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A Universal Notched Episcleral Plaque Set for Brachytherapy of Intraocular Tumors Adjacent to the Optic Nerve

Xiaodong Wu [1] , Timothy G. Murray [2] , Peter Kaiser [3] , J. Randall Hughes [3] , Elizabeth Bossart [4] , Arnold M. Markoe [5]

1. CyberKnife Center of Miami; University of Miami Miller School of Medicine, Miami, FL 2. Department of Ophthalmology/Bascom Palmer Eye Institute; Department of Radiation Oncology/Sylvester Comprehensive Cancer Center 3. Department of Ophthalmology/Bascom Palmer Eye Institute 4. Department of Radiation Oncology/Sylvester Comprehensive Cancer Center 5. Department of Radiation Oncology, University of Miami Sylvester Cancer Center

Corresponding author: Xiaodong Wu, xwu@med.miami.edu

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Abstract

When applying radioactive plaque brachytherapy to intraocular tumors adjacent to the optic nerve, a notched plaque is usually used to produce a dose distribution encircling the optic disc. Due to the posterior tumor location and the limitation in eye rotation, plaque placement, alignment, and anchoring with sutures often presents technical difficulties. This article describes a universal notched episcleral plaque set consisting of a 20 mm base notched plaque, a set of open gold rings, and conventional silicon seed carriers ranging in size from 10 mm to 20 mm. This set is designed to minimize the present difficulties when treating tumors of various sizes located adjacent to the optic nerve. The design also allows for accurate echographic imaging for tumor-plaque alignment. The assembled plaques were tested on a human cadaver eye, showing the effectiveness of echographic localization as well as the ease of plaque fixation.

Categories: Ophthalmology, Radiation Oncology
Keywords: brachytherapy, choroidal melanoma, eye plaque, intraocular tumors, notched episcleral plaque, optic nerve

Introduction

Brachytherapy of intraocular tumors (such as choroidal melanoma) with Iodine-125 episcleral plaques has become a common treatment modality and an alternative to enucleation [1]. Our institution has been participating in the Collaborative Ocular Melanoma Study (COMS), initiated by the National Eye Institute, since 1985. The configurations and dosimetry of the plaques have been standardized by COMS [2-5]. A typical plaque system consists of three components: an outer gold plaque, a silicone seed carrier (insert), and a template. The template is used to determine the location of the plaque before insertion of the radioactive plaque. The localization process is accomplished by intraoperative echographic imaging technique, a procedure that allows visualization of both the tumor and plaque (Figure *1*). When the appropriate location is determined, the plaque is anchored to the sclera using sutures through eyelets on the plaque. Various sized plaques are available to accommodate different tumor sizes.

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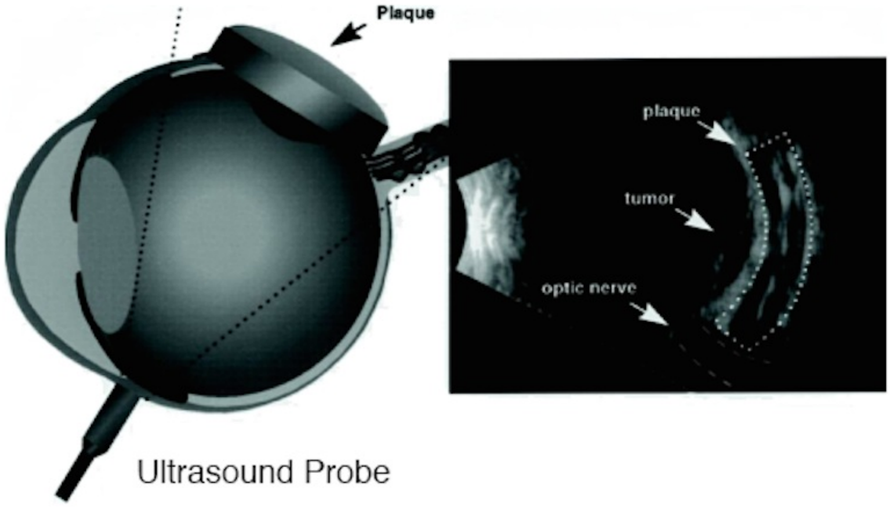

FIGURE 1: Echographic plaque and tumor localization technique.

