# Validation of American Association of Physicists in Medicine TG 43 Dosimetry Data in Commercial Treatment Planning System

Sathiyan Saminathan, K. Maheshraja, K. M. Ganesh

Department of Radiation Physics, Kidwai Memorial Institute of Oncology, Bengaluru, Karnataka, India

## Abstract

**Aims:** This study aimed to validate the dosimetric data of low-energy photon-emitting low-dose rate (LE-LDR) brachytherapy seed sources in commercial treatment planning system (TPS). **Materials and Methods:** The LE-LDR seed sources dosimetric data were published in the American Association of Physicists in Medicine (AAPM) Task Group reports TG-43 (1995), TG-43U1 (2004), TG-43U1S1 (2007), and TG-43U1S2. The Bhabha Atomic Research centre (BARC) $^{125}$I Ocu-Prosta seed dosimetry data are also available in the literature. The commercially available TPSs are using both two-dimensional (cylindrically symmetric line-source) and one-dimensional (1D) (point source) dose-calculation formalisms. TPS used in this study uses only 1D dose-calculation formalism for permanent implant dosimetry. The point-dose calculation, dose summation, isodose representation, and dose–volume histogram quality assurance tests were performed in this study. The point-source dose-calculation tests were performed for all the available sources in the literature. The others tests were performed for the I-125 BARC Ocu-Prosta seeds. The TPS-calculated doses were validated using manual calculation. **Results and Discussion:** In point-source calculation test, the TPS-calculated point-dose values are within ±2% agreement with manually calculated dose for all the seeds studied. The agreement between the TPS and manually calculated dose is 0.5% for the dose summation test. The isodose line pass through the grid points at an equal distance was verified visually on the computer screen for seed used clinically. In dose–volume histogram test, the TPS-determined volume was compared with the real volume. **Conclusion:** Misinterpretation of the TPS test and/or misunderstanding of the TG-43 dose-calculation formalism may cause large errors. It is very important to validate the TPS using literature provided dosimetric data. The dosimetric data of BARC $^{125}$I Ocu-Prosta Seed are validated with other AAPM TG-43-recommended seeds. The dose calculation of Best® NOMOS permanent implant TPS is accurate for all permanent implant seeds studied.

**Keywords:** American Association of Physicists in Medicine TG-43 Report, BARC Ocu-Prosta seed, dosimetry, low dose rate, permanent implant brachytherapy, treatment planning system

## INTRODUCTION

The American Association of Physicists in Medicine (AAPM) published the Task Group No. 43 (TG-43)[1] in the year 1995 by introducing a new brachytherapy dose-calculation formalism based on findings of the Interstitial Collaborative Working Group.[2] AAPM TG-43 presented the dosimetry formalism for three low-energy photon-emitting sources. The source models are shown in Table 1. The dosimetry formalism was updated in 2004 and was termed the AAPM TG-43U1 report.[3] Table 2 shows that the source models were presented in AAPM TG-43U1 report. Several additional sources were introduced in the market, to include the dosimetric datasets, the TG-43 supplement report was introduced in the year 2007 and termed as AAPM

TG-43U1S1 report.[4] AAPM TG-43U1S1 report presented source models which are shown in Table 3. The AAPM and the Groupe Européen de Curiethérapie–European Society for Radiotherapy and Oncology jointly introduced the TG-43 supplement report 2 in the year 2017 and termed as AAPM TG-43U1S2 report.[5] In this report, 11 low-energy photon-emitting brachytherapy source dosimetry datasets were introduced. Table 4 shows the source models presented

### Access this article online

**Quick Response Code:**

**Website:**
www.jmp.org.in

**DOI:**
10.4103/jmp.JMP_20_21

**Table 1: Source models presented in American Association of Physicists in Medicine Task Group-43 Report**

| Manufacturer | Source type |
|---|---|
| Theragenics corporation model 200 | $^{103}$Pd |
| Amersham health models 6702 | $^{125}$I |
| Amersham health models 6711 | $^{125}$I |

