

PHYSICS CONTRIBUTION

THE AMERICAN BRACHYTHERAPY SOCIETY RECOMMENDATIONS FOR PERMANENT PROSTATE BRACHYTHERAPY POSTIMPLANT DOSIMETRIC ANALYSIS

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Purpose: The purpose of this report is to establish guidelines for postimplant dosimetric analysis of permanent prostate brachytherapy.

Methods: Members of the American Brachytherapy Society (ABS) with expertise in prostate dosimetry evaluation performed a literature review and supplemented with their clinical experience formulated guidelines for performing and analyzing postimplant dosimetry of permanent prostate brachytherapy.

Results: The ABS recommends that postimplant dosimetry should be performed on all patients undergoing permanent prostate brachytherapy for optimal patient care. At present, computed tomography (CT)-based dosimetry is recommended, based on availability cost and the ability to image the prostate as well as the seeds. Additional plane radiographs should be obtained to verify the seed count. Until the ideal postoperative interval for CT scanning has been determined, each center should perform dosimetric evaluation of prostate implants at a consistent postoperative interval. This interval should be reported. Isodose displays should be obtained at 50%, 80%, 90%, 100%, 150%, and 200% of the prescription dose and displayed on multiple cross-sectional images of the prostate. A dose-volume histogram (DVH) of the prostate should be performed and the D_{90} (dose to 90% of the prostate gland) reported by all centers. Additionally, the D_{80} , D_{100} , the fractional V_{80} , V_{90} , V_{100} , V_{150} , and V_{200} (i.e., the percentage of prostate volume receiving 80%, 90%, 100%, 150%, and 200% of the prescribed dose, respectively), the rectal, and urethral doses should be reported and ultimately correlated with clinical outcome in the research environment. On-line real-time dosimetry, the effects of dose heterogeneity, and the effects of tissue heterogeneity need further investigation.

Conclusion: It is essential that postimplant dosimetry should be performed on all patients undergoing permanent prostate brachytherapy. Guidelines were established for the performance and analysis of such dosimetry.

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INTRODUCTION

Postimplant dosimetric analysis is standard practice following temporary brachytherapy procedures. Its role following permanent implants is less well established. Previous surveys have shown wide variation in dosimetric methods (1, 2); however, there are no established clinical standards or guidelines for performing prostate dosimetry. The recently issued American Brachytherapy Society (ABS) guidelines for prostate brachytherapy recognized the need for such guidelines (3). Although an increasing number of prostate brachytherapy procedures are performed annually, the need

for, and role of postimplant dosimetry following permanent radioactive seed implantation is occasionally questioned. This prompted the ABS to organize a panel with expertise in the field of implant evaluation to perform a literature review and to share their experience and knowledge to develop guidelines for the performance and analysis of postimplant dosimetry.

Because the treatment plan and the actual implant have already been completed at the time of postimplant analysis, the rationale for its use needs elucidation. The first issue arises from the fact that brachytherapy is an imperfect modality, and certainly, the permanent ultrasound-guided

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prostate implant technique is no exception. The dose distributions following implantation are not the same as those planned prior to the implant (4–10). Because the dose distributions differ, it is important to document the actual dose that the prostate and normal adjacent tissues will receive over the life of the implant. This can only be determined if a postimplant dosimetric assessment is performed.

The information obtained is essential for optimal patient care. Significant underdosing of the prostate, which can lead to treatment failure, can be potentially rectified using supplemental external beam irradiation or additional seed implantation (11). In patients who experience a biopsy-proven local failure, the knowledge of the original dose distribution may prove useful when considering salvage therapy, whether in the form of external beam irradiation reimplantation or radical prostatectomy (12–14). This information is also important in determining the cause of potential complications and appropriate patient management.

Postimplant dosimetry is invaluable for those physicians who are just starting to perform permanent seed implants. Dosimetry results can help physicians assess and modify their implant technique. This is essential because there is a learning curve involved in performing prostate brachytherapy (15, 16). In addition, experienced physicians can use dosimetry to further refine and perfect the procedure (17).

Finally, the data that is provided by postimplant dosimetry could be used in future outcome analysis. It would allow comparison of treatment results from various institutions and could be used as a quality assurance tool in prospective multi-institutional clinical trials.

