
Kang et al. (54)	2010	Retrospective case series	NR	10% (13/133)	NR	2% (2/97)
Koh et al. (117)	2017	Retrospective case series	NR	NR	1.1% (1/95)	0.0% (0/95)

GU = genitourinary; GI = gastrointestinal; NR = not reported.
** Results of EBRT + BT arm, Cox proportional hazard model rates.

interstitial needles are unobstructed before treatment initiation (59). If postimplant MRI is not available, CT can be substituted, and prebrachytherapy MRI used as a reference for accurate tumor delineation. Deformable image registration algorithms have been investigated to register prebrachytherapy MRI to simulation CT, although these remain areas of ongoing research (60,61).

Representative CT acquisition and reconstruction parameters employed for postimplant CT imaging are provided in Table 5. Patients should be positioned supine with the arms folded over the chest to reduce beam hardening artifact throughout the pelvis. The scan range should extend from the vulva to the level of L4, with the minimum cranial endpoint at the uterine fundus to encompass the entire HR-CTV.

In cases where metallic applicators or adaptive applicators associated with rectal and bladder shields are used, artifact may be a significant limitation to treatment planning. Streak artifacts caused by beam hardening and photon starvation may cause substantial degradations to image quality that may impede treatment planning. Several acquisition- and reconstruction-based methods that may be

Table 5
Example CT scan parameters for postimplant treatment planning CT for cervical cancer brachytherapy

Scan parameter	Value
Tube voltage	120 kVp
Tube current – time product	200–400 mAs
Rotation time	0.5–0.75 s
Pitch	0.5–1.0
$CTDI_{vol}$	11.5–30 mGy
Image thickness	≤ 3.0 mm
Image interval	≤ slice thickness
Reconstruction kernel	Medium smooth
Gantry tilt	Optional to reduce metal artifact
Multiplanar reconstructions	Sagittal, coronal
Metal artifact reduction	Optional to reduce metal artifact

used to mitigate metal artifact. The first technique that may be used is a physical tilting of the CT gantry (62). This is particularly useful if shields associated with intracavitary ovoids cause substantial artifact in an axial imaging plane (Fig. 5). The second method for reducing metal artifact involves use of metal artifact reduction software (Fig. 6) (63,64). Metal artifact reduction software is commercially available from all major CT manufacturers (65,66), and has been demonstrated to decrease artifact severity during pelvic CT (67,68). Advanced imaging applications such as dual-energy CT may also be used to reduce metal artifact where available. Dual-energy CT scans can be reconstructed as a virtual monoenergetic image, which can theoretically eliminate beam hardening artifacts (69), and these images may be combined with metal artifact reduction software to further improve image quality.

Recommendations

- Postimplant CT imaging is recommended for treatment planning to minimize genitourinary and gastrointestinal complications compared to treatment planning with orthogonal radiography (Class IIa recommendation, Level of evidence: B-NR)
- CT can identify improper positioning of the applicators, including uterine perforation, and should be used to evaluate applicator positioning, even when volumetric treatment planning is not used. (Class I recommendation, Level of evidence: B-NR)
- Prebrachytherapy T2-weighted MRI should be used as a reference, when available, when contouring the HR-CTV on CT. (Class I recommendation, Level of evidence: B-NR)
- Metal artifact reduction techniques should be considered when artifact from shielded ovoids obscures patient anatomy, including the tumor and OARs. (Class IIb recommendation, Level of evidence: Level C-EO)

Magnetic resonance imaging

MRI is the preferred modality for image-guidance of brachytherapy when available. Although CT enables 3D treatment planning for cervical cancer brachytherapy, the soft tissue contrast is not optimal for delineating tumor from surrounding soft tissues such as normal cervix, uterus, vagina, vulva, and urethra (5,6,58,70). Diagnostic pelvic MRI after EBRT and before brachytherapy allows for accurate assessment of tumor size (6,71–73). As demonstrated in the ACRIN 6651/GOG 183 intergroup multicenter prospective study and other publications, MRI demonstrates superior accuracy relative to CT for tumor visualization, detection of parametrial invasion (5,74,75) and pelvic sidewall invasion (Table 6). Dedicated gynecologic MRI protocols are recommended for optimal detection and delineation of disease (76). Use of vaginal gel for pretreatment MRI can aid in the staging of cervical cancer by defining the vaginal fornices and the cervix (77). To minimize motion artifact due to bowel peristalsis, an antiperistaltic agent (e.g., glucagon or hyoscyamine) may be administered before the exam (76). Imaging can be performed on either 1.5-T or 3-T magnets with a dedicated anterior pelvic, cardiac, or torso coil in combination with an anterior spine array coil. With modern MRI systems, each recommended pulse sequence can generally be acquired within 4–6 min . The total imaging time will depend on the chosen pulse sequences, desired anatomical coverage and image quality, and the hardware and software capabilities of the MRI system.

