

Investigation of optic disc dose reduction in ocular brachytherapy using 125I notched COMS plaques

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Abstract

Background: Notched plaques were devised to reduce radiation dose to the optic disc in ocular brachytherapy. Although notched plaques have been widely used in clinic, optic disc dose reduction by the use of notched plaques has not been discussed in the literature. Therefore, this study investigated optic disc dose reduction in ocular brachytherapy using 125I notched Collaborative Ocular Melanoma Study (COMS) plaques based on our institutional practice. **Methods:** Using our in-house brachytherapy dose calculation program in which the American Association of Physicists in Medicine Task Group-43 Update (AAPM TG-43U1) dosimetry formalism with a line source approximation in a homogeneous water medium and COMS seed coordinates in the AAPM TG 129 were incorporated, optic disc doses for standard COMS plaques (from 12 mm to 22 mm in diameter in 2 mm increments) and notched COMS plaques with one seed removed (Case #1, from 12 mm to 22 mm in diameter in 2 mm increments) and two seeds removed (Case #2, from 14 mm to 22 mm in diameter) were calculated as a function of tumor margin-to-optic disc distance (DT) for various tumor basal dimensions (BDs) for prescription depths from 1 mm to 10 mm in 1 mm intervals. A prescribed dose was 85 Gy for an irradiation time of 168 hours to each prescription depth. Absolute and relative optic disc dose reduction by notched COMS plaques (Cases #1 and #2) for all prescription depths was calculated from optic disc dose differences between standard and notched COMS plaques. **Results:** Optic disc dose reduction by notched COMS plaques (Cases #1 and #2) had five unique trends which are related to maximum optic disc dose reduction and corresponding optimal DT for each BD in each plaque. Optic disc dose reduction increased with increasing prescription depth. **Conclusions:** The results presented in this study (magnitude of optic disc dose reduction and its trends) would enable the clinicians (both ophthalmologist and radiation oncologist) to choose an adequate plaque type among standard 125I COMS plaques and notched 125I COMS plaques (Cases #1 and #2) and a prescription depth to minimize optic disc dose for a given clinical case.

Background

A variety of treatment techniques for juxtapapillary choroidal melanoma (a tumor within 1 mm of the optic disc) [1, 2] have been used and such techniques include enucleation, plaque radiotherapy, charged particle (proton or other heavy ions) radiotherapy, stereotactic radiotherapy and transpupillary thermotherapy [2, 3]. Plaque radiotherapy is a preferred modality to enucleation for medium-sized tumors (apical height from 2.5 mm to 10 mm and maximum tumor basal dimension of ≤ 16 mm) because it allows for eye and vision retention with equivalent tumor control [4, 5]. The Collaborative Ocular Melanoma Study (COMS) randomized trial evaluated 125I plaque radiotherapy versus enucleation for medium-sized choroidal melanomas but excluded juxtapapillary melanoma from the plaque radiotherapy arm and offered enucleation instead [3, 6]. Nevertheless, major institutions have treated juxtapapillary choroidal melanoma using plaque brachytherapy [1, 2, 7].

One of the major contraindications for plaque brachytherapy is visual change/loss, and its substantial risk factors were found to be proximity of the tumor to the optic disc and radiation dose to the optic disc [3, 8, 9]. To spare the optic disc and consequently, to reduce the contraindication, notched plaques were devised primarily for juxtapapillary or circumpapillary (overhanging the optic disc) tumors [3, 10]. Notched COMS plaques, which have usually one radionuclide seed removed from standard COMS plaques, have been widely used [11]. Customized notched plaques or slotted plaques were also designed and have been used to accommodate the optic disc better than notched COMS plaques [3, 10, 12].

Although visual outcomes for the notched plaques mentioned above were reported [1, 3, 11, 12], detailed dosimetry information on radiation dose reduction to the optic disc by the use of notched plaques has received little attention in the literature. Therefore, this study investigated dose reduction to the optic disc in ocular brachytherapy using 125I notched COMS plaques. This investigation was based on our institutional practice but clinical outcomes are not included.

Methods

Calculations of optic disc dose for a prescription depth of 5 mm

In our previous study [13], using our in-house brachytherapy dose calculation program, optic disc dose for standard COMS plaques (seven different-sized plaques from 10 mm to 22 mm in diameter in 2 mm increments) loaded with 125I seeds (IsoAid Advantage IAI-125A, IsoAid, LLC, Port Richey, FL) was comprehensively investigated as a function of tumor margin-to-optic disc distance (DT) for various tumor basal dimensions (BDs) [13]. Based on current clinical practice for plaque brachytherapy (i.e., tissue inhomogeneity not taken into account for dose calculations) [13], the in-house program was developed using the American Association of Physicists in Medicine Task Group-43 Update (AAPM TG-43U1) dosimetry formalism with a line source approximation in a homogeneous water medium [14] and COMS seed coordinates from Table 1 in the AAPM TG-129 report [4]. The in-house program was validated for benchmark calculations in the literature, demonstrating similar accuracy to three commercially available treatment planning systems which use the same dose calculation algorithm as our in-house program [13]. Then optic disc dose calculations were performed for a prescribed dose of 85 Gy normalized to a central-axis depth of 5 mm for an irradiation time of 168 hours [13].

In the current study, optic disc dose for notched COMS plaques loaded with 125I seeds (model IAI-125A) was calculated. Using the validated in-house program, dose calculations were performed in the same way as for standard COMS plaques for the following two cases: Case #1) six (from 12 mm to 22 mm in diameter in 2 mm increments) notched COMS plaques with one seed removed from standard COMS plaques and Case #2) five (from 14 mm to 22 mm in diameter in 2 mm increments) notched COMS plaques with two seeds removed from standard COMS plaques. It is noted that both Case #1) and #2) are not patient cases but cases generated by our in-house brachytherapy dose calculation program. The 10 mm COMS plaque was not included in both cases because it contains only five seeds and notched plaque design is not commercially available. The 12 mm COMS plaque was not included in Case #2 because its seed configuration does not allow for the removal of two seeds. Table 1 shows seed position numbers removed from standard COMS plaques in Figure 1 of the AAPM TG-129 report [4]. After seed(s) were removed from standard COMS plaques, the prescribed dose of 85 Gy was re-normalized to the prescription depth of 5 mm.

Generation of dose conversion factors for different prescription depths

In our previous study [13], dose conversion factors for different prescription depths were generated for standard COMS plaques. Using the in-house program, optic disc dose calculations for standard COMS plaques were performed for various prescription depths from 1 mm to 10 mm in 1 mm intervals. Then ratios of total reference air kerma (TRAK) per seed to obtain 85 Gy for an irradiation time of 168 hours to each prescription depth to that to 5 mm were taken as dose conversion factors [13]. TRAK per seed is defined as the product of air-kerma strength (Sk) per seed and irradiation time, and its unit is μGym^2 ($=U \times \text{hrs}$).

In the current study, dose conversion factors for different prescription depths were generated for both Cases #1 and #2. Using the in-house program, optic disc doses for notched COMS plaques were calculated for prescription depths from 1 mm to 10 mm in 1 mm intervals. Then dose conversion factors were obtained in the same way as for standard COMS plaques. After seed removal, the prescribed dose (85 Gy) and irradiation time (168 hours) were kept the same as for the prescription depth of 5 mm.