METHODS

Members of the ABS with expertise in prostate dosimetry evaluation performed a literature review, and supplemented with their clinical experience, formulated guidelines for performing and analyzing postimplant dosimetry for permanent prostate brachytherapy. The areas of consensus and controversy were noted. Specific dosimetric recommendations (for use in a community setting as well as in the research environment) and directions for future investigations were made. This report was reviewed and approved by the Board of Directors of the ABS.

RESULTS

Available modalities for obtaining postimplant dosimetry

Methods of performing postimplant evaluation of prostate implants can be best categorized by the modality used to generate the images. The brachytherapist is no longer limited to using plane films. Initially developed for computed tomography (CT) (18), prostate brachytherapy dosimetry based upon axial images has been applied to magnetic resonance imaging (MRI), and transrectal ultrasound (TRUS). The term cross-sectional image set will be used to refer generically to all three. Each modality allows, at least to some degree, localization of structures and seeds, as well

Table 1. Relative advantages and disadvantages of each imaging modality for performing post implant dosimetric analysis*

	Plane films	CT	MRI [†]	TRUS
Source identification	++	+	-	--
Source localization	+	++	0	--
Prostate delineation	--	+	++	+
Critical structure delineation	--	+	++	0
Patient comfort	+	+	-	--
Cost and convenience	++	-	--	+

* Grading scale: ++, +, 0, - and --, where ++ is the highest ranking and -- is the lowest.

[†] MRI (magnetic resonance imaging) performed with a body coil.

CT = computed tomography; TRUS = transrectal ultrasound.

as their spatial relationship from the cross-sectional images. While the advantages of this type of dosimetry over plane film are overwhelming, each of the above imaging modalities has limitations. Table 1 summarizes their relative advantages and disadvantages. This has prompted efforts to combine imaging methods by spatially coregistering (i.e., fusing) the information from two or more imaging modalities.

Historically, the earliest method was plain film dosimetry. The geometric reconstruction of source locations from two projection radiographs has been used for many years to perform pre- and postimplant dosimetry. Techniques are available for using films with a common axis and for those taken with a stereo shift (19, 20). Methods of correcting for film skew—films not perpendicular to the axis of the x-ray source—have been developed (21). The errors inherent in these methods have been studied (22–24). Unfortunately, two-film techniques may be used reliably only when the operator is able to match each individual source from one film with its corresponding image on the other film. Because of the number seeds and their irregular spacing, this is extraordinarily difficult in permanent prostate brachytherapy.

To address this problem, three film techniques have been developed (25–27). These methods dramatically improve the accuracy of seed localization in permanent prostate implants, achieving true localization rates on the order of 90% (28). Radiographs or fluoroscopy can be performed in the operating room during or immediately after the implant with equipment that is readily available.

The principal disadvantage of plane film techniques is that they cannot be used to visualize the target (prostate gland) and critical structures (rectum, urethra, bladder). While the dose distribution may be computed and displayed in axial planes, or even viewed as a three-dimensional (3D) object, there is no information about the spatial relationship of this distribution to the prostate or adjacent structures. While other deficiencies exist with this method (organ motion between films, for instance), it is this shortcoming that led to the development of cross-sectional image set dosimetry such as CT-based dosimetry.

CT-based dosimetry was first applied to prostate implants by Roy *et al.* at Memorial Sloan-Kettering Cancer Center in New York (18). The advantage of being able to visualize sources in relation to the target became immediately apparent, particularly with regard to low energy isotopes such as ^{125}I and ^{103}Pd , for which the dose distribution is highly dependent on precisely locating the seed positions. In this technique, abutting slices taken through the gland were displayed and digitized into the treatment planning system. Because the sources often appeared on more than one slice, a seed location reduction method (seed sorting) based upon the nearest neighbors was employed.

The basic methods of CT-based implant dosimetry have changed little. Various authors have published techniques that adjust the slice spacing or the distance between slices, and the task of seed sorting has been automated (28). Properly performed, the accuracy of seed location is on par with, if not superior to, three-film techniques (28, 29).

Limitations of this technique include the required *a priori* knowledge of the number of seeds in the image set at the beginning of the sorting process. This information can be garnered from a single plane film, usually taken in the anterior-posterior direction, or less reliably, from documentation detailing the number of sources implanted within the patient. Additionally, some inherent uncertainty is introduced when the location of the seeds in the axial (i.e., cranio-caudal) direction is determined. This is because axial volume sampling limits the resolution in this direction to the width of each individual slice. Soft tissue contrast with CT is often poor, making it difficult to reliably contour the borders of the prostate, especially at the base and the apex of the gland (30).