A comprehensive cervical cancer protocol should include axial/axial oblique and sagittal/sagittal oblique nonfat saturated T2-weighted fast spin echo (FSE) images with or without a 90° flip back, axial nonfat saturated T1-weighted FSE images, axial diffusion weighted images (DWI), and postcontrast axial and sagittal fat saturated T1-weighted spoiled gradient echo images (Table 7) (78,79). Many experts emphasize the importance of true axial oblique images of the cervix, whereas others prefer to acquire this imaging in the true axial plane, citing greater simplicity and reproducibility (80). Acquisition of a 3D T2-weighted sequence allows for postprocessed multiplanar reformats after MRI if the acquired image orientation is not desirable. Tumor is best differentiated from normal tissue on T2-weighted pulse sequences, with tumor being relatively hyperintense as compared to the cervical stroma. DWI allows for differentiation of tumor from normal tissue, with areas of hypercellular viable tumor typically demonstrating restricted diffusion, evident as increased signal on high b-value DWI and reduced signal on corresponding apparent diffusion coefficient (ADC) maps compared to normal cervix. The b-values in DWI are user-selectable and represent the relative strength of the diffusion-sensitizing gradients, and the sequences consist of at least one low b-value (0–150 s/mm^2) and a higher b-value (800–1000 s/mm^2). ADC is calculated using a monoexponential fit of