Treating tumors adjacent to the optic nerve presents a difficult challenge. Although different sizes of notched plaques can be made to encircle the optic nerve and cover the tumor margin, the posterior location and limits in eye rotation make accurate placement and suturing difficult. Moreover, production of customized notched plaques for each patient can be quite costly. This was the motivation for designing a notched plaque set that could accommodate tumors of various sizes adjacent to the optic nerve without imposing difficulties in plaque placement and suturing. A detailed description of such a notched plaque set developed in our institution is given. The design and test results, illustrated in Figures *2*-*6*, demonstrate the effectiveness of this design.

Materials And Methods

Plaque set configuration

The basic principle of the design is to utilize a large notched plaque as a base plaque for all tumor sizes, then employ different sizes of silicone seed carriers (inserts) for the radiation delivery. As shown in Figure *2*, the use of a large base plaque (B) provides anteriorly positioned suturing eyelets which would facilitate the anchoring of the plaque as compared with a customized small plaque (A). By using different sizes of seed carriers, the plaque set could accommodate tumor dimensions up to and including the size of the base plaque.

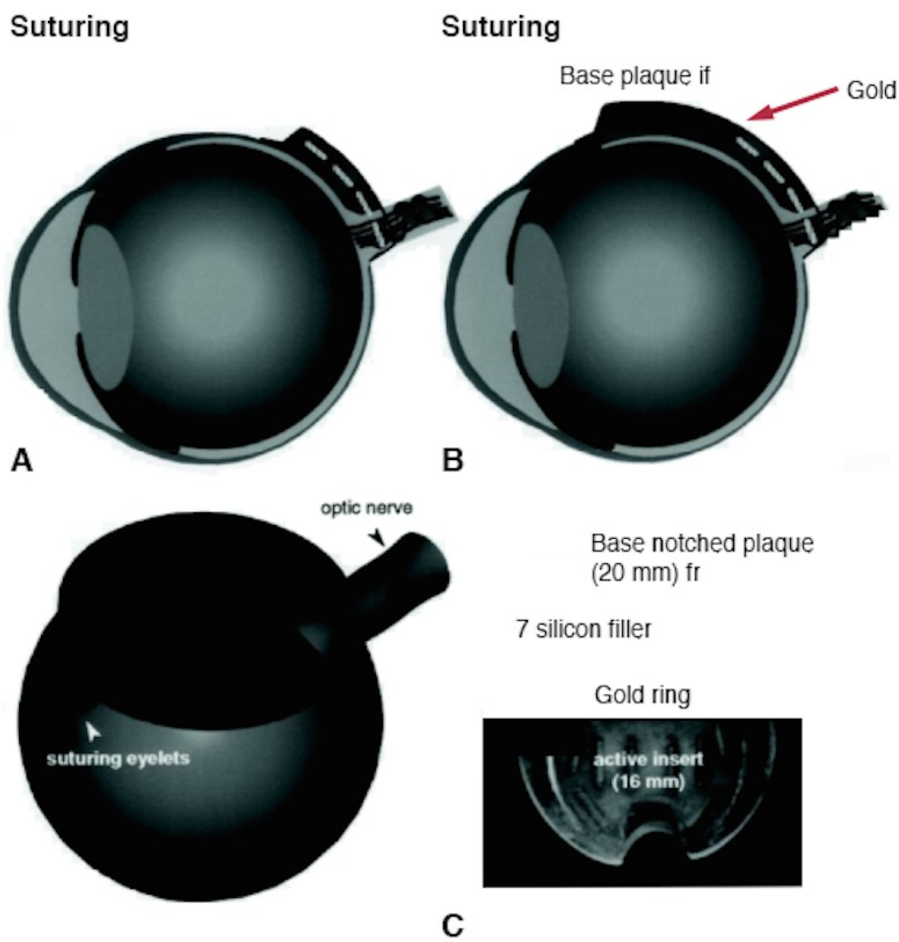

FIGURE 2: The universal notched plaque vs. traditional notched plaque.