**Table 2: Source models presented in American Association of Physicists in Medicine Task Group-43U1 Report**

| Manufacturer | Source type |
|---|---|
| Amersham health model 6702 | $^{125}$I |
| Amersham health model 6711 | $^{125}$I |
| Best model 2301 | $^{125}$I |
| NASI model MED3631-A/M | $^{125}$I |
| BEBIG/Theragenics corporation model I25.S06 | $^{125}$I |
| Imagyn model IS-12501 | $^{125}$I |
| Theragenics corporation model 200 | $^{103}$Pd |
| NASI model MED3633 | $^{103}$Pd |

**Table 3: Source models presented in American Association of Physicists in Medicine Task Group-43U1S1 Report**

| Manufacturer | Source type |
|---|---|
| Amersham health, oncoseed model 6733 | $^{125}$I |
| Best medical model 2335 | $^{103}$Pd |
| Draximage Inc., brachyseed model LS-1 | $^{125}$I |
| Implant sciences 3500 | $^{125}$I |
| IBt, intersource-125 model 1251L | $^{125}$I |
| IsoAid, advantage model 1A1-125A | $^{125}$I |
| Mills biopharmaceuticals Inc., prostaseed model SL/SH-125 | $^{125}$I |
| Sourcetech medical | $^{125}$I |

**Table 4: Source models presented in American Association of Physicists in Medicine Task Group-43U1S2 Report**

| Manufacturer | Source type |
|---|---|
| BEBIG model I25.S17 | $^{125}$I |
| BEBIG model I25.S17plus | $^{125}$I |
| BEBIG model I25.S18 | $^{125}$I |
| Elekta model 130.002 | $^{125}$I |
| Oncura model 9011 | $^{125}$I |
| Theragenics model AgX100 | $^{125}$I |
| CivaTech oncology model CS10 | $^{103}$Pd |
| IBt model 1031L | $^{103}$Pd |
| IBt model 1032P | $^{103}$Pd |
| IsoAid model IAPd-103A | $^{103}$Pd |
| IsoRay medical model CS-1 | $^{131}$Cs |

in AAPM TG-43U1S2 report. The $^{131}$Cs source model were also discussed in this report in addition to $^{125}$I and $^{103}$Pd source models.

In India, BARC $^{125}$I Ocu-Prosta seed is in clinical use, mostly used for ophthalmic application.[6,7] Only a few Radiotherapy centers are using this source for permanent prostate implants. The BARC $^{125}$I Ocu-Prosta seed dosimetry data are also available in the literature.[8,9] The commercial treatment planning system (TPS) used for the permanent implant can be configured either with line source approximation or point-source approximation or both. In our center, we have Best® NOMOS permanent implant TPS. The Best® NOMOS permanent implant TPS uses the point-source approximation for dose calculation.[10,11]

In this study, 27 low-energy photon-emitting low-dose rate (LE-LDR) brachytherapy sources (20 $^{125}$I, 6 $^{103}$Pd, and 1 $^{131}$Cs) dosimetric data were evaluated using commercial TPS. The test cases recommended in the Netherlands Commission on Radiation Dosimetry Subcommittee "Dosimetry and quality control of brachytherapy with low-energy photon sources ($^{125}$I)" are used in this study to evaluate the permanent implant TPS algorithm.[12]

## MATERIALS AND METHODS

The LE-LDR sources dosimetric data such as dose rate constant ($\wedge$), geometry function G (r, $\Theta$), radial dose function g(r), one-dimensional (1D) anisotropy function ($\phi$an(r)), and two-dimensional (2D) anisotropy function F *(r, $\Theta$)* were published in AAPM TG-43 (1995), TG-43U1 (2004), TG-43U1S1 (2007), and TG-43U1S2 reports. The BARC $^{125}$I Ocu-Prosta seed dosimetry data are also available in the literature.[8,9] The commercially available TPSs are using both 2D (cylindrically symmetric line source) and 1D (point source) dose-calculation formalisms. However, some TPS uses 1D dose-calculation formalism for permanent implant dosimetry.