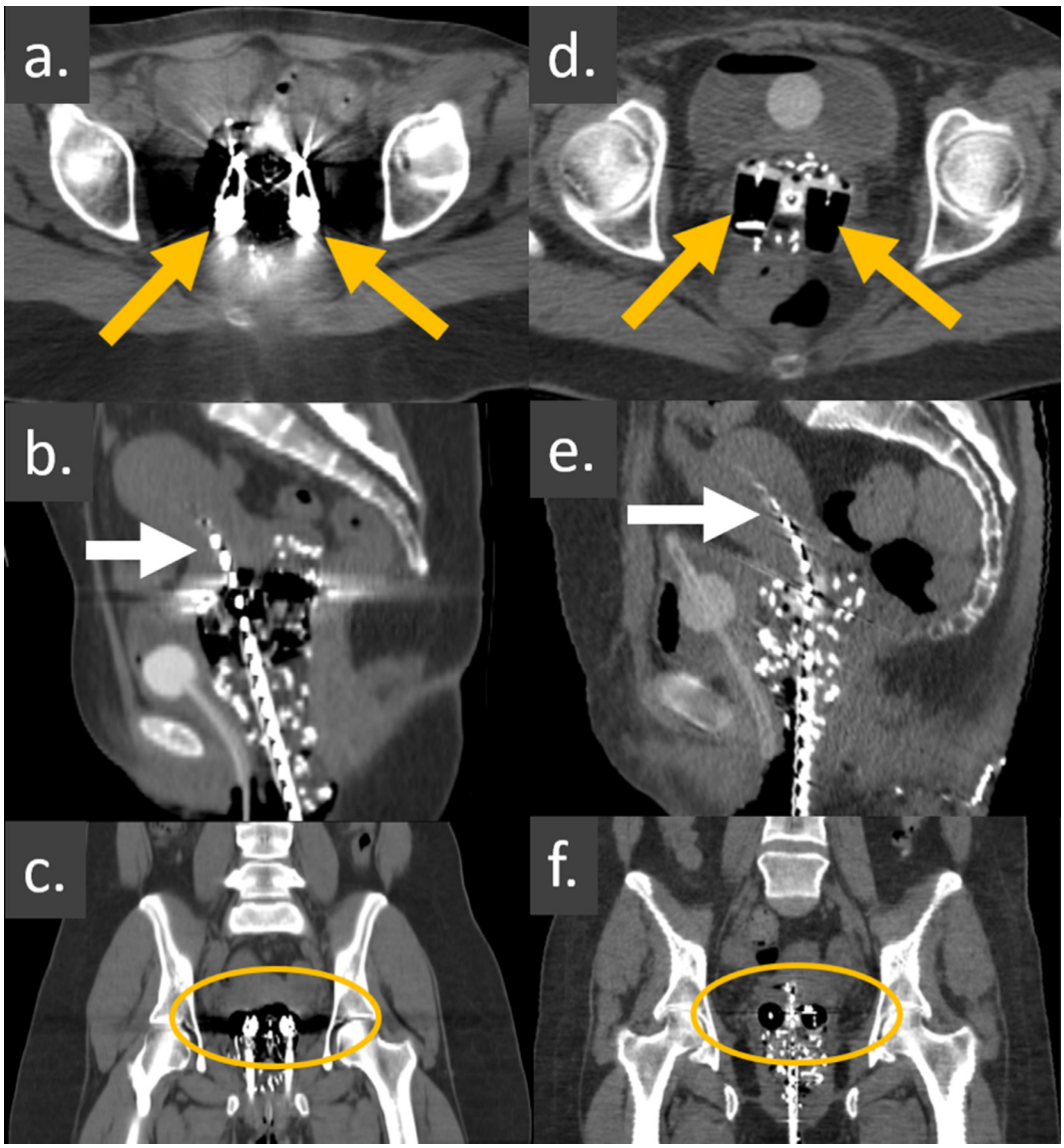

Fig. 5. CT simulations for cervical cancer brachytherapy with Fletcher CT/MR compatible applicators with tandem (white arrows) and adaptive shielded ovoids (gold arrows). Lines of dummy sources have been extended into the tandems. Axial (a), sagittal (b), and coronal (c) pelvic CT acquired without gantry tilt in FIGO stage IIA1 cervical cancer demonstrates severe streaking and signal loss due to metal artifact from shields in the ovoids causes streaking and signal loss (gold circle). True axial (d), sagittal (e), and coronal (f) reformats of pelvic CT acquired with gantry tilt in FIGO stage IIIB cervical cancer allows for clear visualization of the ovoids with their shields, tandem, and surrounding soft tissues. Note that hyperintensity in the vaginal canal is due to vaginal packing material. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 6
Published studies describing receiver operating characteristic analyses for MRI assessment of parametrial invasion in cervical cancer compared to surgical pathologic findings

Study	Year	Study type	*n*	Sensitivity	Specificity	AUC
Hricak et al. (5)	2007	Multicenter prospective observational	152	NR	NR	0.64–0.75
Woo et al. (75)	2017	Systematic review and meta-analysis	1436	0.76	0.94	0.94
Wang et al. (118)	2020	Retrospective case series	137	0.60–0.75	0.79–0.82	NR
Mongula et al. (83)	2019	Prospective observational	65	0.63–0.88*	0.81–0.88	0.85
Kim et al.(119)	2019	Retrospective case series	215	0.53	0.91	0.723

n = number of patients.
NR = not reported.
* Results from T2-weighted MRI with DW-MRI.