The ability of MRI to visualize soft tissue anatomy makes it an enticing choice as an imaging modality for prostate brachytherapy dosimetry. Several authors have used MRI in this regard (31, 32). The MRI set is not restricted to axial acquisition, a particularly useful attribute for delineating the glandular borders at the troublesome apex and base. Critical structures such as the urethra and the neurovascular bundle are more easily visualized on MRI.

There are many problems associated with MRI dosimetry of the prostate. In addition to the same seed sorting problems inherent to any cross-sectional image set, visualization of the seeds themselves is difficult. Because there is no signal from them, they image as low signal areas, making them difficult to distinguish from vessels, calcifications, and other structures with no signal. This is particularly difficult at the periphery and just outside the gland. While some success has been achieved by choosing an imaging sequence using bone windows with a narrow bandwidth (thus enhancing the artifact from the seeds), MRI does not image sources as well as CT does. The acquisition process is certainly slower than CT, possibly contributing to motion artifacts. Distortion of the image set may also be a problem with MRI.

Although no reports have been published on the use of TRUS for postimplant dosimetry, it has been used for re-

implantation of the gland (14). The seed locations are very difficult to discern, and their disruption of the ultrasound signal makes delineation of the prostatic borders more difficult than with the preimplant ultrasound. Because of this, it seems unlikely that ultrasound can be used as a single modality for postimplant dosimetric analysis, unless ultrasound technology is improved. The patient discomfort associated with this examination particularly after surgery adds to the disadvantages of this option unless the dosimetry is performed on-line, during surgery.

Nevertheless, there are some features of TRUS that make it appealing. Ultrasound examination is relative easy and inexpensive. The possibility of using the same imaging modality that was used to perform the preplan and the implant procedure to generate the post plan is enticing. TRUS potentially offers the only practical option for performing on-line dosimetric analysis during the procedure, allowing the brachytherapist to adjust the dose distribution by adding seeds in regions where the dose is inadequate. Like MRI, longitudinal imaging is also possible.

Because each imaging modality offers its own advantages, some authors have combined imaging techniques to optimize the information available for the postimplant analysis (31, 33, 34). Combining two or more modalities usually involves using a modality that optimizes source localization and another that best delineates the prostatic and critical structure boundaries.

Coregistration, sometimes called fusion, relies upon determining a transformation matrix that converts data from one image set to the other. Image information can then be overlaid to calculate and display information from both sets. Defining this transformation matrix requires at least three data points, although the most successful coregistration methods use a much larger number of data points. Examples in prostate brachytherapy include using marker seeds (10), the urethral surface (33), and multiple seed locations (35).

There are pitfalls associated with coregistration of two image sets. There can be changes in the patient position relative to the coordinates used to generate the transformation matrix, or changes in the relative positions between the coordinates themselves. For instance, using a urethra distended by the presence of a catheter in one image set to align an image set that had been generated without a catheter would likely produce errors. For the same reason, extreme care must be exercised when aligning image sets based upon source locations from images produced at two widely different times after the implant. A similar argument can be made against coregistering TRUS images taken before implant with the CT images taken after implant, unless sufficient time has passed for the postimplant edema to resolve.

Distortion can also be a problem. A simple transformation that results in scaling translation and rotation cannot correct for a distorted data set. Fortunately, over the distances of concern in prostate brachytherapy, and with the equipment that is currently available, distortion of any single data set is usually minimal. Coregistration techniques

that ignore distortion have thus far proved adequate for permanent prostate brachytherapy, because the distortion is minimal due to the small distances in prostate brachytherapy (35, 36).

A simple example of coregistration is the overlay of isodose curves generated from plane film dosimetry on axial CT images. Alignment is performed visually, sometimes aided by the placement of a gold marker seed placed at the apex of the gland. Transverse slices in the plane film coordinate system are generated by the planning system and then overlaid on the appropriate CT slice. Although this practice is common, it is fraught with uncertainties, and therefore is of marginal value in permanent prostate brachytherapy. The rapid changes in dose within relatively short distances make it necessary to be as accurate as possible in determining the transformation matrix. This level of accuracy can be achieved only with methods of determination that are quantitative and reproducible.