### General two-dimensional formalism

This formalism assumes the dose to be distributed symmetrically with respect to the longitudinal axis of the source. A polar coordinate system is used with its origin located at the center of the active source and zero angles coinciding with the longitudinal axis of the source.

The reference point $P$ $(r_0, \Theta_0)$ is taken on the source transverse plane ($\Theta_0 = 90°$) at the reference distance of 1 cm [Figure 1].

The dose rate to water at a point $P$ $(r, \theta)$ can be expressed as

$$D\ (r,\ \theta\ ) = S_k \times\ \wedge\ \times\ \frac{G_L\ (r, \theta)}{G_L\ (r_0,\ \theta_0)} \times g_L\ (r)\ F\ (r, \theta) \tag{1}$$

where

$\dot{D}(r, \theta)$ is the absorbed dose rate to water at (r, $\theta$) (in units of cGy h$^{-1}$),

r is the radial distance from the source center to the point of interest,

$\theta$ is the polar angle,

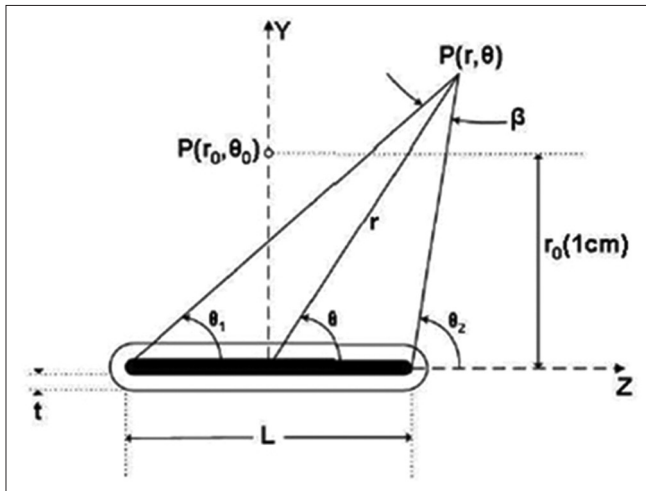$S_k$ is the air-kerma strength of the source (in units of U = $\mu$Gy m$^2$ h$^{-1}$ = cGy cm$^2$ h$^{-1}$),

**Figure 1:** Geometrically assumed dose-calculation formalism

$\Lambda$ is the dose rate constant (in units of cGy h$^{-1}$ U$^{-1}$ which reduces to cm$^{-2}$),

$G_L$ (r, $\theta$) is the geometry function,

$g_L$ (r) is the radial dose function,

$F$ (r, $\theta$) is the 2D anisotropy function

## General one-dimensional formalism

When evaluating implants with a large number of seeds in TPS, it is often difficult to determine the exact orientation of the source longitudinal axis for each individual seed. Moreover, many TPSs assume the seeds to be oriented parallel to the longitudinal axis of the image set, i.e. perpendicular to the transverse images. The 1D point-source approximation (Eq. 2) eliminates the need to determine the orientation of the sources. This model will only approximate the true 2D dose distribution, it applies an average correction for the anisotropy effects and treat the source as isotropic.[12]

The dose rate to water at a point can be expressed as

$$D\ (r) = S_K \times \wedge \times \frac{G_X\ (r, \theta_0\ )}{G_X\ (r_0, \theta_0\ )} \times g_X\ (r)\ \phi_{an}(r) \tag{2}$$

For dose calculation, the equation (2) can be used as

$$D\ (r) = S_K \times \wedge \times \left(\frac{r_0}{r}\right)^2 g_p\ (r)\ \phi_{an}(r) \tag{3}$$

or

$$D\ (r) = S_K \times \wedge \times \frac{G_L\ (r, \theta_0\ )}{G_L\ (r_0, \theta_0\ )} \times g_L\ (r)\ \phi_{an}(r) \tag{4}$$