The base notched plaque of our universal notched plaque set is a regular 20 mm notched plaque. Five different sizes of open gold rings with diameters of 10 mm, 12 mm, 14 mm, 16 mm, and 18 mm are fabricated. The gold rings correspond to the various sizes of the seed carriers. They are 1 mm thick with the same height as the silicon seed carriers. With the creation of these rings, the notched gold plaque set can now be used with six different sizes of seed carriers ranging from 10 mm to 20 mm in diameter. All the seed carriers, except for 10 mm, have the standard configuration recommended by COMS. During application, a conventional silicone seed carrier is modified to eliminate the region that would have normally occupied the notch region. The seed arrangements of all size inserts are illustrated in true proportion in Figure 3. After the 1-125 seeds are loaded, the seed carrier is adhered to the base plaque and, if the seed carrier is less than 20 mm in diameter, the corresponding gold ring is used to crown the active seed carrier (Figure 2D). In such a configuration, the gold ring functions as both a radiation shield and a margin indicator during echographic localization.

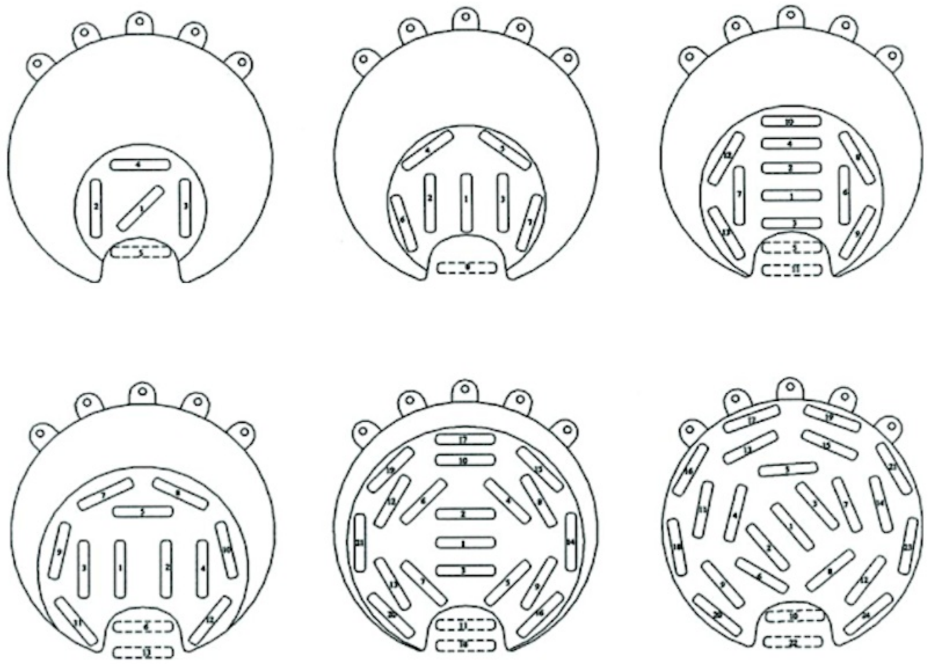

FIGURE 3: Seeds layout of the universal notched plaque set.

Dosimetry

The seed coordinates were determined based on the standard COMS configurations (except for the 10 mm carrier). For dose calculation, the general seed-plaque-implant geometry is defined and illustrated in Figure 4.

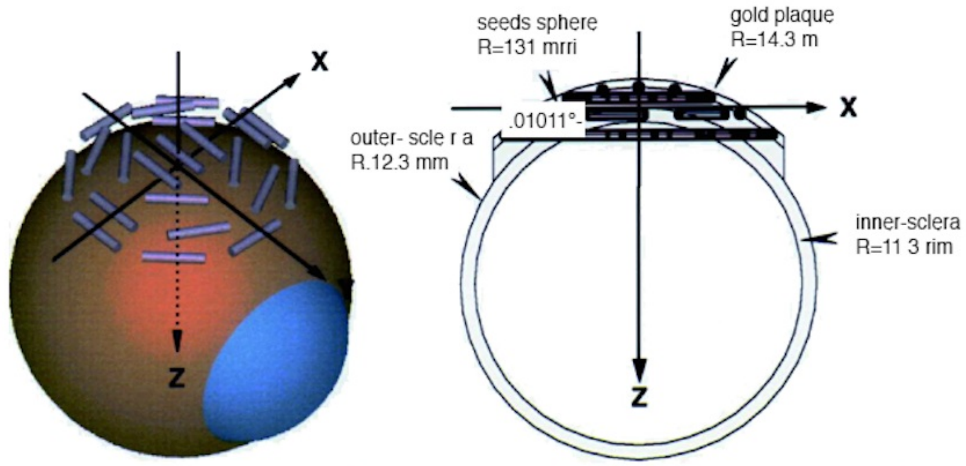

FIGURE 4: General seed-plaque-implant geometry and

coordinate system.