Roberson, Narayana, and colleagues have used marker seeds, as well as the urethral and rectal surfaces, to coregister the preimplant ultrasound and the postimplant CT scan (10, 33). A similar technique in which the urethra and bladder base are visually aligned to coregister postimplant CT and MRI image sets has recently been used by Amdur *et al.* (36). A more rigorous method of coregistering image sets based on the available source locations in each data set has been outlined by Dubois *et al.* (35). This method has been used to coregister postimplant CT and MRI data sets and to fuse postimplant CT data sets to ultrasound image sets acquired to plan a second salvage implant (37).

Recommended CT technique

At the present time, CT-based evaluation of the prostate implant appears to best satisfy the requirements of seed localization target and normal structure delineation and seed-target registration. It is also readily available. Due to possible seed migration or embolization (38–41), the number of seeds implanted may not be the same as the number of seeds present in the prostate at the time of the postimplant scan. Therefore, a better approximation of the number of seeds may be obtained by using plane radiographs. The recommended technique for performing CT-based dosimetry is outlined below.

The region to be imaged by CT should include the prostate, all the seeds within and around the prostate, and any critical structures for which the dose is to be reported. To accomplish this, it is suggested that at minimum, a 2-cm margin be added to the superior and inferior extent of the prostate. A reduced field of view that completely encompasses the volumes and structures of interest, but offers a finer resolution in the plane of the implant, should be used. This will reduce the error associated with seed localization and prostate boundary definition.

Contiguous axial slices are recommended to reduce the chance of missing seeds between scans. The slice thickness and spacing should be no greater than 5 mm (3-mm slice

thickness and spacing are commonly reported in the literature) (6, 10, 17, 18, 42–44).

A catheter placed in the bladder and filled with contrast can be used to localize the urethra and internal bladder wall. However, the use of a catheter should be weighed against the discomfort and potential morbidity of this procedure (especially if the CT scan is not performed in the immediate postimplant period when the patient already has an indwelling catheter).

CT images are acquired using normal body-CT settings. If hardcopy films are to be used for digitization of seeds and prostate, an optimal window setting must be chosen that balances the ability to resolve seeds with the ability to delineate the prostate and adjacent structures of interest. The geometry of the implant, and therefore the dosimetry, is derived directly from the CT images themselves. In some CT scans, the images may contain distortions (such as unequal x and y scaling), and it is important that means of identifying and accounting for such scaling variations be in place.

The TG-43 formalism is recommended for both the pre- and postimplant dosimetry (45–48). Due to the difficulties in using CT scans to determine seed orientation, the use of a point source approximation with anisotropy constant is recommended (49). Calculations should be performed using a matrix with resolution limited to 2 mm or less (50) in an effort to minimize the effects of the large dose gradients inherent in a brachytherapy procedure.

The target is defined as the prostate (without margin) on the individual CT images. Care should be taken to distinguish the prostate from the peri-prostatic tissue. Several studies have noted discrepancies in volume of prostate, as determined by TRUS, MRI, and CT, reflecting the difficulties in differentiating the prostate from the periprostatic musculature and venous plexus using CT (23, 33, 44, 51).

Normal structures of interest that can be defined by using CT include the urethra and the rectum (17, 18, 52, 53). For the urethra, the entire prostatic urethra should be defined. This can be done through use of a central lumen point identified on each slice, or by contouring the urethral wall (52, 54). Catheterization is an accurate method for localization of the urethra within the prostate. If, however, the urethra cannot be visualized, an alternative is to identify, as the urethral dose point, the geometric center of the prostate as imaged on successive CT slices (55). It must be recognized that doing this gives only an estimate of the urethral dose, and is valid only if peripheral seed-loading configuration is used.

For purposes of dosimetry, only the anterior rectal wall, and not the entire rectum, is considered the structure of interest. As with the urethra, several different methods may be used to define the rectal wall. These include the use of single points located along the anterior wall of the rectum, contouring the outer anterior rectal wall for use with surface dosimetry or contouring the anterior rectal wall as a volume excluding the lumen (53, 56, 57). As most commercial planning systems are unable to define the dose to surfaces,

Table 2. Effect of timing on CT-based dosimetric evaluation

Author (ref.)	No. of patients	Post-operative interval (days)	Mean maximum % volume increase	Dose coverage underestimate
Naryana (33)	10	1	53	
Moerland (31)	12	3	30	
Prestidge (58)	19	1, 8, 30, 90, 180	19	10%
Waterman (5)	10	Varied (0–180)	53	9.5%
Merrick (59)	10	0, 3, 14, 28	21	

contouring the anterior rectal wall as a volume represents a compromise (57).