Calculations of optic disc dose reduction by notched COMS plaques

Optic disc dose reduction by notched COMS plaques (Cases #1 and #2) was calculated from optic disc doses for standard and notched COMS plaques for all prescription depths from 1 mm to 10 mm. Absolute optic disc dose reduction, , was computed for each case using equation (1):

(1)

where D_{standard} is optic disc dose for standard COMS plaques and D_{notch} is corresponding optic disc dose for notched COMS plaques. Relative optic disc dose reduction, R , was computed using equation (2):

(2)

where D_{standard} and D_{notch} are the same as for the absolute dose reduction.

Results

Optic disc dose reduction for a prescription depth of 5 mm

Case #1: one seed removal

Fig. 1a-f presents optic disc dose (dashed lines) as a function of DT for various BDs for six notched COMS plaques with one seed removed in comparison to that (solid lines) for six standard COMS plaques. A prescription depth was 5 mm. As expected, when one seed was removed, optic disc dose was reduced.

(Gy) by notched COMS plaques with one seed removed is shown in Fig. 2a-f. A prescription depth was 5 mm. Following unique trends for optic disc dose reduction are observed.

1) (Gy) increases with DT, reaches the maximum value (D_{TmaxD}) and then decreases with DT. For the largest 2-3 BDs, however, dose reduction continuously decreases with DT. Examples include those for BDs of 7 mm and 9 mm in 12 mm notched plaque (Fig. 2a) and those for BDs of 15 mm, 17 mm and 19 mm in 22 mm notched plaque (Fig. 2f).

2) Maximum absolute optic disc dose reduction (R) is usually larger with smaller plaques but does not continuously decrease with plaque size.

3) The magnitude of R does not vary with BD in each plaque except for those for the largest 2-3 BDs (Table 2).

4) DT at which occurs (D_{TmaxD}) decreases by about 1 mm with increasing BD by 2 mm. For example, for 12 mm notched plaque, D_{TmaxD} decreases from 2.7 mm to 1.7 mm as BD increases from 1 mm to 3 mm (Fig. 2a). On the other hand, for the largest 2-3 BDs, D_{TmaxD} is always 0 mm or close to 0 mm. For instance, in 12 mm notched plaque, D_{TmaxD} becomes 0 mm when BD is 7 mm or 9 mm (Fig. 2a).

5) D_{TmaxD} increases with plaque size for the same BD. For BD of 5 mm (blue line in Fig. 2), D_{TmaxD} are 0.7 mm, 1.9 mm, 2.2 mm, 3.5 mm, 4.4 mm and 5.0 mm for 12 mm, 14 mm, 16 mm, 18 mm, 20 mm and 22 mm plaques, respectively (Table 2).

Table 2 summarizes (Gy), R , and corresponding D_{TmaxD} (mm) for each BD and for each notched plaque with one seed removed (Case #1). (are 86.3 Gy (35.5%-35.6%), 57.1 Gy (27.9%-28.3%), 59.9 Gy (29.3%-29.6%), 40.9 Gy (25.3%-25.5%), 38.3 Gy (26.7%-27.1%) and 45.5 Gy (32.3%-32.7%) for 12 mm, 14 mm, 16 mm, 18 mm, 20 mm and 22 mm plaques, respectively, excluding those for the largest 2-3 BDs (Fig. 2 and Table 2). For each plaque and each prescription depth, ranges within 0.4% with varying BD.

Case #2: two seeds removal

Fig. 3a-e displays optic disc dose (dashed lines) as a function of DT for various BDs for five notched COMS plaques with two seeds removed and that (solid lines) for five standard COMS plaques. A prescription depth was 5 mm. When two seeds were removed, optic disc dose was reduced more than when one seed was removed.

by notched COMS plaques with two seeds removed is shown in Fig. 4a-e. A prescription depth was 5 mm. The amount of dose reduction is larger but trends for dose reduction are similar compared with in Case #1.

Table 3 summarizes (Gy), and corresponding and DTmaxD (mm) for each BD and for each notched plaque with two seeds removed (Case #2). (are 101.4 Gy (43.5%-44.0%), 107.5 Gy (44.6%-47.1%), 75.0 Gy (41.5%-41.7%), 59.4 Gy (38.1%-38.2%) and 74.0 Gy (47.9%-48.3%) for 14 mm, 16 mm, 18 mm, 20 mm and 22 mm plaques, respectively, excluding those for the largest 2-4 BDs (Fig. 4 and Table 3).

Case #1 versus Case #2

Although trends for optic disc dose reduction are similar between Case #1 and Case #2 (Fig. 2 and 4), differences in and in DTmaxD between the two cases are fairly distinct (Tables 2-3). Differences in between the two cases are 44.3 Gy (57.1 Gy vs. 101.4 Gy), 47.6 Gy (59.9 Gy vs. 107.5 Gy), 34.1 Gy (40.9 Gy vs. 75.0 Gy), 21.1 Gy (38.3 Gy vs. 59.4 Gy) and 28.5 Gy (45.5 Gy vs. 74.0 Gy) for 14 mm - 22 mm plaques in order, respectively (Tables 2 and 3). In Case #2, DTmaxD becomes shallower by 0.7 mm - 0.8 mm for 14 mm, 16 mm, 18 mm and 22 mm plaques and by 0.5 mm - 0.6 mm for the 20 mm plaque than in Case #1 for the same BD (Tables 2 and 3). For instance, in Case #1, for BD = 1 mm (red line in Fig.2), DTmaxD are 3.9 mm, 4.2 mm, 5.5 mm, 6.3 mm and 6.9 mm for 14 mm - 22 mm plaques in order, respectively, whereas in Case #2, for BD = 1 mm (red line in Fig.4), corresponding DTmaxD are 3.2 mm, 3.4 mm, 4.8 mm, 5.8 mm and 6.2 mm.

Dose conversion factors for different prescription depths

Dose conversion factors for prescription depths from 1 mm to 10 mm for standard COMS plaques were reported in our previous study [13]. In the current study, dose conversion factors are presented in Table 4 for six notched COMS plaques with one seed removed (Case #1) and in Table 5 for five notched COMS plaques with two seeds removed (Case #2). For plaques from 14 mm to 22 mm, dose conversion factors for Case #1 are similar to those for Case #2 within 2.4%. Compared to dose conversion factors for standard COMS plaques [13], those for notched COMS plaques from 14 mm to 22 mm are slightly higher (up to 2.7% for Case #1 and 3.4% for Case #2) at shallow (<5 mm) prescription depths and slightly lower (up to 1.1% for Case #1 and 1.4% for Case #2) at deeper (>5 mm) depths. However, trends for dose conversion factors between standard and notched COMS plaques are similar. The factors increase with increasing prescription depth. Also, the factors increase with increasing plaque size for depth <5 mm but decrease with increasing plaque size for depth >5 mm.

Optic disc dose reduction for different prescription depths

Optic disc dose reduction by notched COMS plaques increases with increasing prescription depth but its trends for the other prescription depths (1 mm - 4 mm & 6 mm - 10 mm) are similar to the five trends mentioned above for the depth of 5 mm (data not shown here). Tables 6 and 7 present for each prescription depth and for each notched plaque with one seed removed (Case #1) and with two seeds removed (Case #2), respectively. Those for the largest 2-4 BDs are not included in Tables 6-7. (Gy) increases with increasing prescription depth for each plaque in both cases. However, corresponding decreases slightly (up to 2.0%) with increasing prescription depth.