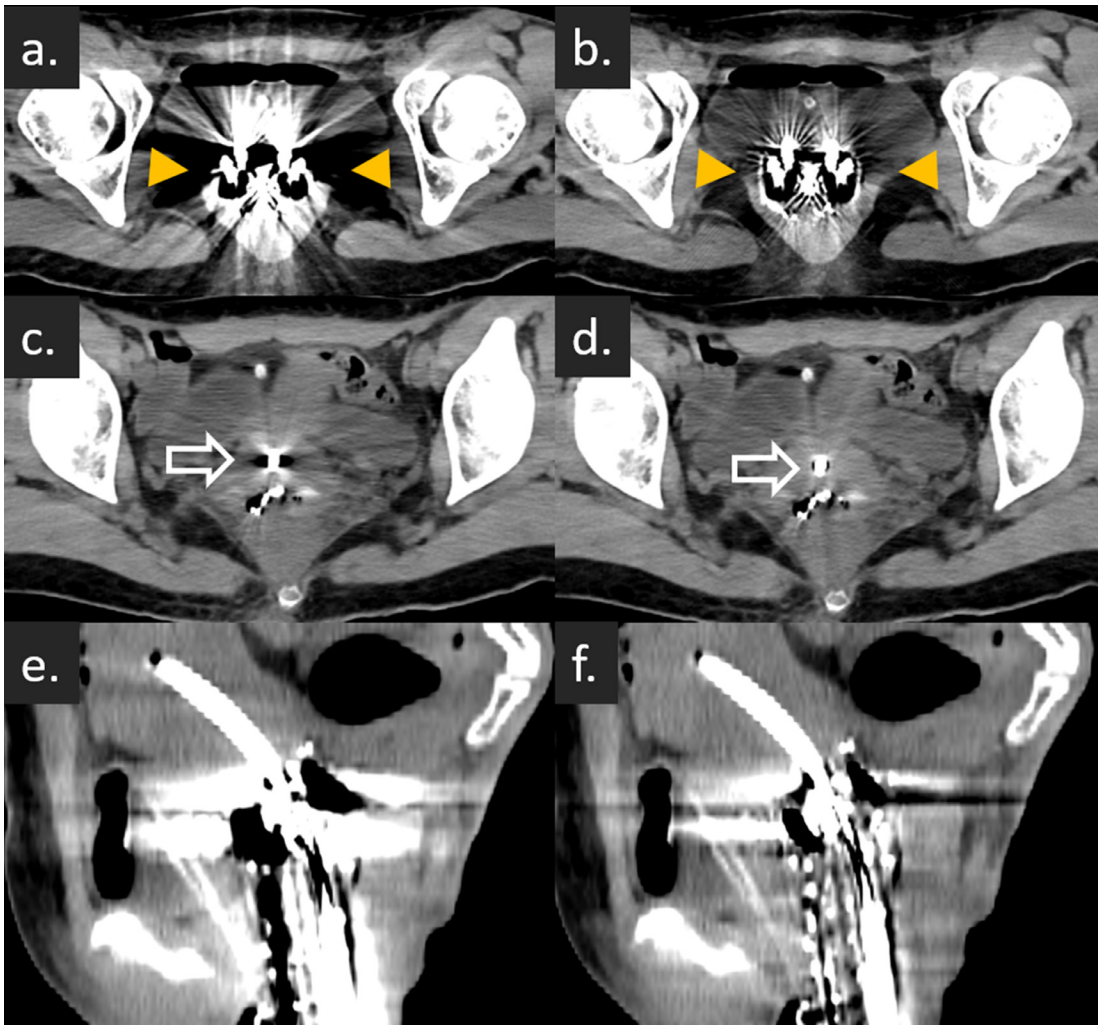

Fig. 6. CT simulation for cervical cancer brachytherapy in FIGO stage IIIC1 cervical cancer with a Fletcher-Suit-Delclos (FSD) titanium applicator with shielded ovoids. Images were reconstructed without (a, c, e) and with metal artifact reduction (b, d, f). Images from the level of the shielded ovoids (a, b) demonstrate severe streaking due that reduces visualization of the surrounding soft tissues (gold arrowheads) when metal artifact is not applied (a), and the use of metal artifact reduction software reduces signal loss (b). Artifact at the level of the cervix (c, d) demonstrates better geometric accuracy near the tandem (open arrow) when metal artifact reduction is used (d). Sagittal images (e, f) demonstrate changes in estimated attenuation without (e) and with (f) metal artifact reduction. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

voxel signal across b-values. ADC in cervical cancer has been shown to be more accurate when the low b-value is between 50 and 150 s/mm^2 to avoid interference from microperfusion effects (81,82). Abnormalities on DW-MRI have also been leveraged to facilitate detection of parametrial invasion (83) and to assess treatment response (84). Pre- and postcontrast T1-weighted MRI allows for identification of small enhancing residual tumor, for identifying necrotic areas of tumor, which will appear as areas of nonenhancement (85) and, rarely for detection of fistulous tracts after EBRT.