It is possible for an individual seed to appear on multiple CT slices. Although the frequency of this event may be reduced by using the larger (5 mm) slice spacing, it is not eliminated. Therefore, a seed-sorting computer program is needed to eliminate this duplication or redundancy, and to yield a final seed count consistent with the presumed number of seeds within the volume. As previously stated, plane radiographs are recommended in conjunction with CT-based dosimetry to aid seed sorting routines that require prior knowledge of the number of seeds to be identified from the larger set of seeds localized on CT. The “z” or cranio-caudal coordinate of seeds identified on multiple CT slices may be better defined by averaging over the CT coordinates of the different slices on which that seed has been localized (18).

Timing of dosimetric evaluation

The degree of volumetric enlargement of the prostate induced by the multiple needle punctures associated with this procedure has been described. It is presumed that the etiology of this volume increase is the trauma-associated fluid accumulation and bleeding within the gland. Although the percent of volume increase has been reported as ranging from 0 to 96%, mean values range from approximately 20% to 50% (5, 31, 33, 58–60) (Table 2). The broad range of values is most likely related to a number of factors, which might include biological variation between patients, as well as differences in experience and technique among brachytherapists. There seems, however, to be better agreement on the rate of resolution of this edema, with reported half-lives of about 10 days.

The magnitude dynamics and resolution of edema may have obvious implications for the timing at which the dose-volume relationship is described. There are few reports of changes in CT-based dosimetry in a serial fashion over time postimplant. In the first, Prestidge and colleagues (58) reported a mean maximum volume increase of 19%. This resulted in a 10% underestimate of prostate coverage by the prescribed dose on postoperative day 1 relative to day 180.

Waterman *et al.* (5) found a mean volume increase of 52% on day 1 relative to preimplant, which resulted in a mean decrease of approximately 10% in calculated dose coverage. In this report, edema was initially calculated

based on interseed spacing in an effort to eliminate the uncertainty introduced by CT-based prostate margin delineation. It was proposed that this alternative would serve as a more accurate estimation for target volume changes. However, the volumes estimated by this method were in reasonable agreement with those determined by contouring the prostate on CT film.

The optimal time to evaluate permanent prostate implant dosimetry is controversial, and may differ by isotope (because of the difference in half-lives). Time-averaged weighting factors (58) and computer modeling (60–62) suggest that ^{103}Pd and ^{125}I implants would best be evaluated after about 2 and 4 weeks, respectively. However, the dosimetric compromise introduced by performing evaluation of ^{103}Pd implants at 1 month was demonstrated to be quite small (58). For various practical and logistical reasons, many brachytherapists prefer to rely on early scanning (2, 3, 6, 18, 38, 59, 63). Many patients come from great distances and may be unwilling to make return trips just for postoperative imaging studies. Additionally, early feedback can be used to compensate an underdosed prostate (by reimplanting or adding external beam) and to improve the implantation technique. With early dosimetry, Willins and Wallner estimated that coverage of the gland by at least 80% of the target isodose line was adequate (6, 63). These considerations may outweigh the 10% underestimation of prostate coverage that can be produced by early dosimetry (58). Based on these considerations it can be stated that:

1. There is controversy and lack of consensus regarding the ideal time to obtain postoperative dosimetry. The clinical significance of obtaining dosimetry at different time intervals has not been established.
2. The most practical postoperative time interval for scanning is within 24 h.
3. The most reproducible dosimetric results will be obtained if the scan is performed 1 month postimplant, although this may not be practical in all patients.
4. Until the ideal postoperative interval for scanning has been determined, each center should perform dosimetric evaluation of prostate implants at a consistent postoperative interval. This interval should be stated in the dosimetry report. It should be kept in mind that dosimetry obtained from CT scan in the immediate postimplant period will underestimate prostate coverage by about 10%, compared to dosimetry obtained from CT scan performed 1 month postimplant.