Estimation of optic disc dose: clinical application of this study

A clinical example (BD = 3 mm, DT = 3 mm and apical height = 3 mm) is given and practical application of the results obtained in this study for this example is demonstrated in Table 8. A prescribed dose is 85 Gy and a 14 mm COMS plaque loaded with 125I seeds (model IAI-125A) is selected. Depending on the type of COMS plaque and prescription depth, six clinical scenarios are possible and optic disc dose can be estimated for each scenario (Table 8). Of these, Scenario #1 (standard COMS plaque and prescription depth of 5 mm) and Scenario #6 (notched COMS plaque with two seeds removed and prescription depth of 3 mm) give the highest (197.6 Gy) and the lowest (65.0 Gy) optic disc doses,

respectively. Optic disc dose difference between these two scenarios is 132.6 Gy. When 85 Gy is prescribed at 5 mm, dose reduction from optic disc dose (197.6 Gy) for the standard plaque is 56.9 Gy for one seed removal (Scenario #2) and 92.7 Gy for two seeds removal (Scenario #3). At 3 mm, dose reduction from optic disc dose (124.5 Gy) for the standard plaque is 37.3 Gy for one seed removal (Scenario #5) and 59.5 Gy for two seeds removal (Scenario #6). Although absolute dose reduction is larger for depth of 5 mm, relative dose reduction is similar between the two depths (i.e., approximately 29% for one seed removal (Scenarios #2 and #5) and 47% for two seeds removal (Scenarios #3 and #6)).

Discussion

This study demonstrated that optic disc dose reduction by notched COMS plaques has its own trends (Fig. 2 and 4), and corresponding reasons for the five trends mentioned in the Results are as follows:

- 1) is usually at maximum farther than 0 mm, while occurs at 0 mm or close to 0 mm for 2-4 largest BDs (Fig. 2 and 4). This is attributed to unique patterns of optic disc dose curves as a function of DT, BD and plaque size (Fig. 1 and 3). For small BDs in plaques ≥ 16 mm, there are regions in which dose does not change much with distance (Fig. 1c-f and 3b-e), making occur at farther distances than 0 mm (i.e., optimal DTmaxD exists for each plaque and for each BD). In contrast, for the largest 2-4 BDs, optic disc dose continuously decreases with DT for both standard and notched plaques (Fig. 1 and 3), thus, continuously decreases with DT (Fig. 2 and 4) and occurs at 0 mm or close to 0 mm. Figure 4 in Lee *et al.* explains this phenomenon with optic disc location relative to seed positions with varying DT [13].
- 2) Since a total number of seeds do not continuously increase with plaque size, dose reduction does not continuously decrease with plaque size. Dose contribution per seed to a point of interest is higher for 12 mm plaque (8 seeds in total) than for 14 mm plaque (13 seeds in total) (TRAK per seed for depth of 5 mm: 677.1 μGym^2 vs. 438.1 μGym^2) and thus, by 12 mm notched plaque is higher than by 14 mm notched plaque (Fig. 2a vs. Fig. 2b). On the other hand, by 14 mm plaque is similar to that by 16 mm plaque (TRAK per seed for depth of 5 mm: 438.1 μGym^2 vs. 459.8 μGym^2) as both plaques contain the same total numbers of seeds (13 seeds in total) (Fig. 2b vs. Fig. 2c). Seed configurations which depend on plaque size would also affect dose to a point of interest even though the effect would be small. A difference in dose reduction between 14 mm and 16 mm plaques is small for Case #1 (Fig. 2b vs. Fig. 2c), whereas it is noticeable for Case #2 (Fig. 4a vs. Fig. 4b).
- 3) does not vary with BD except for those for the largest 2-4 BDs because the number of seeds and seed configurations do not change with BD for the same plaque size.
- 4) For small BDs, DTmaxD decreases with increasing BD because the dose invariant regions usually become shallower with increasing BD (Fig. 1c-f and 3b-e). The decrease of DTmaxD is almost constant (by 1 mm) with increasing BD by 2 mm because DTmaxD is only a function of distance from seeds to the optic disc for the same plaque size. For the largest 2-4 BDs, as discussed in 2) above, occurs at 0 mm or close to 0 mm and therefore, DTmaxD is 0 mm or close to 0 mm (Fig. 1 and 3).
- 5) DTmaxD increases with plaque size for the same BD because distance from seed(s) to the optic disc increases with plaque size (Fig. 1a-f and 3a-e).

In this study, optic disc dose reduction between Case #1 and Case #2 was compared. As more seeds near the optic disc are removed, dose contribution to the direction of the optic disc decreases. As a result, more optic disc dose reduction occurs for Case #2. However, differences in dose reduction between Case #1 and Case #2 do not continuously decrease with plaque size because the number of seeds and seed configurations depend on plaque size. Due to more dose reduction to the optic disc in Case #2, DTmaxD becomes shallower (i.e., DTmaxD moves toward 0 mm) in Case #2 than in Case #1 for the same BD (Fig. 5). However, the difference in DTmaxD between the two cases for the same BD is consistent (0.7 mm - 0.8 mm for 14 mm, 16 mm, 18 mm and 22 mm plaques and 0.5 mm - 0.6 mm for 20 mm plaque)

because in each plaque, seed configurations are the same and only dose contribution per seed to the optic disc is different. The 20 mm plaque has the largest number of seeds (24 seeds in total) and thus, the lowest TRAK per seed, resulting in the smallest differences in and in DTmaxD between the two cases.

As shown in Tables 6-7, has dependence on prescription depth. increases with prescription depth because a deeper prescription depth requires higher TRAK per seed for both standard and notched COMS plaques and thus, dose reduction is larger at a deeper depth.

Juxtapapillary tumors as well as tumors close to the optic disc can benefit from notched COMS plaques in reducing dose to the optic disc. As shown in the Results, DTmaxD is 0 mm only for tumors with the largest 2-4 BDs and there exists optimal DTmaxD (non-zero mm) for tumors with small BDs (Tables 2 and 3). Therefore, notched COMS plaques would be the most beneficial to juxtapapillary tumors or circumpapillary tumors when their BDs are large and to peripapillary tumors (tumor <3.5 mm from the optic disc) or extrapapillary tumors (tumor ≥ 3.5 mm from the disc margin) when their BDs are small [1].

The clinical example discussed in the Results showed that there are various scenarios in selecting COMS plaque type and prescription depth, and this example would help the clinician choose the best scenario to minimize dose to the optic disc. As shown in Table 8, for tumors with apical height <5 mm, prescribing to the tumor apex gives lower optic disc dose than prescribing to a prescription depth of 5 mm for both standard and notched COMS plaques. Depending on the prescription depth, however, a standard COMS plaque can reduce optic disc dose more than a notched COMS plaque. For example, Scenario #4 (standard COMS plaque and prescription depth of 3 mm) gives lower dose to the optic disc than Scenario #2 (notched COMS plaque and prescription depth of 5 mm) (124.5 Gy vs. 140.7 Gy). For tumors with apical height ≥ 5 mm, a prescription depth is always the tumor apex and notched COMS plaques would be always more beneficial.

Conclusions

This dosimetry study has examined dose reduction to the optic disc in ocular brachytherapy using 125I notched COMS plaques based on our clinical practice. Optic disc dose reduction by the use of notched COMS plaques has its own trends. The results obtained in this study (magnitude of dose reduction and its trends) would enable the clinician to choose an adequate plaque type among standard 125I COMS plaques and notched 125I COMS plaques (one seed removal and two seeds removal), and a prescription depth to minimize optic disc dose for a given clinical case.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publish

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YCL analyzed data and wrote a manuscript. SCL performed calculations and collected data. YK designed the study and analyzed data. All authors read and approved the final manuscript.