When acquired immediately after brachytherapy implant placement, noncontrast MRI is typically acquired for treatment planning simulation, employing a focused protocol consisting of sagittal and axial T2-weighted images (Table 8). The sagittal and axial images can be acquired as obliques that are parallel and perpendicular to the tandem, respectively. Frequently, the axial T2-weighted sequence is acquired using a 3D fast spin echo with isotropic voxels (79,86) with or without a 90° "flip-back" pulse (87,88). 3D FSE is available from all vendors under various names (i.e., CUBE from General Electric Healthcare, VISTA from Philips Healthcare, SPACE from Siemens Healthineers, 3D MVOX from Canon, and isoFSE from Hitachi), but all have long echo trains, very short echo spacing, and reduced or variable flip angles that minimize radiofrequency-induced tissue heating (86,88,89). 3D FSE sequences can be acquired with partial Fourier and parallel imaging to keep imaging times between 5 and 10 min. Phase wrap corrections should be used when available to minimize aliasing artifact for small field-of-view acquisitions (77). The applicator itself will appear hypointense on both T1-

Table 7
Suggested diagnostic pelvic MRI protocols for cervical cancer imaging adapted from the Society of Abdominal Radiology's Uterine and Ovarian Cancer Disease Focused Panel (78) and the Gynaecological Groupe Européen de Curiethérapie-European Society for Radiotherapy and Oncology (GEC-ESTRO) (79)

Series description	Dim	Pulse sequence	FOV (cm)	Slice thickness (mm)	Slice gap (mm)	Matrix: frequency encoding	Matrix: phase encoding	Anatomic coverage and notes
Sagittal or sagittal oblique T2-weighted	2D	FSE	24–26	4–5	0	256	192–256	Acetabulum to acetabulum
Axial or axial oblique T2-weighted.	2D	FSE or FRFSE	24–26	3–4	0 - 0.5	256–320	256–320	Perineum to top of L5
Coronal or coronal oblique T2-weighted	2D	ss-FSE	36–40	3–6	0–1	256	192 - 256	Covering uterus, cervix, vagina, tumor, and kidneys
Axial or axial oblique DWI	2D	EPI	28–35	4–5	0	80–128	80–128	Perineum to top of L5; b = 0–150 & 800 - 1000
Axial T1-weighted	2D	FSE	30–34	4–5	0–1	256–320	256–320	Perineum to top of L5
* Sagittal precontrast	3D	Ultrafast GRE	28	3–5	0	256–320	192	Acetabulum to acetabulum
* Sagittal T1-weighted contrast-enhanced	3D	Ultrafast GRE	28	3–5	0	256–320	192	Acetabulum to acetabulum; 40 and 90 second delays
*Axial postcontrast	3D	Ultrafast GRE	28	1–4	0	256–320	192	Perineum to top of L5; 180 second delay

* Optional sequencesDim = dimensions; FOV = field of view; ss = single shot; FSE = fast spin echo; FRFSE = fast relaxation fast spin echo; EPI = echo planar imaging; 2D = two dimensional; 3D = three dimensional; GRE = gradient recalled echo.

Table 8
Suggested pelvic MRI protocols for postbrachytherapy implant placement

Series description	Dim	Pulse sequence	FOV (cm)	Slice thickness (mm)	Slice gap (mm)	Matrix: frequency encoding	Matrix: phase encoding	Anatomic coverage and notes
Sagittal or sagittal oblique T2-weighted	2D	FSE or FRFSE	20–24	2–5	0	256	192–256	Uterus, cervix, tumor, and applicator
Axial or axial oblique T2-weighted	3D	Isotropic FRFSE	24–26	2–5	−1–0	256–320	256–320	Uterus, cervix, tumor, and applicator
*Axial or axial oblique T2-weighted	2D	FSE or FRFSE	24–26	2–5	0	256–320	256–320	Uterus, cervix, tumor, and applicator
*Coronal or coronal oblique T2-weighted	2D	FSE or FRFSE	24–26	2–5	0	256	192–256	Uterus, cervix, tumor, and applicator
*Axial or axial oblique DWI	2D	EPI	28–35	4–5	0	80–128	80–128	Perineum to top of L5; b = 0–150 and 800–1000
*Sagittal T1-weighted	3D	Phase cycled bSSFP	20–24	2–3	−1–0	192	192	Whole applicator; used for imaging positive contrast markers

* Optional sequences.Dim = dimensions; FOV = field of view; ss = single shot; FSE = fast spin echo; FRFSE = fast relaxation fast spin echo; EPI = echo planar imaging; 2D = two dimensional; 3D = three dimensional; bSSFP = balanced steady state free precession.

and T2-weighted images due to the very low T2 signal of the implant. This appearance contrasts well with the intermediate to hyperintense T2 signal of tumor (Fig. 3).