TG-43U1 (2004) recommends the use of Eq.(4) for dose calculation because of an improved accuracy at small distances ($r < 1$ cm). However, many TPS systems use Eq. (3) for dose calculation. Using the Eq.(3), the initial dose rate is converted to total dose when multiplying by the mean lifetime, $\Upsilon$. The mean lifetime is defined as $\Upsilon = 1.44 \times t_{1/2}$, where $t_{1/2}$ represents the half-life.

## Treatment Planning System

In our center, we use the Best® NOMOS (DBA: Best Medical International, Inc., Pittsburgh, PA, USA), TPS, its dual Activity Module creates the treatment plans using multiple activity sources. Octant Therapy™ Module allows the view of DVH values of specific volumes. Slice Shifter™ provides the ability to correct image slice positioning errors. The concurrent two-dimensional (2D) and 3D visualization allows instant visualization of seed placement, dose distribution, and anatomical structures. The pattern loading feature can be used for new plans with user definable seed pattern loading. This TPS supports both the volume plan (Version 4.9n) and computed tomography (CT) plan (Version 4.01). In volume plan, we can perform the preplan or operating room dosimetry (OR) dosimetry. The TPS can be connected to an ultrasound unit to access the live video image. From the live video, the images can be acquired to TPS with a set of Z-values for preplan dosimetry. Real-time planning is not possible with this TPS. However, in the operating room (OR), the intraoperative planning can be performed is known as real-time planning. The patient remains stationary between the time of the volume study and the implant procedure. The postimplant CT provides the postplan dosimetry with the help of auto seed detection method.

The Best® NOMOS permanent implant TPS uses the 1D dose-calculation formalism for permanent implant dosimetry. The source can be configured in the dose kernel model. The input parameters are source name, manufacturer name, source length, isotope type, default activity, half-life, air-kerma rate constant, dose rate constant, radial dose function, and anisotropy function. The configured source model can be used for both preplan and postplan CT dosimetry. In this TPS, BARC $^{125}$I Ocu-Prosta seed and other AAPM TG-43-recommended (26 LE-LDR) seed sources were configured for dosimetric study.

### Quality assurance tests

The following quality assurance tests were reported in the literature.[12]

### *Test 1, point-source calculation*

Calculation of the dose from a single seed in a number of points at different distances perpendicular to the seed axis using the point-source approximation.

### *Test 2, dose summation*

Summation of the dose from two seeds in a number of points at different distances perpendicular to the seed axis using the point-source approximation.

### *Test 3, isodose representation*

Representation of the isodose lines around a single source using the point-source approximation.

### *Test 4, dose–volume histogram*

Calculation of the DVH from a single source using the point-source approximation

### *Test 5, line-source calculation*

Calculation of the dose from a single seed in a number of points at different distances along the transverse and longitudinal axis

of the seed and in three points at angles in between using the line-source approximation.

Tests 1–4 were performed using a 1D anisotropy calculation model. Test 5 is not considered in this study, since this TPS is not supporting line source approximation. The test procedure is as follows.

### Test 1: Point-source calculation test

In this test, the dose was calculated in a number of points at different distances perpendicular to the seed axis of a single seed using the point-source approximation.

### Test procedure

1. The test patient was created in the TPS with ultrasound prostate phantom (CIRS, USA). The phantom is shown in Figure 2
2. The source strength of 100 U was placed at image 5 (z = 2 cm) at the left-most column in the middle
3. The dose points add in the image at grid point on right to the source at distances of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, and 6.0 cm
4. The dose value of TPS was compared with the manually calculated dose values
5. The manual calculation was performed using the equation (3).