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List Of Abbreviations

COMS: Collaborative Ocular Melanoma Study; **DT**: distance from optic disc to tumor margin; **BD**: tumor basal dimension at center in the direction from optic disc; **AAPM**: American Association of Physicists in Medicine; **TG**: Task group; **TRAK**: Total reference air kerma; : Absolute optic disc dose reduction; : Relative optic disc dose reduction; : Maximum absolute optic disc dose reduction; **DT_{maxD}**: DT at which maximum absolute optic disc dose reduction occurs; : Maximum relative optic disc dose reduction

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Tables

Table 1 Seed position number(s) removed from standard COMS plaques. Detailed information on seed positions and configurations for each COMS plaque are found in Figure 1 of the AAPM TG-129 report [4].

Plaque size in diameter (mm)		12	14	16	18	20	22
Seed position number(s)	Case #1	3	4	4	5	5	5
removed from COMS plaques	(one seed removal)						
	Case #2	Unavailable	4, 9	4, 10	5, 12	5, 13	5, 12
	(two seeds removal)						

Table 2 Maximum absolute dose reduction, (Gy) (corresponding relative dose reduction,) and tumor margin-to-optic disc distance (DT) at which occurs (DTmaxD (mm)) for 125I (model IAI-125A) notched COMS plaques with one seed removed (Case #1). A prescribed dose of 85 Gy was normalized at 5 mm after one seed removal.

BD (mm)	Plaque size in diameter (mm)					
	12	14	16	18	20	22
1	86.3 Gy (35.5%)	57.1 Gy (28.3%)	59.9 Gy (29.4%)	40.9 Gy (25.4%)	38.3 Gy (26.7%)	45.5 Gy (32.3%)
	2.7 mm	3.9 mm	4.2 mm	5.5 mm	6.3 mm	6.9 mm
3	86.3 Gy (35.5%)	57.1 Gy (28.2%)	59.9 Gy (29.3%)	40.9 Gy (25.3%)	38.3 Gy (27.0%)	45.5 Gy (32.7%)
	1.7 mm	2.9 mm	3.2 mm	4.5 mm	5.4 mm	6.0 mm
5	86.3 Gy (35.6%)	57.1 Gy (28.3%)	59.9 Gy (29.4%)	40.9 Gy (25.3%)	38.3 Gy (27.0%)	45.5 Gy (32.6%)
	0.7 mm	1.9 mm	2.2 mm	3.5 mm	4.4 mm	5.0 mm
7	84.4 Gy (37.5%)	57.1 Gy (27.9%)	59.9 Gy (29.6%)	40.9 Gy (25.5%)	38.3 Gy (27.1%)	45.5 Gy (32.7%)
	0.0 mm	0.8 mm	1.2 mm	2.5 mm	3.4 mm	4.0 mm
9	60.8 Gy (37.0%)	56.3 Gy (29.3%)	59.9 Gy (29.4%)	40.9 Gy (25.3%)	38.3 Gy (26.9%)	45.5 Gy (32.5%)
	0.0 mm	0.0 mm	0.1 mm	1.4 mm	2.3 mm	2.9 mm
11	Unavailable	40.8 Gy (29.5%)	49.1 Gy (31.3%)	40.9 Gy (25.4%)	38.3 Gy (27.0%)	45.5 Gy (32.6%)
		0.0 mm	0.0 mm	0.3 mm	1.2 mm	1.8 mm
13	Unavailable	Unavailable	29.7 Gy (27.4%)	34.9 Gy (26.9%)	38.3 Gy (27.0%)	45.5 Gy (32.5%)
			0.0 mm	0.0 mm	0.0 mm	0.6 mm
15	Unavailable	Unavailable	Unavailable	20.7 Gy (23.0%)	28.6 Gy (27.2%)	41.8 Gy (34.3%)
				0.0 mm	0.0 mm	0.0 mm
17	Unavailable	Unavailable	Unavailable	Unavailable	15.3 Gy (21.5%)	24.2 Gy (29.4%)
					0.0 mm	0.0 mm
19	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	11.6 Gy (21.6%)
						0.0 mm

(Gy) and are defined in equations (1) and (2), respectively.

Table 3 Maximum absolute dose reduction, (Gy) (corresponding relative dose reduction,) and tumor margin-to-optic disc distance (DT) at which occurs (DTmaxD (mm)) for 125I (model IAI-125A) notched COMS plaque with two seeds removed (Case #2). A prescribed dose of 85 Gy was normalized at 5 mm after two seeds removal.

BD (mm)	Plaque size in diameter (mm)				
	14	16	18	20	22
1	101.4 Gy (44.0%) 3.2 mm	107.5 Gy (46.6%) 3.4 mm	75.0 Gy (41.6%) 4.8 mm	59.4 Gy (38.2%) 5.8 mm	74.0 Gy (48.1%) 6.2 mm
3	101.4 Gy (44.0%) 2.2 mm	107.5 Gy (47.1%) 2.5 mm	75.0 Gy (41.5%) 3.8 mm	59.4 Gy (38.1%) 4.8 mm	74.0 Gy (47.9%) 5.2 mm
5	101.4 Gy (43.5%) 1.1 mm	107.5 Gy (46.6%) 1.4 mm	75.0 Gy (41.6%) 2.8 mm	59.4 Gy (38.1%) 3.8 mm	74.0 Gy (47.9%) 4.2 mm
7	101.4 Gy (43.7%) 0.1 mm	107.5 Gy (46.8%) 0.4 mm	75.0 Gy (41.7%) 1.8 mm	59.4 Gy (38.2%) 2.8 mm	74.0 Gy (48.0%) 3.2 mm
9	90.2 Gy (47.0%) 0.0 mm	102.0 Gy (49.1%) 0.0 mm	73.3 Gy (41.6%) 0.7 mm	59.4 Gy (38.1%) 1.7 mm	74.0 Gy (48.3%) 2.2 mm
11	60.7 Gy (43.9%) 0.0 mm	73.9 Gy (47.2%) 0.0 mm	54.6 Gy (43.2%) 0.0 mm	59.4 Gy (38.2%) 0.6 mm	74.0 Gy (47.9%) 1.0 mm
13	Unavailable	44.1 Gy (40.7%) 0.0 mm	54.6 Gy (42.1%) 0.0 mm	56.9 Gy (40.1%) 0.0 mm	73.9 Gy (48.8%) 0.0 mm
15	Unavailable	Unavailable	31.6 Gy (35.3%) 0.0 mm	39.3 Gy (37.5%) 0.0 mm	60.1 Gy (49.3%) 0.0 mm
17	Unavailable	Unavailable	Unavailable	21.2 Gy (29.8%) 0.0 mm	34.0 Gy (41.3%) 0.0 mm
19	Unavailable	Unavailable	Unavailable	Unavailable	16.7 Gy (31.1%) 0.0 mm

(Gy) and are defined in equations (1) and (2), respectively.

Table 4 Dose conversion factors (ratios of total reference air kerma per seed) for various prescription depths (1 mm – 10 mm in 1 mm intervals) for ¹²⁵I (model IAI-125A) notched COMS plaques with one seed removed (Case #1). The data were normalized to those for a prescription depth of 5 mm.