Brachytherapy treatment planning requires relatively high spatial resolution and geometric accuracy to determine the precise locations of source paths within the applicator. To highlight the applicator lumen and source path for treatment planning, positive contrast line markers have been developed for postimplant MRI that allow for treatment planning directly on MRI without the need for CT imaging with dummy sources (90–92). These markers may require the use of additional MRI sequences such as 3D phase cycled balanced steady state free precession (bSSFP) to optimize marker visualization (92) and assist three-dimensional applicator reconstruction during the treatment planning process. Geometric distortion can alter the ap-

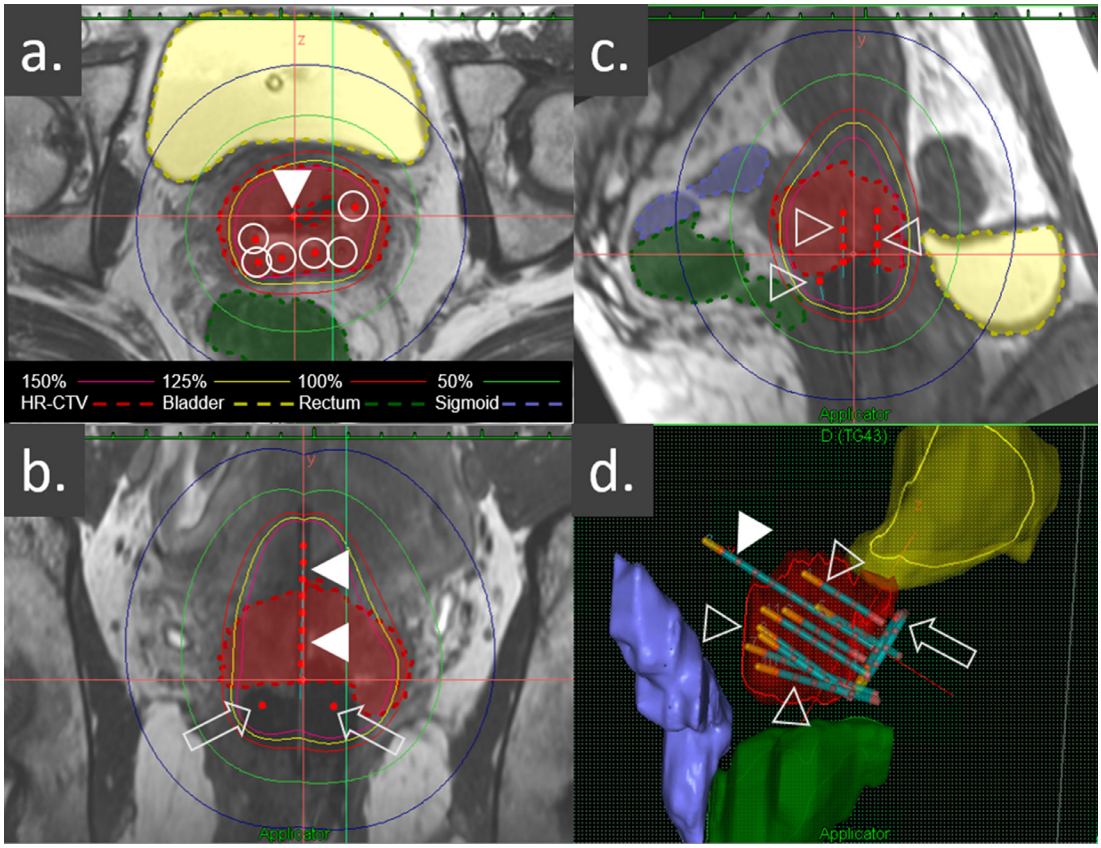

Fig. 7. MR treatment planning for cervical cancer brachytherapy with a tandem and ring applicator with interstitial needles in FIGO stage IIB cervical cancer. (a): Axial T2-weighted MRI is shown with contours of the high-risk clinical target volume (HR-CTV), bladder, sigmoid, and rectum (dotted lines). Red circles represent the source dwell locations within interstitial needles (white circles) and the uterine tandem (filled arrowhead). Percentages in legend refer to isodose lines representing a given percentage of the prescribed dose. (b): Coronal T2-weighted MR showing the source dwell locations in the uterine tandem (filled arrowheads) and ring (open arrows) as well as the resulting pear-shaped dose distribution. (c): Oblique reformat of a sagittal T2-weighted MRI demonstrating the position of several interstitial needles (open arrowheads) relative to the HR-CTV and organs at risk (OAR). (d): 3D rendering of the tandem (closed arrowhead), ring (open arrow), interstitial needles (open arrowheads), HR-CTV, and OAR. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

parent applicator position and source path relative to the surrounding anatomy, resulting in dose uncertainties. However, phantom studies have demonstrated that distortions in the center of the field of view for MRI are typically on the order of 1 mm or smaller at 1.5 T (93), which is considered acceptable for treatment planning purposes. A clinical study involving patients receiving treatment with titanium applicators and undergoing MRI at 3.0 T MRI demonstrated slightly larger deviations of 1.5 mm on T1-weighted gradient echo and up to 6.9 mm on sagittal T2-weighted fast spin echo sequences due to the magnetic susceptibility of the metallic applicator (94). In contrast, plastic applicators and needles do not result in substantial geometric distortion and are the most robust for treatment planning when MRI is the sole imaging modality for planning purposes (95,96).