### Test 2: Dose summation test

In this test, the dose calculation was done using two seeds in a number of points (dose points) at different distances perpendicular to the seed axis.

### Test procedure

1. The same plan was used from the test 1
2. At 1 cm right from the first source, the second source strength of 100U was added at image z = 2 cm
3. The sum of the dose was verified at the distance of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 cm.

### Test 3: Isodose representation test

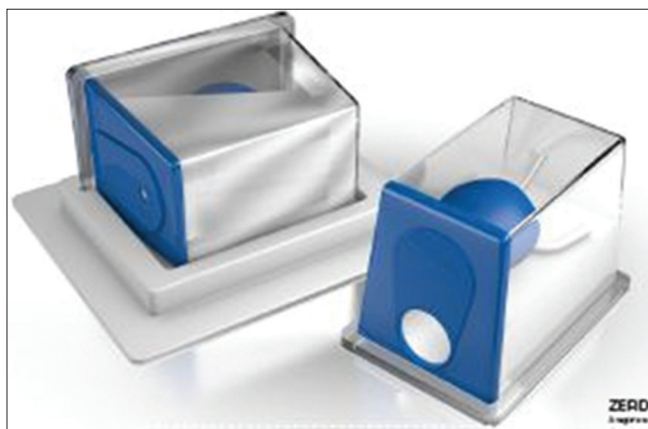In this test, the isodose representation around a single source was verified.



**Figure 2:** Prostate phantom

### Test procedure

1. Using the test plan 1, the source strength of 100 U was added at the central image (z = 5 cm) of center grid
2. The isodose levels equal to dose-calculation points of 1.0, 2.0, and 3.0 cm were selected
3. The isodose lines passing through the grid points were verified.

### Test 4: Dose–volume histogram test

In this test, the dose–volume calculation of the TPS was verified using geometrical DVH values.

### Test procedure

1. In a new test study, a volume (prostate) of 4 cm × 4 cm × 6 cm was created
2. A source was placed at the central image (z = 3.5 cm) of center grid
3. The source strength was determined to get the 100 Gy point dose at a distance of 1.0, 2.0, and 3.0 cm.

Also using the test 1 (point-source calculation), the dosimetry of 27 LE-LDR sources was studied. For all the sources, the TPS-calculated point doses were validated using manually calculated dose.

## Results and Discussion

### Test 1: Point-source calculation test

The calculated point doses in the TPS at various grid point distances of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, and 6.0 cm were validated using manually calculated dose value. The equation (3) was used for the manual calculation. Figure 3a and b shows the variation between TPS and manually calculated point-dose values for BARC Ocu-Prosta ($^{125}$I) and AAPM TG-43U1 (2004)-recommended seeds. Figure 4a and b shows the variation between TPS and manually calculated point-dose values of AAPM TG-43U1S1 (2007)-recommended seeds. Figure 5a-c shows the variation between TPS and manually calculated point-dose values for AAPM TG-43U1S2 (2017)-recommended seeds. The results show the variation between TPS and manually calculated point-dose values are within ± 2% for all the seeds studied.

### Test 2: Dose summation test

In this test, the dose calculation was done using 2 BARC Ocu-Prosta seeds in a number of points (dose points) at different distances perpendicular to the seed axis. The sum of the doses was verified at various distances of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 cm in TPS. The TPS-calculated point-dose values are with 0.5% compared to manually calculated dose value. Figure 6 shows the dose summation test.