Prescription depth (mm)	Plaque size in diameter (mm)					
	12	14	16	18	20	22
1	0.33	0.36	0.41	0.44	0.47	0.47
2	0.45	0.48	0.52	0.55	0.57	0.58
3	0.60	0.62	0.65	0.68	0.70	0.70
4	0.78	0.80	0.81	0.83	0.84	0.84
5	1.00	1.00	1.00	1.00	1.00	1.00
6	1.26	1.24	1.22	1.20	1.19	1.18
7	1.55	1.51	1.48	1.43	1.40	1.38
8	1.89	1.83	1.77	1.70	1.65	1.62
9	2.28	2.20	2.11	2.01	1.94	1.89
10	2.73	2.61	2.50	2.36	2.26	2.19

Table 5 Dose conversion factors (ratios of total reference air kerma per seed) for various prescription depths (1 mm – 10 mm in 1 mm intervals) for 125I (model IAI-125A) notched COMS plaques with two seeds removed (Case #2). The data were normalized to those for a prescription depth of 5 mm.

Prescription depth (mm)	Plaque size in diameter (mm)				
	14	16	18	20	22
1	0.36	0.41	0.43	0.46	0.46
2	0.48	0.52	0.55	0.57	0.57
3	0.62	0.65	0.67	0.69	0.70
4	0.80	0.81	0.83	0.84	0.84
5	1.00	1.00	1.00	1.00	1.00
6	1.24	1.22	1.20	1.19	1.18
7	1.51	1.47	1.43	1.40	1.39
8	1.83	1.77	1.70	1.65	1.62
9	2.19	2.11	2.01	1.94	1.89
10	2.60	2.49	2.36	2.26	2.20

Table 6 Maximum absolute dose reduction, (Gy) (corresponding relative dose reduction,) for various prescription depths for 125I (model IAI-125A) notched COMS plaque with one seeds removed (Case #1). A prescribed dose of 85 Gy was normalized at each depth after seed removal. For each plaque, (Gy) for the largest 2-4 BDs is not included. For each plaque and each prescription depth, ranges within 0.6% with varying BD.

Prescription depth (mm)	Plaque size in diameter (mm)					
	12	14	16	18	20	22
1	30.2 Gy (37.2%-37.3%)	22.2 Gy (29.2%-29.5%)	26.1 Gy (30.4%-30.8%)	19.0 Gy (26.1%-26.5%)	18.8 Gy (27.5%-28.0%)	22.4 Gy (33.4%-33.8%)
2	40.1 Gy (36.5%-36.6%)	28.7 Gy (28.6%-29.0%)	32.4 Gy (30.0%-30.3%)	23.3 Gy (25.8%-26.2%)	28.8 Gy (27.3%-27.7%)	27.4 Gy (33.1%-33.5%)
3	52.6 Gy (36.0%-36.2%)	36.5 Gy (28.2%-28.8%)	39.9 Gy (29.8%-30.1%)	28.3 Gy (25.8%-25.9%)	27.3 Gy (27.0%-27.4%)	32.8 Gy (32.8%-33.2%)
4	68.0 Gy (35.7%-35.8%)	45.9 Gy (28.2%-28.5%)	49.1 Gy (29.5%-29.8%)	34.1 Gy (25.5%-25.7%)	32.4 Gy (26.9%-27.3%)	38.8 Gy (32.6%-32.9%)
5	86.3 Gy (35.5%-35.6%)	57.1 Gy (27.9%-28.3%)	59.9 Gy (29.3%-29.6%)	40.9 Gy (25.3%-25.5%)	38.3 Gy (26.7%-27.1%)	45.5 Gy (32.3%-32.7%)
6	107.6 Gy (35.3%-35.5%)	70.0 Gy (27.7%-28.1%)	72.5 Gy (29.1%-29.4%)	48.7 Gy (25.2%-25.3%)	45.0 Gy (26.5%-26.9%)	53.2 Gy (32.1%-32.5%)
7	132.2 Gy (35.2%-35.3%)	84.9 Gy (27.6%-28.0%)	87.1 Gy (29.0%-29.3%)	57.7 Gy (25.0%-25.2%)	52.8 Gy (26.4%-26.8%)	62.0 Gy (32.0%-32.3%)
8	160.9 Gy (35.2%-35.3%)	102.3 Gy (27.5%-27.9%)	104.2 Gy (28.9%-29.2%)	68.2 Gy (25.0%-25.1%)	61.9 Gy (26.3%-26.7%)	72.1 Gy (32.0%-32.4%)
9	193.7 Gy (35.1%-35.2%)	122.3 Gy (27.4%-27.8%)	123.8 Gy (28.9%-29.1%)	80.2 Gy (24.9%-25.0%)	72.2 Gy (26.2%-26.6%)	83.7 Gy (31.9%-32.3%)
10	230.9 Gy (35.1%-35.2%)	144.8 Gy (27.4%-27.7%)	146.0 Gy (28.8%-29.1%)	93.8 Gy (24.8%-25.0%)	83.9 Gy (26.1%-26.5%)	96.8 Gy (31.8%-32.2%)

(Gy) and are defined in equations (1) and (2), respectively.

Table 7 Maximum absolute dose reduction, (Gy) (corresponding relative dose reduction,) for various prescription depths for 125I (model IAI-125A) notched COMS plaque with two seeds removed (Case #2). A prescribed dose of 85 Gy was normalized at each depth after seed removal. For each plaque, (Gy) for the largest 2-4 BDs is not included. For each plaque and each prescription depth, ranges within 0.6% with varying BD.

Prescription depth (mm)	Plaque size in diameter (mm)				
	14	16	18	20	22
1	38.6 Gy (44.9%-45.2%)	45.8 Gy (47.6%-47.9%)	34.5 Gy (42.7%-43.1%)	29.2 Gy (39.0%-39.2%)	36.3 Gy (49.5%-49.7%)
2	50.1 Gy (44.2%-44.6%)	57.1 Gy (47.1%-47.4%)	42.5 Gy (42.5%-42.7%)	35.3 Gy (38.5%-39.0%)	44.4 Gy (48.9%-49.1%)
3	64.1 Gy (43.8%-44.2%)	70.9 Gy (46.8%-47.1%)	51.7 Gy (42.1%-42.3%)	42.2 Gy (38.2%-38.6%)	53.1 Gy (48.5%-48.7%)
4	81.2 Gy (43.6%-44.2%)	87.6 Gy (46.7%-47.2%)	62.5 Gy (41.8%-42.0%)	50.2 Gy (37.9%-38.4%)	63.0 Gy (48.2%-48.6%)
5	101.4 Gy (43.5%-44.0%)	107.5 Gy (46.6%-47.1%)	75.0 Gy (41.5%-41.7%)	59.4 Gy (38.1%-38.2%)	74.0 Gy (47.9%-48.3%)
6	124.8 Gy (43.4%-43.9%)	130.7 Gy (46.6%-47.1%)	89.5 Gy (41.4%-41.6%)	69.9 Gy (37.9%-38.0%)	86.6 Gy (47.7%-48.1%)
7	151.9 Gy (43.5%-43.9%)	157.5 Gy (46.5%-47.0%)	106.3 Gy (41.2%-41.4%)	82.2 Gy (37.8%-37.9%)	101.1 Gy (47.6%-48.0%)
8	183.4 Gy (43.5%-43.8%)	188.9 Gy (46.5%-47.0%)	125.8 Gy (41.1%-41.4%)	96.4 Gy (37.7%-37.8%)	117.8 Gy (47.5%-47.9%)
9	219.6 Gy (43.4%-43.8%)	224.9 Gy (46.5%-47.0%)	148.2 Gy (41.1%-41.3%)	112.7 Gy (37.6%-37.7%)	136.9 Gy (47.4%-47.8%)
10	260.5 Gy (43.4%-43.8%)	265.6 Gy (46.5%-46.9%)	173.6 Gy (41.0%-41.2%)	131.1 Gy (37.5%-37.7%)	158.5 Gy (47.4%-47.7%)

(Gy) and are defined in equations (1) and (2), respectively.