There are several additional considerations when choosing between imaging at 1.5 T and 3.0 T for postimplant scanning beyond geometric distortion. Signal is inherently higher on 3.0 T magnets, and therefore it is possible to achieve higher signal-to-noise ratio compared to 1.5 T systems if spatial resolution and imaging time are kept relatively consistent. Users also have the option of reducing scan time or increasing spatial resolution at 3.0 T whereas maintaining the signal-to-noise ratio achievable at lower magnetic field strengths. However, tissue heating due to radiofrequency deposition, measured using specific absorption ratio, is greater at 3.0 T compared to 1.5 T systems. Specific absorption ratio limitations imposed by the FDA may require that scan times be extended or different pulse sequences chosen, with gradient echo sequences resulting in less tissue heating than spin echo sequences. However, the protocols recommended in this consensus statement have been successfully implemented on both 1.5 T and 3.0 T systems.

MRI may also be used to provide in-room MRI guidance for applicator insertion, which can be especially beneficial for patients with extensive parametrial tumor invasion or eccentric tumors, for which superior coverage of the HR-CTV with both intracavitary and interstitial im-

Table 9
Recommended elements for radiology reporting of post implant brachytherapy CT or MRI studies

Recommended reporting elements	Examples
Tandem position	Position within uterine fundus; presence or absence of uterine perforation
Ovoid/ring position	Position in relation to external cervical os
Cylinder/dome position	Position within vagina
Tumor extent	Location and extent of tumor with brachytherapy applicators and vaginal packing in place
Interstitial needles	Position relative to tumor; number of needles visualized; presence or absence of nontarget insertion (e.g. into urinary bladder, rectum)
Vaginal packing	Location of vaginal packing
Foley catheter	Placement
Hydronephrosis/hydroureteronephrosis	Extent and severity
Parametrial/pelvic wall invasion	Extent and location of extension
Vaginal invasion	Extent and location
Bladder/rectal invasion	Extent and location
Lymphadenopathy	Pelvic or para-aortic

plants is critical (97–99). Unlike post implant MRI, which is typically obtained after completion of implant insertion, when it is difficult to adjust applicator positioning, real-time MRI guided placement allows the radiation oncologist to confirm needle position within tumor with MRI, then adjust needle placement, as needed, to ensure optimal dosimetry, before completion of the procedure (Fig. 7). Real-time MRI guidance for interstitial needle placement is currently being prospectively investigated at select sites.