### Test 3: Isodose representation test

This test was performed using BARC Ocu-Prosta seed placed at center grid (Z = 5 cm). The isodose levels were passing the grid points at 1.0, 2.0, and 3.0 cm distances. The standard uncertainty of mean for the grid points was within 1%. Figure 7 shows the image of isodose lines passing through the grid points at a distance of 1.0, 2.0, and 3.0 cm.
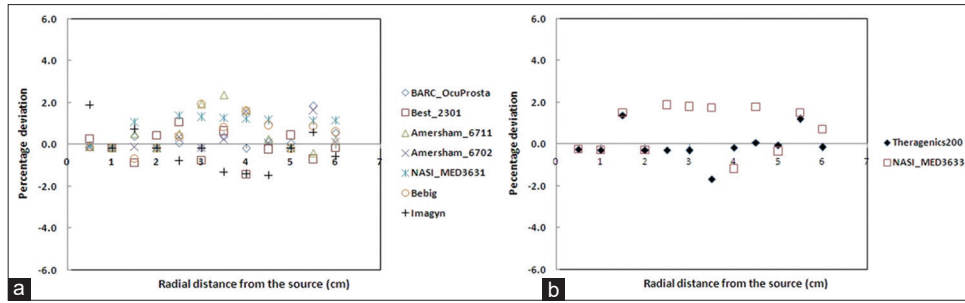
**Figure 3:** (a) Variation between treatment planning system and manually calculated point-dose values for (a) [125]I BARC Ocu-Prosta and American Association of Physicists in Medicine TG-43U1 seeds (b) [103]Pd American Association of Physicists in Medicine TG-43U1 seeds
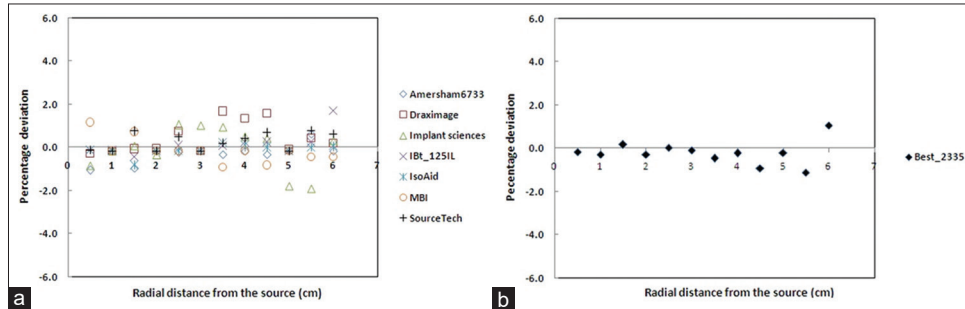


**Figure 4:** (a) Variation between treatment planning system and manually calculated point-dose values for (a) [125]I. American Association of Physicists in Medicine TG-43U1S1 seeds. (b) [103]Pd American Association of Physicists in Medicine TG-43U1S1 seeds
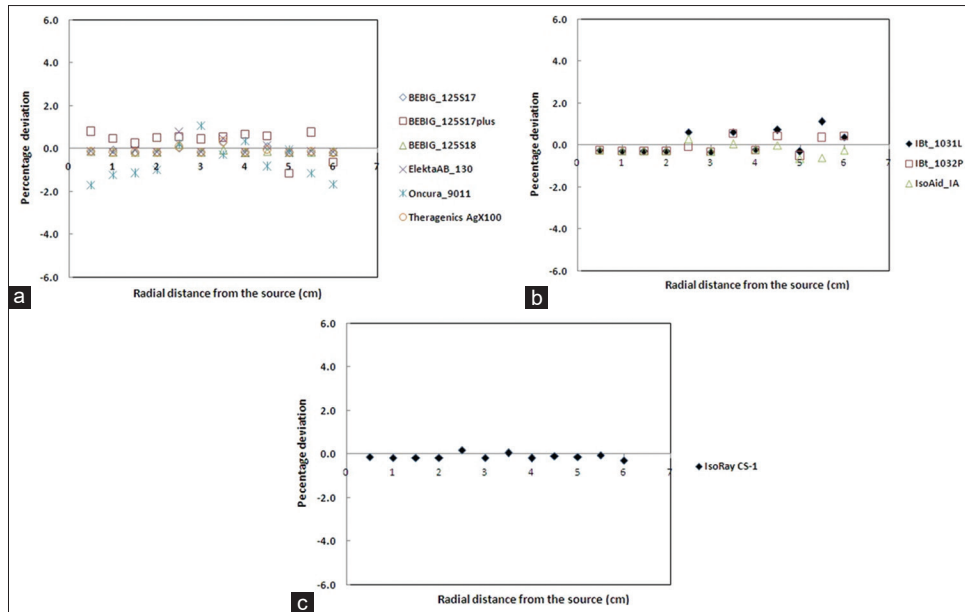