Note that the origin of the coordinate system is at the central, outer surface of the silicone insert, which will be contacted to the outer sclera. The coordinates of the seeds shown in Figure *3* are listed in Table *1*.

Seed No.	Plaque Size					
	10 mm	12 mm	14 mm	16 mm	18 mm	20 mm
1	(0.0,0.0,-1.4)	(0.0, 0.0,-1.4)	(0.0,0.0,-1.4)	(-1.7, 0.0, -1.3)	(0.0, 0.0, -1.4)	(0.0, 0.0, -1.4)
2	(-3.4,0.0,-0.9)	(-2.8, 0.0,-1.1)	(-2.1,0.0,-1.2)	(1.7, 0.0, -1.3)	(-2.2, 0.0, -1.2)	(-2.5, 0.0, -1.2)
3	(3.4,0.0,-0.9)	(2.8, 0.0,-1.1)	(2.1,0.0,-1.2)	(-4.5, 0.0, -0.6)	(2.2, 0.0, -1.2)	(2.5, 0.0, -1.2)
4	(0.0,3.4,-0.9)	(-2.9, 4.0,-0.5)	(-4.0,0.0,-0.8)	(4.5, 0.0, -0.6)	(-3.2, 3.2, -0.6)	(-2.7, 3.6, -0.6)
5	(0.0,-3.4,-0.9)	(2.9, 4.0,-0.5)	(4.0,0.0,-0.8)	(0.0, 4.5, -0.6)	(3.2, 3.2, -0.6)	(2.7, 3.6, -0.6)
6		(-4.8,-1.6,-0.5)	(0.0,4.0,-0.8)	. (0.0, -4.5, -0.6)	(-3.2, -3.2, -0.6)	(-4.3, -1.4, -0.6)
7		(4.8,-1.6,-0.5)	(0.0,-4.0,-0.8)	(-2.8, 5.8, 0.3)	(3.2, -3.2, -0.6)	(4.3, -1.4, -0.6)
8		0	(-2.9,5.0,-0.1)	(2.8, 5.8, 0.3)	(-3.2, 5.5, 0.2)	(0.0, -4.5, -0.6)
9			(2.9,5.0,-0.1)	(-6.4, 1.4, 0.3)	(3.2, 5.5, 0.2)	(-7.0, 0.0, 0.5)
10			(-5.7,0.0,-0.1)	(6.4, 1.4, 0.3)	(-6.4, 0.0, 0.2)	(-k, -4, 0.5)
11			(5.7,0.0,-0.1)	(-5.1, -4.1, 0.3)	im.(6.4, 0.0, 0.2)	(-4.4, 5.5, 0.5)
12			(-2.9,-5.0,-0.1)	(5.1, -4.1, 0.3)	(-3.2, -5.5, 0.2)	(1.6, -6.8, 0.5)
13			(2.9,-5.0,-0.1)	(0.0, -6.5, 0.3)	(3.2, -5.5, 0.2)	(1.6, 6.8, 0.5)
14					(0.0, 8.0, 1.2)	(6.3, -3.0, 0.5)
15					(-5.7, 5.7, 1.2)	(6.3, 3.0, 0.5)
16					(5.7, 5.7, 1.2)	(-3.1, 8.5, 2.0)
17					(-8.0, 0.0, 1.2)	(3.1, 8.5, 2.0)
18					(8.0, 0.0, 1.2)	(-7.8, 4.5, 2.0)
19					(-5.7, -5.7, 1.2)	(7.8, 4.5, 2.0)
20					(5.7, -5.7, 1.2)	(-8.9, -1.5, 2.0)
21					(0.0, -8.0, 1.2)	(8.9, -1.5, 2.0)
22						r (-5.8, -6.9, 2.0)
23						(5.8, -6.9, 2.0)
24						(0.0, -9.0, 2.0)