When employing the MRI suite for either postimplant MRI or for in-room MRI guidance during brachytherapy implant placement, it is critical to be aware of MRI safety principles, which are a priority for both patients and staff involved. Although many intracavitary and interstitial applicators are considered MRI conditional or safe, there are several common exceptions. Stainless steel applicators cannot be assumed to be safe in the MRI environment and their MRI safe or conditional status cannot be visually determined. The patient must be checked postprocedure and before postimplant MRI to ensure there are no ferromagnetic objects remaining on their person before entering the MRI room (100). Care should be taken to identify and count equipment used before and after the procedure to minimize the risk to the patient from potential projectiles and radiofrequency-induced heating during imaging. Additionally, all staff entering the MRI suite must undergo their institution's MRI safety training and screening (100). Brachytherapy implant placement using in-room MRI mandates especially close coordination and communication with ancillary teams, including anesthesiologists, and nursing staff in addition to the radiation oncologist and their support staff (101) to ensure proper training (87). All equipment brought into the MRI suite must be MRI safe or MRI conditional, including, but not limited to implant hardware, forceps, specula, mechanical cutters, patient positioners, and supply carts (87,100).

Recommendations

- MRI is the preferred modality for treatment planning when available due to superior tumor visualization, identification of parametrial and pelvic wall invasion, and image contrast enabling clear delineation of organs at risk. (Level of evidence: Class I recommendation, Level of evidence: B-NR)
- MRI safety is of paramount importance, both when performing postimplant MRI for treatment planning and when utilizing in-room MRI for brachytherapy applicator placement. Routine safety procedures should include ensuring patient eligibility for MRI-guided procedures, the MRI compatibility of applicator and ancillary equipment, and ensuring proper staff MRI safety training. (Class I recommendation, Level of evidence: C-EO)
- Axial and sagittal T2-weighted images are recommended, with brachytherapy applicators in place, for treatment planning. Isotropic 3D T2-weighted imaging may be used as a substitute to 2D axial and sagittal imaging if image quality is sufficient. (Class IIa recommendation, Level of evidence: B-NR)

Role of structured reporting for image-guided brachytherapy

Radiologic interpretation is obtained to facilitate image-guided cervical cancer brachytherapy (102). Given the potential for placement of applicators into nontarget anatomy, such as the bowel, urinary bladder wall, or urethra, irrespective of the imaging modality used for guidance, radiologists should be vigilant in their evaluation of these images and have a low threshold to discuss unexpected findings with the referring radiation oncologist. Structured reporting may also improve content satisfaction for the referring radiation oncologist (103), as has been demonstrated in other clinical scenarios warranting prompt therapeutic intervention (104–106). Table 9 summarizes key concepts to include in radiologic dictations for cervical cancer patients after brachytherapy implant placement, which can assist in

the development of structured reporting templates. Immediate evaluation of postimplant MRI is optimal to assess whether applicator positioning is adequate or requires a return to the operating room. Delivery of treatment often begins within an hour after imaging, so radiologist interpretation should be expedited.

Recommendations

- Radiologists should be aware of essential imaging findings when staffing ultrasound guided endocavitary implant placement and when interpreting post implant CT and MRI in cervical cancer patients to ensure appropriate applicator positioning in relation to the tumor and cervix and to exclude nontarget organ injury, including uterine perforation by the tandem or injury to urinary bladder or rectum by interstitial needles. (Class IIb recommendation, Level of evidence: C-EO)

Conclusions

Brachytherapy is integral to the optimal management of cervical cancer, significantly improving overall survival in patients with locally advanced disease as compared to external beam radiotherapy alone. Image-guided brachytherapy for cervical cancer employing CT and MRI has become the standard of care in recent years, associated with improvements in overall survival and reduced rates of severe toxicity relative to 2D treatment planning. This consensus statement from the Society of Abdominal Radiology and the American Brachytherapy Society summarizes the literature and provides recommendations using a multidisciplinary approach for image-guided brachytherapy. Although the management of cervical cancer patients is expected to evolve in the future, it is anticipated that high quality imaging guidance will remain critical to optimal clinical outcomes.

Disclosures

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