**Figure 5:** (a) Variation between treatment planning system and manually calculated point-dose values for (a) [125]I American Association of Physicists in Medicine TG-43U1S2 seeds. (b) [103]Pd American Association of Physicists in Medicine TG-43U1S2 seeds. (c) [131]Cs American Association of Physicists in Medicine TG-43U1S2 seeds

## Test 4: Dose–volume histogram test

In the TPS, the volume was created using the contouring tools, which was 4 cm × 4 cm × 6 cm (96.0 cm³) and TPS-calculated volume was 96.04 cm³. To get the 100 Gy dose at a distance of 1.0 cm, the source strength used was 5.5U. The source strength was 26.0 U to get the 100 Gy dose at a distance of

2.0 cm and the source strength was 75.0 U to get the 100 Gy dose at a distance of 3.0 cm.

Very often, TPSs come with preloaded TG-43 data for most source models/brands. The user should be well aware of the version of algorithm used in TPS for dose calculation (preplanning, on-line planning, and/or postplanning
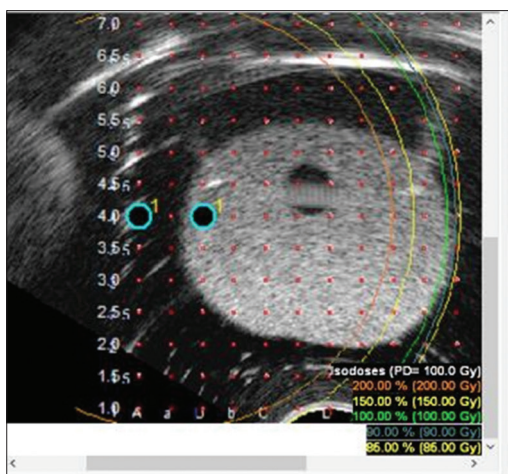
**F*igur*e 6:** Dose summation test



**Figure 7:** Isodose representation test

procedures). The user should verify the TPS for the correct seed model to be used for dose calculation. We verified the dose calculation in a number of points on the longitudinal and transverse axis of the source and compared the calculated dose with manual calculation using data provided in the literature.[3-5] The deviation between the TPS-calculated and manually calculated dose is within ± 2%. It is well agree with the literature recommendation.[12]

The typical implantation involves many seeds (up 50 or more). The TPS calculates the dose distribution from each individual seed and sums up the dose distribution to the total dose. In this process, the source-to-source shielding effects are neglected by the system. The sum dose should be numerically accurate. The tested dose sum accuracy is 0.5%. The isodose line pass through the grid points at an equal distance was verified visually on the computer screen for seed used clinically. In dose–volume histogram test, the TPS-determined volume was compared with the real volume.

## Conclusion

Misinterpretation of the TPS test and/or misunderstanding of the TG-43 dose-calculation formalism may cause large errors.[12] It is very important to validate the TPS using literature provided dosimetric data. Furthermore, it is important to recognize the limitation of TPS; in this TPS, the source orientation is not clearly visible in the postimplant clinical image and also, this TPS cannot compute 2D anisotropy calculation. The dosimetric data of BARC [125]I Ocu-Prosta seed are validated on for with other AAPM TG-43-recommended seeds. The dose calculation of Best® NOMOS permanent implant TPS is accurate for the all permanent implant seeds studied.