Table 8 Six possible scenarios for a clinical example (BD = 3 mm, DT = 3 mm, and apical height = 3 mm in 14 mm plaque) and corresponding estimated optic disc doses

Scenario #	Type of COMS plaque	Prescription depth (mm)	Dose conversion factor relative to depth of 5 mm	Estimated optic disc dose (Gy)	Absolute dose reduction from standard plaque (Gy)	Relative dose reduction from standard plaque (%)	Reference
1	Standard	5	1.00	197.6	Unavailable	Unavailable	Fig. 1b
2	Notched (one seed removed)	5	1.00	140.7	56.9	28.8	Fig. 1b
3	Notched (two seeds removed)	5	1.00	104.9	92.7	46.9	Fig. 3a
4	Standard	3	0.63	124.5	Unavailable	Unavailable	Fig. 1b and Table 3 from Lee <i>et al.</i> [13]
5	Notched (one seed removed)	3	0.62	87.2	37.3	30.0	Fig. 1b and Table 4
6	Notched (two seeds removed)	3	0.62	65.0	59.5	47.8	Fig. 3a and Table 5

Figures

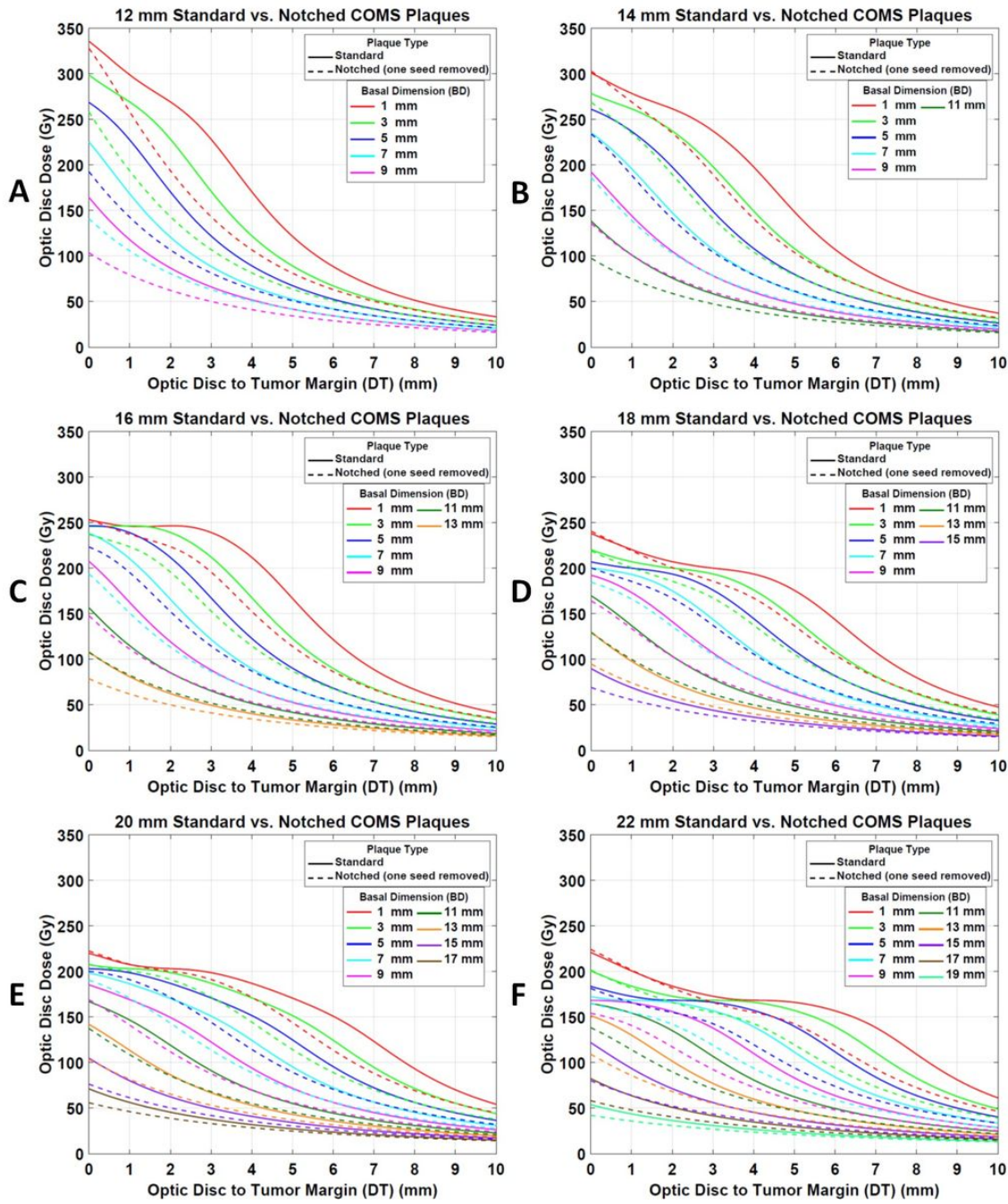


Figure 1

a-f Comparison of optic disc dose between six standard COMS plaques and six notched COMS plaques with one seed removed (Case #1). 125I (model IAI-125A) seeds were loaded. The prescribed dose of 85 Gy for an irradiation time of 168 hours was normalized at a depth of 5 mm.