TABLE 1: Seeds Coordinates (x, y, z,) - mm

The radioactive seed for eye plaque brachytherapy is not limited to Iodine-125. For demonstration purpose, the model 6711 lodine-125 seed is used. The seed parameters are based on the AAPM TG-43 recommendation and the primary calibration standard of 1999 by the National Institute of Standard and Technology (NIST) [6-7]. Although the eye plaque dosimetry calculation has been refined over the years with much improved accuracy [8], to demonstrate the concept, this work uses a point source approximation without anisotropic correction (recommended by COMS) and the formalism for calculating dose rate from a single seed is given by:

$DR(r) = S_k \cdot A \cdot (r_0^2 1r^2) \cdot g(r)$,

where,

r is the distance from the point source in cm, $1\ \cdot_0$ is 1 cm,

Sk is air kerma strength with unit U (= liGy $\cdot m^2/h$) ,

A is 0.98 $cGy \cdot h^{-1} \cdot U^{-1}$, the dose rate constant in water (N 1ST 99), and g(r) is the radial dose function.

In our dose calculation, g(r) is a combination of a polynomial,

$g(r) = a_0 + a_i\ r + a_2 r^2 + a_3 r^3 + a_4 r^4 + a5r5$

where, $a_0{}^{=}1.01376$, a_1=1 .22747E-1, $a_2{}^{=}$-1.73025E-1, a_3=4.02378E-2, a4=-3.85227E-3, a_5=1 .34283E-4, for r>0.5 cm, and the Monte Carlo data by Williamson (9) for r· 0.5 cm. Table *2* gives the calculated g(r) values.

r(cm)	g(r)
0.1	0.682
0.125	0.771
0.15	0.838
0.175	0.886
0.2	0.921
0.3	0.995
0.4	1.024
0.5	1.036
0.6	1.036
0.8	1.021
1	1
1.5	0.926
2	0.832
2.5	0.731
3	0.632
3.5	0.541
4	0.463
4.5	0.397
5	0.344

TABLE 2: Radial Dose Function g(r)

Williamson's Monte Carlo data (9) are used for r=0.1 to 0.5 cm.

Echographic plaque localization

To determine if the echoes visualized during B-scan ultrasonography of the universal plaque design correspond to the appropriate components of the plaque, experiments were conducted using a human cadaver eye. The universal notched plaque was placed around the optic nerve of the cadaver eye and sutured into position using standard microsurgical techniques. B-scan ultrasonography was then performed in real time to visualize the plaque, the active insert, and the gold ring. To insure appropriate acoustic coupling, the ultrasound examination was performed under water. This helped eliminate echo artifacts and provide a more appropriate model of the configuration as it would appear during surgery. Various sized inserts with dummy seeds and the appropriate sized gold ring were utilized to verify that each of the plaque components could be identified. Institutional review board approval of the Bascom Palmer Eye

Institute and University of Miami Miller School of Medicine were obtained for all experiments.

Results

Dosimetry

The plaque central axis dose rates in cGy/hr for all notched plaques with activity of 1 U/seed are presented in Table *3*.

Depth(mm)	10 mm	12 mm	14 mm	16 mm	18 mm	20 mm
1.0 (inner sclera)	36.18	47.95	68.37	51.88	77.59	78.63
2	23.98	33.55	48.87	39.61	59.36	61.63
3	16.76	24.64	36.53	31.09	47.33	49.99
4	12.13	18.58	28.01	24.82	38.5	41.23
5	9.04	14.34	21.92	20.06	31.69	34.39
6	6.97	11.33	17.46	16.34	26.33	28.95
7	5.47	9.04	14.09	13.43	22.02	24.47
8	4.39	7.36	11.54	11.15	18.51	20.83
9	3.57	6.07	9.53	9.32	15.67	17.77
10	2.94	5.04	8	7.85	13.35	15.25
11	2.49	4.24	6.73	6.69	11.43	13.15
12	2.1	3.61	5.75	5.71	9.86	11.39
13	1.79	3.08	4.94	4.94	8.52	9.92
14	1.55	2.66	4.24	4.28	7.43	8.66
15	1.34	2.32	3.69	3.72	6.48	7.61
16	1.16	2.04	3.23	3.26	5.68	6.66
17	1.01	1.79	2.84	2.87	5.01	5.89
18	0.88	1.55	2.49	2.53	4.42	5.22
19	0.77	1.37	2.21	2.24	3.93	4.63
20	0.7	1.23	1.96	1.99	3.51	4.13
21	0.6	1.09	1.75	1.75	3.12	3.69
22	0.52	0.98	1.55	1.58	2.81	3.3
23.0 (opp. Retina)	0.49	0.88	1.4	1.4	2.49	2.98