In case of major system upgrades or improvements in the basic TG-43 data, it is good practice to study the influence of changes for a number of clinical cases by comparing results of previous calculations with the new ones. The TPS should be tested at time of commissioning, at every software upgrade,
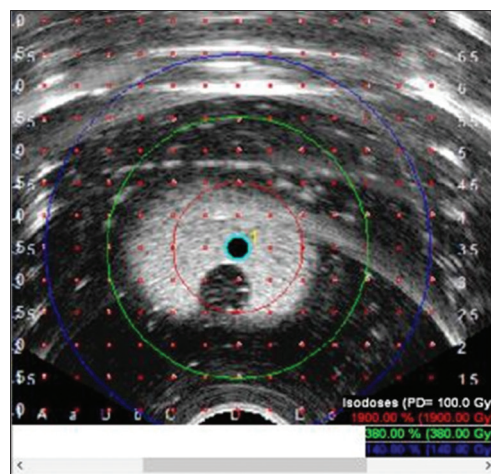
when basic TG-43 data are modified or updated or when a new source model is being used.

## Conflicts of interest

There are no conflicts of interest.

## References

1. Nath R, Anderson LL, Luxton G, Weaver KA, Williamson JF, Meigooni AS. Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. Med Phys 1995;22:209-34.
2. Anderson LL, Nath R, Weaver KA, Nori D, Phillips TL, Son YH, *et al*. Interstitial Collaborative Working Group (ICWG) in Interstitial Brachytherapy: Physical, Biological, and Clinical Considerations. New York: Press; 1990.
3. Rivard MJ, Coursey BM, DeWerd LE, Hanson WF, Huq MS, Ibbott GS, *et al*. Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. Med Phys 2004;31:633-74.
4. Rivard MJ, Butler WM, DeWerd LA, Huq MS, Ibbott GS, Meigooni AS, *et al.* Supplement to the 2004 update of the AAPM Task Group No. 43 Report. Med Phys 2007;34:2187-205.
5. Rivard MJ, Ballester F, Butler WM, DeWerd LA, Ibbott GS, Meigooni AS, *et al*. Supplement 2 for the 2004 update of the AAPM Task Group No. 43 Report: Joint recommendations by the AAPM and GEC-ESTRO. Med Phys 2017;44:297-338.
6. Shah PK, Narendran V, Selvaraj U, Guhan P, Saxena SK, Dash A, Astrahan M. Episcleral Plaque brachytherapy using 'BARC I-`125 Ocu-Prosta seeds' in treatment of intraocular tumours: A single institution experience in India. Indian J Opthalmol 2012;60:289-95.
7. Manolkara RB, Sanea SU, Pillaib KT, Majalia MA. Comparison of methods for preparation of 125I brachytherapy source cores for the treatment of eye cancer. Appl Radiat Isot 2003;59:145-50.
8. Sharma SD, Basu M, Shanta A, Palani Selvam T, Tripathi UB, Bhatt BC. Dosimetry parameters of BARC OcuProsta I-125 seed source. Aust Phys Eng Sci Med 2005;28:14-20.

9.  Sahoo S, Selvam TP. An EGSnrc investigation of the air-kerma strength, dose rate constant, and radial dose function of 125I brachytherapy sources. Radiol Phys Technol 2009;2:198-204.
10. Gossman MS. Addendum to brachytherapy dose-volume histogram commissioning with multiple planning systems. J Appl Clin Med Phys 2016;17:1-4.
11. Gossman MS, Hancock SS, Kudchadker RJ, Lundahl PR, Cao M, Melhus CS. Brachytherapy dose-volume histogram commissioning with multiple planning systems. J Appl Clin Med Phys 2014;15:110-20.
12. Aalbers AH, De Brabandere M, Koedooder C, Moerland MA, Rijnders A, Schaeken B, *et al*. Dosimetry and quality control of brachytherapy with low-energy photon sources ($^{125}$I). Report 20 of the Netherlands Commission on Radiation Dosimetry, Revised edition, June 2012.