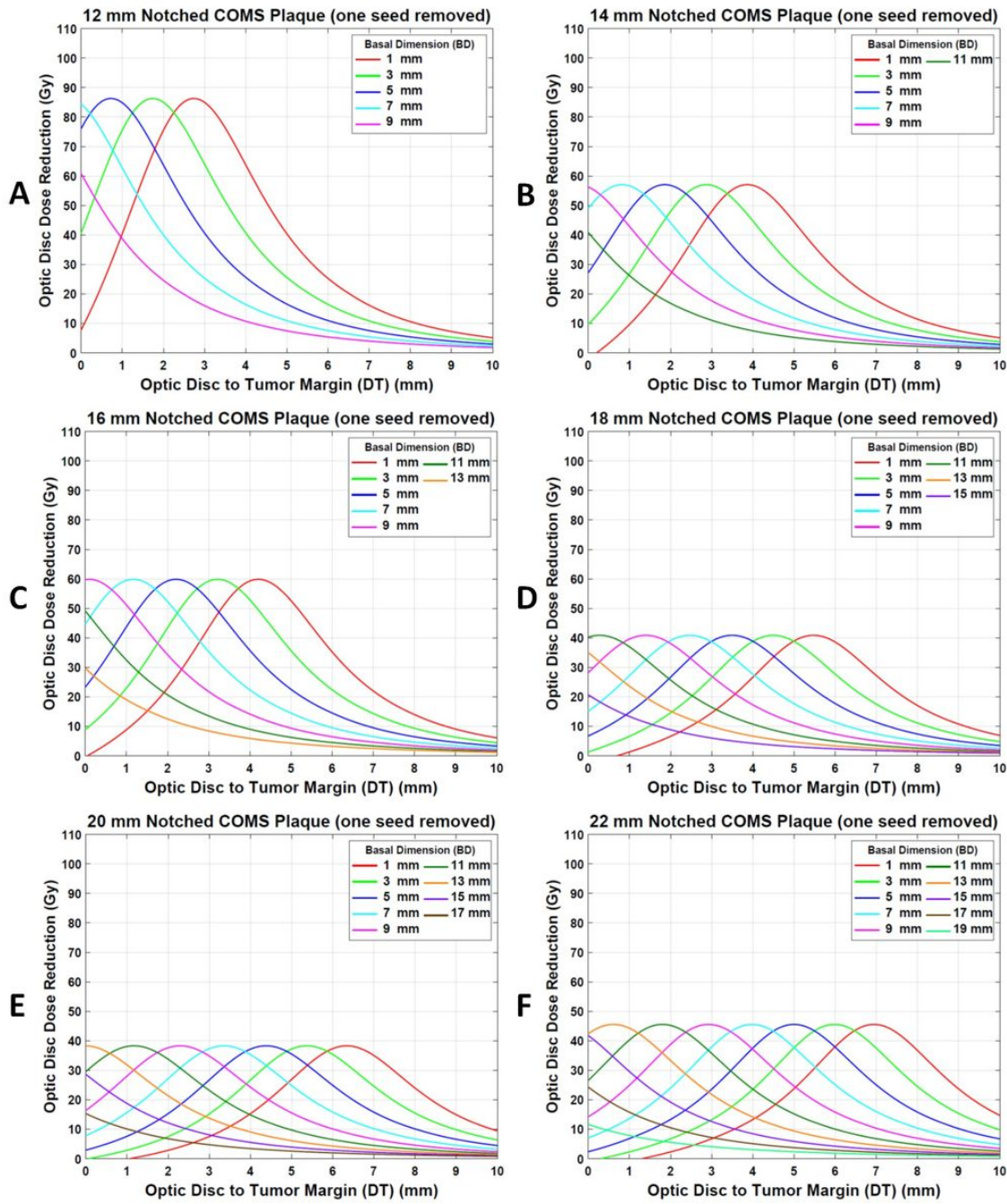


Figure 2

a-f Absolute optic disc dose reduction by notched COMS plaques with one seed removed (Case #1). The prescribed dose of 85Gy was normalized at 5 mm.

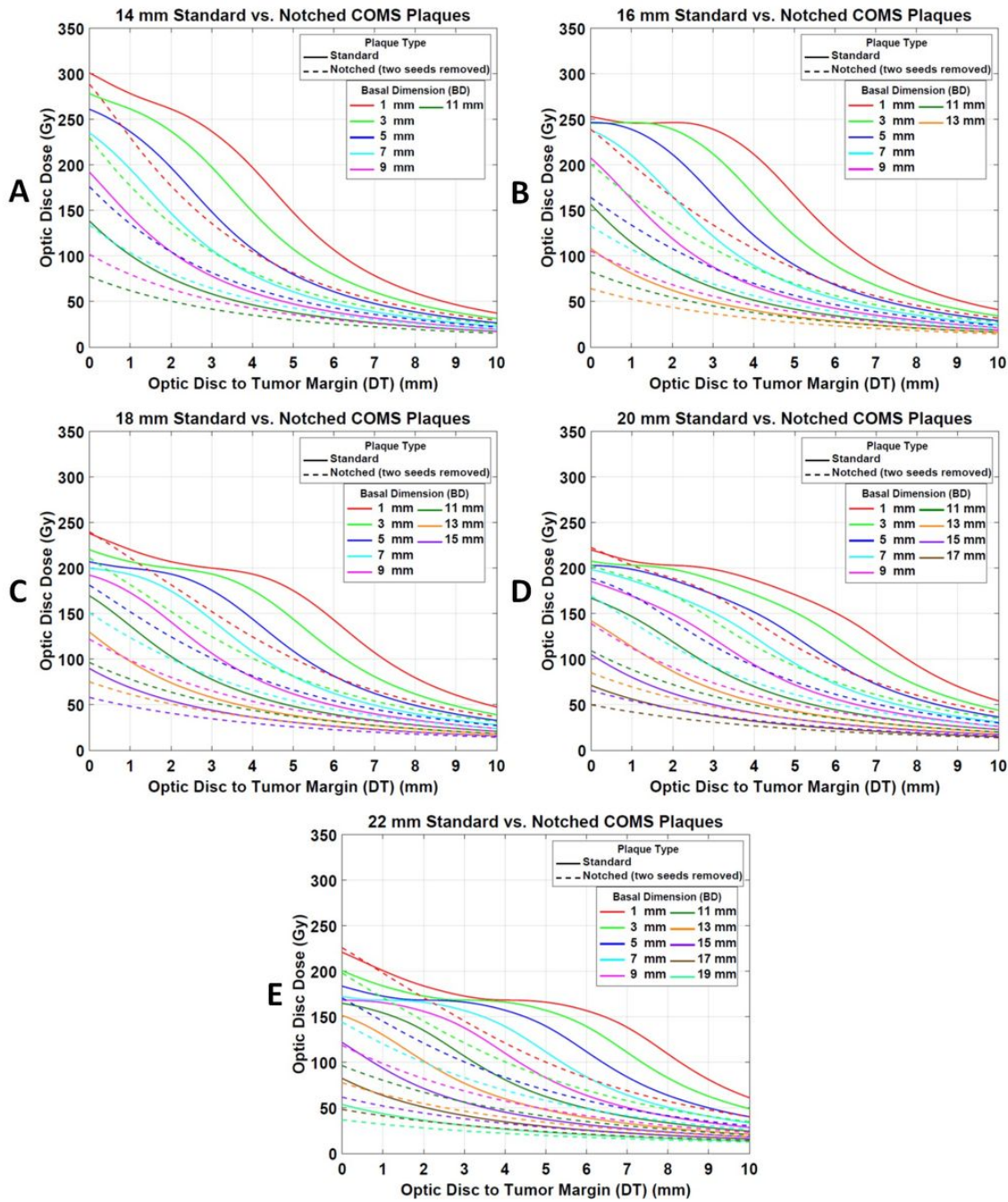


Figure 3

a-e Comparison of optic disc dose between five standard COMS plaques and five notched COMS plaques with two seeds removed (Case #2). 125I (model IAI-125A) seeds were loaded. The prescribed dose of 85 Gy for an irradiation time of 168 hours was normalized at 5 mm.