TABLE 3: CAX Dose Rate (cGy/hr with 1U/seed) for notched plaques

This table is provided to facilitate the determination of the seed activity needed for an implant. In this table, a depth of 1 mm represents the point at the inner sclera assuming the thickness of the sclera is 1 mm. As an example, for an implant with a 14 mm notched plaque to deliver 8500 cGy to the tumor apical height of 4 mm in three days, one finds 21.9 cGy/hr with activity 1U/seed, at depth 5 mm (including 1 mm of sclera thickness) from Table 3. Using the following equation:

D=A .DR(0).Ta.[1-exp(-T/Ta)];

where, D is the total dose (8500 cGy), DR(0) is the initial dose rate with 1U/seed (21.9 cGy/hr), Ta is the mean life of 1-125, and T is the total treatment time (three days), one obtains the required activity per seed, A=5.6 U.

Figure 5 shows the isodose distributions of a 14 mm full plaque and a 14 mm notched plaque, through the notched plane, with activity of 1U/seed. A demonstrative tumor location is shown in reference to the above calculation example.

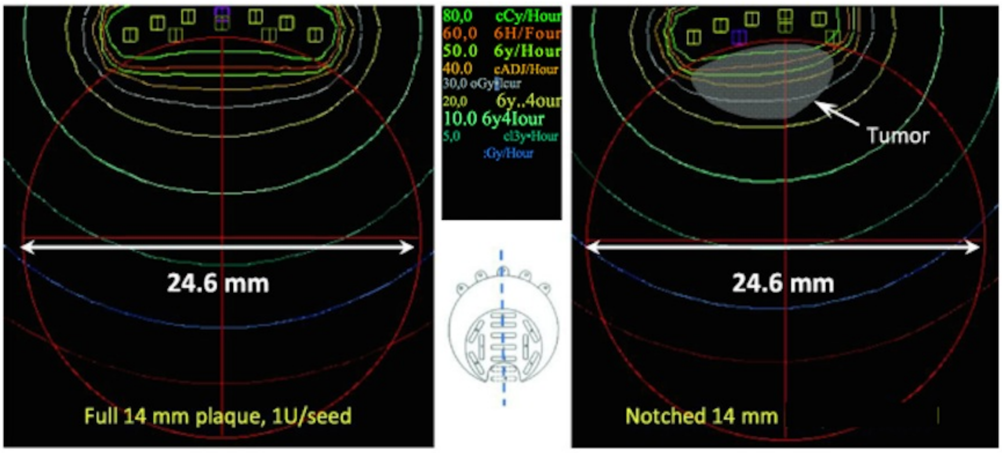

FIGURE 5: Isodose distribution of a 14 mm notched plaque compared with a conventional 14 mm plaque.

Universal notched plaque localization

All six sizes of notched seed carriers with diameters from 10 mm to 20 mm were prepared then attached, along with their corresponding ring, to the 20 mm base notched plaque. After preparation, the base plaque was sutured to the cadaver eye (Figure 6).