Dosimetric evaluation and reporting

Evaluation of postimplant dosimetry is typically carried out in three separate steps: (a) examination of isodose distribution, (b) generation of the dose-volume histogram (DVH), and (c) determination of dose uniformity and dose conformity indices. These three aspects of dosimetric evaluation provide complementary information for assessing the quality of an implant.

A two-dimensional isodose distribution should be gener-

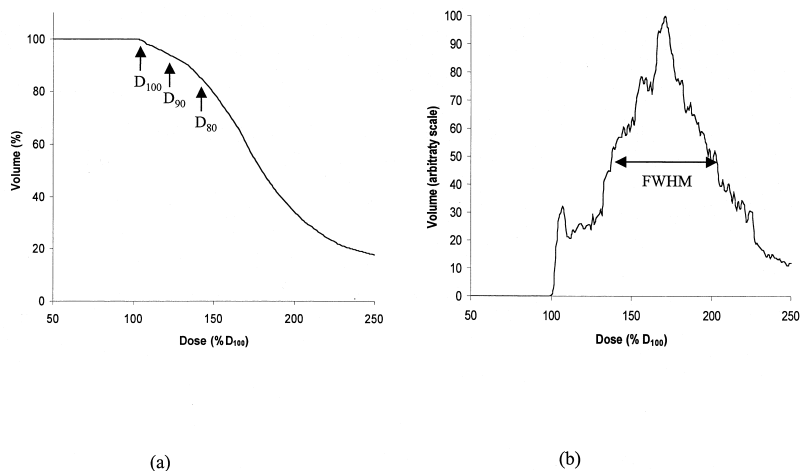


Fig. 1. (a) Cumulative DVH of dose in percent of D_{100} versus volume in percent of the target volume. (b) Differential DVH of dose in percent of D_{100} versus fractional volume in arbitrary scale. The full width at half maximum (FWHM) is obtainable from the DDVH.

ated on multiple slices throughout the prostate and in other areas of concern. Outline of the prostate and any adjacent critical structures as determined by tomographic imaging should be superimposed on the isodose distribution. Such isodose plots offer the most direct assessment of dose coverage, because the location of any underdosage in the prostate can be evaluated based on supplemental clinical judgment. It is recommended that at least the following set of isodose lines be generated as a percentage of the prescription dose: 200%, 150%, 100%, 90%, 80%, and 50%.

Generation of the DVH of the prostate is recommended. The most common format is the cumulative DVH, which shows the percent volume (or total volume) of the prostate that receives greater than or equal to a given dose. A less commonly used representation, the differential dose-volume histogram (DDVH), displays the relative volume of the prostate that receives a given dose (Fig. 1). The full width at half maximum (FWHM) of the DDVH is a measure of the uniformity of the dose distribution. It is generated on the DDVH by taking the peak volume value, dividing by two, and drawing a horizontal line on the graph. The dose where the line first hits the rising curve is subtracted from the dose represented by the last intersection of the line and the falling curve, giving the FWHM. A larger value implies a wider range of doses or a less uniform dose distribution. A smaller value thus reflects a more uniform dose distribution. The unit for FWHM is gray (Gy).

Typically, the DDVH peaks at a dose that is higher than the prescription dose. The spread of the peak is a useful indicator of dose homogeneity (18, 64, 65). A smaller spread indicates greater dose uniformity. It is recommended that a grid size of 2 mm or smaller be used to ensure adequate resolution of the reported parameters in the dosimetric calculation (17, 66–68).

It is recommended that the following be reported to allow adequate evaluation of postimplant dosimetry and to allow correlation with clinical outcome:

1. The values of D_{100} , D_{90} , and D_{80} (the dose that covers 100%, 90%, and 80% of the prostate, respectively).
2. The values of V_{200} , V_{150} , V_{100} , V_{90} , and V_{80} (the fractional volume of the prostate that receives 200%, 150%, 100%, 90%, and 80% of the prescribed dose, respectively).
3. The total volume of the prostate (in cc) obtained from postimplant dosimetry.
4. The number of days between implantation and the date of the imaging study used for dosimetric reconstruction.
5. The urethral and rectal doses.

All of the above volumetric parameters are obtainable from a single compilation of the DVH. Of these, only D_{90} has been shown to correlate with PSA-based clinical outcome (11) and should be reported by all. However, in the research environment, a complete set of dosimetric data should be collected to facilitate future clinical correlation with respect to local control radiation toxicity and for comparison of results between various institutions.