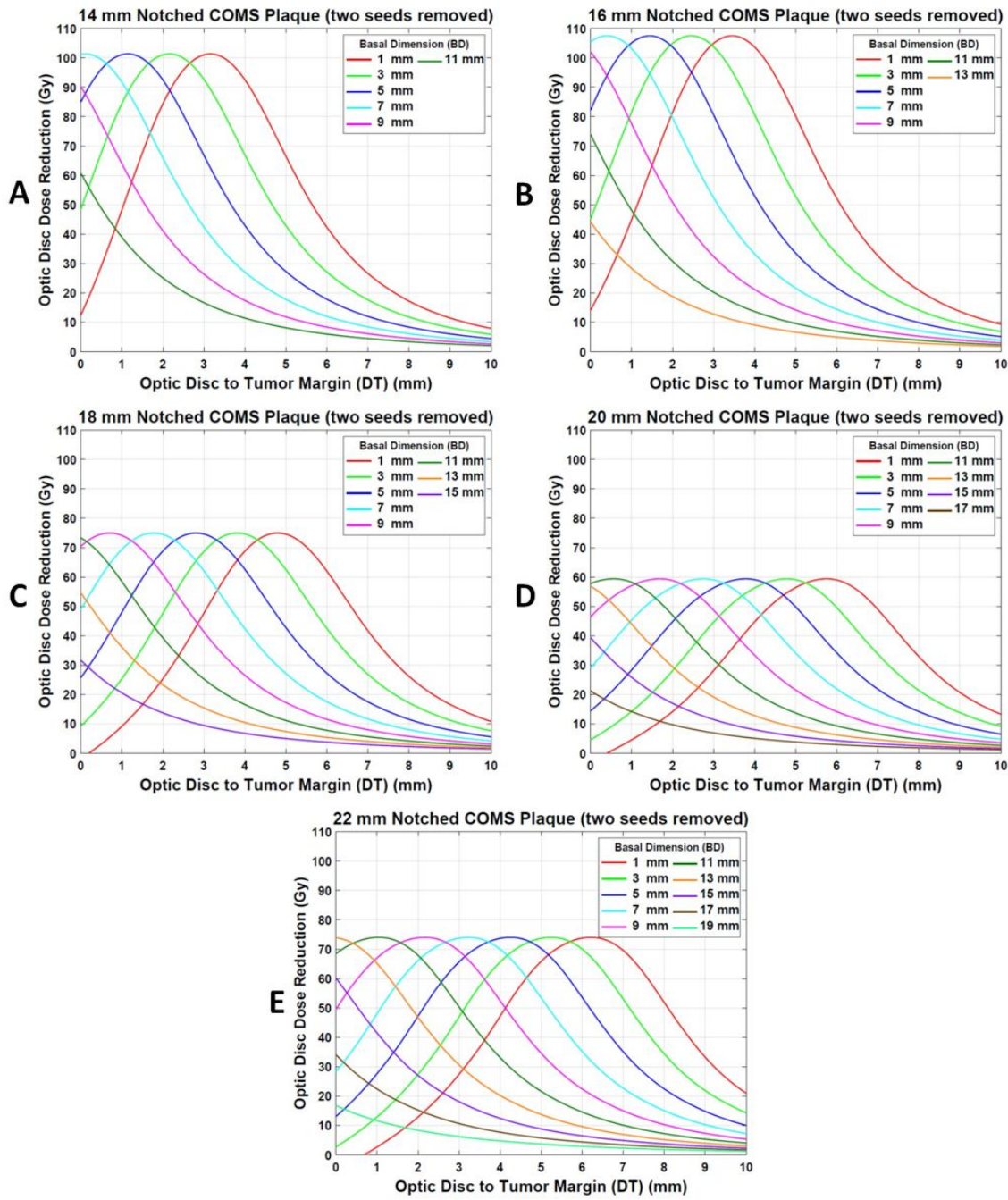


Figure 4

a-e Absolute optic disc dose reductions by ^{125}I (model IAI-125A) notched COMS plaques with two seeds removed (case #2). The prescribed dose of 85 Gy was normalized at 5 mm.

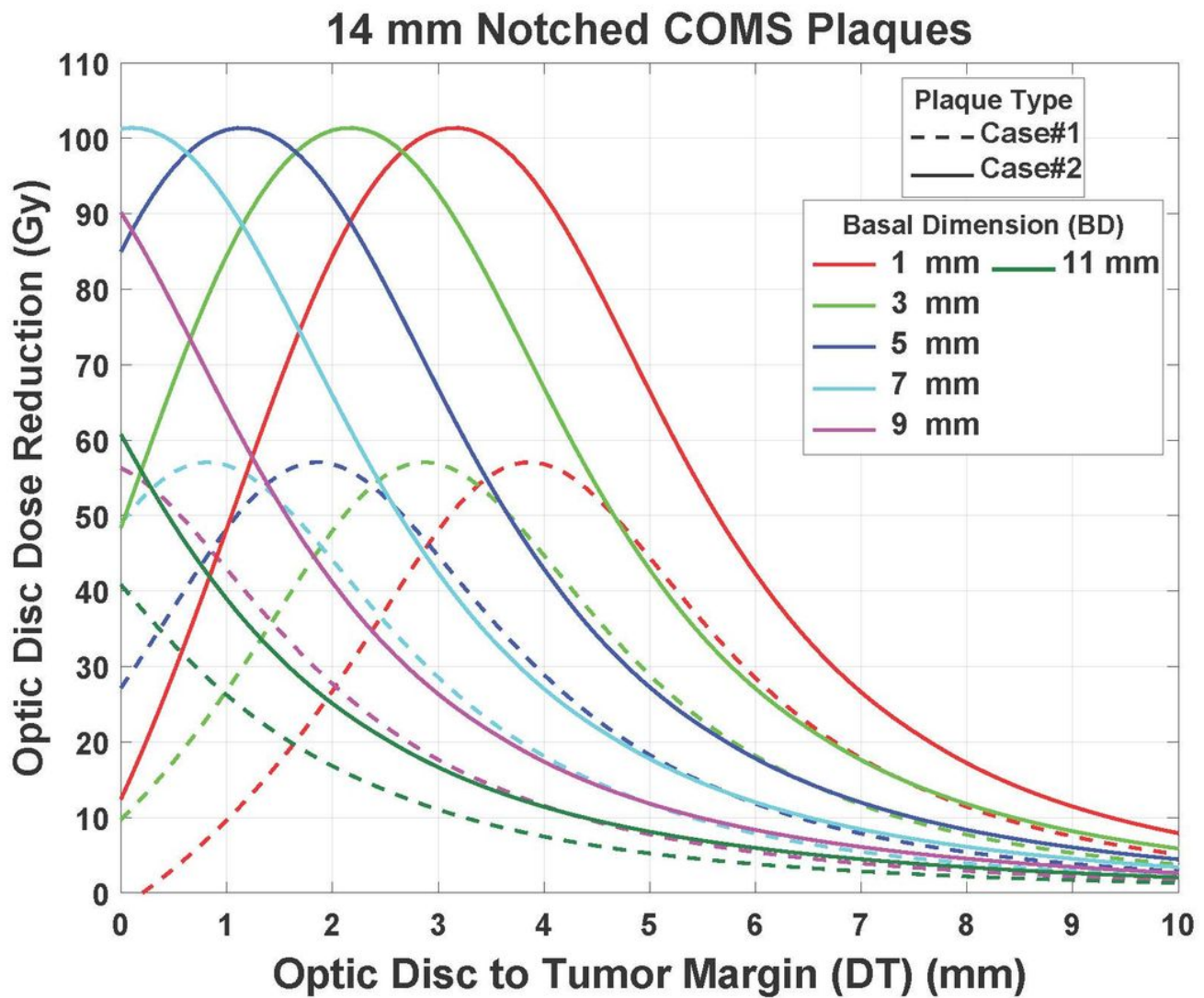


Figure 5

Comparison of optic disc dose reduction between Case #1 and Case #2 for the 14 mm notched plaque.