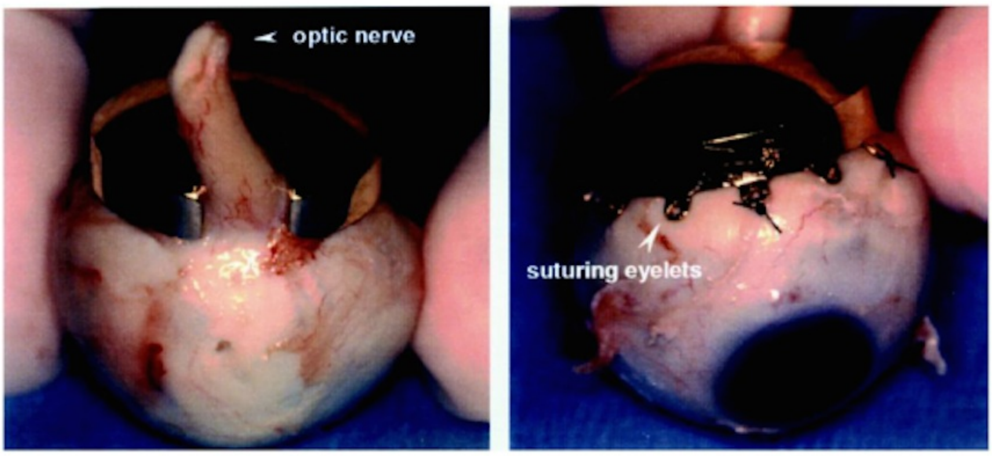

FIGURE 6: Experimental setup: notched plaque placement on a human cadaver eye.

Echographic images were taken with different orientations. Figure 7 shows B-scan echographic images taken in two planes oriented 90 degrees to each other and cutting through the universal notched plaque with a 10 mm seed insert and the corresponding gold ring.

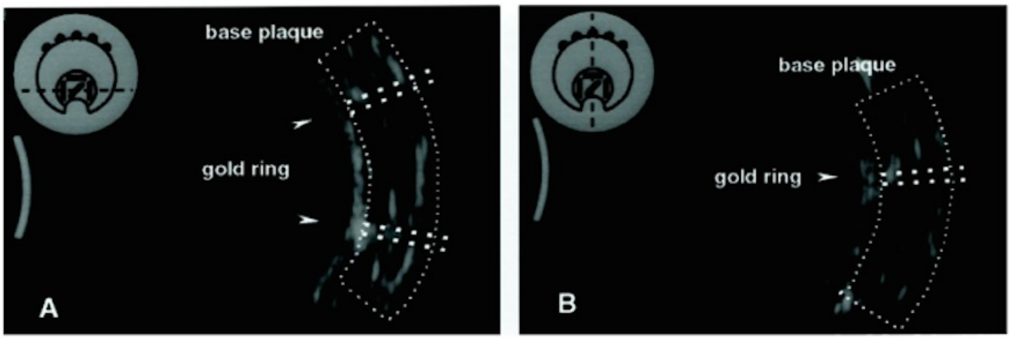

FIGURE 7: Echographic localization of a universal notched plaque placement.

Bright stripes within the plaque are produced by the gold ring due to its high reflectivity (notice that the bright stripes are not present in Figure 1). These strong echoes are used as indicators of the margin of the active insert in relation to the base plaque. Similar images were obtained from the other seed inserts and gold ring configurations (not shown).

When the seed inserts have a diameter smaller than the 20 mm (diameter of the notched base plaque), it is crucial to determine the exact location of the radioactive component to insure proper tumor-dose coverage. These ultrasound experiments show that the gold ring, visualized as the internal stripes during B-scan examination of the universal notched plaque, can well serve to achieve this objective.

Discussion

In view of the challenges using 1-125 plaque brachytherapy to treat intraocular tumors adjacent to the optic nerve with traditional notched plaques, the universal notched plaque set presented herein provides several advantages. First, only one gold notched base plaque is needed for all sizes of tumors, obviating the need to fabricate customized notched plaques. Second, the large base plaque simplifies plaque placement around the optic nerve and eases the suturing process used to anchor the plaque into position. Third, conventional seed carriers can be used in conjunction with the varying sized gold rings, allowing standardization of dosimetry. Finally, the gold rings function both as radiation protection barriers and as indicators for the margins of the radioactive inserts insuring accurate placement and coverage of the tumor margins using standard echographic techniques. The data provided here can facilitate the implementation of this treatment technique.

Conclusions

This technique has been adopted for clinical applications in our institution with favorable outcomes. The results are being analyzed and prepared for publication.

Additional Information

Disclosures

Human subjects: Consent was obtained by all participants in this study. The Bascom Palmer Eye Institute and University of Miami Miller School of Medicine issued approval N/A. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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