A number of dose conformity quantifiers exist in the literature for prostate brachytherapy (64, 69, 70). Of these, the target volume ratio (TVR) is traditionally defined as the ratio of the reference dose volume to the target volume. The concept of TVR is similar to the historical matched peripheral dose and has the same limitation of not addressing the geometrical relationship between the target volume and the reference dose volume: a geometrical miss will not be reflected in the TVR value. It is possible to perform an implant with a $TVR > 1.0$ (seemingly good), where very little dose was actually delivered to the prostate (bad) if most of the sources were outside the prostate. A modified TVR (TVR2), as described by Bice and Prestidge (43), takes into account the volume and the location encompassed by the reference isodose surface. TVR2 is defined as the reference dose volume divided by the volume of the target that receives the reference dose or greater. While this quan-

tifier still has some flaws, TVR2 has the advantage of including the spatial relationship between the target and the dose, but is dependent upon who and how the target is drawn. Because the clinical target volume in prostate brachytherapy is not yet fully understood, this dose conformity parameter was not found to be a useful enough parameter to receive a strong endorsement or a recommendation from the panel. While it may be of value in assessing future clinical outcomes, it is not required of the community brachytherapist.

Calculation and reporting of dose to the prostatic urethra are important components of dosimetric evaluation. Dose to the urethra may be represented in a number of ways. If the urethra is adequately visualized (e.g., by catheterization) in postimplant imaging, a DVH or dose-surface histogram (DSH) can be generated in addition to point dose calculation at the center of the urethra on each axial slice. Less reliably, the geometric center of the prostate may be used as a surrogate for the location of the urethra, particularly for the peripheral loaded implants (55). The urethral dose throughout the prostate should be examined on multiple sections. The length of urethra receiving > 200% of the prescribed dose should be recorded to allow correlation with urethral morbidity.

Similarly, dose to the anterior rectal wall is an important component of postimplant evaluation. Rectal dose may be represented in a DSH or DVH within an annulus that approximates the anterior rectal wall (56). Alternatively, for simplicity, point dose sampling along the anterior rectal wall may be used. Again, the rectal dose should be recorded throughout the implanted area.

It is recognized that detailed DVH analysis may be very labor intensive and may not be supported by all treatment planning systems at present. Therefore, it may not be practical to report all of the above dosimetric parameters in the community setting. However, it is recommended that at a minimum, postimplant dosimetry be performed and the D_{90} reported at all centers, and that all the other parameters be additionally obtained in a research environment.

Clinical correlation

The data collected from dosimetric analysis is relevant in that it has been shown to correlate with treatment outcomes. Historically, measures of implant quality of retropubic prostate brachytherapy have been related to disease control (71–73).

Stock *et al.* analyzed the results of CT-based postimplant dosimetry (using TG43 guidelines) performed 1 month after implantation in 134 patients treated with ^{125}I implants for T1 to T2 prostate cancer over a 6-year period. This study correlated dosimetric findings with PSA control and negative biopsy results. Increasing D_{90} values, from < 100 Gy, 100–119.9 Gy, 120–139.9 Gy, 140–159.9 Gy, and ≥ 160 Gy were associated with improved freedom from PSA failure rates of 53%, 82%, 80%, 95%, and 89%, respectively ($p = 0.02$) at 4 years. A dose cutoff point was found at 140 Gy, with PSA control rates of 68% for those patients re-

ceiving a $D_{90} < 140$ Gy, compared to 92% for those with a $D_{90} \geq 140$ Gy ($p = 0.02$) (11).

Treatment-related morbidity has also been correlated with postimplant dosimetry findings. Wallner *et al.* (52) analyzed 45 patients treated with ^{125}I implantation who had CT-based dosimetry performed 2–4 h after implantation and related these findings to urinary and rectal morbidity. He found that in patients who developed RTOG grade 0–1 urinary morbidity, an average of 10 mm of urethra was irradiated to doses > 400 Gy (pre-TG43) compared to 20 mm for patients experiencing Grade 2–3 morbidity ($p = 0.07$). He concluded that both the dose and length of urethra irradiated were related to urinary morbidity. Similarly, when examining rectal morbidity, he found that in patients developing RTOG Grade 1–2 rectal morbidity an average of 17 mm² of rectal wall was irradiated to doses > 100 Gy, compared to 11 mm² for patients experiencing no rectal morbidity (52).

Desai *et al.* (54) analyzed acute urinary morbidity in 117 patients treated with ^{125}I implants by correlating urinary symptoms as measured by the international prostate symptom score with findings from CT-based dosimetry performed 1 month after implantation. She found that the highest symptom score in each patient correlated with the following dose descriptions of the prostate: D_{100} , D_{95} , D_{90} , D_{80} , V_{90} , V_{100} , and V_{150} . In particular, urinary frequency correlated with the D_{95} , D_{90} , D_{80} , V_{100} , and V_{90} , as well as doses delivered to 5 cm² of urethra, as measured by DSH. The conclusion of this analysis was that attempts at reducing urethral doses can translate into reduced urinary symptoms, and that trials of prostate dose escalation may be limited by the acute urinary symptoms (54).

DISCUSSION

Postimplant dosimetry of the prostate is a constantly evolving dynamic field. The above recommendations represent the current consensus opinion of the ABS. Because of the current paucity of published data, there are areas of controversy that cannot be resolved. For example, the ideal time for obtaining the postimplant dosimetry or an exact dose/volume recommendation to the urethra or rectum cannot currently be identified. The panel identified a number of other parameters that should be considered for further development and refinement of the dosimetric process.

Currently, dosimetric analysis is performed after the implant has been completed. This does not provide a mechanism for correction if suboptimal dose distribution is obtained. Ideally, one should strive for on-line real-time intraoperative dosimetry to allow for adjustment in seed placement to achieve the intended dose. Current ultrasound technology must be improved to localize the individual seed position within the prostate, and isodose calculations must be rapidly performed on-line and updated as subsequent seeds are implanted. Correlation of the resultant implant dose distribution to the clinical outcome has yet to be studied.

The dose distribution in a prostate implant is very inhomogeneous. The degree of dose heterogeneity varies from implant to implant. The tumor control probability (TCP) depends on the degree of heterogeneity in addition to the prescribed dose (74). For example, in two implants with the same D_{90} , the dose may be much higher (or lower) in some regions of one than in similar regions of the other. The implant with the more heterogeneous dose may have a greater TCP, because parts of the tumor will receive a dose that is much higher than the prescribed dose. The therapeutic advantage and tradeoff of dose heterogeneity are not yet adequately documented for the purpose of clinical correlation.

Another factor to be considered is the presence of large prostate calcifications that can affect the dose delivered. The higher atomic number of calcium ($z = 20$) compared to that of prostatic tissue ($z = 7.6$) leads to a greater absorbed dose increased attenuation and increased dose deposition at the calcium/soft tissue interface. Interseed effects may also adversely affect the dose distribution, because the seeds, being denser than tissue, will absorb some of the radiation from other seeds (75, 76). The actual effect of these heterogeneities on the dose distribution needs further investigation.

Finally, these recommendations are intended to be advisory in nature; the responsibility for the medical decisions ultimately rests with the treating physician who has to consider the cost-benefit ratio. We also recognize that some of the recommendations given in this report may be too

complex to be practical for the practicing community radiation oncologist, and may be more relevant for the larger brachytherapy centers planning to compare their outcome results. This differentiation has been mentioned in the relevant section of the text.

SUMMARY

The ABS recommends that postimplant dosimetry should be performed on all patients undergoing permanent prostate brachytherapy for optimal patient care. At present, CT-based dosimetry is recommended based on availability, cost and the ability to image the prostate as well as the seeds. Additional plane radiographs should be obtained to verify the seed count. Until the ideal postoperative interval for CT scanning has been determined, each center should perform dosimetric evaluation of prostate implants at a consistent postoperative interval. This interval should be reported. Isodose displays should be obtained at 50%, 80%, 90%, 100%, 150%, and 200% of the prescription dose and displayed on multiple cross-sectional images of the prostate. A DVH of the prostate should be performed and the D_{90} reported by all centers. Additionally, the D_{80} , D_{100} , the fractional V_{80} , V_{90} , V_{100} , V_{150} , V_{200} , the rectal, and urethral doses should be reported and ultimately correlated with clinical outcome at larger centers. On-line, real-time dosimetry, the effects of dose heterogeneity, and the effects of tissue heterogeneity need further investigation. These recommendations should be a practical guide for performing postimplant dosimetry for permanent prostate brachytherapy.

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